# APOLLO OPTICAL SUBSYSTEM AND LM ALIGNMENT OPTICAL TELESCOPE

**FINAL REPORT**

**VOLUME II**
**(1 of 2)**



**February 1970**

**Prepared For**
**AC Electronics Division**
**General Motors Corporation**
**Milwaukee, Wisconsin**

Kollsman Instrument Corporation
Syosset, New York

NASA CR 108359

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(1 of 2)

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Syosset, New York

## CONTENTS

| Section | | Page |
|---|---|---|
| | SECTION 1 -- INTRODUCTION | 1-1 |
| | SECTION 2 -- APOLLO PROGRAM MANAGEMENT | |
| 2.1 | INTRODUCTION | 2-1 |
| 2.2 | CONTRACT VALUE | 2-2 |
| 2.3 | ORGANIZATION | 2-2 |
| | 2.3.1 Responsibilities | 2-2 |
| 2.4 | FACILITIES | 2-7 |
| | 2.4.1 Syosset Facilities | 2-7 |
| 2.5 | MANPOWER | 2-10 |
| | 2.5.1 MIT Resident Support | 2-10 |
| | 2.5.2 Field Assignments | 2-10 |
| | 2.5.3 In-House Engineering | 2-16 |
| | 2.5.4 Manufacturing | 2-16 |
| 2.6 | MANLOADING | 2-16 |
| 2.7 | CONTRACT ACTIVITY | 2-20 |
| | 2.7.1 Prior to Novation | 2-20 |
| | 2.7.2 Novation | 2-25 |
| | 2.7.3 After Novation | 2-32 |
| 2.8 | MANAGEMENT CONTROLS | 2-49 |
| | 2.8.1 PERT | 2-49 |
| | 2.8.2 Configuration Control | 2-50 |
| 2.9 | PERFORMANCE | 2-57 |
| | 2.9.1 Risk Assumption | 2-57 |
| | 2.9.2 Early Recognition of Problems | 2-59 |
| 2.10 | ACCOMPLISHMENTS | 2-59 |

CONTENTS (Cont.)

Section Page

SECTION 3 -- TECHNICAL APPROACH

3.1 DESCRIPTION OF OPTICAL SUBSYSTEM . . . . . 3-1

3.2 OPTICAL BASE . . . . . 3-2

3.2.1 Optical Base and Navigation Base Interface . . . 3-2
3.2.2 Optical Base, Sextant, and Telescope Alignment . . . . . 3-4

3.3 OPTICS AXES . . . . . 3-4

3.4 TELESCOPE . . . . . 3-4

3.4.1 Description . . . . . 3-5
3.4.2 Precision Requirements . . . . . 3-5
3.4.3 Target Optics . . . . . 3-5
3.4.4 Telescope Servo System . . . . . 3-8
3.4.5 Readout Provision . . . . . 3-8
3.4.6 Drive Assemblies . . . . . 3-11

3.5 SEXTANT . . . . . 3-11

3.5.1 Description . . . . . 3-11
3.5.2 Precision Requirement . . . . . 3-13
3.5.3 Target Optics . . . . . 3-13
3.5.4 Servo System . . . . . 3-16
3.5.5 Drive Assemblies . . . . . 3-16

3.6 OPTICAL SUBSYSTEM MECHANIZATION . . . . . 3-18

3.6.1 Modes of Operation . . . . . 3-19
3.6.2 CDU Mechanization of Optics Subsystem . . . . . 3-19
3.6.3 Integrating Servo Loops . . . . . 3-21
3.6.4 Zero Optics Operation . . . . . 3-25

3.7 POSITION SERVO LOOPS . . . . . 3-27

3.7.1 Sextant Position Servo Loop Operation . . . . . 3-27
3.7.2 Telescope Position Servo Loop Operation . . . . . 3-27

3.8 POWER SUPPLIES . . . . . 3-30

3.8.1 Optics 800-Cycle Power Supply . . . . . 3-30
3.8.2 Optics 25.6-KC Power Supply . . . . . 3-30

CONTENTS (Cont.)


| Section | | Page |
|---|---|---|
| 3.9 | DISPLAY AND CONTROLS PANELS | 3-31 |
| | 3.9.1 G and N Indicator Control Panel | 3-31 |
| | 3.9.2 Optical Panel | 3-33 |
| 3.10 | MAP AND DATA VIEWER | 3-34 |
| | 3.10.1 Functional and Operational Description | 3-34 |
| | 3.10.2 Description of Optics | 3-36 |
| | 3.10.3 Cartridge and Gear Box Assembly | 3-36 |
| | 3.10.4 Panel and Door Assembly | 3-39 |
| | 3.10.5 Electronics Package | 3-39 |
| 3.11 | ALIGNMENT OPTICAL TELESCOPE | 3-39 |
| | 3.11.1 Telescope Shaft Assembly | 3-41 |
| | 3.11.2 Telescope Eyepiece Assembly | 3-44 |
| | SECTION 4 -- ENGINEERING | |
| 4.1 | ENGINEERING - PERIOD ENDING 31 DECEMBER 1962 | 4-1 |
| | 4.1.1 External Engineering | 4-1 |
| | 4.1.2 Internal Engineering | 4-3 |
| | 4.1.3 Study Analysis | 4-4 |
| 4.2 | ENGINEERING - PERIOD ENDING 31 DECEMBER 1963 | 4-6 |
| | 4.2.1 External Engineering | 4-6 |
| | 4.2.2 External Engineering - LM | 4-12 |
| | 4.2.3 Internal Engineering | 4-15 |
| 4.3 | ENGINEERING - PERIOD ENDING 31 DECEMBER 1964 | 4-19 |
| | 4.3.1 External Engineering | 4-19 |
| | 4.3.2 Internal Engineering | 4-19 |
| | 4.3.3 Internal Engineering - Block II (with Electronics) | 4-28 |
| | 4.3.4 Internal Engineering - MDV | 4-30 |
| | 4.3.5 Internal Engineering - AOT | 4-34 |
| | 4.3.6 Internal Engineering - FTE/GSE | 4-34 |

CONTENTS (Cont.)


| Section | | Page |
|---|---|---|
| 4.4 | ENGINEERING - PERIOD ENDING 31 DECEMBER 1965 | 4-35 |
| 4.4.1 | External Engineering | 4-35 |
| 4.4.2 | External Engineering - LM | 4-37 |
| 4.4.3 | Internal Engineering | 4-45 |
| 4.5 | ENGINEERING - PERIOD ENDING 31 DECEMBER 1966 | 4-77 |
| 4.5.1 | Command Module Engineering | 4-77 |
| 4.5.2 | OUA Components and Subassembly Performance | 4-78 |
| 4.5.3 | Lunar Module Engineering | 4-152 |
| 4.6 | ENGINEERING - PERIOD ENDING 31 DECEMBER 1967 | 4-157 |
| 4.6.1 | Engineering Activities | 4-157 |
| 4.6.2 | GSE Engineering | 4-181 |
| 4.6.3 | Lunar Module Project Engineering | 4-181 |
| 4.6.4 | Engineering Activities | 4-182 |
| 4.6.5 | Qualification Program | 4-184 |
| 4.7 | ENGINEERING - PERIOD 1968 - 1969 | 4-185 |
| 4.7.1 | Command Module Engineering | 4-185 |
| 4.7.2 | Engineering Activities | 4-185 |
| 4.7.3 | Lunar Module Project Engineering | 4-187 |
| 4.7.4 | Engineering Activities | 4-188 |
| 4.7.5 | Field Site Activity | 4-188 |
| 4.7.6 | Rangefinder | 4-189 |
| | SECTION 5 -- RELIABILITY | |
| 5.1 | SUMMARY OF YEAR ENDING 31 DECEMBER 1962 | 5-1 |
| 5.1.1 | Establishments of Standards and Techniques | 5-1 |
| 5.1.2 | Preparation of Reliability Plan | 5-1 |
| 5.1.3 | Assignments | 5-1 |
| 5.1.4 | Accomplishments | 5-3 |
| 5.2 | SUMMARY OF YEAR ENDING 31 DECEMBER 1963 | 5-12 |
| 5.2.1 | Assignments | 5-12 |
| 5.2.2 | TD K-11 Vendor Reliability and Quality Control | 5-12 |

CONTENTS (Cont.)


| Section | | | Page |
|---|---|---|---|
| | | SECTION 5 -- RELIABILITY (Cont.) | |
| | 5.2.3 | TD K-28 Reliability Analysis | 5-13 |
| | 5.2.4 | TD K-29 Reliability Test and Evaluation | 5-14 |
| | 5.2.5 | TD K-30 Reliability Training | 5-18 |
| | 5.2.6 | TD K-42 Design Evaluation and Qualification Test Program | 5-18 |
| | 5.2.7 | TD K-48 Shipping Container Design | 5-19 |
| | 5.2.8 | TD K-60 Thermal Analysis | 5-20 |
| | 5.2.9 | TD K-62 Optical Unit Stress Analysis | 5-20 |
| | 5.2.10 | TD K-61 AGE-2 Mechanical Integrity Tests | 5-21 |
| | 5.2.11 | TD K-81 Optics-Navigation Base Assembly Shipping and Handling Container | 5-22 |
| | 5.2.12 | TD K-83 AGE-1 Optical Subsystem Thermal Vacuum Test | 5-22 |
| | 5.2.13 | TD K-79 AGE-1 and -2, MDV Thermal-Vacuum and Mechanical Integrity Tests | 5-26 |
| | 5.2.14 | TD K-76 Failure Reporting System (Data Center) | 5-27 |
| | 5.2.15 | TD K-103 Fabrication 4 OSS Shipping Containers | 5-27 |
| 5.3 | SUMMARY OF YEAR ENDING 31 DECEMBER 1964 | | 5-29 |
| | 5.3.1 | C/M Reliability Plan | 5-29 |
| | 5.3.2 | TD K-11 Vendor Reliability and Quality Control | 5-29 |
| | 5.3.3 | TD K-28 Reliability Analysis | 5-32 |
| | 5.3.4 | TD K-30 Reliability Training | 5-33 |
| | 5.3.5 | TD K-42 Design Evaluation and Qualification Test Program | 5-34 |
| | 5.3.6 | TD K-76 Failure Reporting System | 5-35 |
| | 5.3.7 | TD K-79 AGE-1 MDV Thermal Vacuum and Mechanical Integrity Tests | 5-50 |
| | 5.3.8 | TD K-48 Shipping Container Design | 5-51 |
| | 5.3.9 | TD K-103 Fabricate Four OSS Shipping Containers | 5-54 |
| | 5.3.10 | TD K-81 Optics-Navigation Base Assembly Shipping and Handling Container | 5-54 |
| | 5.3.11 | TD K-60 and K-98 Thermal Analysis | 5-54 |
| | 5.3.12 | TD K-61 AGE-2 Mechanical Integrity Tests | 5-58 |
| | 5.3.13 | TD K-62 Optical Unit Stress Analysis | 5-61 |
| | 5.3.14 | TD K-83 AGE-1 Optical Subsystem Thermal/Vacuum Tests | 5-63 |
| | 5.3.15 | TD K-104 Failure Effects Analysis | 5-73 |

CONTENTS (Cont.)


| Section | | Page |
|---|---|---|
| | SECTION 5 - RELIABILITY (Cont.) | |
| 5.3.16 | TD K-127 Block II Reliability Program Plan | 5-77 |
| 5.3.17 | TD K-80 Parts Qualification Program | 5-77 |
| 5.3.18 | TD K-126 LM Reliability Analysis | 5-100 |
| 5.3.19 | Reliability Report Analyses (Reports No. AAR-1 thru AAR-6) | 5-101 |
| 5.4 | SUMMARY OF YEAR ENDING 31 DECEMBER 1965 | 5-104 |
| 5.4.1 | Introduction | 5-104 |
| 5.4.2 | Reliability Activities | 5-104 |
| 5.4.3 | Component Data | 5-107 |
| 5.4.4 | SCD Upgrading | 5-107 |
| 5.4.5 | Support of Manufacturing Modified Class A Parts | 5-108 |
| 5.4.6 | Extended Performance Test (EPT) Program | 5-108 |
| 5.4.7 | Vendor Design Review | 5-109 |
| 5.4.8 | Failure Analysis Reports | 5-110 |
| 5.4.9 | Reliability Report Analyses (Report Nos. AAR-8 thru AAR-47) | 5-112 |
| 5.5 | SUMMARY OF YEAR ENDING 1966 | 5-121 |
| 5.5.1 | Introduction | 5-121 |
| 5.5.2 | Major Reliability Problems | 5-121 |
| 5.5.3 | Parts and Materials Program | 5-122 |
| 5.5.4 | Reliability Training Program for Personnel Certification | 5-127 |
| 5.5.5 | Extended Performance Testing Program | 5-127 |
| 5.5.6 | Qualification Test Program | 5-127 |
| 5.5.7 | Failure Analyses | 5-132 |
| 5.5.8 | Reliability Reports | 5-137 |
| 5.6 | SUMMARY OF YEAR ENDING 31 DECEMBER 1967 | 5-140 |
| 5.6.1 | Introduction | 5-140 |
| 5.6.2 | Major Reliability Problems | 5-140 |
| 5.6.3 | Parts and Materials Program | 5-145 |
| 5.6. | Reliability Training Program for Personnel Certification | 5-147 |
| 5.6.5 | Extended Performance Testing Program | 5-148 |
| 5.6.6 | Qualification Test Program | 5-149 |
| 5.6.7 | Design Change Activity | 5-149 |

CONTENTS (Cont.)

| Section | | Page |
|---|---|---|
| | SECTION 5 -- RELIABILITY (Cont.) | |
| 5.6.8 | Failure Reports | 5-149 |
| 5.6.9 | Reliability Report Analyses (Reports ARR-64 through ARR-78) | 5-156 |
| 5.7 | SUMMARY OF YEARS 1968 - 1969 | 5-161 |
| 5.7.1 | Introduction | 5-161 |
| 5.7.2 | Major Reliability Problems | 5-161 |
| 5.7.3 | Parts and Materials Program | 5-172 |
| 5.7.4 | Reliability Failure Action Summary | 5-173 |
| 5.7.5 | Extended Performance Testing Program | 5-173 |
| 5.7.6 | Design Activity | 5-174 |
| 5.7.7 | Failure Report Summary | 5-174 |
| 5.7.8 | Reliability Report Analysis (ARR-79) | 5-174 |
| 5.7.9 | Reliability Effort on Rangefinder | 5-174 |
| 5.7.10 | Waiver Summary | 5-180 |
| | SECTION 6 -- QUALITY ASSURANCE | |
| 6.1 | SUMMARY OF YEAR ENDING 31 DECEMBER 1962 | 6-1 |
| 6.1.1 | Program Effort | 6-1 |
| 6.2 | SUMMARY OF YEAR ENDING 31 DECEMBER 1963 | 6-3 |
| 6.2.1 | Program Effort | 6-3 |
| 6.3 | SUMMARY OF YEAR ENDING 31 DECEMBER 1964 | 6-13 |
| 6.3.1 | Program Effort | 6-13 |
| 6.3.2 | Accomplishments | 6-14 |
| 6.3.3 | Problem Areas | 6-16 |
| 6.4 | SUMMARY OF YEAR ENDING 31 DECEMBER 1965 | 6-17 |
| 6.4.1 | Management | 6-17 |
| 6.4.2 | Motivation | 6-17 |
| 6.4.3 | Problem Areas and Corrective Action | 6-21 |
| 6.4.4 | Procurement | 6-21 |
| 6.4.5 | Quality Engineering | 6-54 |
| 6.4.6 | Fabrication Control | 6-54 |
| 6.4.7 | Material Review Board | 6-69 |
| 6.4.8 | Problem Areas and Corrective Action | 6-69 |
| 6.4.9 | Audits | 6-89 |

CONTENTS (Cont.)


| Section | | Page |
|---|---|---|
| | SECTION 6 -- QUALITY ASSURANCE (Cont.) | |
| 6.5 | SUMMARY OF YEAR ENDING 31 DECEMBER 1966 | 6-94 |
| 6.5.1 | Management | 6-94 |
| 6.5.2 | Accomplishments | 6-94 |
| 6.5.3 | Motivation | 6-101 |
| 6.5.4 | Procurement | 6-101 |
| 6.5.5 | Audits | 6-122 |
| 6.6 | SUMMARY OF YEAR ENDING 1967 | 6-142 |
| 6.6.1 | Management | 6-142 |
| 6.6.2 | Milestones | 6-142 |
| 6.6.3 | Major Problems | 6-142 |
| 6.6.4 | Documentation | 6-142 |
| 6.6.5 | Procurement | 6-144 |
| 6.6.6 | In-House Activities | 6-153 |
| 6.7 | SUMMARY OF YEARS 1968 - 1969 | 6-167 |
| 6.7.1 | Management | 6-167 |
| 6.7.2 | Milestones | 6-167 |
| 6.7.3 | Major Problems | 6-167 |
| 6.7.4 | Procurement | 6-169 |
| 6.7.5 | Fabrication | 6-176 |
| | SECTION 7 -- DOCUMENTATION | |
| 7.1 | SUMMARY OF YEAR ENDING DECEMBER 31, 1962 | 7-1 |
| 7.1.1 | Program Effort | 7-1 |
| 7.1.2 | Assignments | 7-1 |
| 7.1.3 | Accomplishments | 7-1 |
| 7.2 | SUMMARY OF YEAR ENDING DECEMBER 31, 1963 | 7-2 |
| 7.2.1 | Assignments | 7-2 |
| 7.2.2 | Accomplishments | 7-3 |
| 7.3 | SUMMARY OF YEAR ENDING DECEMBER 31, 1964 | 7-8 |
| 7.3.1 | Assignments | 7-8 |
| 7.3.2 | Accomplishments | 7-8 |

CONTENTS (Cont.)


| Section | | | Page |
|---|---|---|---|
| | SECTION 7 -- DOCUMENTATION (Cont.) | | |
| 7.4 | SUMMARY OF YEAR ENDING DECEMBER 31, 1965 | | 7-13 |
| | 7.4.1 | Assignments | 7-13 |
| | 7.4.2 | Accomplishments | 7-13 |
| 7.5 | SUMMARY OF YEAR ENDING DECEMBER 31, 1966 | | 7-19 |
| | 7.5.1 | Assignments | 7-19 |
| | 7.5.2 | Accomplishments | 7-19 |
| 7.6 | SUMMARY OF THE YEARS 1967, 1968, AND 1969 | | 7-26 |
| | 7.6.1 | Assignments | 7-26 |
| | 7.6.2 | Accomplishments | 7-26 |
| | SECTION 8 -- FIELD OPERATIONS | | |
| 8.1 | SUMMARY OF PERIOD 1964 - 1965 | | 8-1 |
| | 8.1.1 | Organization | 8-1 |
| | 8.1.2 | Accomplishments | 8-1 |
| | 8.1.3 | Support Reporting | 8-4 |
| | 8.1.4 | Test Stations | 8-4 |
| 8.2 | SUMMARY OF YEAR ENDING 31 DECEMBER 1966 | | 8-4 |
| | 8.2.1 | Assignments | 8-4 |
| | 8.2.2 | Accomplishments | 8-9 |
| | 8.2.3 | Maintenance Analysis Support | 8-9 |
| | 8.2.4 | Field Operations Personnel Deployment | 8-10 |
| | 8.2.5 | Support Reporting | 8-10 |
| 8.3 | SUMMARY OF YEAR ENDING 31 DECEMBER 1967 | | 8-11 |
| | 8.3.1 | Assignments | 8-11 |
| | 8.3.2 | Accomplishments | 8-11 |
| | 8.3.3 | Field Operations Deployment | 8-12 |
| | 8.3.4 | Support Reporting | 8-12 |

CONTENTS (Cont.)

| Section | | Page |
|---|---|---|
| | SECTION 8 -- FIELD OPERATIONS (Cont.) | |
| 8.4 | SUMMARY PERIOD 1968 - 1969 | 8-13 |
| | 8.4.1 Accomplishments | 8-13 |
| | 8.4.2 Material and Spares Integration | 8-14 |
| | 8.4.3 Support Reporting | 8-14 |

ILLUSTRATIONS


| Figure | Title | Page |
|---|---|---|
| 2-1. | Target Costs and Actual Costs | 2-3 |
| 2-2. | Apollo Program Subdivision of Funds Summary Chart | 2-4 |
| 2-3. | Apollo Organization (Early Manufacturing and Development) | 2-5 |
| 2-4. | Apollo/LM Program Organization | 2-6 |
| 2-5. | OUA/AOT Assembly and Test Area, Clean Room | 2-9 |
| 2-6. | Total MIT Residents | 2-12 |
| 2-7. | Field Activity Site Assignments | 2-14 |
| 2-8. | CM/AOT Field Site Deployment Map | 2-15 |
| 2-9. | Manpower Manhour Profile Apollo/LEM Total Program | 2-19 |
| 2-10. | Master Schedule Apollo Program Phasing of Major Tasks | 2-21 |
| 2-11. | Apollo PERT Detailed Networks | 2-51 |
| 2-12. | Apollo Line of Balance Chart | 2-53 |
| 3-1. | Optical Subsystem and Navigation Base | 3-3 |
| 3-2. | Optical Subsystem Axes | 3-6 |
| 3-3. | Telescope | 3-7 |
| 3-4. | Telescope, Optical Schematic | 3-9 |
| 3-5. | Telescope, Position Loop | 3-10 |
| 3-6. | Sextant, Cutaway View | 3-12 |
| 3-7. | Sextant Trunnion Axis Assembly | 3-14 |
| 3-8. | Sextant, Optical Schematic | 3-15 |

ILLUSTRATIONS (Cont.)


| Figure | Title | Page |
|---|---|---|
| 3-9. | Sextant, Position Loop | 3-17 |
| 3-10. | Optics Mechanization, Block Diagram | 3-18 |
| 3-11. | Sextant Target Image Motion | 3-20 |
| 3-12. | Trunnion CDU Mechanization | 3-21 |
| 3-13. | Integrating Loop, Manual Direct Mode | 3-23 |
| 3-14. | Integrating Loop, Manual Resolved Mode | 3-24 |
| 3-15. | Gain Variation Circuit, Simplified Diagram | 3-25 |
| 3-16. | Zero Optics Mode | 3-26 |
| 3-17. | Sextant Position Loop | 3-28 |
| 3-18. | Telescope Position Loop | 3-29 |
| 3-19. | G & N Indicator Control Panel, Optical Subsystem | 3-32 |
| 3-20. | Map and Data Viewer | 3-35 |
| 3-21. | Map and Data Viewer Component Arrangement | 3-37 |
| 3-22. | Map and Data Viewer Cartridge Assembly | 3-38 |
| 3-23. | AOT Cutaway View | 3-40 |
| 3-24. | AOT Controls | 3-42 |
| 3-25. | AOT Eyeguard Assemblies | 3-47 |
| 3-26. | AOT High Density Filter Assembly | 3-47 |
| 4-1. | Accuracy Test Data with Fine Indicator Receiver as Load | 4-54 |
| 4-2. | Accuracy Test Data without Receiver as Load | 4-55 |

ILLUSTRATIONS (Cont.)


| Figure | Title | Page |
|---|---|---|
| 4-3. | JDQ 03004, AGE-123 | 4-57 |
| 4-4. | JDQ 03004, AGE-110 | 4-58 |
| 4-5. | Adjustable Reticle Assembly SCT (3 Sheets) | 4-65 |
| 4-6. | New Mounting of SCT Objective Lens Elements | 4-68 |
| 4-7. | Solvere Motor Thermal Vacuum Test | 4-79 |
| 4-8. | TDA vs 64X Resolver Accuracy | 4-83 |
| 4-9. | OUA Eyepieces (3 Sheets) | 4-85 |
| 4-10. | Prism Housing Assemblies | 4-89 |
| 4-11. | Primer Pull Test | 4-91 |
| 4-12. | Vibration Profile | 4-94 |
| 4-13. | Pull Test Set-up OUA Flexprints | 4-95 |
| 4-14. | Purge Valve | 4-98 |
| 4-15. | Gas Injection Valve | 4-99 |
| 4-16. | Flowmeter | 4-100 |
| 4-17. | SCT Manual Adjust Knob | 4-102 |
| 4-18. | LOS Measurements During Thermal-Vacuum Exposure AGE 204 | 4-105 |
| 4-19. | Sextant TDA Assembly | 4-106 |
| 4-20. | Proposed SXT TDA Bearing | 4-107 |
| 4-21. | SXT Readout Loop | 4-108 |
| 4-22. | SCT Readout Loop | 4-108 |
| 4-23. | Operation of OUA | 4-115 |
| 4-24. | Resolver Test Setup | 4-116 |

ILLUSTRATIONS (Cont.)


| Figure | Title | Page |
|---|---|---|
| 4-25. | SXT Design Features Affecting SXT SDA Alignment | 4-118 |
| 4-26. | SXT SDA Resolver Mounting | 4-119 |
| 4-27. | Mounting of 16X Resolver 2012736 Stage | 4-121 |
| 4-28. | SXT Head Mirror Mounting (2 Sheets) | 4-122 |
| 4-29. | Thermal Vacuum Test Schedule | 4-125 |
| 4-30. | SXT Head Alignment Pins | 4-128 |
| 4-31. | SXT SDA Resolver Alignment Relationship | 4-133 |
| 4-32. | Precision Test Fixture, Left Side | 4-134 |
| 4-33. | SXT SDA Zero Ref. Shift | 4-146 |
| 4-34. | SXT Index Head and Wedges Assembly | 4-148 |
| 4-35. | ERP 192, Fuse and Stress Relief | 4-162 |
| 4-36. | SXT Eyepiece Assembly, PN 2012700 | 4-163 |
| 4-37. | SXT Vibration Shifts, Original Design | 4-165 |
| 4-38. | SXT Vibration Shifts Latest Design, P/N 2011213, Revision A | 4-165 |
| 4-39. | Flexprints in Sextant Shaft | 4-167 |
| 4-40. | Scheduling | 4-176 |
| 4-41. | Program Flow | 4-177 |
| 5-1. | Milestone Chart for Reliability Events | 5-2 |
| 5-2. | Apollo Reliability Milestone Chart | 5-4 |
| 5-3. | Reliability Analysis Part Usage and Application Form | 5-6 |
| 5-4. | Functional Block Diagram, Apollo Optical Subsystem | 5-8 |

ILLUSTRATIONS (Cont.)


| Figure | Title | Page |
|---|---|---|
| 5-5. | Functional Block Diagram, Apollo Optical Subsystem Scanning Telescope | 5-9 |
| 5-6. | Reliability Part Summary | 5-10 |
| 5-7. | Dual Space Chamber | 5-24 |
| 5-8. | Apollo Reliability Optical Test Setup AGE-1 | 5-25 |
| 5-9. | MDV Test Setup | 5-52 |
| 5-10. | MDV Shipping Container | 5-53 |
| 5-11. | Optical Unit Shipping Container | 5-55 |
| 5-12. | Optical Unit Arranged for Random Vibration Along $Y_{CM}$ Axis | 5-59 |
| 5-13. | Test Setup for Chamber Partition Movement Evaluation | 5-67 |
| 5-14. | Chamber Schematic (Sectional View from Top Looking Down) | 5-67 |
| 5-15. | Environment Schedule for AGE 1 Optical Unit | 5-68 |
| 5-16. | AGE 1 Thermal Vacuum Optical Test Layout | 5-69 |
| 5-17. | AGE 1 Thermal Vacuum Optical Test Layout, Apollo Mission Profile Cycle #1 | 5-71 |
| 5-18. | Solar Beam Analyzer Test | 5-72 |
| 5-19. | Environment Schedule for AGE 1 Optical Unit, Thermal Vacuum Apollo Mission Profile, Cycle # 1 | 5-74 |
| 5-20. | Test Layout Showing Positioning of Three Piers Used During Optical Metrology of AGE 1 Testing | 5-75 |
| 5-21. | Rear of Space Chamber Showing Optical Instrumentation T2 (SXT) and T3 (SCT) in Alignment Position at Start of Evaluation Test. The Solar Simulator is to the Left of the Optical Pier | 5-76 |

ILLUSTRATIONS (Cont.)


| Figure | Title | Page |
|---|---|---|
| 5-22. | Slip Clutch Qualification Tests | 5-89 |
| 5-23. | Resolver Qualification Tests | 5-90 |
| 5-24. | Flexprint Qualification Tests | 5-91 |
| 5-25. | Friction Torque Fixture for Resolver Size 8 (1010341) | 5-92 |
| 5-26. | Accuracy Testing Fixture for Resolver (1010341 and 1011371) | 5-93 |
| 5-27. | Functional Fixture for Projection Lens (1011374) | 5-95 |
| 5-28. | Functional Fixture for Differential (1011281) | 5-96 |
| 5-29. | OUA Failure Summary | 5-157 |
| 5-30. | LM Failure Summary | 5-158 |
| 5-31. | Overstress Condition | 5-162 |
| 5-32. | Power Spectral Density, Comparison of Levels | 5-163 |
| 5-33. | High-Mass Gearshaft | 5-168 |
| 5-34. | Sextant Trunnion | 5-168 |
| 5-35. | Pechan Prism | 5-169 |
| 5-36. | Block II, OUA Failure Summary | 5-177 |
| 5-37. | LM AOT Failure Summary | 5-178 |
| 5-38. | OUA Waiver Summary | 5-181 |
| 5-39. | AOT Waiver Summary | 5-181 |
| 6-1. | Organization Chart, Space Division Product Assurance Department | 6-18 |
| 6-2. | Product Assurance Functional Organization for Apollo/LM Programs | 6-19 |
| 6-3. | Manpower Status | 6-20 |
| 6-4. | Procured Material (Shipment) Nonconformance Trend | 6-28 |

ILLUSTRATIONS (Cont.)


| Figure | Title | Page |
|---|---|---|
| 6-5. | Procured Material (Unit) Nonconformance Trend . . . . | 6-29 |
| 6-6. | Material Review Activity Trend CM/LM . . . . . . . . . . | 6-32 |
| 6-7. | Trend of Suppliers in 100-84% Quality Rating Category . . . . . . . . . . . . . . . . . . . . . . | 6-56 |
| 6-8. | Trend of Suppliers in 84-40% Quality Rating Category . . . . . . . . . . . . . . . . . . . . . . | 6-57 |
| 6-9. | Trend of Suppliers in 40-0% Quality Rating Category . . . . . . . . . . . . . . . . . . . . . . | 6-58 |
| 6-10. | Process Control (4 pages) . . . . . . . . . . . . . . . . . | 6-71 |
| 6-11. | Percentage of Parts/Optics Defective . . . . . . . . . . | 6-78 |
| 6-12. | Percentage of Assemblies Defective . . . . . . . . . . . | 6-79 |
| 6-13. | CM/LM Material Review Activity Trend . . . . . . . . . | 6-81 |
| 6-14. | CM/LM Material Review Corrective Action (2 pages) . | 6-82 |
| 6-15. | Product Assurance Functional Organization for Apollo/LM Programs . . . . . . . . . . . . . . . . | 6-95 |
| 6-16. | Manpower Status . . . . . . . . . . . . . . . . . . . . . . | 6-96 |
| 6-17. | Process Control (2 pages) . . . . . . . . . . . . . . . . . | 6-97 |
| 6-18. | Process Control (2 pages) . . . . . . . . . . . . . . . . . | 6-99 |
| 6-19. | Procured Material (Shipment) Nonconformance Trend . . . . . . . . . . . . . . . . . . . . . . . . . . | 6-102 |
| 6-20. | Percent Overall Audit Conformance . . . . . . . . . . . | 6-132 |
| 6-21. | Quality Control Audit Sheet . . . . . . . . . . . . . . . | 6-135 |
| 6-22. | Product Assurance Functional Organization for Apollo/LM Programs . . . . . . . . . . . . . . . . | 6-143 |
| 6-23. | Procured Material (Shipment) Nonconformance Trend . | 6-146 |
| 6-24. | Material Review Activity Trend CM/LM . . . . . . . . . | 6-148 |

ILLUSTRATIONS (Cont.)


| Figure | Title | Page |
|---|---|---|
| 6-25. | CM/LM Procured Material Review Dispositions (2 pages) | 6-150 |
| 6-26. | Percentage of Parts/Optics Defective | 6-155 |
| 6-27. | Percentage of Assemblies Defective | 6-157 |
| 6-28. | CM/LM Material Review Activity Trend | 6-159 |
| 6-29. | MRB Corrective Action | 6-160 |
| 6-30. | Disposition of Nonconforming Material (2 pages) | 6-161 |
| 6-31. | MRB Assignment to OUA | 6-163 |
| 6-32. | Prime MRB Assignment to AOT | 6-165 |
| 6-33. | Carried-over MRB Assignment to AOT | 6-166 |
| 6-34. | Product Assurance Functional Organization for Apollo/LM Programs | 6-168 |
| 6-35. | CM/LM Procured Material Review Dispositions (2 pages) | 6-173 |
| 6-36. | Disposition of Nonconforming Material (2 pages) | 6-179 |
| 6-37. | MRB Assignment to OUA (CM) | 6-181 |
| 6-38. | Prime MRB Assignment to AOT | 6-183 |
| 6-39. | Carried-over MRB Assignment to AOT (LM) | 6-184 |
| 7-1. | C/M Documentation Requirements - 1 | 7-14 |
| 7-2. | C/M Documentation Requirements - 2 | 7-15 |
| 7-3. | C/M Documentation Requirements - 3 | 7-16 |
| 7-4. | LM Documentation Requirements - 1 | 7-17 |
| 7-5. | LM Documentation Requirements - 2 | 7-18 |
| 7-6. | Block II Specification, Family Tree | 7-20 |

ILLUSTRATIONS (Cont.)


| Figure | Title | Page |
|---|---|---|
| 7-7. | LM Specification, Family Tree | 7-21 |
| 7-8. | Procurment Specification Workload | 7-22 |
| 7-9. | Block II/LM, Internal Specification Status | 7-23 |
| 7-10. | Block II, Manual Revision Status | 7-24 |
| 7-11. | ADP and RIB Status | 7-25 |
| 8-1. | Field Operations Organization Chart | 8-2 |
| 8-2. | Field Operations Site Tenure | 8-3 |
| 8-3. | AOT/LM Test Station | 8-6 |
| 8-4. | Universal Test Station (TYP) G & N Lab Area | 8-7 |
| 8-5. | S/C-C/O Area | 8-8 |

## TABLES


| Table | | Page |
|---|---|---|
| 2-1 | KI Facilities Utilized on Apollo . . . . . . | 2-8 |
| 2-2 | MIT Resident Support . . . . . . . . . . . . | 2-11 |
| 2-3 | Field Operations Manpower . . . . . . . . . | 2-13 |
| 2-4 | Manloading (Equivalent Man Hours) . . . . . . | 2-18 |
| 2-5 | Contract Target Verses Actual Hours . . . . | 2-18 |
| 2-6 | Active TD's (3 pages) . . . . . . . . . . . | 2-22 |
| 2-7 | Overscope TD's . . . . . . . . . . . . . . . | 2-24 |
| 2-8 | Technical Directive Manhours Planned/ Expended (6 pages) . . . . . . . . . . . | 2-26 |
| 2-9 | First Increment Status . . . . . . . . . . . | 2-43 |
| 2-10 | KI Reports (13 pages) . . . . . . . . . . | 2-61 |
| 2-11 | Project Engineering Reports (4 pages) . . . | 2-74 |
| 4-1 | Optical Unit, Drawing Status . . . . . . . . | 4-9 |
| 4-2 | Map and Data Viewer Drawing Status . . . . . | 4-10 |
| 4-3 | Optical Unit Block I, Drawing Status . . . . | 4-23 |
| 4-4 | Optical Unit Block II, Drawing Status . . . | 4-23 |
| 4-5 | Block I Map & Data Viewer, Drawing Status . . | 4-24 |
| 4-6 | Motor Generator Axis Error . . . . . . . . . | 4-26 |
| 4-7 | Finalized TDRR Action . . . . . . . . . . . | 4-38 |
| 4-8 | Module Assembly Revisions . . . . . . . . . | 4-48 |
| 4-9 | Calculation of Radiated Heat Transfer from Rotor to Stator . . . . . . . . . . . . | 4-80 |

TABLES (Cont'd)


| Table | | Page |
|---|---|---|
| 4-10 | 64X Res[illegible]es . . . . . . . . . . . . . | 4-82 |
| 4-11 | 64X Resolver, Clifton . . . . . . . . . . . . . | 4-82 |
| 4-12 | Functional Tester Compatibility . . . . . . . . | 4-109 |
| 4-13 | Angular Repeatability Requirements . . . . . | 4-117 |
| 4-14 | SXT SDA Test Data Summary . . . . . . . . . . | 4-136 |
| 4-15 | SXT SDA Nonrepeatability Summary . . . . . . | 4-137 |
| 4-16 | Spring Back Magnitudes . . . . . . . . . . . . | 4-168 |
| 4-17 | Material Performance . . . . . . . . . . . . . | 4-169 |
| 4-18 | Program Outline . . . . . . . . . . . . . . . . | 4-175 |
| 5-1 | Reliability Test Fixture Status . . . . . . . . | 5-15 |
| 5-2 | Internal/External Failures (6 pages) . . . | 5-44 |
| 5-3 | Reliability Test Fixture Status (6 pages) . | 5-80 |
| 5-4 | Reliability Part Qualification Program Environmental Tests (2 pages) . . . . . . . . | 5-87 |
| 5-5 | Reliability Subassembly Qualification Program Environmental Tests (2 pages) . . . | 5-98 |
| 5-6 | LM Subsystem Qualification Status . . . . . . | 5-128 |
| 5-7 | LM Documentation Status . . . . . . . . . . . | 5-128 |
| 5-8 | Apollo Parts Qualification Status . . . . . . | 5-129 |
| 5-9 | Failure Analysis Completed (4 pages) . . . . | 5-132 |
| 5-10 | AOT Qualification Failure Summary (3 pages) . | 5-141 |

TABLES (Cont'd)

| Table | | Page |
|---|---|---|
| 5-11 | Apollo Parts Qualification Status . . . . . . | 5-150 |
| 5-12 | LM Documentation Status . . . . . . . . . . . | 5-152 |
| 5-13 | LM Subsystem Qualification Status. . . . . . | 5-152 |
| 5-14 | OUA Design Problem Status . . . . . . . . . . | 5-153 |
| 5-15 | AOT Design Problem Status . . . . . . . . . . | 5-155 |
| 5-16 | Physical Investigation (2 pages) . . . . | 5-164 |
| 5-17 | Stress Analysis (2 pages). . . . . . . . . | 5-166 |
| 5-18 | OUA Design Problem Status. . . . . . . . . . . | 5-175 |
| 5-19 | AOT Design Problem Status . . . . . . . . . . | 5-176 |
| 6-1 | Management Problems Resolved (5 pages) . . | 6-22 |
| 6-2 | Command Module/Lunar Excursion Module. . . . | 6-27 |
| 6-3 | Nonconforming Material Evaluation for 1965 Reporting Periods . . . . . . . . . . . . | 6-30 |
| 6-4 | Procurement Material Review Action for 1965 Reporting Periods . . . . . . . . . . . . | 6-31 |
| 6-5 | Status of ND 1015404 Supplier Surveys. . . . | 6-33 |
| 6-6 | Detailed Status of Active Conditionally Approved Sources . . . . . . . . . . . . . . . | 6-34 |
| 6-7 | Detailed Status of Inactive Conditionally Approved Sources. . . . . . . . . . . . . . . . | 6-35 |
| 6-8 | Detailed Status of Limited Approval Sources (3 pages). . . . . . . . . . . . . . . . . . | 6-36 |

TABLES (Cont'd)


| Table | | Page |
|---|---|---|
| 6-9 | Quality Control Supplier Survey Visits (4 pages) . . . . . . . . . . . . . . . . . . | 6-40 |
| 6-10 | Quality Control Supplier Resurvey Visits . . | 6-44 |
| 6-11 | Quality Control Supplier Surveillance Visits (2 pages) . . . . . . . . . . . . . . . | 6-45 |
| 6-12 | Quality Control Supplier Surveillance and Negotiation Vists . . . . . . . . . . . . | 6-47 |
| 6-13 | In-House Conferences with Suppliers (2 pages) . . . . . . . . . . . . . . . . . . | 6-48 |
| 6-14 | ND 1015404 Class I & II Suppliers Command Module/Lunar Excursion Module . . . | 6-50 |
| 6-15 | ND 1015404 Process & Documentation Command Module/Lunar Excursion Module . . . | 6-51 |
| 6-16 | Purchase Requisitions & Orders Processed-Command Module . . . . . . . . . . . . . . . . | 6-52 |
| 6-17 | Purchase Requisitions & Orders Processed Lunar Excursion Module . . . . . . . . . . . | 6-53 |
| 6-18 | Job Parts List Releases Command Module/Lunar Excursion Module . . . | 6-53 |
| 6-19 | Quality Rating Status Chart . . . . . . . . . | 6-55 |
| 6-20 | Procurement Problem Areas (4 pages) . . . . | 6-59 |
| 6-21 | Procurement Problems Resolved (6 pages) . . | 6-63 |
| 6-22 | Inspection Procedures Processed (CM) . . . . | 6-70 |
| 6-23 | Inspection Procedures Processed (LM) . . . . | 6-70 |
| 6-24 | Problem/Corrective Action Status (2 pages). | 6-75 |

TABLES (Cont'd)


| Table | | Page |
|---|---|---|
| 6-25 | Command Module/Lunar Excursion Module Parts/Optics Fabrication-Inspected/ Rejected | 6-77 |
| 6-26 | Command Module/Lunar Excursion Module Assembly Fabrication - Inspected/ Rejected | 6-77 |
| 6-27 | In-House Material Review Action Command Module/LM | 6-80 |
| 6-28 | In-House Fabrication Problems Resolved Command Module/Lunar Excursion Module (5 pgs) | 6-84 |
| 6-29 | Control of Areas Limited to Authorized Personnel | 6-90 |
| 6-30 | Electrical Standards Laboratory Audit | 6-91 |
| 6-31 | Plating & Finishing Facility Audit | 6-91 |
| 6-32 | Raw Material Stockroom Audit | 6-92 |
| 6-33 | Failure Data Feedback System Audit | 6-92 |
| 6-34 | Material Review Board Audit | 6-93 |
| 6-35 | Drawing Change Control Audit | 6-93 |
| 6-36 | Procurement Problem Areas | 6-104 |
| 6-37 | Procurement Problems Resolved (5 pages) | 6-105 |
| 6-38 | Problem/Corrective Action Status (2 pages) | 6-110 |
| 6-39 | Detailed Status of Active Conditionally Approved Sources | 6-112 |
| 6-40 | Detailed Status of Inactive Conditionally Approved Sources | 6-113 |
| 6-41 | Quality Control Supplier Survey Visits (2 pages) | 6-114 |

TABLES (Cont'd)


| Table | | Page |
|---|---|---|
| 6-42 | Quality Control Supplier Surveillance Visits | 6-117 |
| 6-43 | Quality Control Supplier Surveillance and Negotiation Visits | 6-118 |
| 6-44 | In-House Conferences with Suppliers at Kollsman | 6-119 |
| 6-45 | ND 1015404 Class I & II Suppliers | 6-120 |
| 6-46 | ND 1015404 Critical Process Lists Required | 6-121 |
| 6-47 | Hardware Audit Conformance | 6-122 |
| 6-48 | Receiving Inspection | 6-123 |
| 6-49 | Plating and Finishing/Parts Inspection | 6-124 |
| 6-50 | Optical Fabrication | 6-124 |
| 6-51 | Electrical Standards Laboratory | 6-126 |
| 6-52 | Optical Inspection | 6-126 |
| 6-53 | Finished Parts Stockroom | 6-127 |
| 6-54 | Limited Shelf Life Articles | 6-127 |
| 6-55 | Test Equipment Laboratory | 6-128 |
| 6-56 | Model Parts Shop | 6-129 |
| 6-57 | In-Process Inspection Model Parts Shop | 6-130 |
| 6-58 | Final Inspection | 6-131 |
| 6-59 | Procedural Audits Summary | 6-134 |
| 6-60 | Percent of Conformance (5 pages) | 6-136 |
| 6-61 | Summary Document Review | 6-144 |

TABLE (Cont'd)


| Table | | Page |
|---|---|---|
| 6-62 | Material Received for Command Module/ Lunar Excursion Module | 6-145 |
| 6-63 | Procurement Material Review Action for Command Module/Lunar Excursion Module | 6-147 |
| 6-64 | Material Review Corrective Action Status | 6-149 |
| 6-65 | ND 1015404 Status Command Module/ Lunar Module | 6-152 |
| 6-66 | Parts/Optics Fabrication-Inspected/ Rejected | 6-154 |
| 6-67 | Assembly Fabrication-Inspected/ Rejected | 6-156 |
| 6-68 | In-House Material Review Action | 6-158 |
| 6-69 | Material Received Command Module/ Lunar Module | 6-170 |
| 6-70 | Procurement Material Review Action Command Module/Lunar Module | 6-171 |
| 6-71 | Material Review Corrective Action Status Command Module/Lunar Module | 6-172 |
| 6-72 | ND 1015404 Status Command Module/ Lunar Module | 6-175 |
| 6-73 | Parts/Optics Fabrication-Inspected/ Rejected | 6-177 |
| 6-74 | Assembly Fabrication-Inspected/Rejected | 6-177 |
| 6-75 | In-House Material Review Action | 6-178 |
| 7-1 | Apollo Specification Status | 7-6 |
| 7-2 | Apollo Specification Prepared and Submitted to NASA | 7-10 |
| 8-1 | Kollsman F/O Training Schedule | 8-5 |

# SECTION I

# INTRODUCTION

Volume II consists of seven major sections: Management, Technical, Engineering, Reliability, Quality Assurance, Documentation and Field Operations. These sections are presented in chronological order to enable the reader to follow the progress of the Apollo Program from 1962 to its completion in 1969. Volume II is further further divided into two parts:


| | | |
|---|---|---|
| <u>Part 1</u> | Section 1 | Introduction |
| | Section 2 | Program Management |
| | Section 3 | Technical Approach |
| | Section 4 | Engineering |
| <u>Part 2</u> | Section 5 | Reliability |
| | Section 6 | Quality Assurance |
| | Section 7 | Documentation |
| | Section 8 | Field Operations |


The year 1969 marked the culmination of the Apollo effort with the successful moon landing of Apollo 11.

The Apollo program structure during this period was subjected to a continuous streamlining in order to keep it in consonance, both cost and schedule wise, with the rapidly shifting Apollo requirements that prevailed.

The mission of Kollsman's Apollo effort did not end with the Apollo 11 moon mission, nor with the end of the contract NAS 9-497 in December 1969, but will continue for the duration of the follow-on contract NAS 9-10356 until the end of 1972, supplying the same professional support and management excellence to the support phase as was rendered to the development and manufacturing phases.

Section 2

# APOLLO PROGRAM MANAGEMENT

## 2.1 INTRODUCTION

The Apollo Project was a unique program demanding outstanding management talents and disciplines. Since the inception of Apollo, Kollsman Corporate management has recognized this need and has dedicated its efforts to the success of this undertaking. Toward this end, it provided a projectized program organization whose sole function was the successful execution of all aspects of the program. This resulting organization prevailed throughout the entire Apollo effort, successfully meeting the challenges and demands of this dynamic program.

Kollsman management achievements and its record of performance becomes specially noteworthy when consideration is given to the unique character of the interrelationship that existed between ACED and KI on a subcontract basis with MIT retaining overall responsibility for design direction of the program. Within this complex interface, Kollsman management was able to create optimum coordination by blending its action and philosophies smoothly into the overall plan to achieve the mutual mission objectives.

Kollsman's expertise in the management of this complex technical task was further enhanced by the fact that its record of high level performance was achieved within the constraints of a rigid cost control and cost reduction program. The effectiveness of this cost conscious climate is dramatically shown by the $1 million underrun that was achieved. Kollsman management instituted several vigorous cost reduction programs, several of which resulted in recommendations to reduce scope which were subsequently acted upon.

In summary, Kollsman Apollo management continually provided the organization, facilities, manpower guidance, control, support, and priorities necessary to fulfill all Apollo commitments.

This report is an account of this management role. It provides the details of management's record of performance along with the philosophy of operation.

## 2.2 CONTRACT VALUE

Kollsman executed the Apollo Program under two (2) discrete contracts:

NAS 9-499 - January 1962 through July 1964 - KI prime to NASA

NAS 9-497 - July 1964 through December 1969 - KI subcontractor to ACED

Figure 2-1 shows the target costs of $38,137,000 and the actual costs of $36,900,000 related to NAS 9-497 (FNP 12726) and the resultant underrun of approximately $1,200,000.

Figure 2-2 shows the allocation of this total expenditure for each discipline.

## 2.3 ORGANIZATION

The Kollsman Apollo Project organization changes are shown in Figures 2-3 and 2-4. Figure 2-3 shows the organization in the early manufacturing and development stages of the Apollo contract while Figure 2-4 shows the later organization structure which prevailed through a large part of the contract. Subsequent changes occurred at planned intervals in response to changing requirements of the program and insured optimum management mesh at all times.

### 2.3.1 Responsibilities

#### 2.3.1.1 Programs Director

The Programs Director served as Kollsman's principal contact with the customer, established operating policies and made program policy decisions. He coordinated the activities being implemented by subordinate specialized managers. He supervised all program planning, reviewed all subcontractor changes in technical requirements, cost or schedules and established adequate technical and management liaison and control of subcontractors, flow of cost and technical information and system engineering control.

The Apollo/LM Programs Director reported directly to the Space Division General Manager.

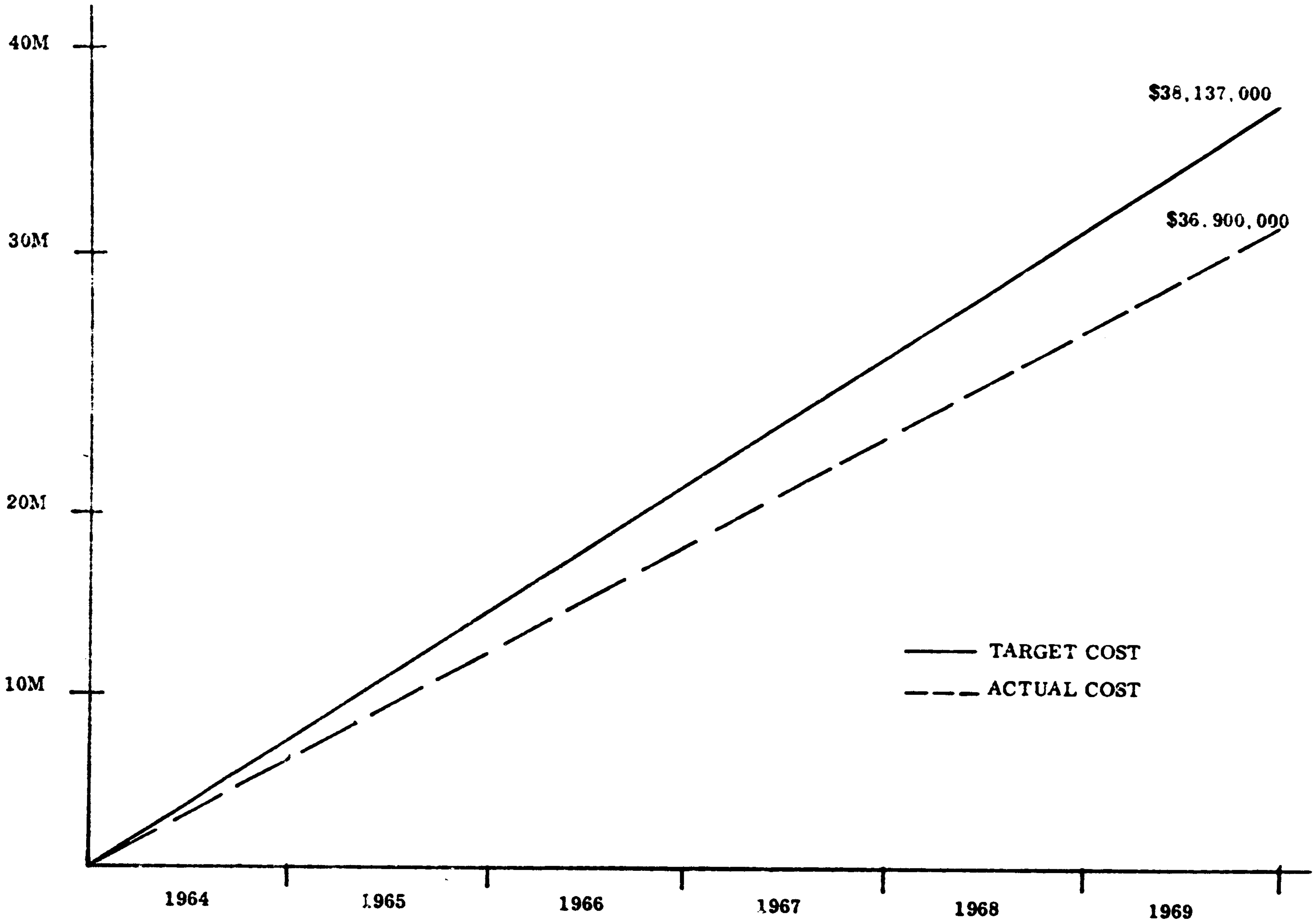



Figure 2-1. Target Costs and Actual Costs

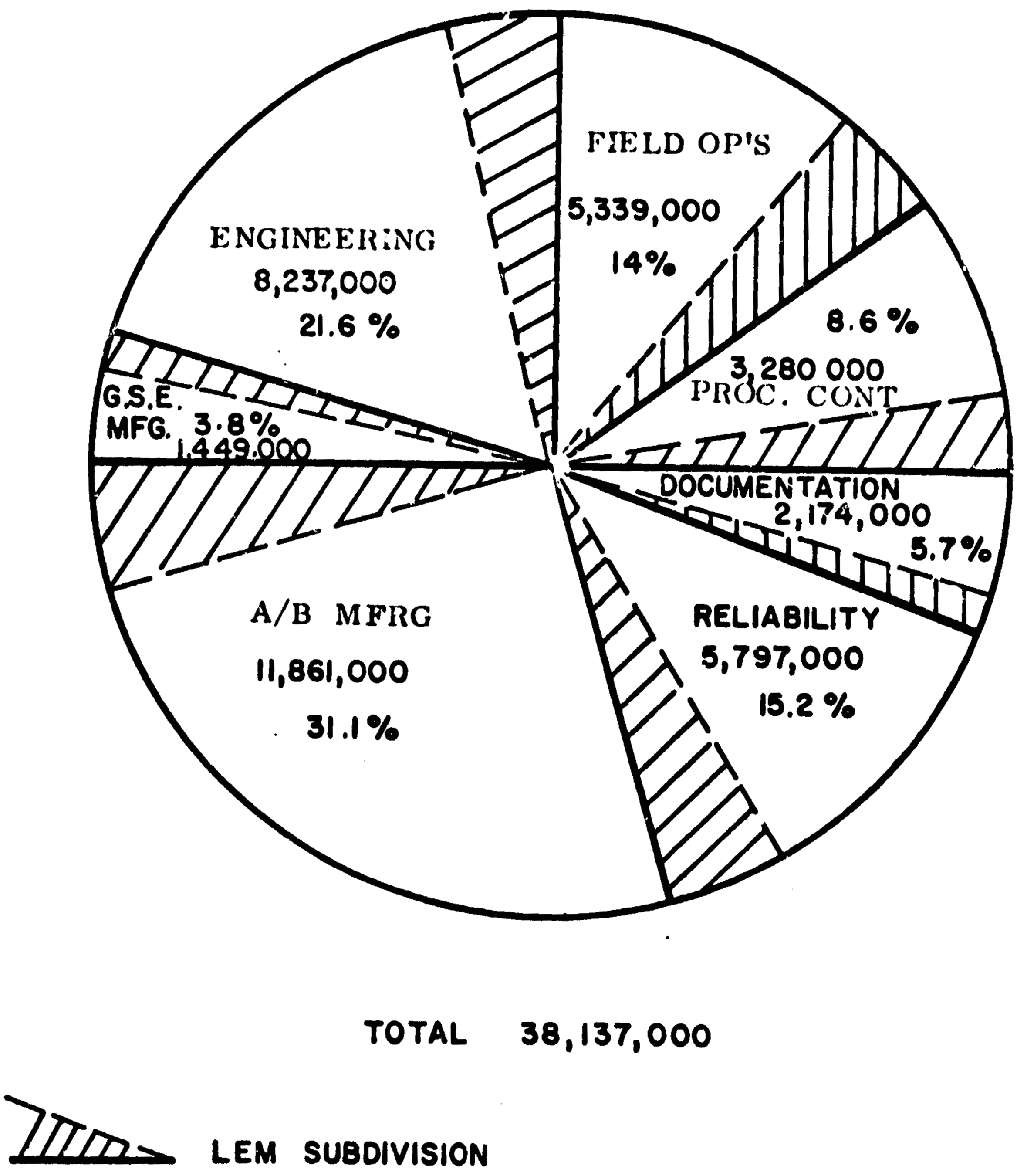



Figure 2-2. Apollo Program Subdivision of Funds Summary Chart

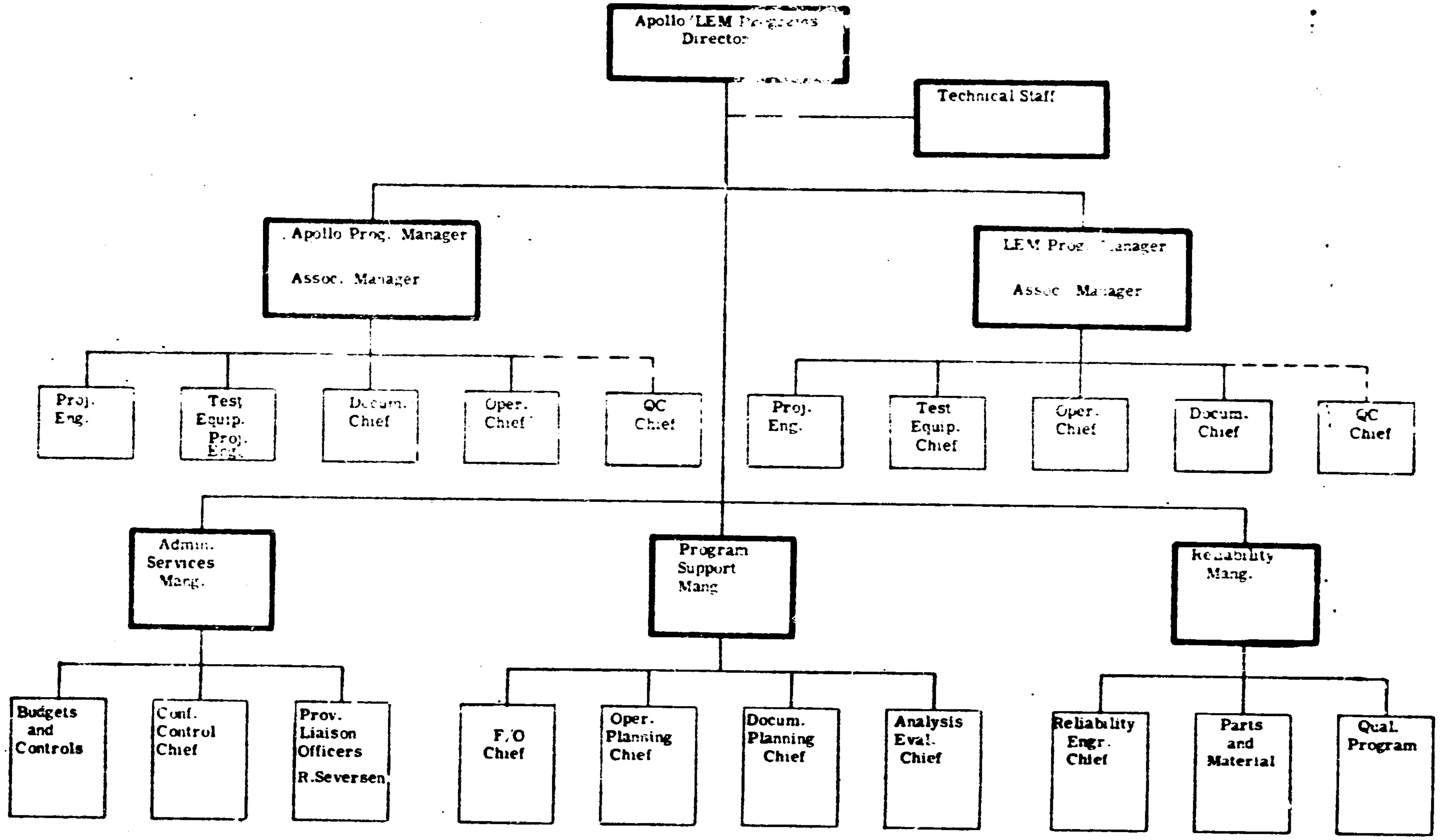



Figure 2-3. Apollo Organization
(Early Manufacturing and Development)

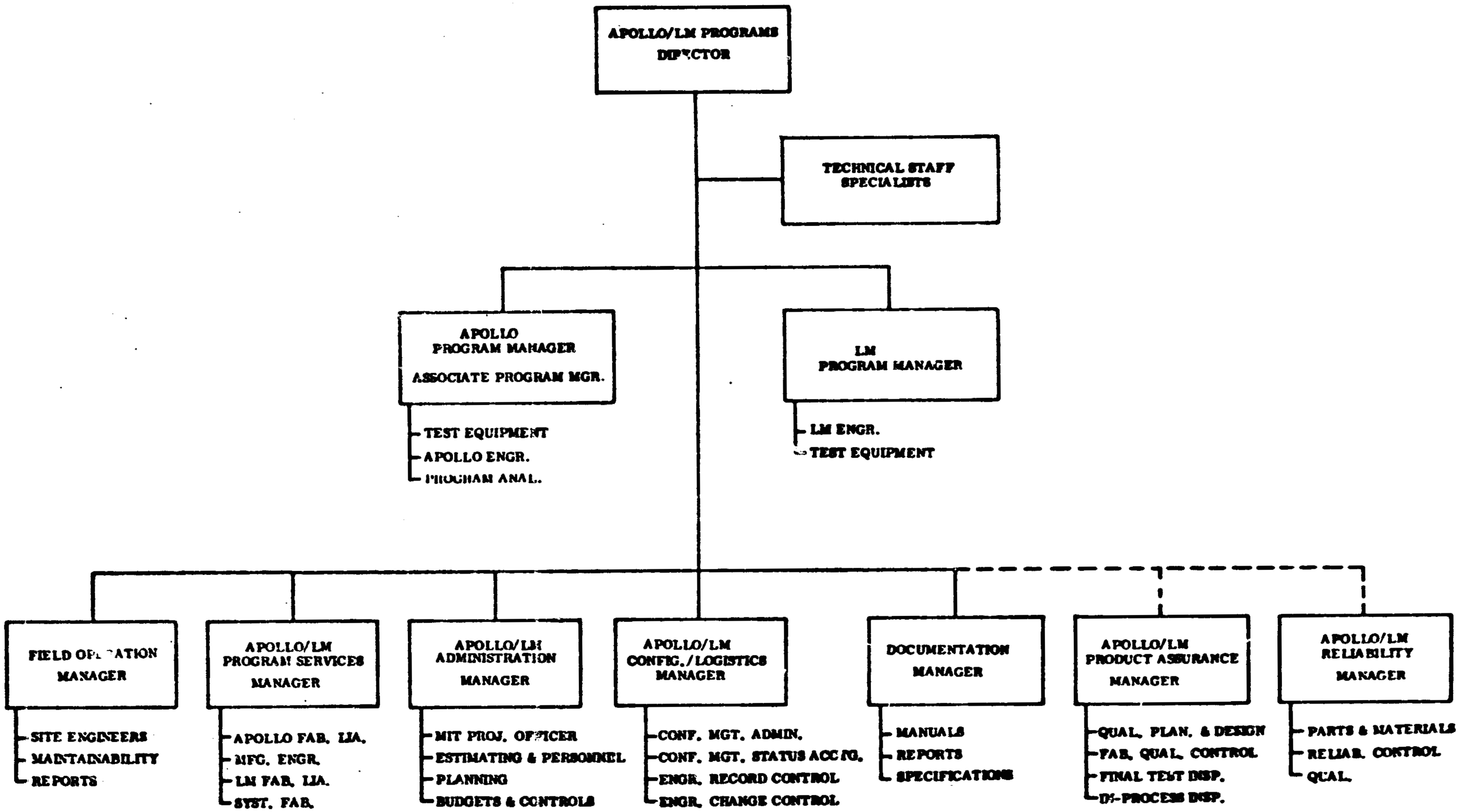



Figure 2-4. Apollo/LM Program Organization

2.3.1.2 Managers Responsibilities

- Program Management and Direction
- Program Planning
- Program Coordination and Liaison with Kollsman, MIT/IL and AC.
- Program Reviews
- Program Control
- Negotiations and Proposals
- Special Activities

The responsibilities and activities of the other disciplines include: Engineering, Reliability, Quality Control (Product Assurance), Documentation and Field OPerations. They are detailed in chronological order in later sections of Volume II of this final report.

## 2.4 FACILITIES

### 2.4.1 Syosset Facilities

The modern plant at Syosset was primarily devoted to the manufacture and assembly of instrumentation for complex space programs, missiles, and electronics system prior to the Apollo program.

These facilities provided administrative and engineering offices, laboratories and complete manufacturing operations. The facilities were further supported by environmental test installations, experimental laboratories, tool manufacturing, production control, inspection, quality control and product assurance, purchasing and personnel activities.

When the Apollo program began, Kollsman management allocated and spent an additional 1.5 million dollars to add special Apollo equipment and facilities to this complex. This resulted in a Syosset facility that was completely "space oriented" and equipped from high level Class III clean rooms to special Beryllium model shops. Table 2-1 details the KI facilities used on Apollo.

SUMMARY

As shown, Apollo management had provided the finest facilities and capability for the execution of the Apollo Program. These facilities were available throughout the course of the program.

Figure 2-5 highlights one of the clean room areas.

## TABLE 2-1

## KI FACILITIES UTILIZED ON APOLLO

Precision Beryllium Machine Shop

6 - Surface Grinders
6 - Precision Lathes
5 - Milling Machines
3 - Drill Presses
2 - Jig Borers
1 - Band Saw
Precision Measurement Equipment
Approved Beryllium Vacuum Facilities

Class 100,000 Clean Room

Opto/Mechanical Assembly Area

Laminar Flow Benches
Optical Alignment Stands
Precision Welding Stands

Potting, Cleaning and Piece Marking Area

Ultrasonic Cleaning Equipment
Vacuum Ovens

Kollsman Laboratories

Metrology Laboratory

Coorindate Measuring Machine
Stereo Microscope
Spectroradiometer

Environmental Test Laboratory

Dual Thermal Vacuum Chamber
Solar Simulator
Sine/Random Vibration Exciter
Shock Machines
Miscellaneous Test EQuipment

Engineering and Administrative facilities were rearranged to meet new Apollo organizational concepts as well as meet AC Resident requirements.

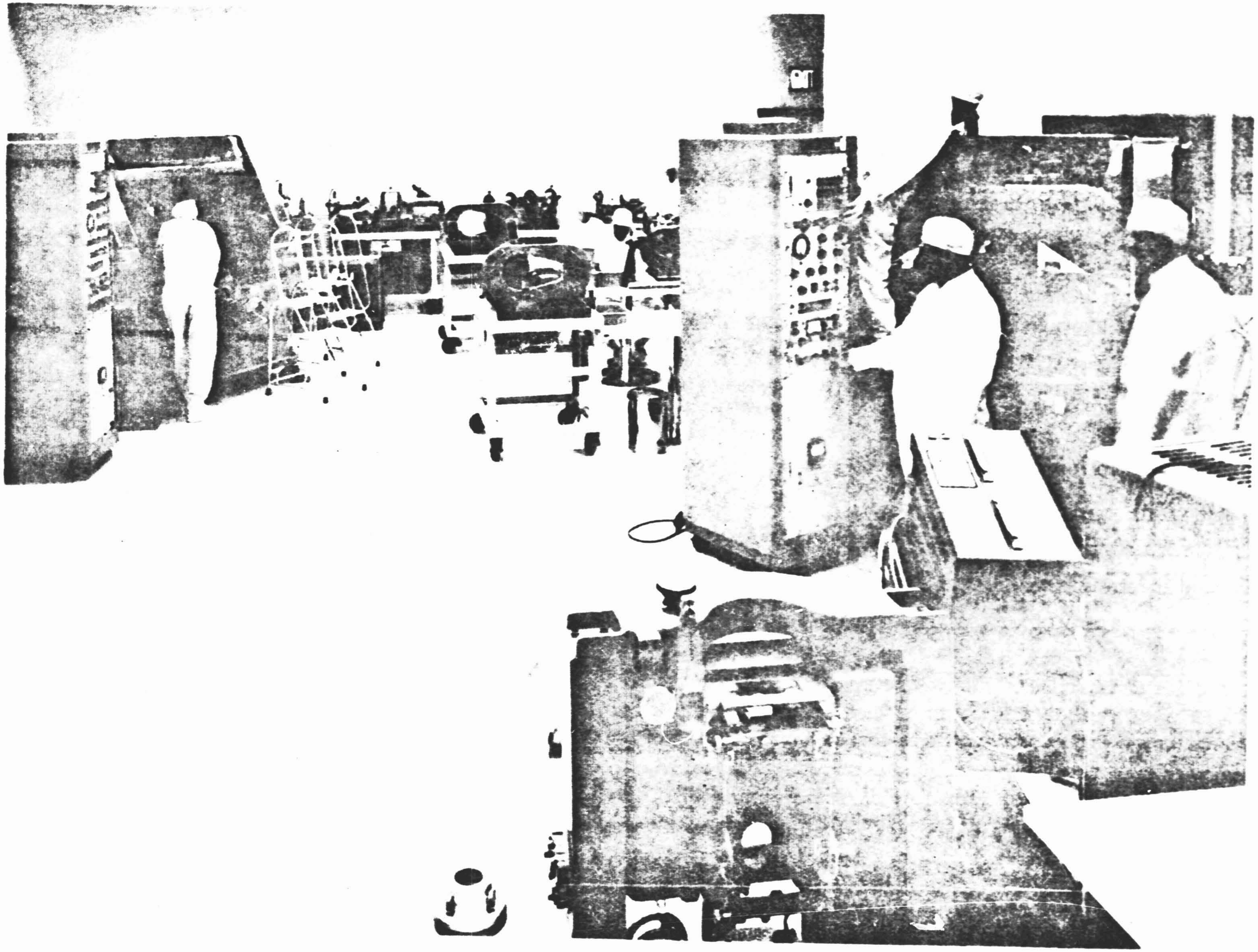


Figure 2-5. OUA/AOT Assembly and Test Area, Clean Room

## 2.5 MANPOWER

The longevity of individual personnel assignments had been a most important factor in the success of this program. The majority of people assigned to Apollo prior to novation remained throughout the program, thus ensuring continuity of support both to Kollsman and AC in the subcontract relationship.

### 2.5.1 MIT Resident Support

Table 2-2 details the tenure of the MIT Resident Support. It is to be noted that 96% of the personnel assigned to MIT remained in residence until completion of assignments.

Figure 2-6 summarizes the total MIT Resident coverage from 1962 through 1966 when planned reductions were made. A dotted line indicates the time of novation.

Anticipating broad scope of assistance that these personnel would provide, Kollsman Apollo management assigned only experienced and well trained personnel in the disciplines required. The average years of experience of this assigned personnel was in excess of 15 years. The engineering mesh that was achieved between the MIT design group and Kollsman internal engineering was optimum and allowed expeditious action in many areas even before design was solidified. The detail activity of this group is discussed under Engineering in Volume II and is testimony to their effectiveness.

### 2.5.2 Field Assignments

Table 2-3 details the tenure of the Field personnel at all sites. Here again, the continuity of personnel can be noted with no turnover in personnel at any site.

Figure 2-7 summarizes the total field activity from 1964 through 1969.

Figure 2-8 shows the geographical location of the field personnel at the various sites: NAA, MSC, KSC, GAEC and AC.

Here again as in the MIT support, Apollo management not only supplied highly qualified personnel, but made the assignments and relocations on a timely basis with no impact to mission G & N objectives. The details of activity of this group is discussed under Field Operations in Volume II and demonstrates the superior performance that they consistently rendered under very demanding conditions. Round the clock support operations were not uncommon during the compressed stages prior to the first Apollo flight. The award by NASA of membership in the "Snoopy" Club to the Kollsman, North American Field Site engineer was an award not only to the individual but to the entire Kollsman field support effort.

TABLE 2-2

MIT RESIDENT SUPPORT

Tenure from 6/62 - 6/66:

| | |
|---|---|
| Total number of personnel assigned: | 26 |
| Period of assignment: | |
| Longer than 3 years | 12 |
| Longer than 2 years | 19 |
| Longer than 1 year | 24 |
| Less than 1 year (Short Term Assignments) | 6 |

Qualified personnel for short and long terms consistently assigned upon MIT/IL and A.C. Electronics request.

96% of the personnel at MIT since novation remained in residence until completion of assignments.

| | |
|---|---|
| Average years at KI: | 8.9 |
| Average years of experience: | 15.4 |

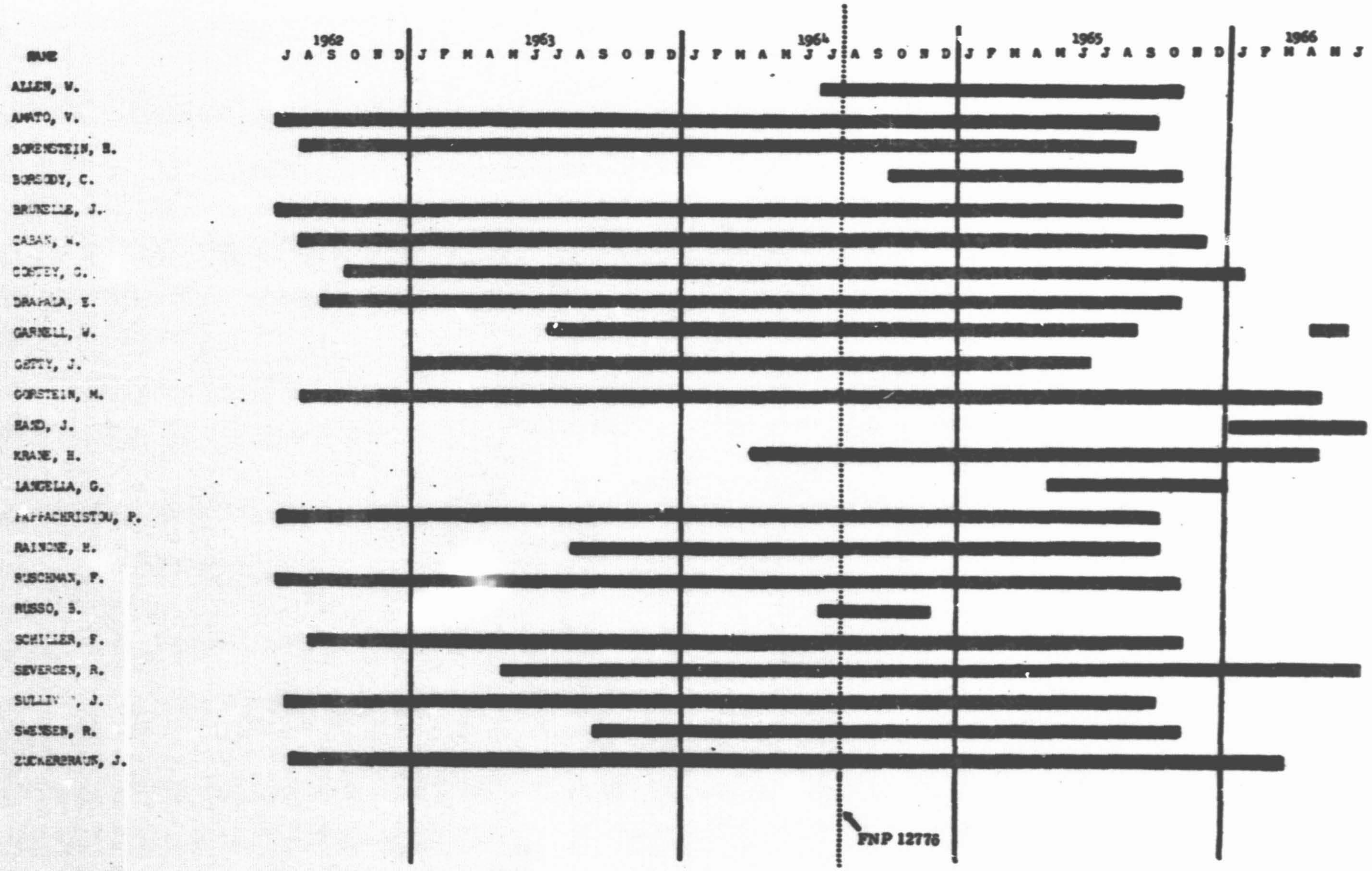



Figure 2- 6. Total MIT Residents

KOLLSMAN INSTRUMENT CORPORATION

## TABLE 2-3

## FIELD OPERATIONS MANPOWER

Total number of personnel assigned: 19

Period of Assignment:

| | |
|---|---|
| Longer than 2 years | 7 |
| Longer than 1 year | 11 |
| Less than 1 year | 8 |

No turnover in personnel at any Site.

Qualified personnel were always available for Field Site assignment upon the request of A. C. Electronics.

| | |
|---|---|
| Average years at KI: | 3.5 |
| Average years of experience | 14 |

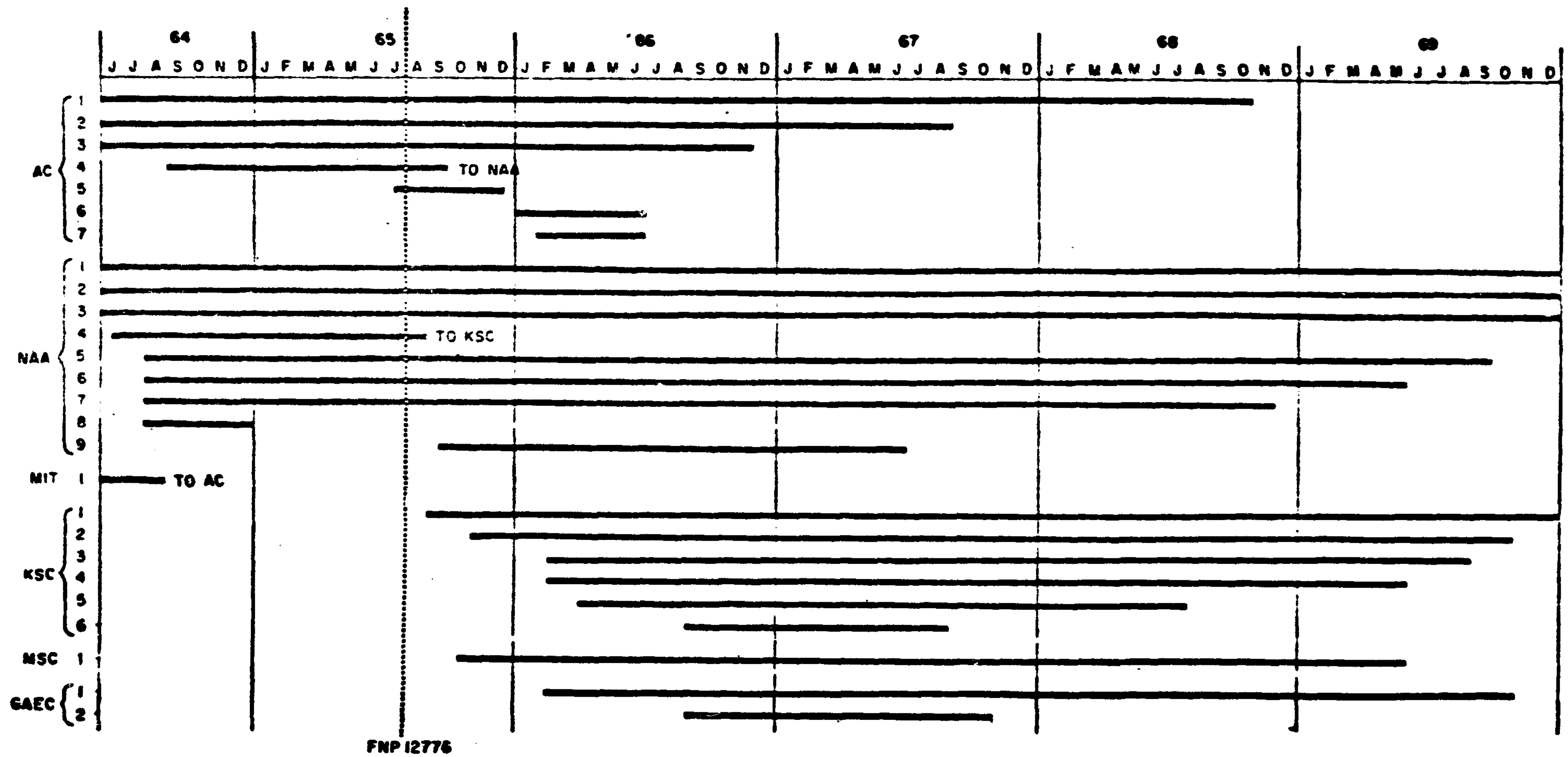



Figure 2-7. Field Activity Site Assignments

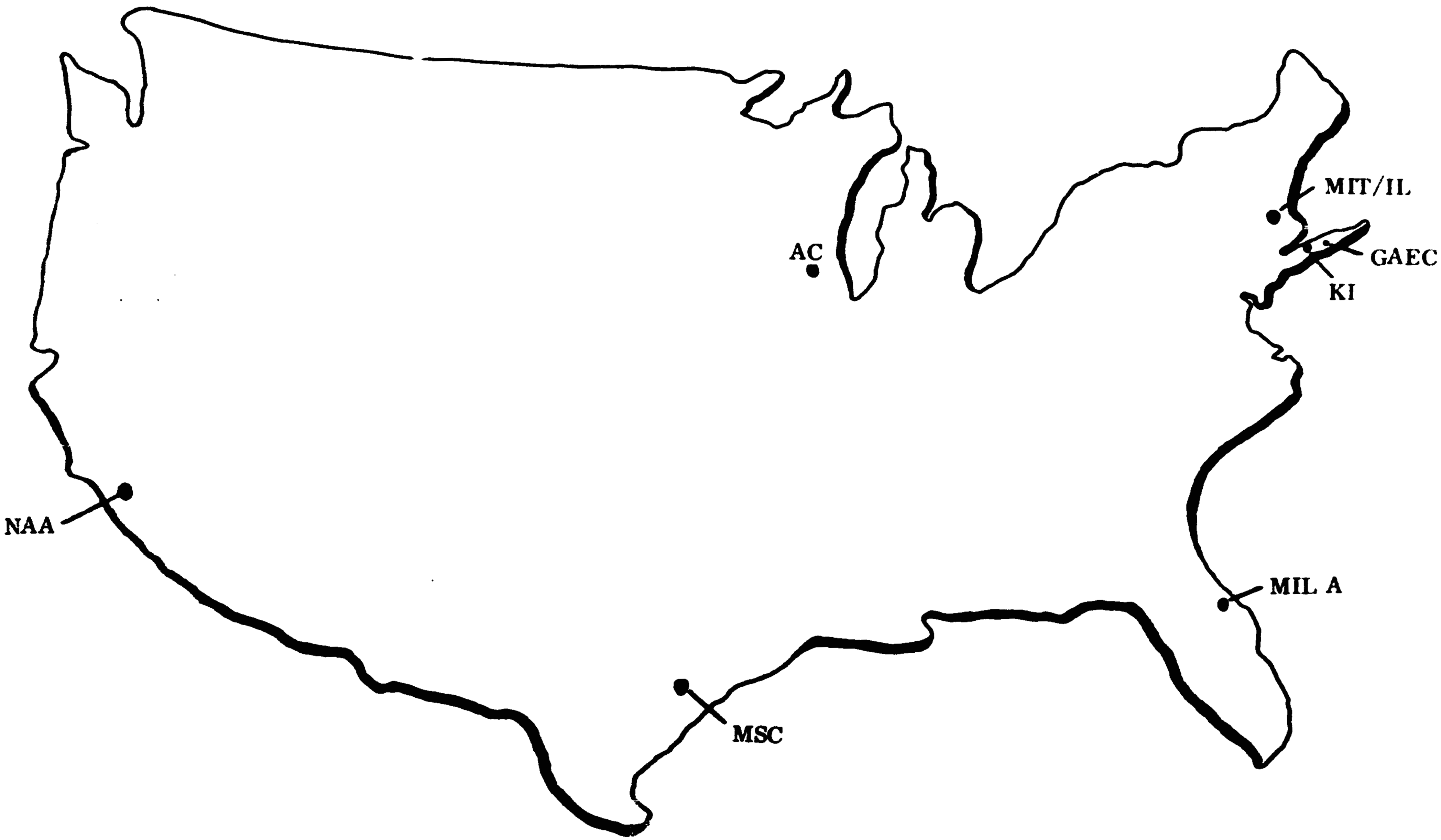



Figure 2-8. CM/AOT Field Site Deployment Map

### 2.5.3 In-House Engineering

As part of Apollo management's dedication to the success of Apollo, senior engineers with outstanding capabilities in optics, mechanical engineering, test equipment design and fabrication and production engineering were assigned to Apollo on a full-time basis. This impressive array of talent was assigned early in the program and remained with practically no turn-over for the entire period that their services were required. In addition, Apollo management made available, when required, specialists in structural and thermal evaluation, electrical engineering, component engineering and chemistry.

### 2.5.4 Manufacturing

Kollsman management, recognizing that skilled optical/mechanical/electrical technicians would be required to assemble the Apollo hardware under exacting conditions, instituted an intensive training program including both "on the job" (learner's model) and classroom instruction. They additionally provided a highly skilled technical lead man for each assembly group to monitor and assist in special problem areas. Management's services in this area is highlighted by the fact that in a recorded period of 4,193 OUA operating hours, there were no significant failures. In addition, performance of the optical units in the field was at such a high level of integrity that the program requirements for spares support had been drastically reduced from what was envisioned as normal logistics support requirements at the outset of a program of this scope.

#### SUMMARY

Kollsman Apollo management did succeed in supplying and assigning highly qualified personnel to the required disciplines. They additionally succeeded in motivating this personnel to do their job professionally and expeditiously within the constraints of maintaining high quality and minimizing costs.

### 2.6 MANLOADING

Manpower loading on the Apollo Program presented a special challenge to Apollo management. Plans were made to staff the program, commensurate with the time phasing of the various efforts of work. Accordingly, a projected manpower curve was established.

Table 2-4 provides the actual man-loading information based on equivalent man hours from 1964 through 1969.

This chart clearly indicates the build-up of manpower when many varied activities were at their peak.

It can be noted also that in the interests of cost reduction, Apollo management effected a large decrease in personnel during 1966. (Ref. next paragraph on cost reduction plan.) A further levelling off occurred during 1967 and early 1968 followed by a planned decline to the end of the contract. It is interesting to note that a slight increase interrupted this decline in the first quarter of 1969. This was due to the impact of designing and producing the rangefinder.

Figure 2-9 is a manhour profile which is included to show the effects of a major cost reduction plan that Apollo management launched during 1966. As the chart shows, the target hours for completion at that time was 2,461,372; whereas, after the implementation of the cost reduction plan, this target was reduced to 2,236,000 hours. Upon completion of the Apollo contract in December 1969, the target contract hours were 2,321,000 and the actual hours expended were 2,177,100, a total even lower than the cost reduction target projected in 1966. Table 2-5 sums up this information in chart form.

<u>SUMMARY</u>

The final results of the Apollo contract confirm that Apollo management handling of manpower was most effective. Not only was a highly efficient and skilled labor effort developed and utilized, but it was accomplished within the constraints of a rigid cost reduction plan.

## TABLE 2-4

### MAN LOADING (EQUIVALENT MAN HOURS)

| July 1964 | 1965 | | | | 1966 | | | | 1967 | | | | 1968 | | | | 1969 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| QTRS | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 |
| 157 | 395 | 525 | 560 | 460 | 370 | 347 | 252 | 190 | 163 | 121 | 121 | 121 | 121 | 118 | 94 | 77 | 82 | 67 | 50 | 40 |

## TABLE 2-5

### CONTRACT TARGET VERSUS ACTUAL HOURS

| | Estimate 1966 | Actual 1969 |
|---|---|---|
| Contract Target | 2,461,372 | 2,321,000 |
| Cost Reduction | 2,236,000 | 2,177,000 |

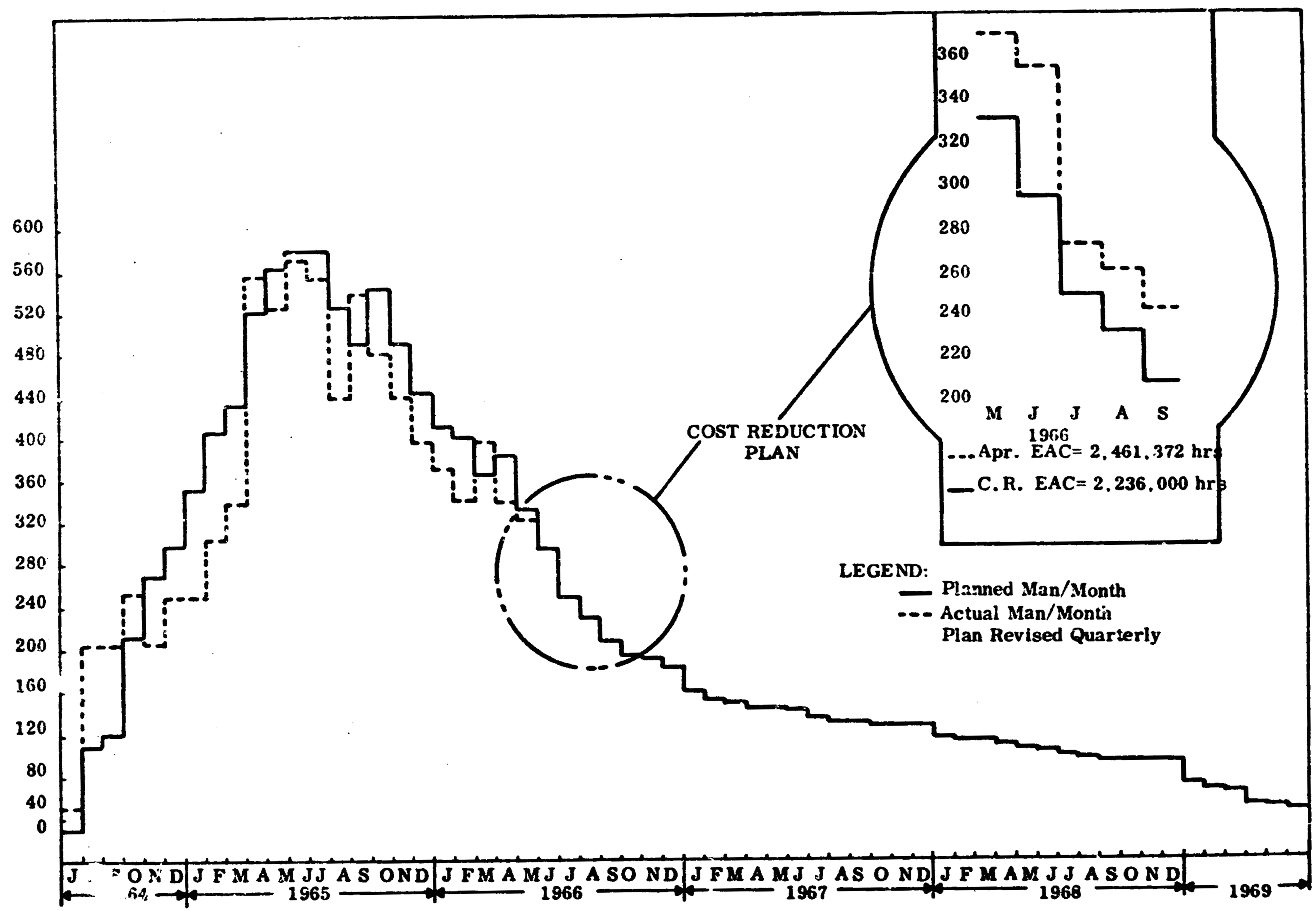



Figure 2-9. Manpower Manhour Profile
Apollo/LEM Total Program

## 2.7 CONTRACT ACTIVITY

### 2.7.1 Prior to Novation

NASA-MSC (Manned Spaceflight Center) and Kollsman entered into Letter Contract NAS 9-499 for a 90 day period on 28 May 1962. The total letter contract authorized expenditure at that time was $240,000.00. On 16 August 1962 Kollsman received Amendment No. 1 authorizing an additional expenditure of $85,000.00 and extending the expiration date of the contract to 30 September 1962. Amendment No. 2 further increased the authorized funding limitation and extending the term of the letter contract.

The following is an account of some of the contractual activity that prevailed from the original NASA contract NAS 9-499 through the completion of the Apollo effort under the KI subcontract to AC NAS 9-497.

The master schedule for the major areas of effort are shown in Figure 2-10. As effort was authorized by Technical Directives (TD), hours were assigned from the applicable task. The projected duration of effort was shown by the bar on the figure.

The fully executed definitive contract NAS 9-499 was delivered to Kollsman by NASA/MSC on October 23, 1963. The fully executed copies of Amendments 18 and 19, increasing the funding limitation, were received in December.

A reference listing of active Technical Directives (TD's) at this time is provided in Table 2-6. Table 2-7 lists the overscope TD's.

During the early phase of the NASA/KI contract, the following major events also took place.

A revised proposed (KI Bid No. S/HUM 7-300113A) for the LM Concept Design Program was submitted. The proposal requested authorization to continue the program for two additional months and sought coverage for the additional costs associated with the effort extension. Additional resident effort at MIT for the two month period was not included in the reproposal. Negotation of the proposal for the total effort was performed in the month of December 1963.

On the basis of additional information received from NASA/MSC relative to the Field Operations Statement of Work, a revised proposal (KI Bid No. S/HUM 6-3-0112A) for the CM Field Operations effort was submitted during this quarter. The initial phases of the NASA/KI negotiation of this proposal was begun.

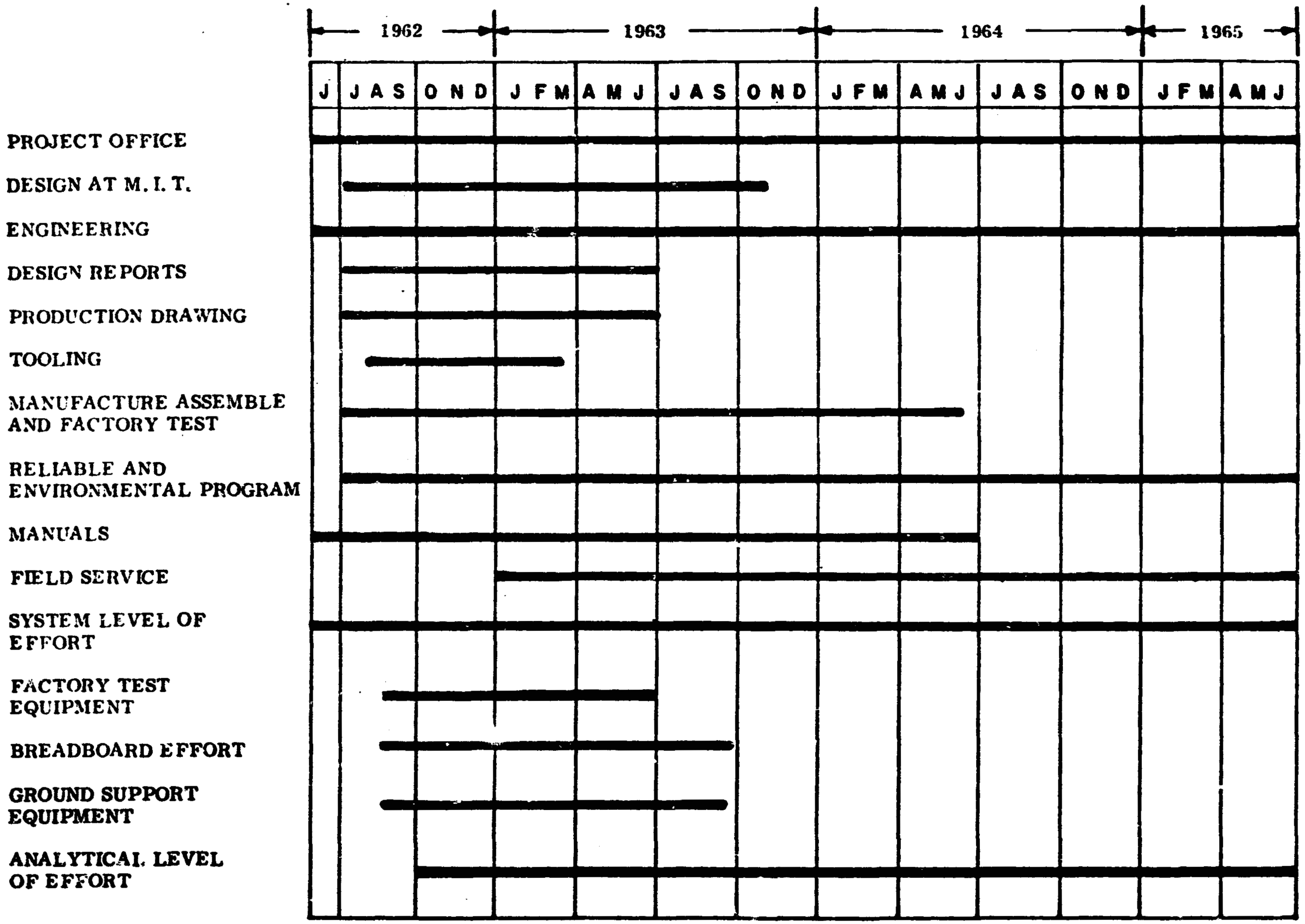



**Figure 2-10. Master Schedule Apollo Program Phasing of Major Tasks**

TABLE 2-6

ACTIVE TD'S

| TD Number | Title |
|---|---|
| 1 | Project Office |
| 5 | External Engineering Effort |
| 7 | PERT |
| 8 | MIT Design and Drafting |
| 10 | Design and Fabrication F.T.E. |
| 11 | Vendor Reliability |
| 12 | Internal Engineering |
| 13 | Engineering Support to B.B. |
| 14 | Manufacturing Planning |
| 19 | Breadboard Manufacture |
| 22 | Design Model Effort |
| 23 | Documentation Administration |
| 26 | Program Progress Reports |
| 28 | Reliability Analysis |
| 29 | Reliability Test Equipment and Planning |
| 30 | Reliability Training |
| 31 | Interface Purch. Proc. and Mtl. Spec. |
| 32 | Display and Control |
| 35 | Map and Data Viewer |
| 41 | Moore Tables (GSE) |
| 42 | Reliability Test Program |
| 44 | Non-Visual Eyepiece |
| 48 | Shipping Container Design |
| 49 | Optic Subsystem Mfr. (Block I) |
| 51 | Computer Support to Resident Effort |
| 53 | MDV Breadboard Manufacture |
| 54 | MDV Manufacture Block I |
| 55 | Optics Design Analysis |
| 56 | Analytical Support (Thrust Vector Control) |
| 57 | Design and Fabrication of MDV (GSE and Additional Tester |
| 58 | Factory Test Plan |
| 60 | Thermal Analysis AGE I |
| 61 | AGE 2 Mechanical Integrity Test |

TABLE 2-6 (Cont'd)

ACTIVE TD'S

| TD Number | Title |
|---|---|
| 62 | Stress Analysis AGE 2 |
| 66 | Optical Subsystem Mock-up |
| 67 | Training Program |
| 68 | F/O Management |
| 69 | F/O Material and Spares Integration |
| 70 | F/O Resident Effort |
| 71 | F/O Procurement Specification |
| 72 | F/O Maintenance Analysis Support |
| 73 | F/O Special Test Equipment |
| 74 | Procure 5" Autocollimators |
| 75 | Design GSE (including addendum) |
| 76 | Failure Reptg. System |
| 77 | Spares Procurement |
| 79 | AGE 1 and 2 MDV Mechanical Integrity and Thermal Analysis |
| 81 | Optics Navigation Base Assembly Shipping Container |
| 82 | Assembly of Optical Subsystems 1,2,3 |
| 83 | AGE 1 Optical Subsystem Thermal/ Vacuum Tests |
| 84 | Breadboard Parts Fabrication - Optics |
| 85 | Procurement of Optical GSE |
| 86 | Design and Fabricate AGE Post Installation Optical GSE |
| 87 | MDV Simulator Fabrication |
| 88 | Fabricate 5 Optical Subsystems 5 MDV |
| 89 | Fabricate 4 Short Ret.Periscope (GSE) |
| 90 | Fabricate 5 Align. Mirrors (GSE) |
| 91 | Fabricate 2 Functional Testers (GSE) |
| 92 | Fabricate Additional 2-1/2" Autocollimators |
| 94 | Design and Procure Optical Wedges |
| 95 | Maintenance and Repair Manuals |
| 96 | Mech. of Resolver Digitizer |
| 97 | MIT Resident Engineer |
| 98 | Thermal Analysis for AGE 1 MDV |
| 100 | Fabricate Long Eye Relief Eyepiece |
| 101 | Breadboard Parts Fab. - Optics |
| 102 | Evaluation of Optical Holding Stands |
| 103 | Procure 4 O.S.S. Shipping Containers |
| 105 | Deployment of Field Test and Operational Personnel |

TABLE 2-6 (Cont'd)

ACTIVE TD'S

| TD Number | Title |
|---|---|
| 106 | Resident Effort |
| 107 | Design and Procure Theodolities |
| 108 | Design and Procure 1-1/2" Autocollimators |
| 109 | Design and Procure Autocollimator Mounting Plates |
| 110 | Design and Procure Adjustable Mirrors |
| 112 | Motion Picture Progress Report |
| 113 | F/O Training Extension |
| 114 | SCD's |
| 1L | Resident Effort |
| 2L | Internal Engineering |
| 3L | Project Management |
| 4L | Documentation |
| 5L | Design Analysis |

TABLE 2-7

OVERSCOPE TD'S

| TD Number | Title |
|---|---|
| 80 | Part Qualification Test Program |
| 111 | MDV Condition Light Assembly |
| 115 | Resolver Digitizer |
| 1L | LEM Resident Effort Extension |

Kollsman put into effect the measures necessary for compliance with the Contracting Officer's directive to freeze manpower levels and suspend replacement action for normal attrition of Apollo Program personnel. It was Kollsman's understanding that this directive would remain in force until further action was taken by NASA as a result of their assessment of planned employment levels in relation to the Fiscal Year 1964 budget.

Definitive contract NAS 9-3632 for the initial LM effort was received by Kollsman during the month of August for review and execution. During the month of September, properly executed documents were exchanged between Kollsman and NASA/MSC and there existed a fully executed definitive contract covering a period of performance ending December 31, 1964.

Kollsman understood that the continuation of LM effort subsequent to December 31, 1964 would be accomplished under an AC Electronics subcontract issued at the direction of NASA/MSC. KI's proposal for this phase of the LM effort was forwarded to ACSP.

Prior to the termination of this NASA/KI contract NAS 9-499, KI was within its planned expenditure and expected to maintain the same posture for the duration of the Apollo Command Module and LM program.

2.7.2 Novation

Pursuant to the NASA goal for accomplishment of contract realignment for continuation of the Apollo C/M G & N Program, all required documents for this action were executed by responsible representatives of NASA/MSC, AC Electronics Division of General Motors and Kollsman Instrument Corporation. These documents included the NASA termination notice against Contract NAS 9-499 and the subcontract with ACSP (FNP 12776) providing for the continuation of all authorized program effort. The effectivity of these documents was to be 12:01 AM July 25, 1964.

Effective July 25, 1964 Contract NAS 9-499 with NASA was terminated and Subcontract FNP 12776 was negotiated with the AC Electronics Division of General Motors Corporation for the continuation of all authorized program effort.

Purchase Order alteration No.1 to ACSP subcontract FNP 12776 provided for a continuation and completion of all the TD's that were started and authorized by NAS 9-499 contract. See Table 2-8.

Purchase Order alteration No. 2 to ACSP subcontract FNP 12776 provided the contractual coverage for all overscope tasks (remaining to be completed as of July 25, 1964) previously authorized by NASA/MSC, but not incorporated by amendement into Contract NAS 9-499. See Table 2-8.

# TABLE 2-8 (Sh.1 of 6)
# TECHNICAL DIRECTIVE MANHOURS PLANNED/EXPENDED
# FNP - 12776 POA #1

TECHNICAL DIRECTIVE MANHOURS PLANNED/EXPENDED
FNP - 12776 POA #1

APOLLO ORIGINAL WORK STATEMENT CHANGEOVER

| T.D K– | WORK ORDER NUMBER | SUBJECT | MIT ENGINEER KIC ENGINEER | DATE ISSUE DATE ACCEPTED | MAN HOURS A | MAN HOURS B | MAN HOURS C | REMARKS |
|---|---|---|---|---|---|---|---|---|
| 1 | 807002 | Project Office | A.M. Ferraro | 7-25-64 | 7520 | 3091 | 184 | |
| 7 | 807012 | PERT | | | 2342 | 1468 | 135 | |
| 12 | 806002 | Internal Engr. Support | A.M. Ferraro | | 8256 | 5060 | 778 | |
| 14 | 806012 | Mfg. Plan | | | 5184 | 5349 | 433 | |
| 23 | 809002 | Documentation | | | 3760 | 2456 | 413 | |
| 26 | 809012 | Program Progress Reports | A.M. Ferraro | | 3760 | 1846 | 461 | |
| 28 | 826012 | Reliability Analysis | L. DeBonis | | 1752 | 1247 | 359 | |
| 30 | 826022 | Reliability Training | | | 930 | 94 | 80 | |
| 31 | 809022 | Preparation of Documents | A.M. Ferraro | | 1344 | 1313 | 385 | |
| 42 | 826052 | Reliability Test Program | | | 3096 | 1069 | 955 | |
| 54 | 811002 811052 | MDV Block I Mfg. | | | 616 | 5317 | 1207 | |
| 55 | 806022 | Optics Des. Analysis | | | 1368 | 43 | 0 | |
| 60 | 806032 | Thermal Analysis | | | 1212 | 942 | 295 | W.D. #510 Rev. O |
| 76 | 826032 | Fail. Rep'g. Sys. | L. DeBonis | | 1184 | 918 | 492 | |
| 88 | 810012 811012 | OUA Fab. | A.M. Ferraro | | 4148 | 6111 | 2291 | |
| 104 | 826042 | Fail. Eff. Anal. | L. DeBonis | | 1032 | 852 | 272 | |
| | POA #1 | AUTHORIZED TO DATE | | 12-31-64 | 57216 | 51053 | 9939 | |

A – TOTAL ESTIMATED MAN-HOURS FROM INITIATING PERIOD TO COMPLETION OF T.D.
B – CUMULATIVE MAN-HOURS EXPENDED TO DATE
C – ESTIMATED MAN-HOURS EXPENDED FOR PREVIOUS MONTH

CHART
ISSUED-24SEPT 1964
ART FERRARO
PROJECT MANAGER

KOLLSMAN INSTRUMENT CORPORATION

# TABLE 2-8 (Sh. 2 of 6)
# TECHNICAL DIRECTIVE MANHOURS PLANNED/EXPENDED
# FNP - 12776 POA #2

TECHNICAL DIRECTIVE MANHOURS PLANNED/EXPENDED
FNP - 12776 POA #2

AMENDMENT #2

| T.O K- | WORK ORDER NUMBER | SUBJECT | MIT ENGINEER KIC ENGINEER | DATE ISSUE DATE ACCEPTED | MAN HOURS A | MAN HOURS B | MAN HOURS C | REMARKS |
|---|---|---|---|---|---|---|---|---|
| 61 | 820002 | AGE 2 Mechanical Integrity Test | A. M. Ferraro | 7-25-64 | 4488 | 2944 | 250 | |
| 67 | 808002 | F/O Training | | | 3443 | 411 | 0 | |
| 68 | 808012 | F/O Management | | | 3734 | 4286 | 682 | |
| 69 | 808022 | F/O Mat'l & Spares | | | 3443 | 800 | 144 | |
| 71 | 808042 | F/O Proc. Specif. | | | 3740 | 835 | 395 | |
| 72 | 808052 | F/O Maint. Anal. | | | 2253 | 855 | 168 | |
| 73 | | F/O Spec. Test Equip | | | 0 | 0 | 0 | |
| 74 | 813002 | 5" Autocoll. | | | 51 | 69 | 12 | |
| 75 | 803002 613012 | Design G.S.E. | | | 459 | 374 | 7 | |
| 77 | 814002 | Spares Proc. | | | 3116 | 2947 | 390 | |
| 79 | 821002 | M.D.V. AGE 1 & 2 Test | | | 4012 | 707 | 343 | |
| | 820012 821012 | | A.M. Ferraro | | | | | |
| 80 | 820022 821022 | Parts Quality Test Program | L. DeFonis | | 46699 | 11619 | 1467 | |
| | 820032 821032 | | | | | | | |
| | 820072 | | | | | | | |
| 81 | 800012 810042 | Des. & Fab. Ship. Containers | A.M. Ferraro | | 833 | 1286 | 519 | |
| 83 | 820042 | AGE 1 OUA Ther. Vacuum Test | A.M. Ferraro | 7-25-64 | 12495 | 4910 | 244 | |

A — TOTAL ESTIMATED MAN-HOURS FROM INITIATING PERIOD TO COMPLETION OF T.D.
B — CUMULATIVE MAN-HOURS EXPENDED TO DATE
C — ESTIMATED MAN-HOURS EXPENDED FOR PREVIOUS MONTH

CHART
ISSUED-24 SEPT 1964
ART FERRARO
PROJECT MANAGER

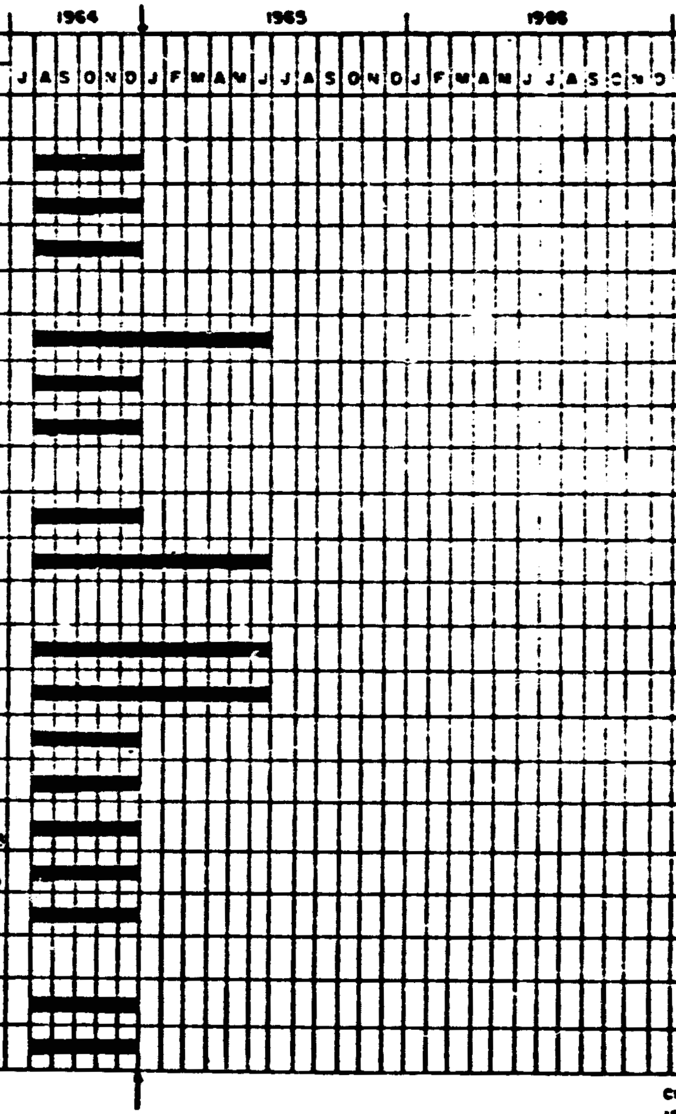
KOLLSMAN INSTRUMENT CORPORATION

# TABLE 2-8 (Sh. 3 of 6)
# TECHNICAL DIRECTIVE MANHOURS PLANNED/EXPENDED
# FNP - 12776 POA #2

TECHNICAL DIRECTIVE MANHOURS PLANNED/EXPENDED
FNP - 12776 POA #2

AMENDMENT #2

| T.D K- | WORK ORDER NUMBER | SUBJECT | MIT ENGINEER KIC ENGINEER | DATE ISSUE DATE ACCEPTED | MAN HOURS A | MAN HOURS B | MAN HOURS C | REMARKS |
|---|---|---|---|---|---|---|---|---|
| | 803022 813032 | | | | | | | |
| 86 | 803032 813042 | G.S.E. Hold. Fixt. | A.M. Ferraro | 7-25-64 | 1173 | 2837 | 469 | |
| 87 | 811032 | M.D.V. for N.A.A. | | | 153 | 203 | 92 | |
| 92 | 813052 | 2 1/2" Autocoll. | | | 51 | 17 | 5 | |
| 95 | | Maint. & Repair Manuals | | | | | | |
| 105 | 808062 808072 | F/O Deployment | | | 27456 | 10051 | 1926 | |
| 108 | 811072 | 1 1/2" Autocoll. | | | 51 | 6 | 0 | |
| 111 | 821042 | Cond. Lite Assy. | | | 1309 | 121 | 0 | |
| 112 | 839072 | Motion Pict. Prog. | | | 0 | 0 | 0 | |
| 114 | 806052 | S.C.D.'s | | | 578 | 1856 | 349 | |
| 119 | 800022 810062 | OUA B.B. Mfg. | | | 24853 | 946 | 251 | |
| | 800032 810072 | | | | | | | |
| 121 | 808082 | G.S.E. Inst'l | | | 2083 | 257 | 59 | |
| 124 | 806072 | Blk. I Dwg. Maint. | | | 7191 | 1939 | 333 | |
| 127 | 826062 | Rel. Program | | | 880 | 559 | 0 | |
| 132 | 803112 813132 | (5) Retroref. Prisms | A.M. Ferraro | 7-25-64 | 1428 | 58 | 2 | |
| 133 | 805002 | Res. Effort | A.M. Ferraro | 7-25-64 | 10297 | 8940 | 1658 | |
| 134 | 807022 | Project Office | | | 4220 | 5531 | 3109 | |
| 135 | 810082 810092 | Long Lead Proc. | | | 3222 | 5580 | 3161 | |
| | Various | | | | | | | |
| 138 | 806092 816002 | Inter. Engr. | A.M. Ferraro | 7-25-64 | 70664 | 30488 | 6689 | Closed 11-11-64 Closed 11-11-64 |
| 139 | 803042 | G.S.E. Plan. Cont. | | | 400 | 372 | 24 | |




A – TOTAL ESTIMATED MAN-HOURS FROM INITIATING PERIOD TO COMPLETION OF T.D.
B – CUMULATIVE MAN-HOURS EXPENDED TO DATE
C – ESTIMATED MAN-HOURS EXPENDED FOR PREVIOUS MONTH

CHART
ISSUED-24 SEPT 1964
ART FERRARO
PROJECT MANAGER

KOLLSMAN INSTRUMENT CORPORATION

# TABLE 2-8 (Sh. 4 of 6)
# TECHNICAL DIRECTIVE MANHOURS PLANNED/EXPENDED
# FNP - 12776 POA #2

TECHNICAL DIRECTIVE MANHOURS PLANNED/EXPENDED
FNP -12776 POA # 2

AMENDMENT # 2

| T.D K- | WORK ORDER NUMBER | SUBJECT | MIT ENGINEER KIC ENGINEER | DATE ISSUE DATE ACCEPTED | MAN HOURS A | MAN HOURS B | MAN HOURS C | 1964 J A S O N D · 1965 J F M A M J J A S O N D · 1966 J F M A M J J A S O N D | REMARKS |
|---|---|---|---|---|---|---|---|---|---|
| 140 | 803052 813092 | Autocollimator & Theodolite Modif. | | 7-25-64 | 1489 | 457 | 112 | | |
| 141 | 803062 813092 | G.S.E. Fixt. & Stands | | | 1081 | 1209 | 116 | | |
| 142 | 803072 813102 | Prec. Test Fixt. Modification | | | 2227 | 1430 | 597 | | |
| 145 | 803092 | Post Inst. Test Fixt. Modification | | | 2085 | 336 | 89 | | |
| 146 | 803102 813122 809062 | Funct. Test Modif. | | | 2397 | 2359 | 1305 | | |
| 150 | | G & N Glossary | | | | | | | |

A — TOTAL ESTIMATED MAN-HOURS FROM INITIATING PERIOD TO COMPLETION OF T.D.
B — CUMULATIVE MAN-HOURS EXPENDED TO DATE
C - ESTIMATED MAN-HOURS EXPENDED FOR PREVIOUS MONTH

CHART
ISSUED—24SEPT 1964
ART FERRARO
PROJECT MANAGER

KOLLSMAN INSTRUMENT CORPORATION

# TABLE 2-8 (Sh. 5 of 6)
# TECHNICAL DIRECTIVE MANHOURS PLANNED/EXPENDED
# FNP - 12776 POA #2

TECHNICAL DIRECTIVE MANHOURS PLANNED/EXPENDED

FNP - 12776 POA #2

ALTERATION #2

| T.D K- | WORK ORDER NUMBER | SUBJECT | MIT ENGINEER KIC ENGINEER | DATE ISSUE DATE ACCEPTED | MAN HOURS A | MAN HOURS B | MAN HOURS C | REMARKS |
|---|---|---|---|---|---|---|---|---|
| 502 | 810102 | Diversion of (3) 000 Series (Block 100) | S. Millman | 11-21-64 | 11343 | 980 | 980 | Rev. 2 |
| 503 | 810112 | Fab. (8) OUA's (Block 100) | S. Millman | 11-21-64 | 63311 | 715 | 715 | Rev. 2 |
| 504 | 811062 | Fab. (3) MDV's (Block 100) | S. Millman | 11-21-64 | 10569 | 1087 | 1087 | Rev. 2 |
| 512 | | (TD 60) | | | | | | Rev. 1 |
| 511 | 800042 810122 | Thermal Instr. | L. DeBonis | 11-21-64 | 409 | 23 | 7 | |
| 515 | 803402 813422 | Blk. I-100 FTE Opto. Mech. | L. Mironov | 12-14-64 | 1414 | 0 | 0 | Rev. 1 |
| 517 | 803422 813442 | Blk. I-100 SER. GSE PTF | L. Mironov | 12-14-64 | 3571 | 0 | 0 | Rev. 2 |
| 518 | 803412 813432 | Blk. I-100 FTE Electronics | L. Mironov | 12-14-64 | 4491 | 32 | 32 | Rev. 1 |
| 519 | 803492 813492 | Blk. I-100 GSE Fun. Test. | L. Mironov | 12-14-64 | 5229 | 92 | 92 | Rev. 1 |
| 520 | 803482 813502 | Blk I-100 GSE Star Horizon Simulator | L. Mironov | 12-14-64 | 11349 | 19 | 19 | Rev. 1 |
| 521 | 803472 813452 | Blk. I-100 GSE Var. Deviation Wedges | L. Mironov | 12-14-64 | 36 | 0 | 0 | Rev. 1 |
| 522 | 803462 813462 | Blk. I-100 GSE 0° Autocol. Plate Ass'y | L. Mironov | 12-14-64 | 235 | 0 | 0 | Rev. 1 |
| 523 | 803452 913512 | Blk. I-100 GSE 45° Autocol. Plate Ass'y | L. Mironov | 12-14-64 | 108 | 0 | 0 | Rev. 1 |
| 524 | 803442 813472 | Blk. I-100 GSE SXT/SCT Lens Covers | L. Mironov | 12-14-64 | 791 | 0 | 0 | Rev. 1 |
| 525 | 803432 813482 | Blk. I-100 GSE OUA Connector Covers | L. Mironov | 12-14-64 | 52 | 0 | 0 | Rev. 1 |
| 526 | 809092 | Blk. I-100 GSE Documentation | M. Kahn | 12-14-64 | 220 | 113 | 113 | |

A – TOTAL ESTIMATED MAN-HOURS FROM INITIATING PERIOD TO COMPLETION OF T.D.
B – CUMULATIVE MAN-HOURS EXPENDED TO DATE
C – ESTIMATED MAN-HOURS EXPENDED FOR PREVIOUS MONTH

CHART
ISSUED-24SEPT 1964
ART FERRARO
PROJECT MANAGER

KOLLSMAN INSTRUMENT CORPORATION

# TABLE 2-8 (Sh. 6 of 6)
# TECHNICAL DIRECTIVE MANHOURS PLANNED/EXPENDED
# FNP - 12776 POA #2

TECHNICAL DIRECTIVE MANHOURS PLANNED/EXPENDED
FNP - 12776 POA #2

| T.D K- | WORK ORDER NUMBER | SUBJECT | MIT ENGINEER KIC ENGINEER | DATE ISSUE DATE ACCEPTED | MAN HOURS A | MAN HOURS B | MAN HOURS C | REMARKS |
|---|---|---|---|---|---|---|---|---|
| | 800002<br>810002 | Changes OHA | A.M. Ferraro | 7-25-64 | | | | |
| | 801002<br>811022 | Changes MRY | A.M. Ferraro | 7-25-64 | 4318 | 24518 | 3168 | |
| | 803012<br>813022 | Changes GSE | A.M. Ferraro | 7-25-64 | | | | |
| Sub- | Total | P.O.A. #1 Authorized | | 12-31-64 | 57216 | 51053 | 9939 | |
| Sub- | Total | P.O.A. #2 Authorized | | 12-31-64 | 378474 | 112542 | 28011 | |
| | Total | FMP -12776 Authorized | | 12-31-64 | 435690 | 163595 | 37950 | |

A – TOTAL ESTIMATED MAN-HOURS FROM INITIATING PERIOD TO COMPLETION OF T.D.
B – CUMULATIVE MAN-HOURS EXPENDED TO DATE
C – ESTIMATED MAN-HOURS EXPENDED FOR PREVIOUS MONTH

CHART
ISSUED–24 SEPT 1964
ART FERRARO
PROJECT MANAGER

KOLLSMAN INSTRUMENT CORPORATION

During the latter part of 1964, the following major events took place:

- Supplemental Agreement No. 3 to NAS 9-2632, provided additional funding against the initial LM effort on this prime contract, was fully executed by Kollsman and NASA/MSC. The balance of the available funding under the contract was processed at NASA for early release to KI.

- Additional funding was provided by AC Electronics to cover KI expenditures for the LM follow-on effort through the executed period of contract execution. It was understood that the definitive contract provided additional funding for future cost accruals.

- "Stop Work" instructions was received as preparatory actions toward deletion from the contract of the MDV and OLPD units plus four units each of Block I-100 and Block II OUA's and two AOT's. Kollsman quotations on the impact of these actions were either in process or submitted.

- Negotations continued in progress with AC Electronics toward making definitive a subcontract for the performance of LM effort through 31 December 1969.

- Completely executed copies of the NASA facilities acquisition contract, NAS 9-3231 (F), and use contract, NAS 9-3230 (F), were received by Kollsman.

- Within defined dollar limitations, Kollsman was authorized to proceed with inspection and/or repair of GFP when returned to Kollsman for such purpose. A separate contract amendment was not required for this activity.

### 2.7.3 After Novation

An excellent contract relationship was maintained throughout the balance of the Apollo contract with ACED. The respective contracts administration personnel exercised and displayed keen insight toward the recognition and resolution of mutual administration problems. The excellent relationship evolved from day to day contacts and timely exchange between this personnel. Some highlights of the significant achievements are listed below:

- The advanced notice and efforts toward resolution of IR & D and sale-lease back provisions of the basic contract negotiation.

- OUA and AOT delivery incentive schedule problems expeditiously resolved as they related to the schedule stretch-out change order.
- KI initiative in formulating a basis for negotiation of the second increment fee schedule.
- Cooperation and action in the establishment of funding formulas and the timing of request releases.

The balance of this report dealing with control activity is outlined in chronological order starting with the first quarter of 1965 and will provide an historical record of the contracts events and activities.

2.7.3.1 1st Quarter - 1965

Kollsman quotations for the following authorized activities were submitted during this quarter:

TD K-119A, TD K-124A, TD K-157; CRN K-87, CRN K-104, CRN K-175; Pellicle Repair; A/B Spares Procurement; GSE Spares Procurement; Block I and Block II Design Evaluation Program.

Kollsman quotations for the following tasks, which were not yet authorized, were also submitted:

Change Request Proposals: T-4 and T-5
Engineering Revision Proposals: K3, K-4, K-5, K-6, K-7, K-8
Resolver Retrofit and Material Reporting

During the reporting period, the OUA and MDV AGE 17, first units for which delivery incentive fee were allocated (under POA No. 8), were delivered on time and earned the full fee designated.

2.7.3.2 2nd Quarter - 1965

During the second quarter of 1965, AC Electronics released the following contract authorizations for KI implementation of effort.

| POA No. | Description |
|---|---|
| 8 | Definitive Block II and LEM Contract |
| 9 | Funding |
| 10 | Funding |

| Change Order | Description |
|---|---|
| 36 | Maintenance of the CMR Manual |
| 37 | OLPD Deletion |
| 38 | Build SN 101 and 102 |
| 39 | Shipping Container Mod |
| 40 | Delete AOT 600 |
| 41 | Material Reports |
| 42 | Redefinition of Block II and LEM Mech. Gauge Requirements |
| 43 | Qual. Program Redefinition |
| 44 | Delete AOT Breadboard |
| 45 | Add one (1) Spare OUA |
| 46 | Ten (10) System Deletions |
| 47 | MDV Deletion |
| 48 | Turning Fork Change |
| 49 | Qual. Program Redefinition |
| 50 | Spares |
| 51 | Delete (1) AOT Tester |
| 52 | (1) Trimming Module |
| 53 | Approval of Heaters (ERP K-41) |
| 54 | OUA and GSE Acceptance Criteria |

Change Order coverage was expected shortly to confirm mutual agreement relative to delivery extension against Breadboards 1 and 2 and AGE 121. In addition, full approval to proceed with the Design Evaluation program was expected momentarily.

Negotiation of a delivery extension for 121 EP (GSE) by reason of Change Order 54 was anticipated. An authorized reticle mount change to LEM breadboards necessitated an adjustment in delivery schedule.

During this reporting period the following units were delivered which earned the incentive fee: OUA Learner Model, Breadboard Electronics No. 1 and Breadboard Electronics No. 2.

During this reporting period, a total of eight firm proposals and twenty-six budgetary proposals were issued in response to ACSP requirements.

NAS 9-2632 effort was concluded at the end of this quarter. Additional funding was provided and a balance of the funding requested was in process. The AOT Mechanical Gauge was shipped under this contract during the month of June.

Negotiation of open Change Orders was initiated during the month of June. The "Deletion" proposals and more recent Change Orders remained as open items for which negotiations would be solicited at an early date.

Funding requests for the remainder of June and the next calendar quarter were open and required ACSP action on a priority basis.

2.7.3.3 3rd Quarter - 1965

During the third quarter of 1965, AC Electronics Division (hereinafter referred to as AC) released the following contract authorizations for Kollsman implementation of effort:

| POA No. | Description |
|---|---|
| 11 | Negotiation of 22 Change Orders |
| 12 | Funding |
| 13 | Negotiation of 7 Change Orders |
| 14 | Funding |

| Change Orders (CO's) | Description |
|---|---|
| 79 | Proceed with new SXT and SCT Housing |
| 80 | Reduction of Microfilm requirements - Paragraph 6.3.3 of Exhibit "D" from three to two. |

As reflected by POA No. 11 and POA No. 13, significant negotiation activity was conducted with AC during this third calendar quarter. Of the change orders remaining to be negotiated, 18 were scheduled for negotiation during the first week of October 1965. One of the agenda items during this negotiations was the conclusion of the major program deletion proposal negotiations.

With the completion of this forecasted negotiation, the only major negotiation items outstanding were those associated with the Program Stretch-Out (CO No. 66) and the Design Evaluation and Parts Qualification Test Program efforts (CO No. 38). It was expected that, through the mutual endeavors of KI and AC, the fact-finding/negotiation of proposals currently being generated or recently submitted against ERP approvals were concluded expeditiously. Thus the future backlog of negotiation effort was reduced considerably.

All authorized effort by KI against the LEM prime contract with NASA/MSC (NAS 9-2632) was completed by the end of the second quarter of 1965. Therefore, effective 1 July 1965, all LEM effort being performed by KI was now under the cognizance of AC Subcontract FNP 12776.

2.7.3.4 4th Quarter - 1965

During the fourth quarter of 1965 AC Electronics released the following contract authorizations for Kollsman implementation of effort.

| POA No. | Description |
|---|---|
| 15 | Funding |
| 16 | Revision of POA 13 |

| Change Orders (CO's) | Description |
|---|---|
| 81 | PRM 2437-002 |
| 82 | PRM 2437-006 |
| 83 | Deletion of Block I (100) Tracker/Photometer |
| 84 | Impact of CO 83 on GSE |
| 85 | PRM 2437-009 and 2438-004 |
| 86 | PRM 2437-007 and 2438-002 |
| 87 | Approval of ERP K-38R3 |
| 88 | Addition of (2) Theodolite and Support Assemblies |
| 89 | PRM 2437-008 and 2438-003 |
| 90 | GFP Autocollimator Use |
| 91 | Revision of Table II, Exhibit D |
| 92 | Approval of ERP K-67 |
| 93 | Approval of ERP K-50R |
| 94 | Deletion of Block II Tracker/ Photometer |
| 95 | MIT Resident Engineer |
| 96 | Approval of ERP K-52R2 |
| 97 | PRM 2437-010 |

Present funding authorization was sufficient for the remainder of Calendar Year 1965. A funding forecast of additional requirements for the first quarter of 1966 was forwarded to AC.

All major program deletion proposals were negotiated. Significant negotiation activity was conducted in October (16 Change Orders) and November (eight Change Orders plus two POA's against FNP 14867 and one POA against FNP 37075).

2.7.3.5 1st Quarter - 1966

During the first quarter of 1966 AC Electronics released the following contract authorizations for Kollsman implementation of effort.

| POA No. | Description |
|---|---|
| 17 | Incorporates negotiation results |
| 18 | Incorporates new DD 250 instructions. Changes point of government acceptance for OUA and Retrofit Kits |
| 20 | Funding |
| 21 | Provides final acceptance at KI for Block II Spare OUA. |

| Change Orders (CO's) | Description |
|---|---|
| 98 | Approval of ERP K-76 Design only |
| 98 A-1 | Approval of design only of FTE for Vacuum Focus Adapter |
| 98 A-2 | Authorization to proceed with ERP K-76. KI to initiate drawing and specification change |
| 99 | PRM 2437-11 and 2438-005 |
| 100 | Approval of ERP K-55R1 Resolver Trim Module |
| 101 | LEM Qualification Testing - Deletion of parts from AOT Qualification Test Plan |
| 102 | Releases AOT's 606-610, AOTT and reactivates manual preparation, training and site activation. |
| 103 | PRM 2438-006 (1 counter). |

| Change Orders (CO's) | Description |
|---|---|
| 104 | Release of PRM 2438-008 (cancels 5 items). |
| 105 | Approval of ERP-K60R2 Purge Valve Adapter. |
| 106 | Design Evaluation Repair Blanket Coverage. |
| 107 | AOTT FAT Test. |
| 108 | SOW Change - Deletion of Maintainability Prediction. |
| 109 | Addition of two Tripods, PN 1001653. |
| 110 | Submittal costs for SN 2 repair authorization under KD-2194 in conjunction with ERP K-56 modification. |
| 111 | Approval of KD-2240 dated 8 February 1966 (Repair of OUA SN 11). |
| 112 | Authorization of spares on PRM 2437-12 and 2438-9. |
| 113 | Authorization of Beryllium Corrosion protection - OUA and AOT cancels ERP K-110 and requests resubmittal of ERP K-109. |
| 113 A1 | RIB no longer required for 202, 203 and 204. Nameplate only to be provided. |
| 114 | SOW Changes Block II and LEM GSE adds Pedestal Assembly, Theodolite and Optics Cleaner Kit. |
| 115 | Authorization of LEM AOT Eyepiece Heaters, Thermostat and Insulation Blankets. |

PROPOSAL ACTIVITY. A summary of proposal activity during the initial quarter of 1966 against FNP 12776 is as follows:

| | Budgetary | Firm |
|---|---|---|
| January | 2 | 3 |
| February | 4 | 2 |
| March | 2 | 5 |
| Totals | 8 | 10 |

2.7.3.6 2nd Quarter - 1966

FUNDING. Present funding authorization was sufficient until April 1966. A funding forecast for the remainder of the second quarter of 1966 was submitted to AC upon completion of Monthly Financial Report NASA 533 forms.

PROPOSALS NEGOTIATED. All major open proposals were negotiated in March with the exception of Change Orders (CO's) 83, 94 and 66. A total of 18 CO's were finalized at this negotiation.

| Change Orders (CO's) | Description |
|---|---|
| 124 | Deletes Block I, II and LEM PERT Requirements. |
| 125 | Deletes Field Operations secretaries. |
| 125 A1 | Change Order cancelled. |
| 126 | Qualification of CCRD |
| 127 | Deletes Project Office at MIT/IL. |
| 128 | Deletes 40MM of KI Resident effort at AC. |
| 129 | Deletes and revises Documentation Requirements, Block I and II. |
| 130 | Cancels Tracker Photometer Parts Qualification. |

| Change Orders (CO's) | Description |
|---|---|
| 131 | Deletion of Field Operations requirements. |
| 132 | Field Operations Requirements MSC-Site. |
| 133 | Repair of OUA 201A. |
| 134 | Thermocouple Installation, OUA and AOT. |
| 135 | Deletes (1) Weight and CG (LEM). |
| 136 | Authorizes Nonconforming Material Addendum |
| 137 | Thermal Analysis of OUA with Ablative Shield |
| 138 | Retest of Block II Spare OUA |
| 139 | Spare Release PRM 2437-13 |

FUNDING

Funding forecasts were provided on a weekly basis for the remainder of the second quarter and the beginning of the third quarter to ensure sufficient funding coverage. Current Funding authorization was sufficient until the end of the second quarter 1966 and additional funding of the third quarter was to be released on a bimonthly basis.

PROPOSAL ACTIVITY

A summary of proposal activity during the second quarter of 1966 against FNP 12776 was as follows:

| | Budgetary | Firm |
|---|---|---|
| April | 1 | 6 |
| May | 0 | 5 |
| June | 3 | 9 |
| | 4 | 20 |

2.7.3.7 3rd Quarter - 1966

During the third quarter of 1966, AC Electronics released the following contract authorizations for Kollsman implementation of effort.

| POA | Description |
|---|---|
| 22 | Incorporates negotiation results |
| 23 | Additional funding and first increment unallocated fee disposition. |

A total of 23 Basic Change Orders and 35 Change Order Amendments were issued during this period. A breakdown of these is as follows:

| | |
|---|---|
| OUA - 10 | Repair - 3 |
| AOT - 19 | PERT - 2 |
| Spares - 9 | AC/MIT Resident - 3 |
| Qualification Test - 10 | GSE - 2 |

PROPOSALS NEGOTIATED

During this period, negotiations were completed for Second Increment Incentives. In addition, a total of 15 Change Orders were negotiated with AC Electronics, including the major Statement of Work deletions and the Eyepiece incorporation.

PROPOSAL ACTIVITY

A summary of proposal activity during the third quarter of 1966 against FNP 12776 was as follows:

| | Budgetary | Firm |
|---|---|---|
| July | 5 | 9 |
| August | 0 | 7 |
| September | 7 | 12 |

## 2.7.3.8 4th Quarter - 1966

This period marked the end of calendar year 1966 and the end of the First Increment of Performance in June 1966. At this point in time a formal Kollsman management report was issued to ACED which outlined the events and achievements of this period. (See Table 2-9).

During the last quarter of 1966, AC Electronics released the following contract authorizations for Kollsman implementation of effort:

| POA | Description |
|---|---|
| 25 | Incorporates agreements on Second Increment Incentive Fee Allocation |
| 27 | Provides for drop shipment of AOT Tester #2 from Moore Tool and increases funding |

A total of 18 Basic Change Orders and 10 Change Order Amendments were issued during this period, as listed in the following breakdown.

| | | | |
|---|---|---|---|
| OUA | 1 | Eyepieces | 1 |
| AOT | 1 | Repair | 2 |
| Spares | 13 | GSE | 2 |
| Qualification Test | 1 | Motors | 7 |

Proposals Negotiated - During this period a total of 24 Change Orders were negotiated with AC Electronics, includding the Solvere Motor Change, Block II Qualification Tests and deletions of MIT/IL residence and LEM Qualification Testing.

PROPOSAL ACTIVITY - A summary of proposal activity during the last quarter of 1966 against FNP 12776 is as follows:

| | Budgetary | Firm |
|---|---|---|
| October | 6 | 6 |
| November | 2 | 10 |
| December | 4 | 4 |

TABLE 2-9

FIRST INCREMENT STATUS

| Cost | Target | Incurred |
|---|---|---|
| | $23,158,000 | $21,743,889 |

| Available Fee | | Amount | Percent of Target Cost |
|---|---|---|---|
| Base | | $694,740 | 3.0 Percent |
| Cost | | 926,320 | 4.0 Percent |
| Delivery | | 463,160 | 2.0 Percent |
| Performance | | 926,320 | 4.0 Percent |
| | Totals | $3,010,540 | 13.0 Percent |

| Earned Fee | Amount | Percent of Target Cost | Percent of Incurred Cost |
|---|---|---|---|
| Base | $ 694,740 | 3.00 Percent | 3.20 Percent |
| Cost | 926,320 | 4.00 Percent | 4.26 Percent |
| Delivery | 260,337 | 1.12 Percent | 1.20 Percent |
| Subtotal | $1,881,397 | 8.12 Percent | 8.66 Percent |
| Performance Award | 510,000 | 2.20 Percent | 2.35 Percent |
| *Total | $2,391,397 | 10.32 Percent | 11.01 Percent |

* Subject to final cost

2.7.3.9 1st Quarter - 1967

During the first quarter of 1967, AC Electronics released the following contract authorizations for Kollsman implementation of effort:

| POA | Description |
|---|---|
| 26 | Incorporates negotations of September 1966 |
| 28 | Incorporates new delivery and incentive dollars for OUA's 209, 210, 207, 211, 213 and three retrofits |
| 29 | Incorporates negotiation of December 1966 |

A total of 14 Basic Change Orders and 1 Change Order Amendment were issued during this period, listed as follows:

| | |
|---|---|
| OUA-3 | Repairs - 4 |
| AOT-4 | Motors - 1 |
| Spares - 2 | |

PROPOSALS NEGOTIATED - During this period a total of 33 Change Orders (12/16 and 1/30) were negotiated with AC Electronics subsequent to the cutoff date of last report.

PROPOSAL ACTIVITY - A summary of proposal activity during the first quarter of 1967 against FNP 12776 is as follows:

| | Budgetary | Firm |
|---|---|---|
| January | 3 | 7 |
| February | 2 | 6 |
| March | 3 | 5 |

2.7.3.10 2nd Quarter - 1967

During the second quarter of 1967, AC Electronics released the following contract authorizations for Kollsman implementation of effort:

| POA | Description |
|---|---|
| 30 | Confirms and definitizes CO #162, 163, 168, 172, 177, 178 and 179 |
| 31 | Confirm and definitizes CO #165, 169, 171A1, 176, 182A2 and 191 |

A total of 18 Basic Change Orders and 6 Change Order Amendments were issued during this period, listed as follows:

| | |
|---|---|
| OUA - 7 | Spares - 3 |
| AOT - 13 | Motors - 1 |

PROPOSALS NEGOTIATED - During this period a total of 17 Change Orders (18 April and 19 May) were negotiated with AC Electronics subsequent to the cutoff date of the last report.

PROPOSALS ACTIVITY - A summary of proposal activity during the second quarter of 1967 against FNP 12776 is as follows:

| | Budgetary | Firm |
|---|---|---|
| April | 13 | 3 |
| May | 2 | 2 |
| June | 2 | 2 |

2.7.3.11 3rd Quarter - 1967

During the four month period ending October 31,1967, AC Electronics released the following contract authorizations for Kollsman implementation of e fort:

| FNP 12776 POA | Description |
|---|---|
| 30 | Incorporates negotiations of January 1967 |
| 31 | Incorporates negotiations of May 1967 |
| 32 | Incorporates negotiations of April 1967 |

Additionally, a TWX letter of intent was received, funding Fiscal Year (FY) 1968 repair under a new Subcontract GNP 03700.

A total of 14 basic Change Orders and 7 Amendments to previously issued Change Orders were released by AC Electronics during this period. This input comprises:

OUA - 9

AOT - 9

Repairs (GNP 03700) - 4

PROPOSALS NEGOTIATED - During this period a total of 15 Change Orders were negotiated with AC (July 18, 1967). Of this quantity, six were associated with non-"shopping-list" repair authorizations under the FY 1967 Repair Contract (FNP 64600). Further, the "shopping-list" for the FY 1968 Repair Contract w s negotiated during this same time interval. Kollsman awaited AC confirmation of these negotiations by appropriate contract documents.

PROPOSAL ACTIVITY - A summary of proposal activity (GNP 03700 and FNP 12776) as measured by the number of submittals to AC was as follows:

| | Budgetary | Firm |
|---|---|---|
| July | 1 | 12 |
| August | 1 | 5 |
| September | - | 3 |
| October | - | - |
| Subtotal | 2 | 26 |
| FY'67 Total to Date | 27 | 51 |

Approximately ten additional change-in-scope items were presently in-house awaiting completion of proposal packages by Program Administration.

2.7.3.12 4th Quarter 1967 thru December 1969

Much of contract's activity during last quarter of 1967, 1968 and 1969 concerned itself with the processing of change orders and directives related to retrofit activity at Kollsman and in the field. Additionally, much activity centered around the implementation of the Sunshade for the AOT and the Rangefinder. The details of these efforts are defined under Engineering.

Change Orders released during the last quarter of 1967 were:

224 - AOT Conical Sunshade

231 - Eyepiece Flammability

232 - AOT Flammability

222 - SXT Air Focusing Spaces

Change Orders released during 1968 were:

| | | | |
|---|---|---|---|
| 233 | 242 | 251 | 260 |
| 234 | 243 | 252 | 261 |
| 235 | 244 | 253 | 262 |
| 236 | 245 | 254 | 263 |
| 237 | 246 | 255 | |
| 238 | 247 | 256 | |
| 239 | 248 | 257 | |
| 240 | 249 | 258 | |
| 241 | 250 | 259 | |

Change Orders released during 1969 were:

| | |
|---|---|
| 264 | 272 |
| 265 | 273 |
| 266 | 274 |
| 267 | 275 |
| 268 | 276 |
| 269 | 277 |
| 270 | 278 |
| 271 | |

**SUMMARY**

This period marked the end of the NAS 9-497 Apollo Contract and also the end of the second increment of performance July 1966 thru December 1969.

Perhaps the best assessment of Kollsman's performance during this period can be taken from a periodic Performance Evaluation issued by ACED for the period March 1, 1968 through August 31, 1968. It reads as follows:

> "The overall Kollsman performance for this period is assessed as above average. This rating is given in recognition of the fine job which Kollsman has done in overall control and management of the optical subsystem effort. Program visibility has been maintained and the costs controlled in a manner quite acceptable to ACED. Kollsman should be complimented for their rapid and comprehensive response to NASA's request for cost elimination during Fiscal Year 1969."

## 2.8 MANAGEMENT CONTROLS

Much of the source for the effective execution of the Apollo contract was due to the controls that Apollo management implemented and employed. As shown, earlier in this report under manpower and finances much control was exercised to ensure a "finger on the pulse" posture in these areas. As subsequently demonstrated, this control was most effective in achieving the $1,200,000 underrun. In addition to these controls, however there were schedule and quality controls which closed the control loop by ensuring not only cost controls b ut also timely deliveries of hardware of a high quality level consistent with the "0" defects goal of NASA.

### 2.8.1 PERT

From the inception of the Apollo contract, it was evident that a reporting system was required by management in order to control this fast-moving project so that effective and timely decisions could be made. Upon receipt of the contract award therefore, Apollo management immediately put into effect a detailed PERT network on the Apollo Command Module, LM Alignment Optical Telescope, Map and Data Viewer, and Ground Support Equipment.

An in-house PERT team was established at Kollsman to develop and maintain PERT networks in accordance to the requirements of NASA/PERT handbook NPC-101. The PERT Group was responsible for ensuring that the reporting of schedules of the Optical Unit Assembly (OUA), Map and Data Viewer (MDV), Optical Alignment Telescope (OAT) and Ground Support Equipment (GSE).

Master charts and individual networks were developed for all of Kollsman's effort on Apollo. Individual networks on Quality Control, and on Documentation, were prepared and incorporated in the overall network. A summary network for the Map and Visual Display Unit was completed and times added.

Effort was applied to the development of a revised PERT program for the IBM 1401.

PERT runs have highlighted problem areas, in both the networks and in information handling. Revisions and improvements in the networks and in our procedures reduced critical path times.

Factory test equipment events were on the two critical paths.

The master charts and summary chart required revisions as a result of these modifications.

A series of small networks covering key assemblies were made to enable concerned personnel to more closely control the flow of effort on these units. The networks were 11 x 17 abstracts of parts of the complete network.

Additional modifications were made in the overall networks as problem areas were revealed, in order that the network be kept current.

Examples of the Apollo PERT networks and a typical Line of Balance chart are illustrated in Figures 2-11 and 2-12.

This PERT control provided Apollo management with a much needed tool that gave visibility to problem areas when they first occurred. This allowed immediate remedial action to take place and prevented any schedule delinquencies.

### 2.8.2 Configuration Control

Under the requirements of NPC 500-1, "Configuration Management Manual," the Apollo Configuration Management Staff (CMS) was established as a program management function to control and account for the change activity of all changes, revisions or modifications to released engineering documents. The CMS was responsible for the following specific functions:

a. Serving as a focal point for establishing configuration management requirements.

b. Coordination of change activity with the designing agency.

c. Coordination of change activity with the procuring agency.

d. Maintenance of change records.

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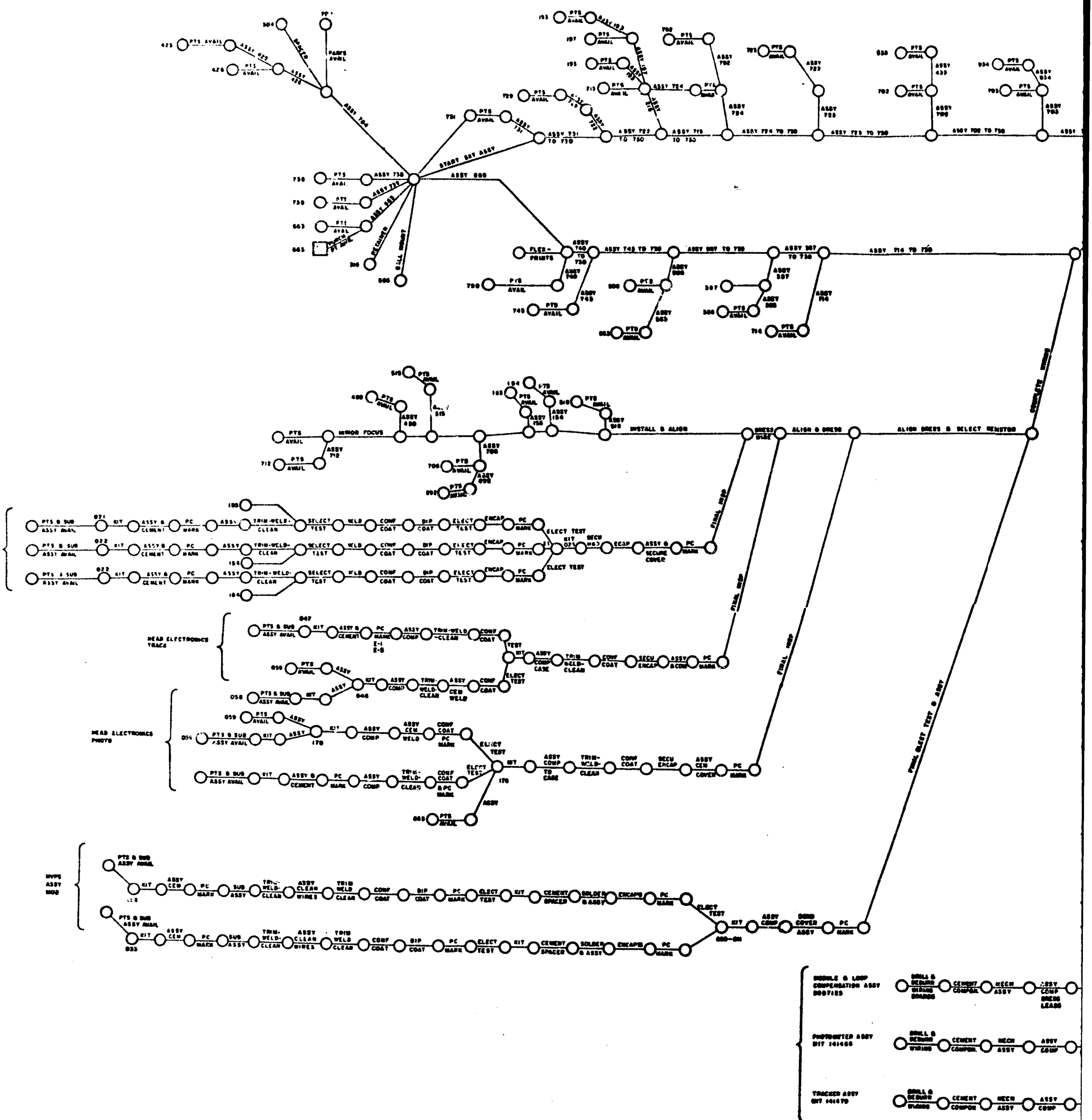


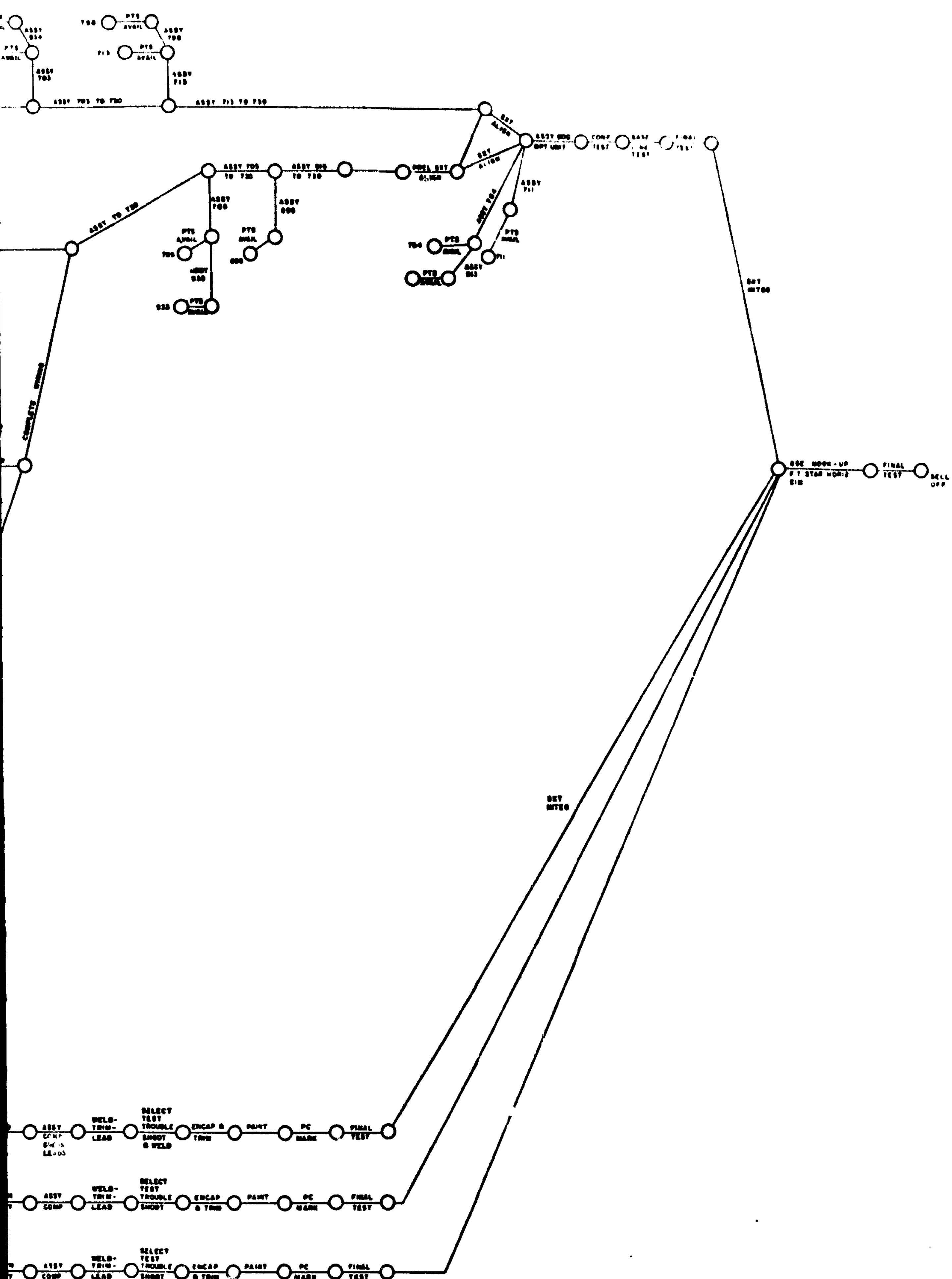



Figure 2-11. Apollo PERT Detailed Networks

## DELIVERY SCHEDULE

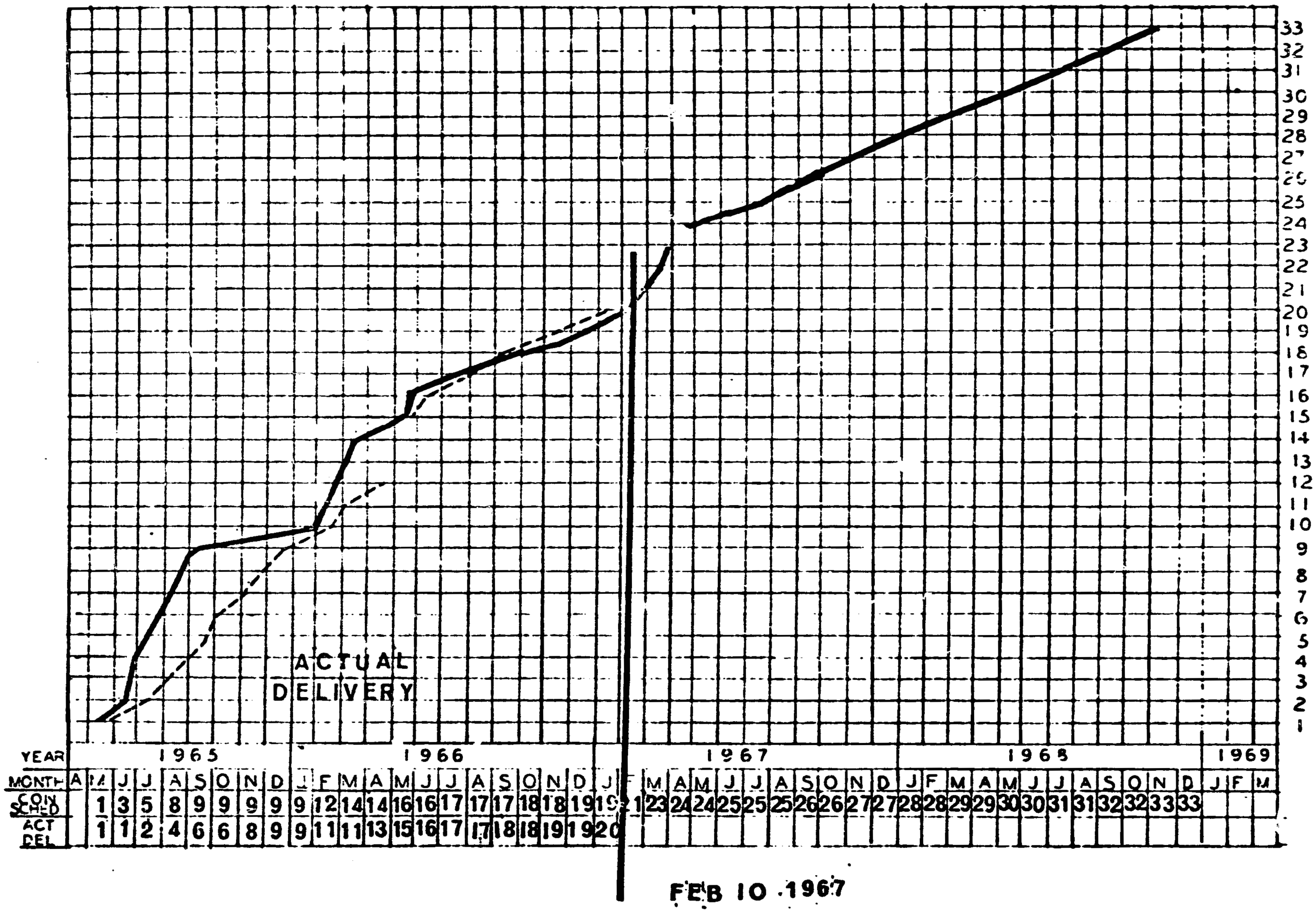



Figure 2-12: Apollo Line of Balance Chart (Sheet 1 of 3)

KOLLSMAN INSTRUMENT CORPORATION

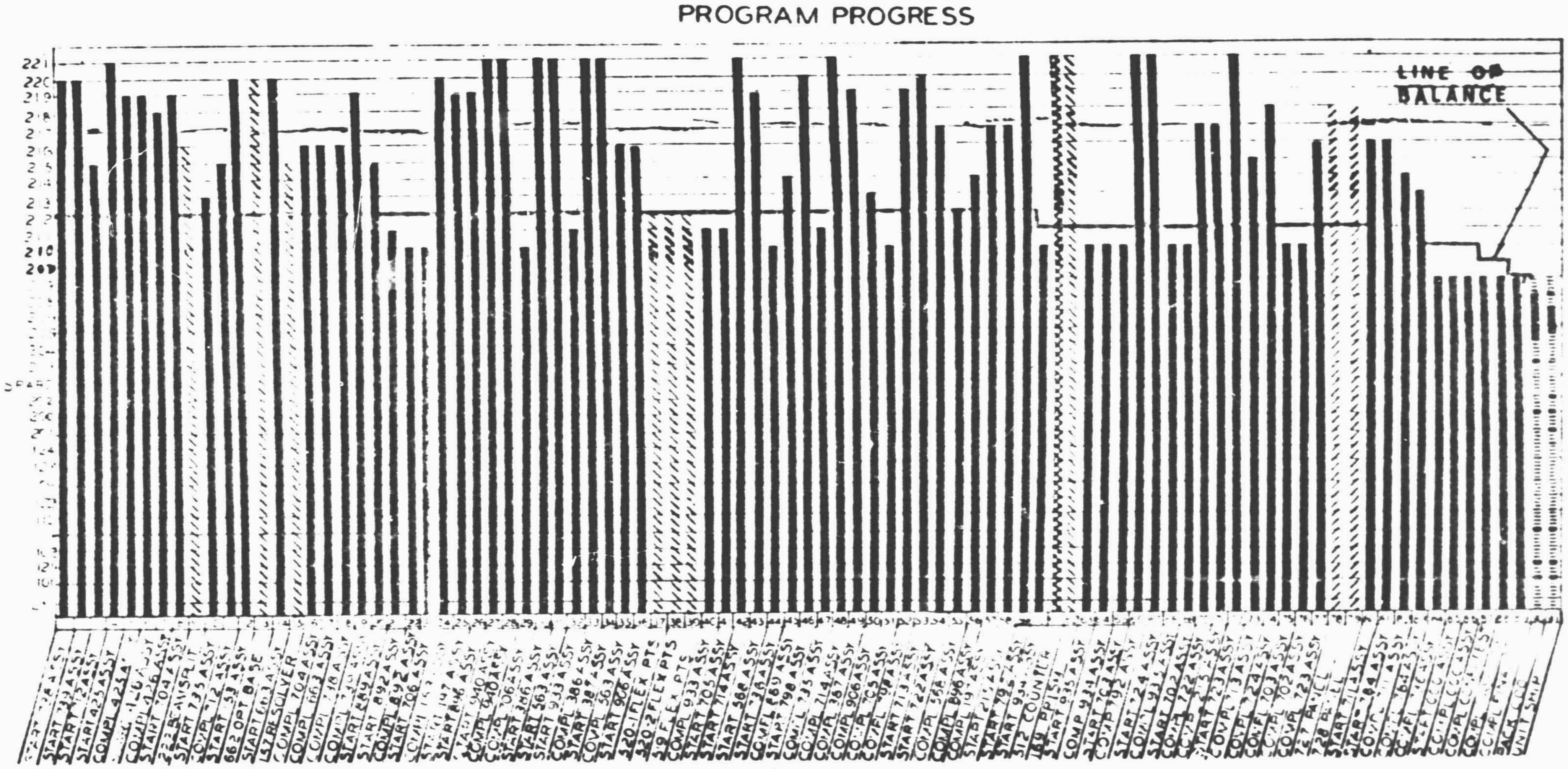



Figure 2-12. Apollo Line of Balance Chart (Sheet 2 of 3)

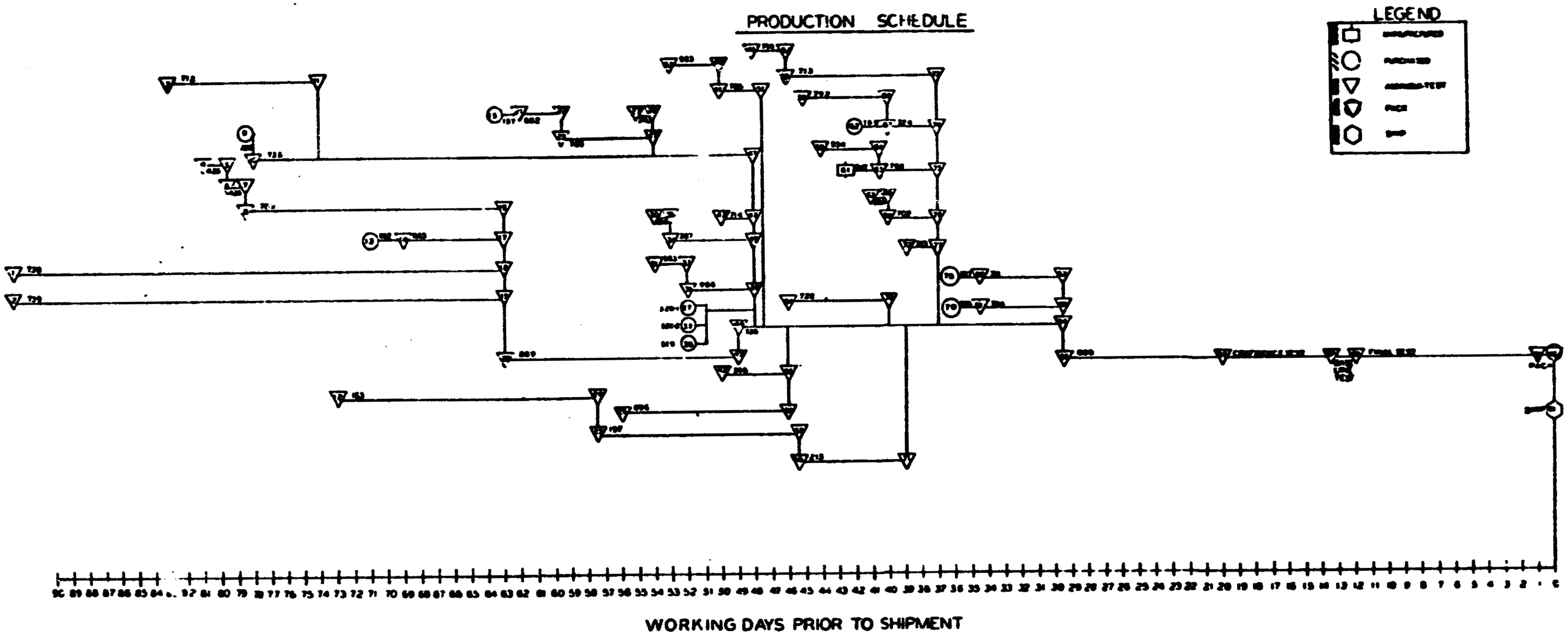



Figure 2-12. Apollo Line of Balance Chart (Sheet 3 of 3)

e. Publication configuration status reports.

f. Establishing and chairing the Configuration Control Committee (CCC).

g. Liaison with the procuring agency and the design activities for all configuration matters.

h. Preparation and accounting of Engineering Revision Plans (ERP's).

The CMS established a composite Configuration Control Committee (CCC) to evaluate cost/schedule impact of proposed changes. The committee represented all functional areas under cognizance of the program office as follows:

a. Command Module Engineering

b. Lunar Excursion Module Engineering

c. Factory Test and Ground Support Equipment

d. Reliability

e. Quality Control

f. Documentation

g. Production Planning

h. Production Control

i. Manufacturing

k. Field Operations

l. Administration

The CMS, in addition to internal records, prepared and transmitted to AC thirteen issues of the Weekly ERP Status Reports.

2.8.2.1 Engineering Revision Plan (ERP). Formal change proposals of major magnitude or schedule impact were presented to NASA/CCB through ACSP on a periodic basis.

A typical reporting status reflecting the activity for the first quarter of 1966 is shown below:

| | | |
|---|---|---|
| Changes received | - | 214 |
| Changes cancelled | - | 15 |
| Feeless changes | - | 186 |
| ERP's processed | - | 43 |
| Changes open | - | 12 |

2.8.2.2 Traceability Requirements

A very important part of configuration management was the maintenance of adequate and well controlled documents to substantiate the build versus the design concept of the particular hardware. This control was carried out across many disciplines, through a well documented procedure and inspection certifications. In producing the end product, (ADL) acceptance data list which presented S/N, lot # and Rev letter of every part, subassembly, and assembly used in the given hardware. In Block II, this information was translated through Kollsman IBM procedures to a magnetic tape (CAT file). This was in accord with a contractual requirement covering all OUA's from 201 and up and all ACT's from 601 and up.

This Kollsman tape was forwarded to the AC master tape bank at Milwaukee upon delivery of the hardware, where it was integrated with the total G & N master tape information.

The accuracy of the Kollsman inputs were attested to on several occasions, one which resulted in a Pride of Performance Award to the Configuration group. Even since this award, during the last 3 years of the program, there was not a single Kollsman traceability error or anomaly reported from the master tape bank.

Information deemed from these tapes were most helpful during the unfortunate Apollo fire and in other areas of design uncertainity.

2.9 PERFORMANCE

In addition to the management efforts already discussed in this report, there remained some management judgments and perogatives that were exercised and which contributed much through fulfilling the programs. These areas included:

- Risk assumption
- Early recognition of Schedule/Performance

2.9.1 Risk Assumption

Apollo management had regularly demonstrated initiative in "moving out"on problem areas. Kollsman very frequently assumed the risk of initiating effort without authorization where in management's judgment it was prudent to do so. Typical examples of this type of risk are:

KOLLSMAN INSTRUMENT CORPORATION

1. Instituted hold on LM optical BB in advance of ACSP contract change.

2. Proceeded with fabrication of design evaluation units prior to contract change.

3. Proceeded with fabrication of GSE prior to MIT/IL approval of mechanization drawings.

4. Instituted star tracker and horizon photometer modules changes prior to MIT release of changes.

5. Released new SXT air vacuum reticles prior to MIT release.

6. Started fabrication of FTE prior to finalization or design releases of airborne equipment.

7. Agreed to produce two additional OUA's during early part of schedule to expedite design evaluation program.

8. The OUA Sextant Trunnion Hesitation problem where a series of special tests were conducted by KI to determine the cause of the problem prior to a formal request to do so.

9. The Apollo Rangefinder effort which required an expedite management action to achieve the schedule requirement.

10. The resolution of the AOT reticle "false star" problem and the associated design modifications.

11. The AOT simulator update to rigid schedule requirements.

12. The design and fabrication of the AOT sunshade.

13. The sextant limit stop problem wherein KI ran several sets of limit stops through 2,000 cycles of operation each and fabricated new parts to the extremes of the allowable tolerances so that we were able to retrofit field units almost immediately after request was made to do so.

14. Eyepiece refurbishment.

### 2.9.2 Early Recognition of Problems

Early recognition of problems was also a continuing part of Apollo managements posture. Typical examples of efforts in this area were:

1. Provided extraordinary technical assistance to component vendors e.g. tuning forks, resolvers and phototubes.

2. Developed "work around" technique to avoid schedule slippage because of changes such as SXT reticle, coatings, etc.

3. Development lab. evaluation of star tracker and horizon photometer prior to production to identify and correct problem areas as early as possible.

4. 64-speed resolvers.

5. Concurrent KIC fabrication of some purchased parts to meet schedule where necessary such as transformers, gears, tuning forks, phototube housings.

6. On emergency basis, initiated evaluation program to solve potting compound problem.

7. Recognition of electronic problems inherent in the Tracker/Photometer design.

8. Recognition of the Beryllium Corrosion problem.

9. Recommendations for solution of the various eyepiece program directives.

10. Recognition and definition of the problems associated with OUA Qual testing.

### 2.10 ACCOMPLISHMENTS

Perhaps the best measure of Apollo managements expertise is the record of timely deliveries of high quality hardware. The total Apollo Hardware that was delivered throughout this program is shown in Tables 1, 2, and 3 of Volume I.

A particularly significant hardware achievement was accomplished in the retrofit area. Specifically, a minimum of 10 Block II OUA's and 9 AOT's were returned to Kollsman for major updating to the latest configuration. These dissimilar configured units were updated to a common and latest in-line configuration within the constraints of maintaining traceability, quality and reliable integrity. These units not only were upgraded to the same level as new hardware but were also delivered on a ahead of AC requirements.

In addition to hardware deliveries, the Apollo program was highly documented. The soft-ware commitments in the execution of the contract were carried out with the same expertise throughout the period. Table 2-10 and 2-11 list the many reports issued by KI and which now form part of our information library.

## SUMMARY

The successful moon flights paid the ultimate tribute to the NASA Apollo team and became living evidence that KI contribution was excellent as evidenced in the report.

Table 2-10

KIC REPORTS

| Number | Title |
|---|---|
| AA-63-001 | Development Plan - Optical Subsystem |
| AA-63-002 | Basic Elements of PERT |
| AA-63-003 | Apollo Sextant & Scanning Telescope GSE (Rev. B) |
| AA-63-004 | Preliminary Plan Proposed for Apollo Optical Sub-System FTE |
| AA-63-005 | Optical Target Progress Report No. 1 (TDK-15) |
| AA-63-006 | Double Dove Scanning Prisms (Engineering Report No. 2 Sept. 1962) |
| AA-63-007 | Reliability Manual No. 1 Rev. A (Apollo Optical Sub-System) |
| AA-63-008 | Block I Q.C. Manual |
| AA-63-009 | Documentation Plan for Optical Subsystems |
| AA-63-010 | Industrial Aspects of Beryllium |
| AA-63-011 | Staff Electronics Engineering Report No. 191 A Resolver Digitizer |
| AA-63-012 | Consisting of: |

| | |
|---|---|
| 650092-03-1 | Transearth Injection Guidance |
| 650092-03-2 | Injection Simulation |
| *650092-04-1 | Velocity Steering Loop Pulse Transfer Function |
| *650092-04-2 | Controller Design |
| *650092-04-3 | Controller Design II |
| 650092-04-4 | Optimization of the Velocity Steering Loop |
| *650092-04-5 | Limit Cycle Analysis |

*See 650092-04-6 Errata

| | | |
|---|---|---|
| AA-63-012 (Cont.) | 650092-04-7 | Revised System Analysis |
| | 650102-1 | Network Rooting and Cost Evaluation Considerations |
| | 650102-2 | Computational Procedure for Best Path Determination Through a Network with a Single Cost Function |
| | 650102-3 | Network Rooting and Costing - Sample Problem |
| | 650122-1 | Basic Concepts in Earth Orbital Perigee Control |
| | 650122-02 | Calculation Procedures for Orbit Sensitivity |
| | 650122-3 | A Simplified Statistical Navigation Procedure |
| | 650132-1 | Continuous and Flashing Light Sources for Visual Acquisition |
| | 650132-2 | Visual Acquisition of the CM by the LM |
| | 650132-3 | Pyrotechnic Flash Cartridges and Electronic Flashtubes as Light Sources for Visual Acquisition |
| | 650182-04-1 | Linear Analysis I |
| | 650182-04-2 | Linear Analysis II |
| | 650182-04-3 | Limit Cycle Analysis |
| | 650182-04-4 | CDU Analysis |
| | 650182-04-5 | Statistical Analysis of Digital Integration |
| | 650192-4 | Pyrotechnic Flash Cartridge Characteristics |
| | 650192-5 | Narrow Band Optical Transmission Filters |
| | 650192-6 | The Steady Light Equivalent of Flashing Lights |
| | 650092-04-6 | Errata for: 650092-04-1, 650092-04-2, 650092-04-3, 650092-04-5 |
| AA-63-013 | | MDV Checkout and Repair Manual ND 1021069 |

Table 2-10 (Cont.)

| Number | Title |
| --- | --- |
| AA-63-014 | Final Report on TDK-33 Apollo Analytical Level of Effort Program |
| AA-63-015 | Management Outline for Adaptation of Package for Utilization in the AES Manned Earth Orbital Experiment Program |
| AA-63-016 | Reliability Analysis for the Optical Sub-System and MDV |
| AA-63-017 | Final Report on TDK-56 1 November 1963 |
| AA-63-018 | Final Report on TDK-64 15 November 1963 |
| AA-63-019 | Final Report on TDK-45 and TDK-59 |
| AA-63-020 | Apollo Optical Unit Center of Gravity Report 15 December 1963 |
| AA-63-021 | Optical Unit Maintenance - Checkout and Repair Procedure ND 1021067 |
| AA-63-022 | LM Design Concept Final Report |
| AA-63-023 | Optical Unit Moments of Inertia Study |
| AA-63-024 | Evaluation Study of Optical Holding Stands (TDK-102) |
| AA-63-025 | Qualification Tests of Reusable Shipping/ Storage Container for Optical Unit P/N 1011000 |
| AA-63-026 | Error Analysis Report (PTF) |
| AA-63-027 | PTF Checkout, Maintenance, and Repair Manual |
| AA-63-028 | SCT & SXT Shaft Axis Lateral Vibration Analysis |
| AA-63-029 | Contingency Analysis: The Selection of Alternate of Backup Guidance and Navigation Modes for a Manned Spaceflight |
| AA-63-030 | MDV, Tester, Checkout, and Maintenance & Repair Manual |

Table 2-10 (Cont.)

| Number | Title |
|---|---|
| AA-63-031 | Apollo GSE Autocollomator Alignment Report |
| AA-63-032 | A General Discourse on Celestial Navigation with the Apollo Optical Sub-System |
| AA-63-033 | Report on the Hand-Held Stadimeter and Sextant |
| AA-63-034 | KIC Apollo Publications Monthly Report |
| AA-63-035 | Apollo GSE Description List |
| AA-63-036 | CM Reliability & Quality Status Report |
| AA-63-037 | KIC Space Division Experience and Facilities |
| AA-63-038 | Ground Support and Factory Test Equipment |
| AA-63-039 | FTP for OUA P/N 1011000 and MDV P/N 1011559 |
| AA-63-040 | Reliability Manual for Apollo Optical Sub-System No. 1 |
| AA-63-041 | Apollo/LM Organization Charts |
| AA-63-042 | Reliability and Quality Assurance Presentation to AC 20 October 1965 |
| AA-63-043 | Tech. Proposal for Apollo Visual Simulator |
| AA-63-044 | Vol. I-Tech. Proposal for an Optical Sub-System for Apollo<br>Vol. II- Business Management Proposal for Apollo Optical Sub-System<br>Vol. III- Cost Estimate and Cost Control Proposal for Optical Sub-System for Apollo |
| AA-63-45 | Vol. I- Revised Proposal for the Apollo Optical Sub-System Vol. I (AA-63-044)<br>Vol. II- Revised Proposal for Cost Estimate and Control Vol. III (AA-63-044) |

Table 2-10 (Cont.)

| Number | Title | |
|---|---|---|
| AA-63-046 | Final Report on TDK-18 | |
| AA-63-047 | Apollo Optical Technical Description | |
| AA-63-048 | Monthly Program Progress Report No. 2<br>31 Aug. 1962 | |
| AA-63-049 | Quarterly Program Progress Report No. 1<br>30 Sept. 1962 | |
| AA-63-050 | Quarterly Program Progress Report No. 2<br>31 Dec. 1962 | |
| AA-63-051 | A Simple Optical Ranging Technique for Orbital Rendezvous | |
| AA-63-052 | Consisting of: | |
| | 650032-04-1 | Initial Condition Generation for Abort Maneuver Studies |
| | 650032-04-2 | A Short Description of the Abort Maneuver Simulation Program |
| | 650032-06-1 | Status of Apollo Ascent Abort Problem |
| | 650042-03-1 | Launch Injection Error Program |
| | 650042-03-2 | Launch Delay Computer Program |
| | 650042-03-3 | Launch Delay Computations |
| | 650042-04-1 | Effects of Time Delay at Launch |
| | 650042-05-1 | Propagtion of Parking Orbit Errors |
| | 650052-05-1 | Apollo Space Sextant and Scanning Telescope Error Models |
| | 650052-05-2 | Apollo Space Sextant Error Analysis |
| | 650052-05-3 | Apollo Space Sextant Computer Program |
| | 650052-05-4 | Apollo Scanning Telescope Computer Program |
| | 650082-05-1 | Analysis of Optical Error due to Double Dove Scanning Prism |
| | 650082-05-2 | SCT Gear Train Analysis |

Table 2-10 (Cont.)

| Number | Title |
|---|---|
| AA-64-100 | Apollo/LM Organization Charts |
| AA-64-101 | Error Analysis Report-Opt. Lab. Target-Short Periscope and Align Mirror Assy. |
| AA-64-102 | Qualification Test, Reusable Shipping Container MDV |
| AA-64-102A | CM Monthly Report #16 - 5-31-64 |
| AA-64-103 | Optical Unit Shaft Axis Bearing Preload Study |
| AA-64-104 | CM Block II GSE Development Plan |
| AA-64-105 | CM Monthly Report No. 18, 8-31-64 |
| AA-64-106 | Quarterly Summary of Quality Program Performance Audits |
| AA-64-107 | Quarterly Tech. Progress No. 9 9/30/64 |
| AA-64-108 | Apollo Monthly Center of Gravity Report 10/30/64 |
| AA-64-109 | Final Report of Structual Analysis of Optical Unit 1011000 |
| AA-64-110 | Quality Test of Projection Lens 101137, Final Report |
| AA-64-111 | Structual Analysis of Optical Unit 1011000 |
| AA-64-112 | Apollo Program Command Module (Monthly) |
| AA-64-113 | Apollo Program Command Module Monthly Reliability Report No. 1 |
| AA-64-114 | Apollo Program Command Module Monthly Tech. Progress Report #19 |
| AA-64-115 | Apollo Program CM Monthly Quality Assurance Progress Report #2 |

Table 2-10 (Cont.)

| Number | Title |
|---|---|
| AA-64-116 | Apollo Monthly Progress Report #20 |
| AA-64-117 | CM Monthly Reliability Report #2-30 |
| AA-64-118 | Apollo Program CM Tech. Progress Report 12/31/64 |
| AA-64-119 | Status Report 12/31/64 |
| AA-64-120 | Apollo Program CM 1/4 Reliability Report #1 12/31/64 |
| AA-64-121 | Fourth Quarterly Q.C. Perf. Audit |
| AA-64-122 | Quality Test of Connectors |
| AA-64-123 | Apollo GSE Autocollimator Alignment Report |
| AA-64-108A | Computer Program for Beam Natural Frequencies |
| AA-65-201 | Apollo Reliability Quality Test of Diff. |
| AA-65-202 | Quality Test of Optical Unit/Navigation Base Shipping Container P/N 1019720 Jan. 1965 |
| AA-65-202A | Space Division Presentation Book (Astronaut Scott's Visit) |
| AA-65-203 | Tech. Progress Report Jan. 1965 |
| AA-65-204 | Study of Optical Axis Align as effected by Reticle Shaft |
| AA-65-205 | Block II Tech. OUA Description |
| AA-65-206 | CM Monthly Report Feb. 1965 |
| AA-65-207 | Reliability Q.C. Presentation to AC Electronics |
| AA-65-207A | Apollo/LM Program Office Presentation to NASA |

Table 2-10 (Cont.)

| Number | Title |
|---|---|
| AA-65-208 | Monthly GSE Planning List |
| AA-65-209 | CM Quarterly Tech. Progress No. 1 |
| AA-65-210 | Thermal MDV Analysis TDK - 98 |
| AA-65-211 | CM & LM Quarterly Quality Status |
| AA-65-212 | History Evaluation Per, Up to 31 March 1965 |
| AA-65-213 | FTP (Preliminary Factory Test Plan for Block II OUA) |
| AA-65-214 | Q.C. per Audits 31 March 1965 |
| AA-65-215 | Q.C. Manual |
| AA-65-216 | Combined CM & LM Quality Reliability Report No. 2 |
| AA-65-217 | Apollo/LM Reliability Program Plan |
| AA-65-218 | Apollo Program CM Tech. Progress Report -Monthly |
| AA-65-219 | Thermal and OUA TDK-60 May 1965 |
| AA-65-220 | Q.C. Manual |
| AA-65-221 | Computer Program for Evaluation Beams on Lateral Vibrations |
| AA-65-222 | CM Monthly No. 24 Quarterly Test Program Report |
| AA-65-223 | TDK-61 OUA AGE 2 - Mechanical Integrity Test |
| AA-65-224 | KIC OU Checkout Supplement |
| AA-65-225 | Universal Eyepiece |
| AA-65-226 | Combined CM/LM No. 2 Quarterly Tech. Progress Report |

Table 2-10 (Cont.)

| Number | Title |
|---|---|
| AA-65-227 | Combined CM/LM Quarterly Tech. Progress Reliability Report |
| AA-65-228 | Combined CM/LM Quarterly Quality Status (3) |
| AA-65-229 | Quarterly Quality Perf. Audits |
| AA-65-230 | Final Report MDV |
| AA-65-231 | SXT Index Mirror, Flatness and Warpage Problem Analysis |
| AA-65-232 | (TDK-83) Final Report Thermal Vacuum Evaluation Test Program Optical Unit Assembly AGE-1 |
| AA-65-233 | Apollo Program Materials Report |
| AA-65-234 | Quality Plan for the Apollo/LM Programs 6 August 1965 |
| AA-65-235 | Maintainability Design-Evaluation Report Optical Unit Assembly 2011000 Block I-100 |
| AA-65-236 | Apollo Program - CM and LM (combined) Weight, CG, and Electrical Requirements Report 20 August 1965 |
| AA-65-237 | Apollo Program CM and LM Monthly Reliability Report August 1965 |
| AA-65-238 | Optical Unit Assembly - Components and Assembly Flowgrams 19 July 1965 - Contract No. NAS 9-497 |
| AA-65-239 | Combined CM and LM Quarterly Tech. Progress Report No. 3 |
| AA-65-240 | CM and LM Quality Status Report |
| AA-65-241 | Quarterly Reliability Report No. 4 CM/LM 30 September 1965 |
| AA-65-242 | QC Audits Quarterly Summary PA - 5009 - 3 |

Table 2-10 (Cont.)

| Number | Title |
|---|---|
| AA-65-243 | Evaluation and Function Results - OUA AGE 101 |
| AA-65-244 | A Study of Effective Gravity References for Autocollimation |
| AA-65-245 | Thermal Vacuum Cycling Test OUA AGE 102 Interim |
| AA-65-246 | Interim Report Acceleration and Acceleration Overstress Tests - OUA AGE 101 12 October 1965 |
| AA-65-247 | Interim Report - Acoustic Test OUA AGE 101 12 October 1965 |
| AA-65-248 | Interim Report - Shock and Shock Overstress Tests - OUA AGE 101 12 October 1965 |
| AA-65-249 | Interim Report - Oxygen Overpressure Temperature Test - OUA AGE 101 15 October 1965 |
| AA-65-250 | Mission Cycling Test OUA AGE 102 - 5 November 1965 |
| AA-65-251 | Monthly Technical Report No. 1 15 November 1965 |
| AA-65-252 | Evaluation of RTV-103 Silicone Rubber Adhesvie in a Thermal Vacuum Environment |
| AA-65-253 | Combined CM & LM Weight, CG, and Electrical Requirement Report 15 November 1965 |
| AA-65-254 | Functional Tester Report |
| AA-65-255 | Star-Horizon Simulator Evaluation Report 24 November 1965 |
| AA-65-256 | Alignment Optical Telescope Component and Assembly Flowgrams |
| AA-65-257 | Catalog of Blocks I & II FTE 31 December 1965 |
| AA-65-258 | Design Evaluation OUA AGE 102 Thermal Vacuum Cycling and Simulated Mission Cycle Tests 15 December 1965 |

Table 2-10 (Cont.)

| Number | Title |
|---|---|
| AA-65-259 | Apollo/LM Program Organization Charts 15 December 1965 |
| AA-65-260 | Report of Assembly High Voltage Power Supply Star Tracker P/N 2007175 16 December 1965 |
| AA-65-261 | CM & LM Quarterly Reliability Report No. 5 31 December 1965 |
| AA-65-262 | Interim Report - Evaluation and Functional Test Results for Vibration Overstress Tests OUA AGE 101 |
| AA-65-263 | CM & LM Quarterly Quality Status Report 31 December 1965 |
| AA-65-264 | Combined CM & LEM Quarterly Technical Progress Report |
| AA-66-301 | Apollo Engineering Analysis Design Evaluation Program - OUA - 2/2/66 |
| AA-66-302 | Apollo/LM Organization Charts 2/4/66 |
| AA-66-303 | Analysis of Photomutiplier Dark Noise 10 February 1966 |
| AA-66-304 | Study of the Manufacturing Tolerances on Error Gradient 14 Feb. 1966 |
| AA-66-306 | Tracker Error Signal Linearity Investigation 2/28/66 |
| AA-66-307 | Mechanical Integrity Test - OUA AGE 101 - Excluding Earth Landing Shock Test and all Eyepiece Tests 3/10/66 |
| AA-66-308 | Be Corrosion Tests and Evaluation Report and Analysis 2/28/66 |

Table 2-10 (Cont.)

| Number | Title |
|---|---|
| AA-66-309 | Combined CM and LM Weight, CG, and Electrical Requirement Report 3/15/66 |
| AA-66-310 | Apollo/LM Loctite Progress Report 3/29/66 |
| AA-66-311 | CM and LM Quarterly Status Report 3/31/66 |
| AA-66-312 | Combined CM & LM Quarterly Technical Progress Report 3/31/66 |
| AA-66-313 | |
| AA-66-314 | Combined CM and LM Quarterly Reliability Report No. 6 3/31/66 |
| AA-66-315 | Combined CM and LM Quarterly Technical Progress Report 6/30/66 |
| AA-66-316 | Quarterly Quality Control Report |
| AA-66-317 | Combined CM and LM Quarterly Reliability Report No. 7 6/30/66 |
| AA-66-317A | KIC Management Report to AC Electronics, First Increment Performance Period Ending 30 June 1966. |
| AA-66-320 | CM/LM Quarterly Tech. Progress Report #7 |
| AA-66-321 | C/M/LM Quarterly Reliability Report |
| AA-66-322 | Materials Report |
| AA-66-323 | Method of Analyzing Non Uniform Beams |
| AA-66-324 | Apollo/LM Progress Achievements 1 Nov. 1966 |
| AA-66-325 | OUA Program Plan; Recycle Motors for Additional Lubrication |

Table 2-10 (Cont.)

| Number | Title |
|---|---|
| AA-66-326 | Quarterly QC Report |
| AA-66-327 | Quarterly Tech Progress Report |
| AA-66-328 | Quarterly Reliability Report #9 |

All AA reports thru 66-328 are in storage

Table 2-11

PROJECT ENGINEERING REPORTS

| Number | Title |
|---|---|
| AE-66-001 | Configuration Determination of 2012723 Counter-weight |
| AE-66-002 | Evaluation and Plan of Action for Correction of Failures Associated with SXT Shaft perpendicularity |
| AE-66-003 | Evaluation and Plan of Action for Correction of Failures Associated with SCT SDA Alignment |
| AE-66-004 | Evaluation and Plan of Action for Correction of Failures Associated with SXT SDA Zero Alignment |
| AE-66-005 | Measurement of Electrical Zero of 2X Resolver Receiver on SXT Trunnion |
| AE-66-006 | Status of OUA/AOT Purge Valve Problem |
| AE-66-007 | Trunnion Transmittance |
| AE-66-008 | Dust Cover Investigation |
| AE-66-009 | Report of Assembly Work Performed, FR 9687 |
| AE-66-010 | Loctite Evaluation Test Report |
| AE-66-011 | Status, Black Anodize of SXT and SCT Panels |
| AE-66-012 | Flexprints, Interim Report |
| AE-66-013 | Interferometric Measurement of Flatness and Coplanarity of SXT Mirror Mounting Surfaces |
| AE-66-014 | Interim OUA Connector Investigation |
| AE-66-015 | Interim Luxorb Performance Review as Used on the OUA |
| AE-66-016 | Manual Adjust Knobs |

Table 2-11

| Number | Title |
|---|---|
| AE-66-017 | Study of Shifts on OUA's |
| AE-66-018 | |
| AE-66-019 | Effectiveness of Epoxied Wedges in Limiting SXT SDA Shifts Induced During Vibration Testing |
| AE-66-020 | Sextant Trunnion Mirror Mount Bearing Modification |
| AE-66-021 | Contamination Protection Study, Ablative Parts |
| AE-66-022 | Corrosion of Hardware in Shipping Containers |
| AE-66-023 | AGE 207 Special Thermal Vacuum Conditioning |
| AE-66-024 | Report on OUA Thermal Vacuum Tests |
| AE-66-025 | Learner Model Thermal Vacuum Tests with Proposed New Flanged Trunnion Bearing Design |
| AE-66-026 | Rationale for Field Modification to SXT Eyepiece Interchangeability Shim P/N 2012608 on OUA's Prior to AGE 205, S/N 017 |
| AE-66-027 | Control of SXT Index Mirror Flatness Characteristics Through SXT Index Head Assembly |
| AE-66-028 | Synopsis of SCT Stiction Investigation |
| AE-67-029 | Storage and Maintenance Requirements for OUA Bearings and Lubrication |
| AE-67-030 | SXT Shaft Axis Spring-Back |
| AE-67-031 | SXT-SDA Variation Differences Between AC and KI |
| AE-67-032 | Preforming of Self Locking (Long Lock) Screws |
| AE-67-033 | SXT Trunnion Hesitation Study |

Table 2-11 (Cont.)

| Number | Title |
|---|---|
| AE-67-034 | Purge Valve Investigation |
| AE-67-035 | Limit Stop Tests - Results |
| AE-68-101 | SXT Trunnion Limit Stop Evaluation |
| AET-66-001 | Proposed Methods of Obtaining a Spectral Response Curve for the Pritchard Photometer Used in the SXT Luminous Transmittance Measurement |
| AET-66-002 | Compatability of 30 Second Star Output of SH Simulator with Learner Model OUA |
| AA-67-401 | Materials Report |
| AA-67-402 | Quarterly QC Report |
| AA-67-403 | Quarterly Technical Progress Report |
| AA-67-404 | Quarterly Reliability Report |
| AA-67-405 | Thermal Analysis of OUA with Ablative Shield |
| Sup. I | |
| AA-67-406 | Be Corrosion test, Evaluation Reports & Analysis |
| AA-67-407 | Apollo GFP Potential Failures |
| AA-67-408 | Quarterly Tech Progress Report 6-30-67 |
| AA-67-409 | Quarterly Product Assurance Report 6-30-67 |
| AA-67-410 | TV Retest of OUA Blk II with -4 Motors |
| AA-67-411 | Inventory Procedures and Inventory Controls |

Table 2-11 (Cont.)

| Number | Title |
|---|---|
| AA-67-412 | Qual. Test Report of Blk II Eyepieces |
| AA-67-413 | Qual. Test Report of Size 8 Resolver P/N 1012157 |
| AA-67-414 | Materials Report |
| AA-67-415 | CM/LM Tri-Annular Progress Report |
| AA-67-416 | Product Assurance Periodic Status Report |
| AA-68-501 | Product Assurance Periodic Status Report |
| AA-68-502 | Program Period Progress Report 11/1/67 - 2/29/68 |
| AA-68-503 | Materials Report |
| AA-68-504 | Program Quarterly Presentation to AC |
| AA-68-505 | Product Assurance Periodic Status Report 3/1/68 - 6/30/68 |
| AA-68-506 | Periodic Tech Progress Report |
| AA-68-507 | Quarterly Presentation to AC Electronics |
| AA-68-508 | Materials Report |
| AA-68-509 | Structural Analysis Review, OUA 220 Overstress |
| AA-69-601 | Final Report Repair Contract FNP 03700. |

# Section 3

# TECHNICAL APPROACH

## 3.1 DESCRIPTION OF OPTICAL SUBSYSTEM

The Guidance and Navigation (G & N) System is one of the Apollo Spacecraft systems. The G & N system, located at the lower navigation station in the Command Module, performs two basic functions - inertial guidance and optical navigation.

For optical navigation, a scanning telescope and sextant are used to take sightings on celestial bodies and landmarks. The sightings are used to: (1) determine the spacecraft position and velocity which define the trajectory, and (2) establish proper alignment of the stable platform. Communications with ground tracking stations serve as backup and may be used to assist in navigation.

The G & N system is divided into three major subsystems: inertial, optical, and computer. The G & N system is designed so each subsystem can be operated independently during an emergency or backup mode. Therefore, the failure of one subsystem will not place the entire G & N system out of commission. The three subsystems, or combinations of subsystems, can perform the following functions:

1. Periodically establish an inertial reference which is used for measurements and computations.
2. Align the inertial reference by precise optical sightings.
3. Calculate the position and velocity of the spacecraft by optical navigation and inertial guidance.
4. Generate steering signals and thrust commands necessary to maintain the required spacecraft trajectory.
5. Provide the astronaut with a display of data which indicates the status of the guidance and navigation problem.

The optical subsystem enables the astronaut to take precision optical sightings on celestial objects by means of a telescope and sextant. These sightings are used in calculating the vehicle's position and velocity and in aligning the IMU. The celestial bodies serve as the primary reference for navigation of the spacecraft with possible backup from ground stations.

The taking of optical sightings is a semi-automatic operation and requires the astronaut to point the optical instruments. If the celestial objects cannot be acquired by operating the optical controls alone, the astronaut must change the attitude of the spacecraft by commanding roll, pitch, and yaw motion with the attitude control stick.

At the instant the optical sighting is taken, the time of sighting and the angles of the optical instruments are recorded by the AGC. Data pertaining to the location of the celestial objects and programs for navigational calculations have been stored in the AGC. The navigational measurement is accomplished during earth and lunar orbit by measuring the angles to landmarks with the telescope and during midcourse by measuring the angle between a landmark and a star with the sextant. The IMU is aligned during flight by measuring the angle between the navigation base and two stars with the sextant. The optical instruments may also be utilized in prelaunch IMU alignment.

In case of a failure in the optics electronics, the astronaut may be required to operate the telescope manually with a universal tool and read the angles off counters on the telescope axes. In such emergencies the astronaut would calculate, with possible assistance from the ground, a navigational fix and velocity correction.

## 3.2 OPTICAL BASE

The optical base is a rigid structure in which the telescope and sextant shaft axis components are mounted. (See Figure 3-1). Trunnion and shaft drive mechanisms, resolvers, and angle counters for the telescope and sextant are housed in the base assembly. Telescope and sextant panel assemblies are mounted on the underside of the base. The telescope panel has provision for manual positioning of telescope shaft and trunnion axes, and also includes viewing windows for position angle counters within the gear box.
gear box.

### 3.2.1 Optical Base and Navigation Base Interface

The optical base is mounted to the navigation base in the space vehicle. (See Figure 3-1) The critical alignment of the optical base with the navigation base is achieved with a kinematic mounting procedure. The optical base alignment is obtained by the use of three steel balls of equal diameter (within 40 millionths of an inch). The balls are assembled in conical seats mounted on the optical base. One conical seat is rididly anchored on the optical base. A second conical seat is mounted on a "Vee" in line with the first seat. A third conical seat has two degrees-of-freedom in the same

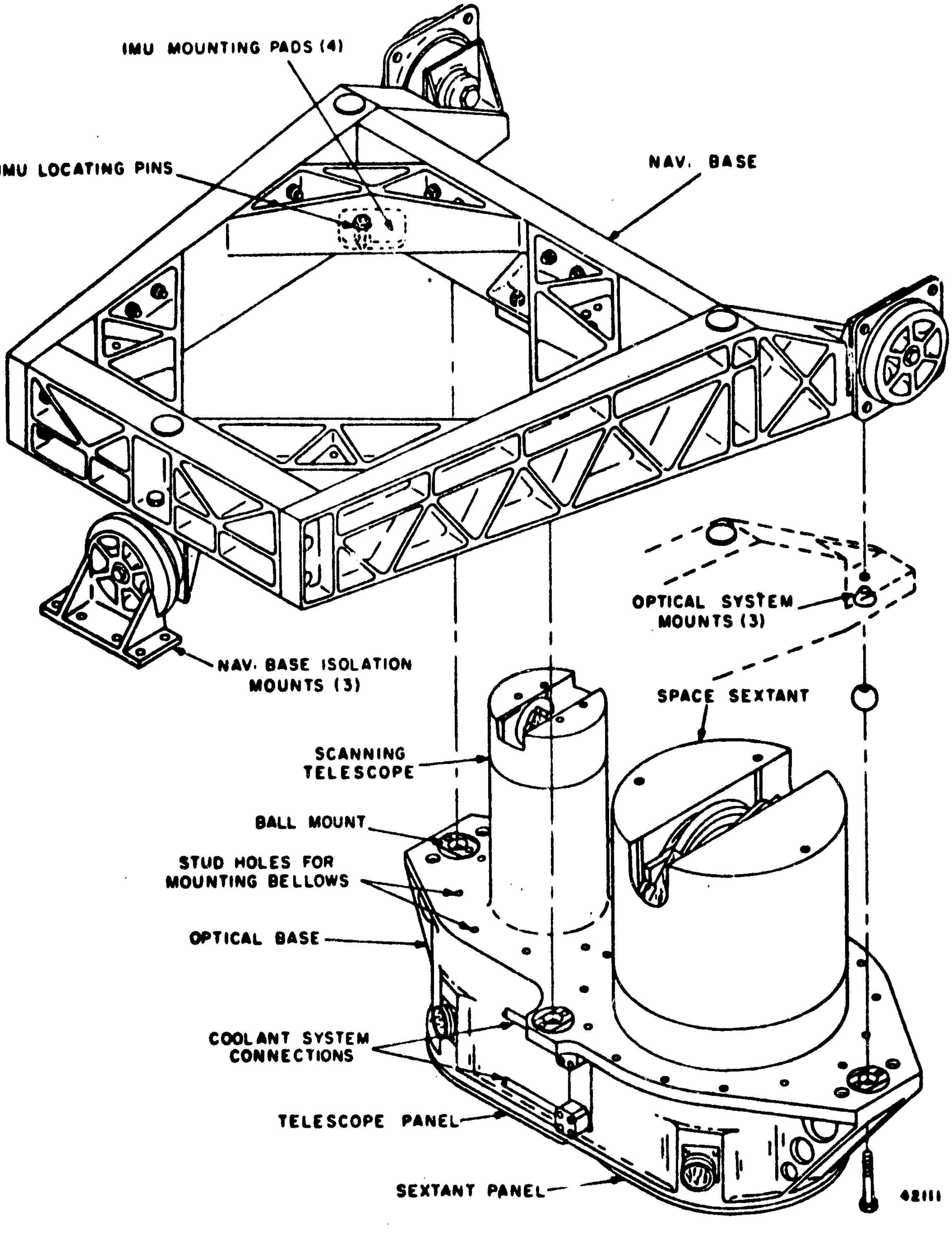



Figure 3-1. Optical Subsystem and Navigation Base

plane as the first two. This plane is perpendicular to the sextant shaft axis. The mounting arrangement maintains the optical base in the required fixed relationship with the inertial measurement unit (IMU) and still permits freedom for tolerance variations between optical and navigation base mounts.

### 3.2.2 Optical Base, Sextant, and Telescope Alignment

The scanning telescope and space sextant are mounted in two protruding tubular sections of the opticalbase assembly. The telescope and sextant shaft axes are aligned paralled to each other and afford a common line-of-sight (LOS) to selected targets.

## 3.3 OPTICS AXES

The optics subassembly motion is about two right-hand, orthogonal sets of axes. One set rotates in accordance with the shaft movements of the sextant and scanning telescope. The other set rotates in accordance with trunnion movements of the sextant and scanning telescope.

Figure 3-2 shows the relationship of the optics and navigation base axes and their associated angles. Positive rotation of the optics trunnion about the trunnion drive axis (TDA) causes a positive increasing trunnion angle ($A_t$).

At all times the shaft drive axis is aligned with the navigation base Z axis ($Z_{nb}$) and the shaft Z axis ($Z_s$) for a common reference line for the navigation base and optics coordinate systems. (See Figure 3-2) The trunnion drive axis also is aligned with the trunnion Y axis ($Y_t$) and the shaft Y axis ($Y_s$) at all times, giving a common reference line for the two optics coordinate systems.

## 3.4 TELESCOPE

The telescope (Figure 3-3) function is similar to a theodolite in its ability to accurately measure elevation and azimuth angle of a single target using an established reference. The telescope lenses provide 60-degree true field of view at 1X or 20-degree field of view at 3X magnifications. The 1X and 3X lens are mounted in the turrent dual eyepiece assembly. The telescope prism traverses through LOS angles from 0 degrees, in line with the shaft axis, to 58 degrees off shaft axis in either direction, thus providing a total scanning cone of 116 degrees LOS. The telescope prism rotates 360 degrees about the shaft axis.

### 3.4.1 Description

General construction of the telescope, shown in Figure 3-3, consists of three basic assemblies: trunnion axis, shaft axis, and base section. The trunnion axis assembly contains the prism and mount, drive worm shaft and gear, and trunnion structure. Shaft axis components include the tube with associated optics. Housed on the base section are related drive gears, resolver receivers, motor generators, and angle counters. In addition, to drive components, the base section includes the telescope panel assembly. The panel contains turret eyepiece mount, lighted bezel windows, and manual input adapters.

### 3.4.2 Precision Requirements

The telescope requires accurate LOS measurement of elevation and azimuth angle for a single target with respect to the optical axis. Allowable LOS error in elevation is 1 minute of arc rms with maximum repeatability of 15 arc-seconds. Shaft axis accuracy is measured at approximately 40 arc-seconds.

### 3.4.3 Target Optics

Telescope target optics basically consist of a double dove prism, unit power telescope, and eyepiece assembly. Figure 3-4 illustrates location, and light transmission function of the three optical assemblies of the telescope.

Light source enters the target optics through the double dove prism. The prism is attached to a mounting assembly, and driven in elevation by a worm reduction drive. (See items 7 and 8, Figure 3-3.) Shaft axis reduction gear drives, in the optical base, rotate the prism 360 degrees about the shaft axis. Entering light is passed from the prism to the lens assemblies.

The unit power telescope has a 60-degree true field of view. Components include an objective lens assembly, reticle, pechan prism, and relay lens. (See Figure 3-4.) The objective lens is 1.25 inches in diameter, and has a 27.4 mm EFL. The illuminated reticle, located in the optical path of the objective lens assembly, aligns the selected target. The pechan prism is employed to erect the target image (see prism sectional view illustrated in Figure 3-4). The relay lens assembly reproduces the reticle image in the eyepiece assembly.

The eyepiece assembly consists of two individual lens systems which provide either 1X or 3X magnification. A 60-degree true field of view is provided by a 1X lens assembly. The assembly measures

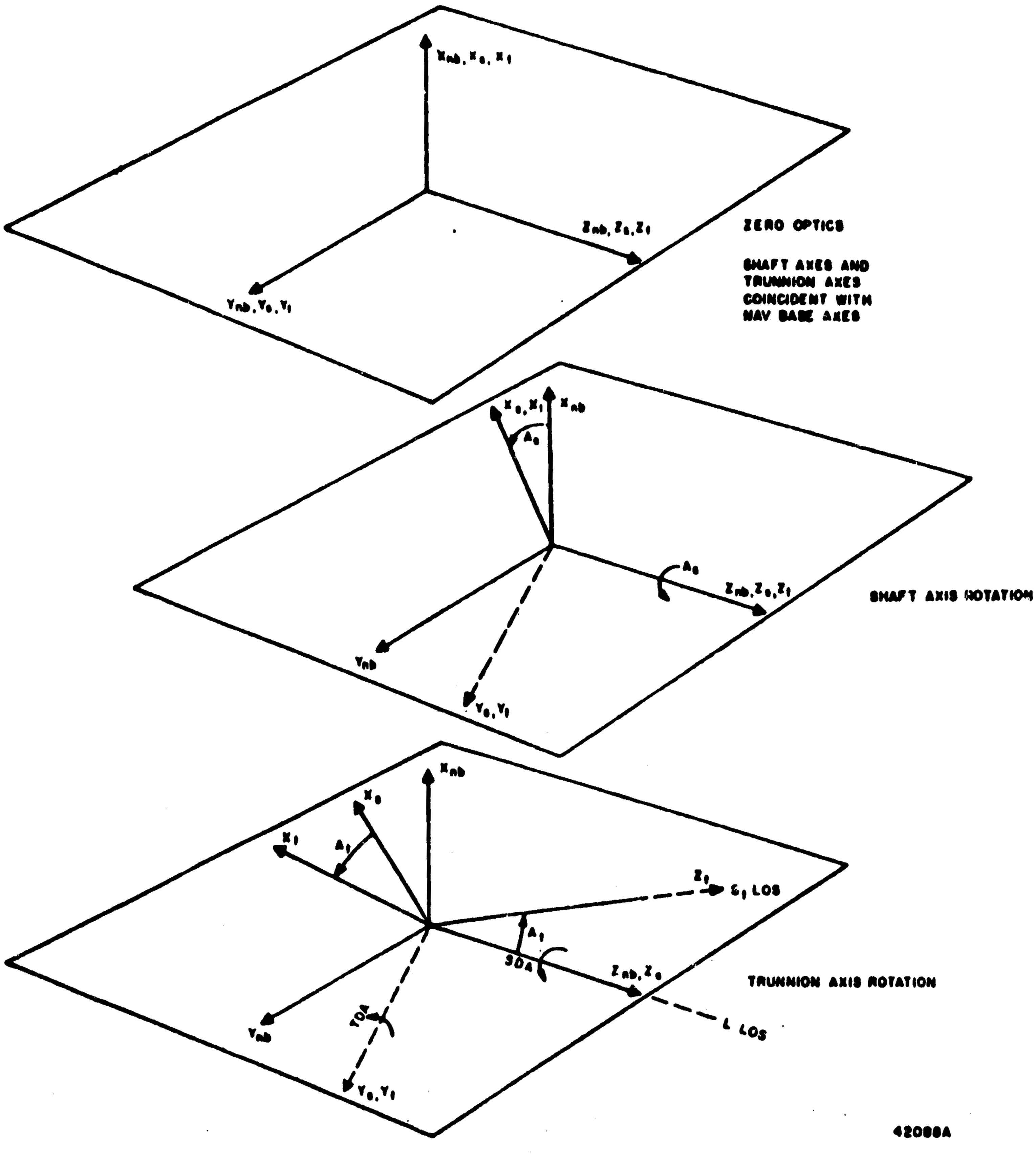
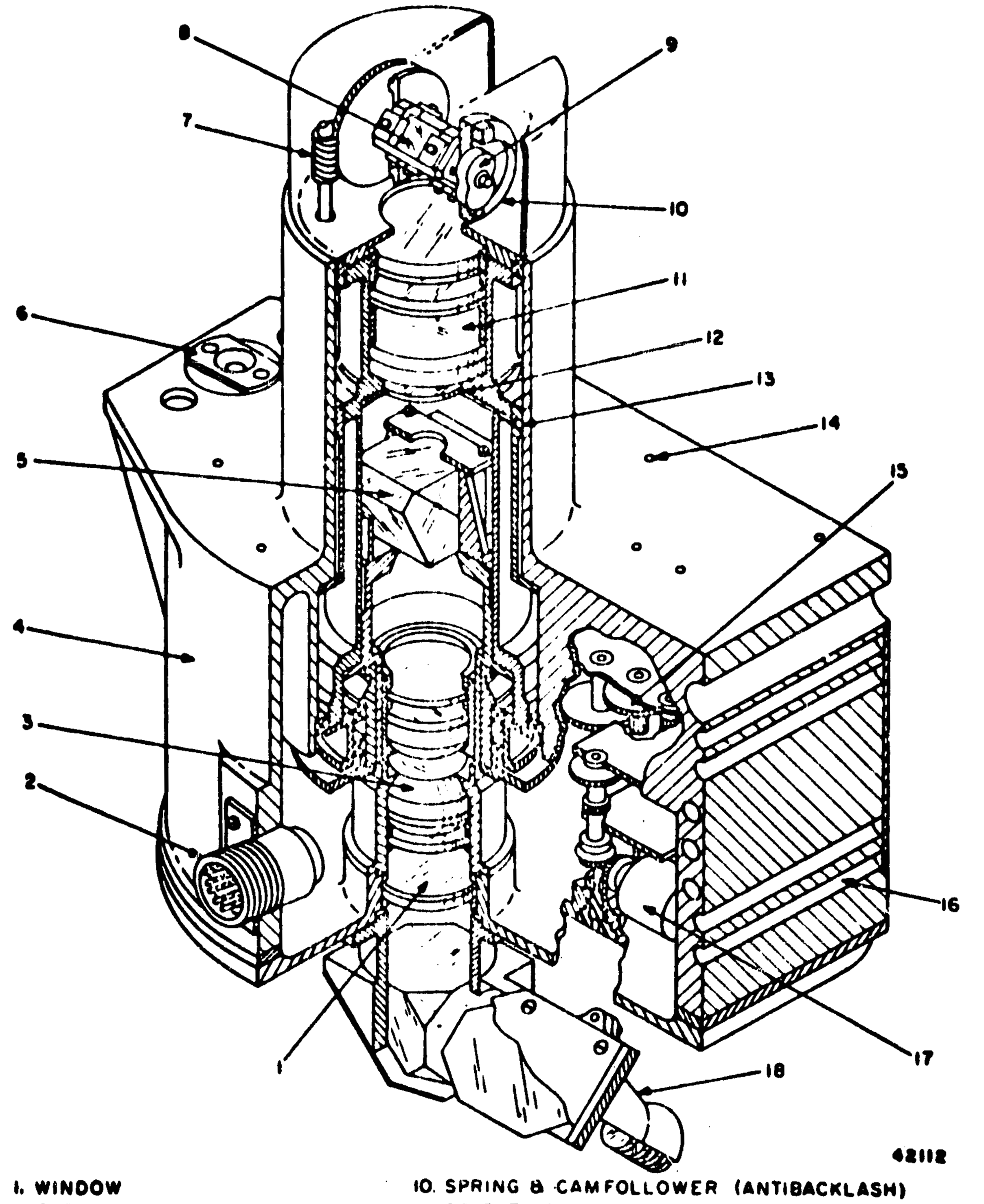



Figure 3-2. Optical Subsystem Axes




1. WINDOW
2. ELECTRICAL CONNECTOR
3. RELAY LENS ASSEMBLY
4. OPTICAL BASE
5. PECHAN PRISM
6. BALL MOUNT
7. TRUNNION DRIVE WORMSHAFT
8. PRISM & MOUNT ASSEMBLY
9. CAM
10. SPRING & CAMFOLLOWER (ANTIBACKLASH)
11. OBJECTIVE LENS ASSEMBLY
12. RETICLE
13. RETICLE ILLUMINATION
14. STUD HOLES FOR BELLOWS COVER
15. SHAFT DRIVE GEAR BOX
16. HEAT EXCHANGER CHANNELS
17. COUNTER (SHAFT AXIS)
18. EYEPIECE ASSEMBLY

Figure 3-3. Telescope

1.25 inches in diameter, and has 27.4 mm EFL. The 3X lens assembly affords 20-degree true field of view, has 9.1 mm EFL., and measures 0.41 inch in diameter.

Figure 3-4 illustrates the transmission of light source through the telescope optics. The light is acquired by the double dove prism, and transmitted through the objective lens assembly, forming an image at the illuminated reticle. Light is then transmitted through the pechan prism. The prism erects and transfers the light to the relay lens assembly. The relay lens reproduces the image at the eyepiece assembly. Light transmission through the telescope optics is approximately 27 percent.

### 3.4.4 Telescope Servo System

A conventional single speed servo loop is utilized to position the telescope about the trunnion and shaft axes. The trunnion drive servo channel, with the exception of 0 and 25-degree offset relays, is basically similar to the shaft servo channel. The command signal, originated in the optical control stick, is fed to a selector switch in the G & N indicator control panel. The magnitude of the command signal is proportional to the degree of displacement of the control stick from neutral position, while the phase relationship is determined by direction of displacement. Control stick direction is correlated with telescope direction; up-down for trunnion elevation, and left-right for shaft azimuth direction in the direct mode. The command signal is supplied to the appropriate servo channel by a selector switch. Figure 3-5 illustrates the telescope position loop.

Conventional 800-cps, size 8 resolver receivers, with accuracies of 3 minutes, are incorporated in the telescope positioning loops. The resolver electrical angle with respect to the shaft mechanical angle is 1/2X, and 1X with respect to the trunnion angle. Motor generators, housed in the optical base assembly, are employed to drive the telescope trunnion and shaft axes. Operating voltage is fed to the motor control windings from amplifier modules in the PSA.

### 3.4.5 Readout Provision

Angular position readout of telescope shaft and trunnion axes is provided by angle counters within the optical base. Telescope angle counters are viewed through windows in the telescope panel, and are readable, by the unaided eye, to within 0.02 degree.

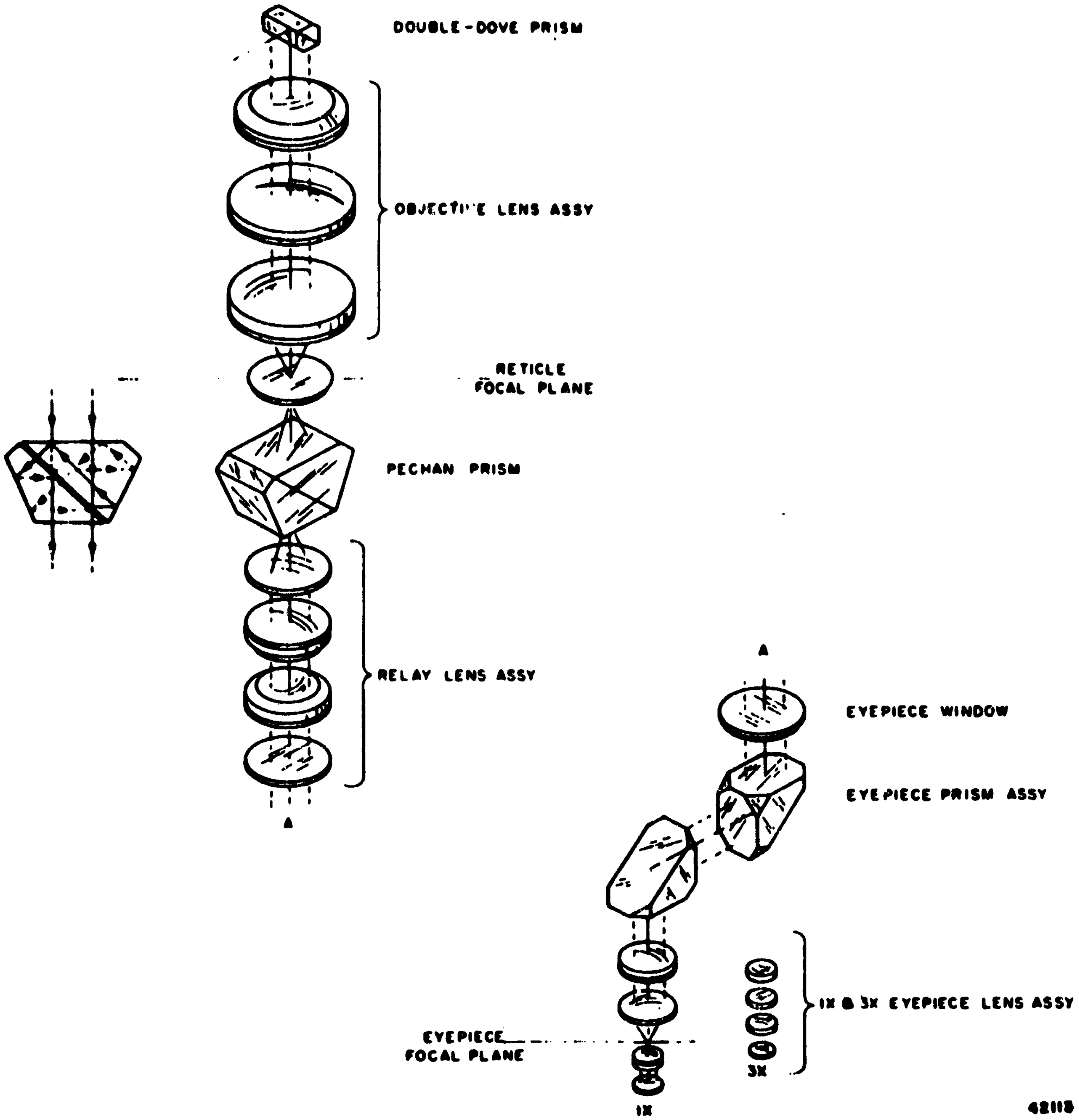



Figure 3-4. Telescope, Optical Schematic

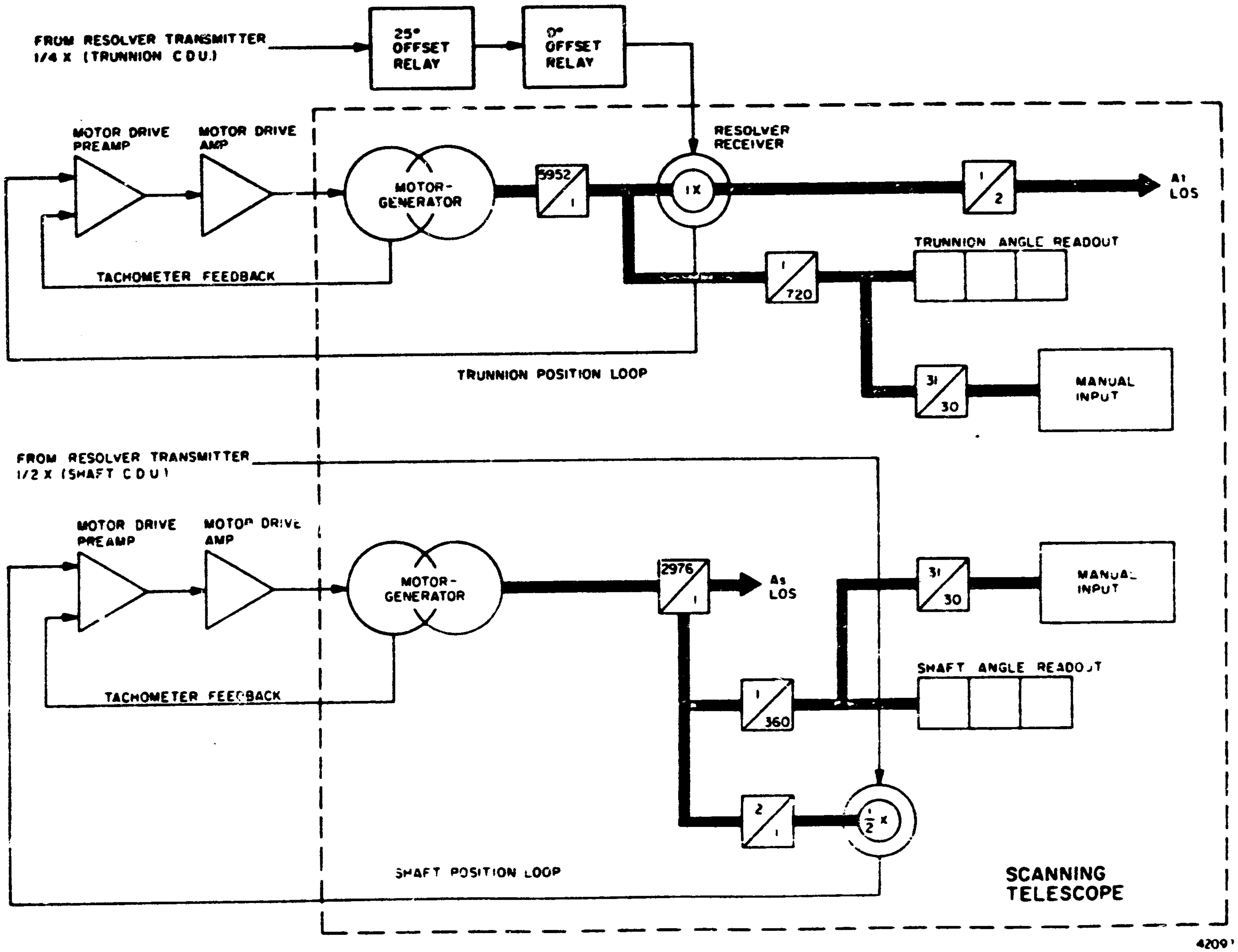



Figure 3-5. Telescope, Position Loop

### 3.4.6 Drive Assemblies

Both telescope shaft and trunnion axes are driven by motor generators geared to reduction drives located in the optical base. The double dove prism is driven about the trunnion axis through a 5,952:1 gear reduction ratio, which includes a precision worm and spur gear drive. (See items 7 and 8, Figure 3-3) Worm-driven mesh is made at 10 arc-seconds lead accuracy. Special manufacturing techniques, such as interferometer inspection, are employed to achieve this degree of precision.

Shaft axis drives are afforded by reduction gearing at a 2,976:1 ratio. The differential assembly within the shaft gear train permits independent shaft axis rotation without introduction of rotational errors in the trunnion axis. Both telescope trunnion and shaft axes drive rates range from 50 arc-seconds per second LOS minimum to 17 degrees per second LOS maximum.

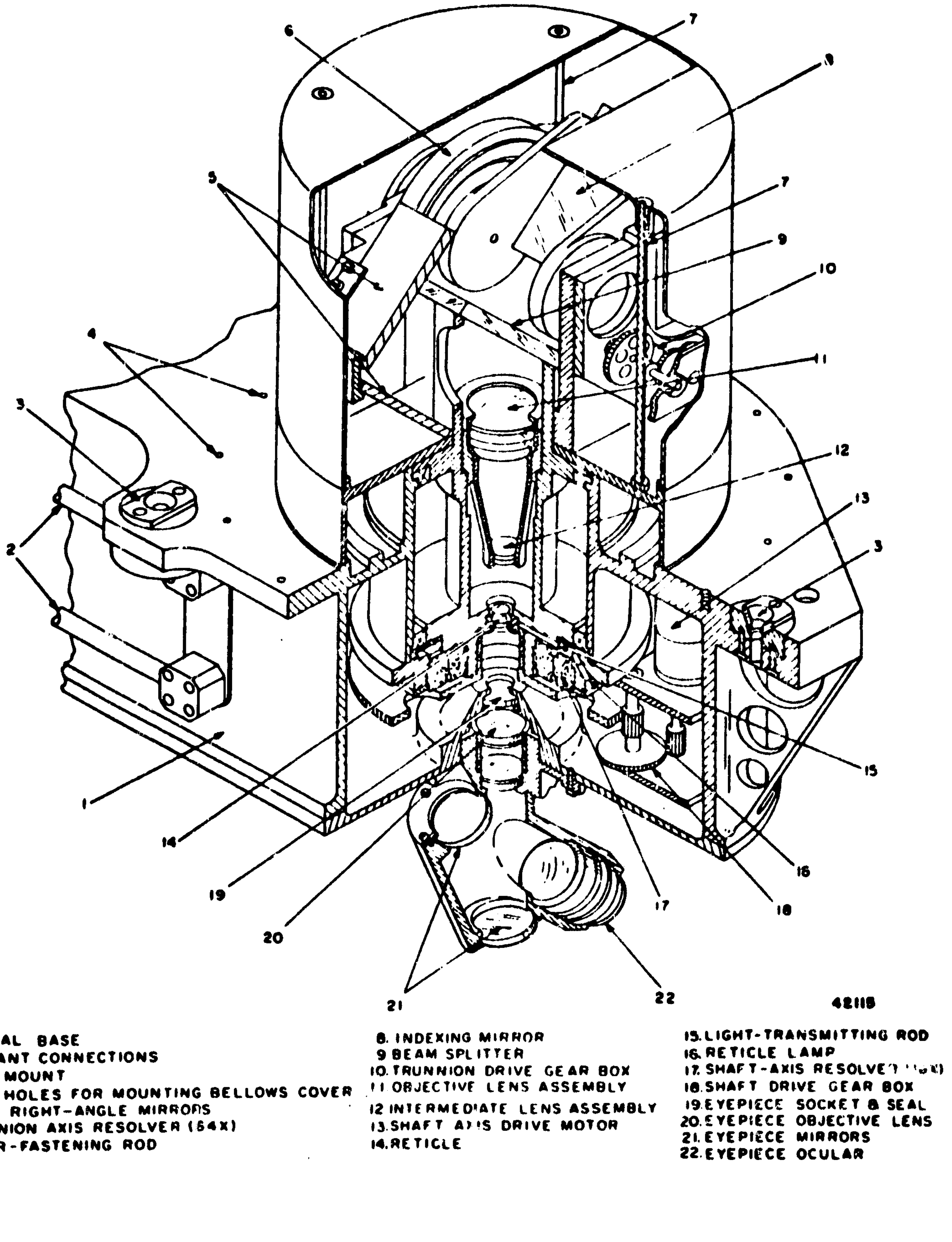
## 3.5 SEXTANT

The sextant (Figure 3-6) is a highly accurate optical device capable of measuring the included angle between two targets. Angular sightings of two targets are made through a fixed beam splitter and movable mirror located in the sextant head. The sighting head assembly is rotatable to 270 degrees in shaft axis position in either direction, from the zero reference point. The sextant lens provides 1.8-degree true field of view with 28X magnification. The movable mirror is capable of sighting a target to 57 degrees LOS from the shaft axis.

### 3.5.1 Description

Three major assemblies of the sextant are similar to the telescope: the trunnion axis, shaft axis, and optical base section. The trunnion axis assembly includes a movable mirror and mount, two fixed-angle mirrors, beam splitter, trunnion drive gear box, resolvers, and motor generator. (See Figure 3-7) The components are mounted in the trunnion axis housing, which has a cylindrical base and two vertical supports. The gear box drive is mounted on one support, and the resolvers on the other. The mirrors, beam splitter, and motor generator are mounted in the center portion. The fixed and movable mirrors are made of beryllium; the beryllium is Kanigen coated and aluminized to obtain maximum reflectivity.

The shaft axis assembly comprises the objective and intermediate optics, reticle, shaft drive gear, and resolver rotor. These components are mounted in the protruding tube of the sextant base section




1. OPTICAL BASE
2. COOLANT CONNECTIONS
3. BALL MOUNT
4. STUD HOLES FOR MOUNTING BELLOWS COVER
5. FIXED RIGHT-ANGLE MIRRORS
6. TRUNNION AXIS RESOLVER (64X)
7. COVER-FASTENING ROD
8. INDEXING MIRROR
9. BEAM SPLITTER
10. TRUNNION DRIVE GEAR BOX
11. OBJECTIVE LENS ASSEMBLY
12. INTERMEDIATE LENS ASSEMBLY
13. SHAFT AXIS DRIVE MOTOR
14. RETICLE
15. LIGHT-TRANSMITTING ROD
16. RETICLE LAMP
17. SHAFT-AXIS RESOLVER (16X)
18. SHAFT DRIVE GEAR BOX
19. EYEPIECE SOCKET & SEAL
20. EYEPIECE OBJECTIVE LENS
21. EYEPIECE MIRRORS
22. EYEPIECE OCULAR

Figure 3-6. Sextant, Cutaway View

Major structural components of the shaft axis are made of beryllium. The shaft axis drive gears, motor generator, resolver stator and housing, are enclosed in the base assembly. The base structural components, similar to the shaft axis components, are fabricated from beryllium.

### 3.5.2 Precision Requirements

The sextant requires highly accurate measurement of the LOS angle between two selected targets. The mechanical accuracy of the trunnion axis is twice that of the LOS requirement. The increased accuracy is due to mirror reflection which doubles any angular displacement in trunnion axis.

### 3.5.3 Target Optics

The sextant target optics include an indexing mirror assembly and a beam splitter, telescope, and eyepiece assembly. Figure 3-8 illustrates relative position and light transmission function of the four optical components of the space sextant.

The index mirror assembly contains two fixed mirrors set at a 90-degree included angle and a movable mirror. The movable mirror is mounted on the trunnion assembly and driven in LOS angle by the trunnion drive motor generator through a usable angle of 57 degrees. (See Figure 3-7) The beam splitter is assembled to the sextant index head assembly. The head assembly is mounted on the shaft axis assembly and driven by a motor generator in the optical base. It can be rotated 270 degrees in either direction from a zero reference point about the shaft axis.

The sextant telescope provides high power magnification of two target images. Telescope components include 1.58 diameter, f5.5 objective lens, an intermediate lens assembly, and illuminated reticle. The two target images and the reticle image are located in the focal plane of the objective lens assembly for the purpose of aligning the target image. These components are a part of the shaft axis assembly. (See Figure 3-3.)

The sextant eyepiece assembly consists of two relay lens and eye lens assemblies. Together, the lens assemblies make up a telemicroscope of 0.34 inch focal length. Individually, the relay lenses contribute approximately 3X magnification, while the eye lens contributes 2X magnification to the 28X telescope total magnification.

The simultaneous sighting of two targets is accomplished by positioning the fixed LOS of the sextant on one target, and positioning the movable mirror about the shaft and trunnion axes until a second target is acquired. (See Figure 3-8) Light from the first

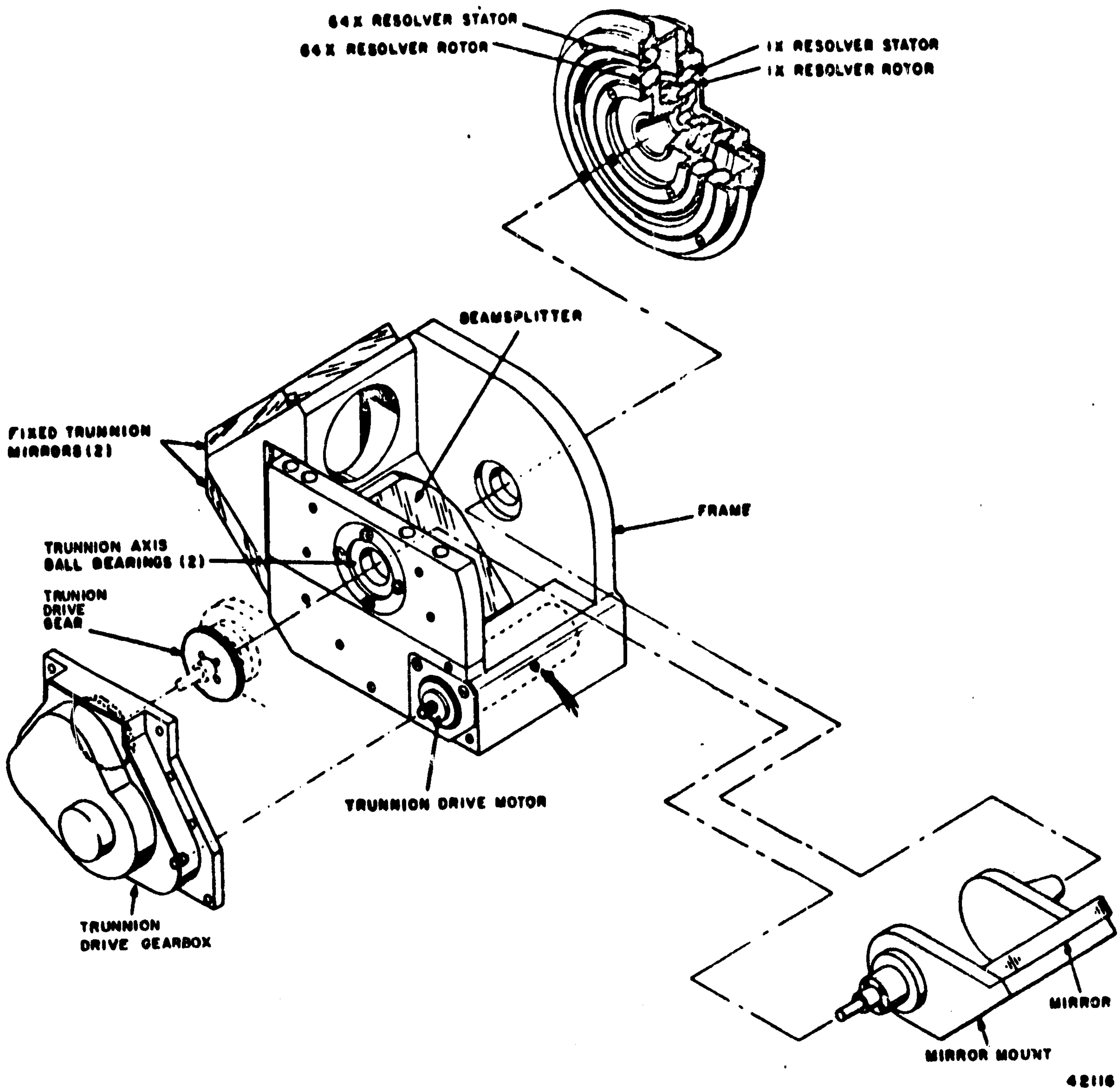



Figure 3-7. Sextant Trunnion Axis Assembly

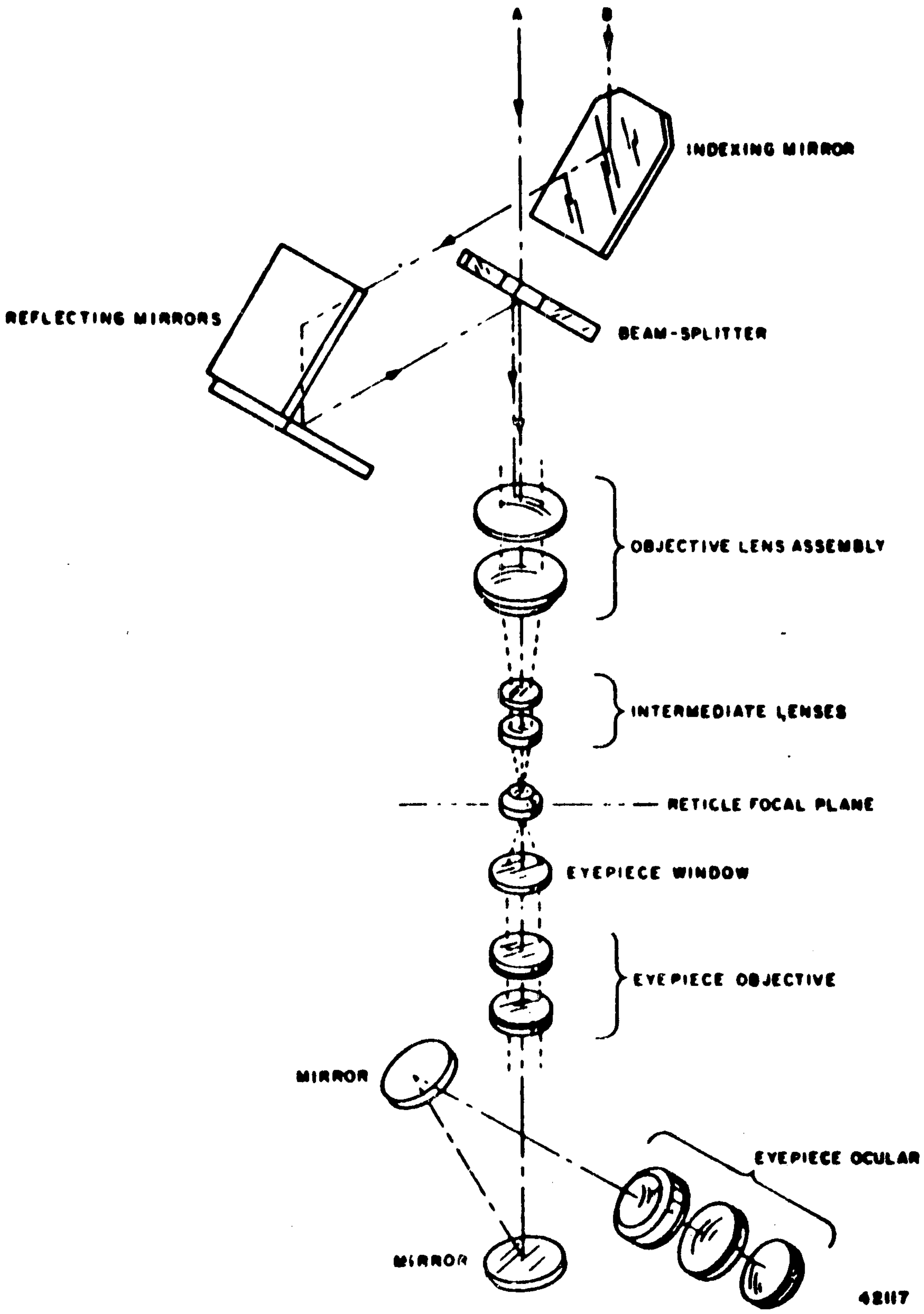



Figure 3-8. Sextant, Optical Schematic

target (A) is passed through the beam splitter with approximately 20 percent transmission. Light from the second target (B) is acquired on the indexing mirror. This light is reflected by a pair of fixed mirrors back towards the underside of the beam splitter; thus, the beam splitter combines light from both targets into the lens system. Light from both LOS's passes through the telescope lens system in coincidence. The telescope lens system affords high power magnification of the two target images. Magnified target images are then transmitted from the lens system into the eyepiece assembly. Since there is considerable difference in light intensity among various star and landmark targets, the sextant optics is designed to provide a suitable contrast in light intensities for two coincident images. (See Figure 3-8) Overall light losses in the sextant are such that approximately 2 percent of the impinging light is transmitted along path A (fixed LOS landmark target) while approximately 38.5 percent of the light is transmitted along path B (movable mirror star target). The significant difference is due to the 80 percent reflectivity of the beam splitter surface. Further variation in landmark intensity is provided by use of a polaroid filter attached to the beam splitter.

### 3.5.4 Servo System

The sextant trunnion and shaft servo channels (Figure 3-9)each utilize two-speed resolver loops, both coarse and fine. The trunnion channel is driven at 1X and 64X speeds and the shaft channel at 1/2X and 16X speeds. These loops are explained in paragraph 3.7.1.

Two Bendix-type multipole "pancake" resolvers are used in trunnion drive, and both multipole and conventional type resolvers in shaft drive. Both shaft and trunnion drive motor generators are operated by input control voltage source supplied from motor drive amplifiers in the PSA.

### 3.5.5 Drive Assemblies

The sextant is driven by motor generators and reduction gearing in optical base and trunnion axis assemblies. High precision gearing within the base assembly affords 2,423:1 motor shaft reduction for trunnion drive axis. A torsion spring and cam arrangement, mounted on the trunnion drive mechanism, minimizes backlash error in either direction of rotation. The sextant trunnion drive rate ranges from 34 degrees per second LOS maximum, to 100 arc-seconds per second LOS minimum. Sextant shaft drive is provided by a 3,011:1 reduction gear box in the optical base. The shaft drive rate is from 17 degrees per second LOS maximum, to 50 arc-seconds per second LOS minimum.

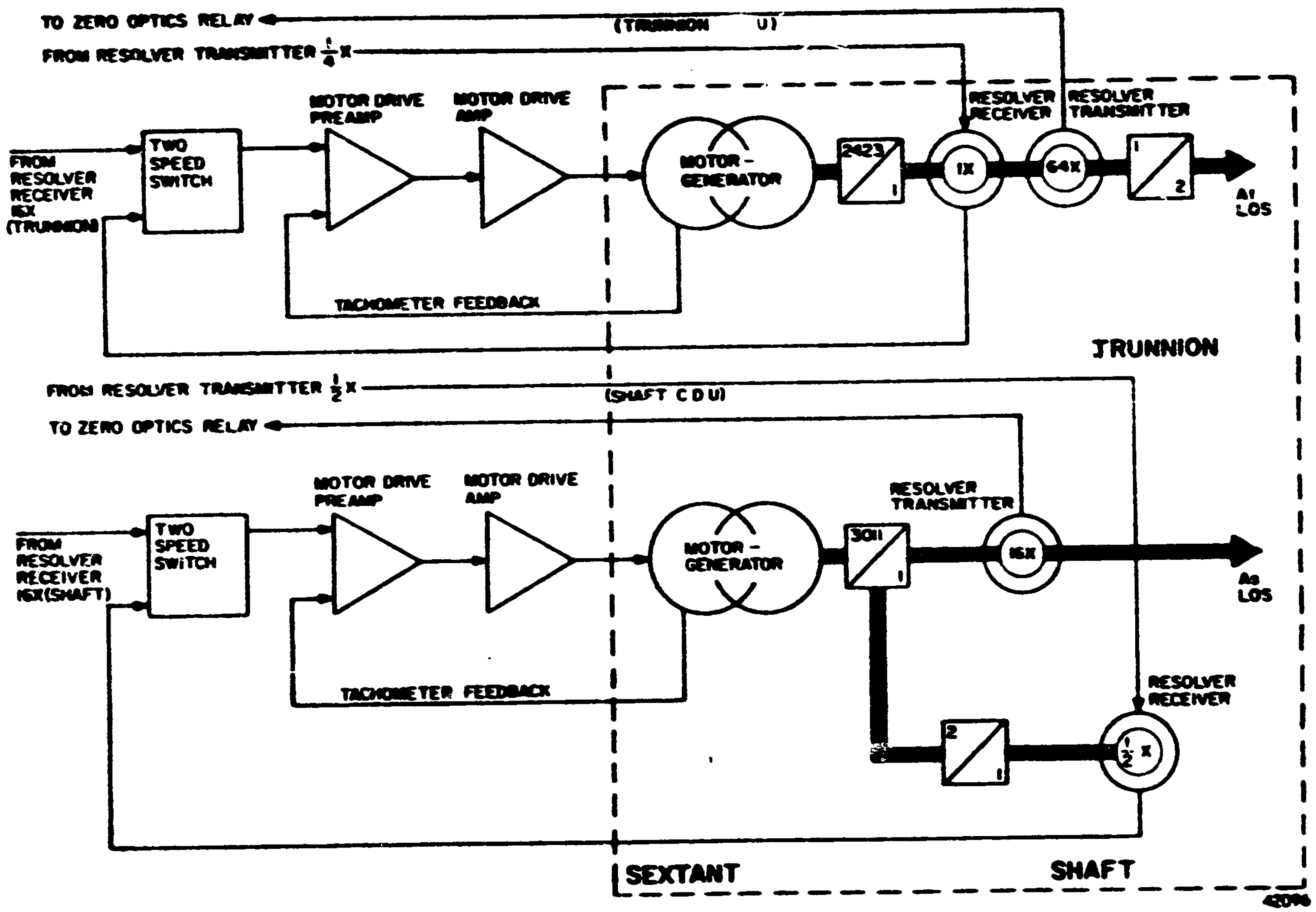



Figure 3-9. Sextant, Position Loop

## 3.6 OPTICAL SUBSYSTEM MECHANIZATION

The optical subsystem mechanization positions the sextant and telescope according to command signals from the optics hand controller. A simplified block diagram of the optics mechanization is shown in Figure 3-10.

The optics functions in either the manual, computer, or zero modes as selected by the astronaur. The manual mode is the normal optics operating mode. Zero mode is used to automatically drive the CDU to zero position prior to making an optical sighting. The computer mode will be used in future systems to automatically drive the optics to predetermined positions.

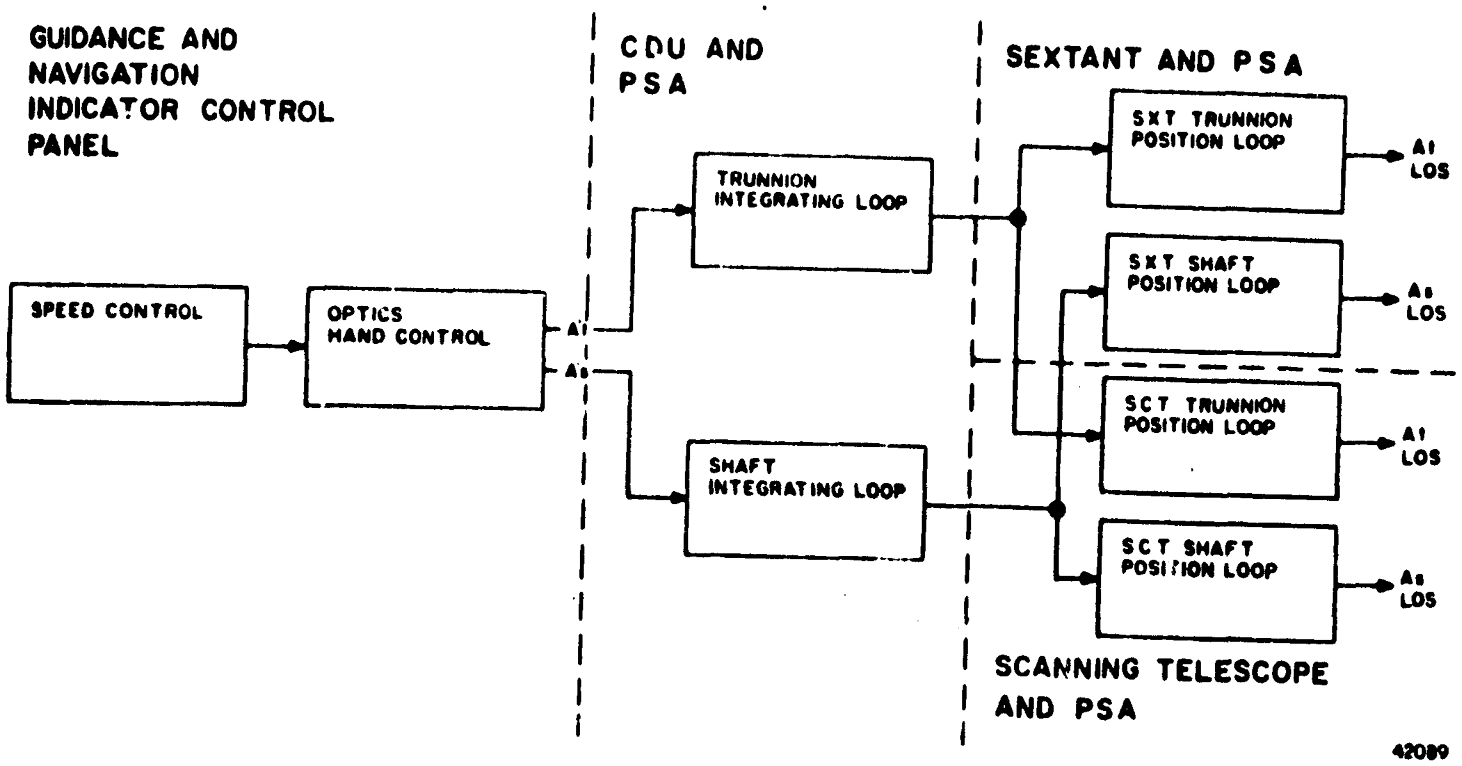



Figure 3-10. Optics Mechanization, Block Diagram

The optics subsystem mechanization is accomplished with integrating servo loops and position servo loops as shown in Figure 3-10. The integrating servo loops operate as a coarse-fine resolver system for the sextant and as a coarse resolver system for the telescope.

They send position information from the CDU to the sextant and telescope. The position servo loops receive the position information from the CDU's and drive the servo motors that position the trunnions and shafts of the sextant and telescope.

### 3.6.1 Modes of Operation

The optics subsystem operates in one of three optics modes and can be controlled in one of two control modes. An optics mode switch on the G & N indicator control panel enables the astronaut to select either the manual, computer or zero optics mode. In the manual mode, the optics may be driven to a desired position with the optics hand controller. In the zero optics mode, the CDU's automatically drive to a zero position. Both of these modes are discussed in detail later in this chapter. The computer mode is not used in the present system.

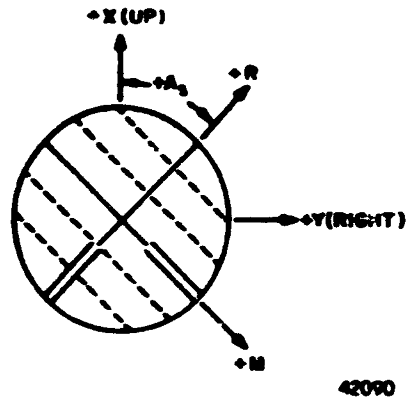
When the optics mode switch is in the manual position, the astronaut may select either a direct or resolved controller mode of operation by operating the controller mode switch. The direct mode causes the image in the optics eyepiece to move in a shaft-centered, polar motion in accordance with the optics hand controller movement. In the resolved mode, the image moves up-down or left-right in accordance with the optics hand controller movement.

Figure 3-11 indicates the direction of target image movement in the sextant eyepiece for movements of the optics hand controller in both the direct and resolved mode. In direct mode, the image moves in the R (reference) and M (measurement) coordinate system. In resolved mode, the image movement is in the spacecraft X-Y coordinate system which is independent of the shaft angle. In either mode, the RM coordinate system is rotated about the shaft axis through the angle $A_s$ (shaft angle).

Also, in the resolved mode shaft rotation speed is automatically reduced as the trunnion angle is increased. The reduction in shaft speed is necessary to keep a constant image motion rate for various trunnion angles.

### 3.6.2 CDU Mechanization of Optics Subsystem

In the optics mechanization (Figure 3-12), the 1/4X resolver in the trunnion integrating loop and the 1/2X resolver in the shaft integrating loop function as transmitters. The 16X resolvers function as transformers in both integrating loops. The 1/2X resolver in the trunnion integrating loop functions as a variable gain device. The 1X resolver in the shaft loop resolves polar coordinates into rectangular coordinates when the optics controller mode switch is in the resolved position. The coordinate transformation is not used in the direct mode.




| Controller Mode | Controller Motion | Apparent Target Image Motion | Trunnion CDU Readout | Shaft CDU Readout | Sextant Trunnion Angle | Sextant Shaft Angle |
|---|---|---|---|---|---|---|
| Direct Mode *$-90^{\circ} < A_s < +90^{\circ}$ $A_t > 0^{\circ}$ | Down | -R | Increase | | Increase | |
| | Up | +R | Decrease | | Decrease | |
| | Left | -M | | Increase | | Increase |
| | Right | -M | | Decrease | | Decrease |
| Resolved Mode *$0^{\circ} < A_s < 90^{\circ}$ $A_t > 5^{\circ}$ | Down | -X | Increase | Increase | Increase | Increase |
| | Up | -X | Decrease | Decrease | Decrease | Decrease |
| | Left | -Y | Increase | Decrease | Increase | Decrease |
| | Right | +Y | Decrease | Increase | Decrease | Increase |

In Direct Mode: Movement is along a coordinate system that is rotated through angle $A_s$.
In Resolved Mode: Movement is along an X-Y axis (independent of $A_s$).

*Angular limits are for illustration purposes only.

Figure 3-11. Sextant Target Image Motion

The 64-tooth encoder, as used in the optics subsystem, generates two pulses per gear tooth. For operation of the telescope only, each pulse represents approximately 10 arc-seconds of motion of the 1/4X resolver in the trunnion loop (20 arc-seconds LOS) and 20 arc-seconds of motion of the 1/2X resolver in the shaft loop. (40 arc-seconds LOS). When the sextant is energized, only one pulse per tooth is used and represents approximately 5 arc-seconds of motion of the 1/4X resolver in the trunnion loop (10 arc-seconds LOS).

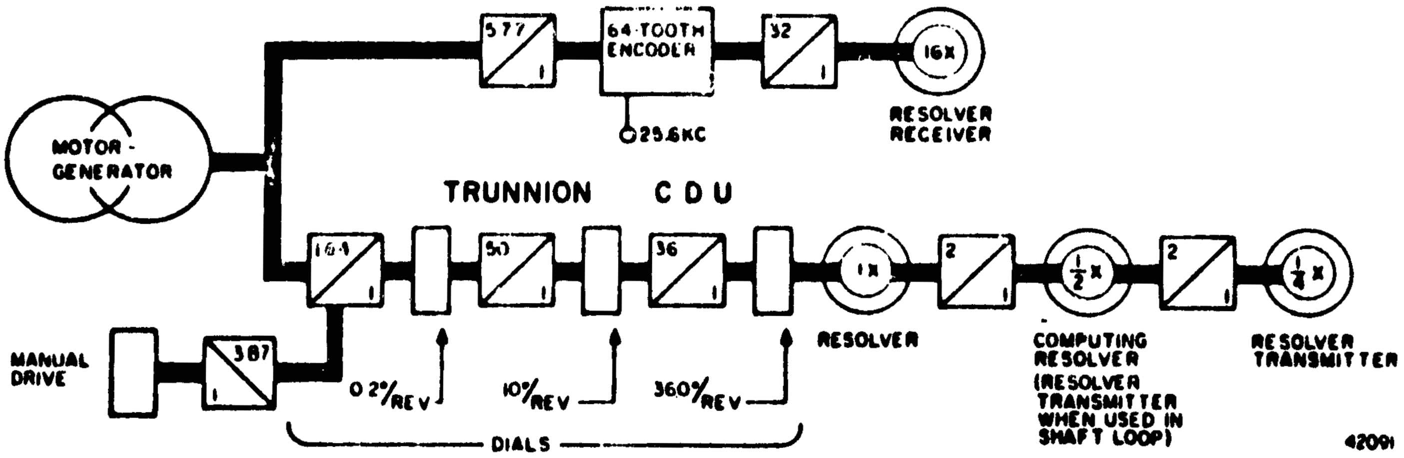



Figure 3-12. Trunnion CDU Mechanization

### 3.6.3 Integrating Servo Loops

The shaft and trunnion integrating servo loops (Figures 3-13 and 3-14) convert the electrical drive rate signals from the optics hand control to shaft rotations in the CDU's. The optics hand control and the speed control (not shown), enable the astronaut to control the integrating loops drive rates. The speed control is a transformer with three taps on the secondary winding. The astronaut may select the desired maximum optics drive rate with a three-position switch which selects the proper transformer tap. The trunnion LOS maximum optics drive rates are: 8.56 degrees per second for the high setting, 1.0 degree per second for the medium setting, and 0.1 degree per second for the low setting. The shaft LOS maximum drive rates are: 17.1 degrees per second at the high setting, 1.0 degree per second for the medium setting, and 0.1 degree per second for the low setting. The transformer primary is excited with 28 volts ± 1 percent, 800 cycles zero phase. The optics hand control consists of a control handle, two resolvers and dead zone switches. As the control handle is moved by the astronaut, it positions the rotors of the resolvers. The resolver rotor windings are excited by the output of the speed control. The voltage induced in the resolver stator windings will then depend upon the rotor winding excitation and the angular position of the rotor.

In the direct mode, a fore-aft movement of the control handle generates a trunnion drive rate signal, $\dot{A}_t$. A left-right movement generates a shaft drive rate signal $\dot{A}_s$. The drive rate signals are now sent through the optics mode switch to the controller mode switch and then to their respective CDU motor drive preamplifiers. After preamplification, $\dot{A}_t$ and $\dot{A}_s$ are power amplified in the motor drive amplifiers and are then used to drive the rate-damped motor tachometer sets. The tachometers provide a degenerative feedback voltage for the preamplifiers. The motors position the components of the CDU's to the angles $A_t$ and $A_s$. The 1/4X resolver in the trunnion loop and 1/2X resolver in the shaft loop transmit electrical analog voltages of $A_t$ and $A_s$ to the sextant and telescope position loops.

The operation of the integration loops differ in the direct and resolved modes. In the resolved mode, the drive rate signals $\dot{A}_s$ and $\dot{A}_t$ are transmitted from the optics hand controller to two resolver drive amplifiers. The $\dot{A}_s$ signal is amplified and applied to one rotor winding of the 1X resolver in the shaft CDU. The $\dot{A}_t$ signal is amplified and applied to the other rotor winding. The rotor of the 1X resolver is positioned to the angle $A_s$ (shaft angle). The voltages induced in the stator windings are a function of the two input voltages and the shaft angle ($\dot{A}_s \cos A_s - \dot{A}_t \sin A_s$ and $\dot{A}_s \sin A_s + \dot{A}_t \cos A_s$). The polar coordinate (R and M) drive rate signals are resolved by the 1X resolver into rectangular coordinate (X and Y) drive rate signals. (See Figure 3-11) The signal $\dot{A}_s \sin A_s + \dot{A}_t \cos A_s$) is sent directly from the resolver stator winding to the trunnion integrating loop motor drive preamplifier.

The operation of the trunnion integrating loop in the resolved mode is similar to operation in the direct mode with the addition of the 1/2X resolver. The 1/2X resolver is used in conjunction with a cosecant amplifier to vary the control gain of the shaft integrating loop as a function of trunnion angle.

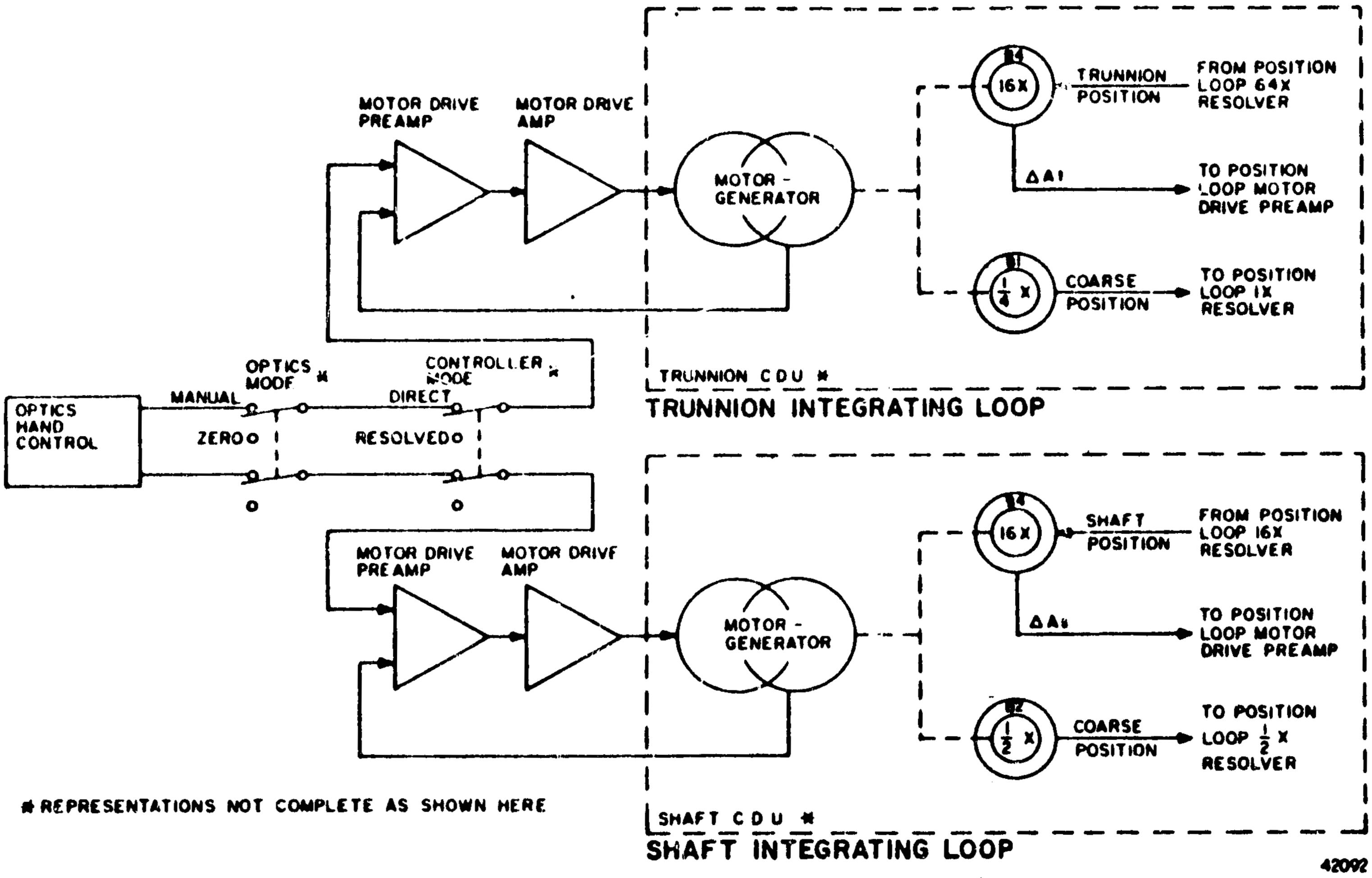



Figure 3-13. Integrating Loop, Manual Direct Mode

Figure 3-15 is a simplified diagram of the gain variation circuit. The output from the 1X resolver ($\dot{A}_s \cos A_s - \dot{A}_t \sin A_s$) designated as B, is summed with a negative feedback voltage from the 1/2X resolver stator winding, designated as C sin $A_t$. The summed voltage is then applied to the cosecant amplifier. The cosecant amplifier derives its name from the sine feedback voltage. Figure 3-15 also shows the derivation of the cosecant function.

The output of the cosecant amplifier, designated C is equal

to $\frac{\dot{A}_s \cos A_s - \dot{A}_t \sin A_s}{\sin A_t}$ . This output serves as the drive signal is transmitted from the cosecant amplifier to the preamplifier of the shaft integrating loop.

The cosecant amplifier functions as a variable gain device between trunnion angles of 10 to 60 degrees. The gain is 5.76 volts per volt (± 10 percent) at 10 degrees and 1.16 volts per volt (± 10 percent) at 60 degrees. This makes the image angular velocity independent of the size of the trunnion angle by decreasing the shaft speed as trunnion angle increases.

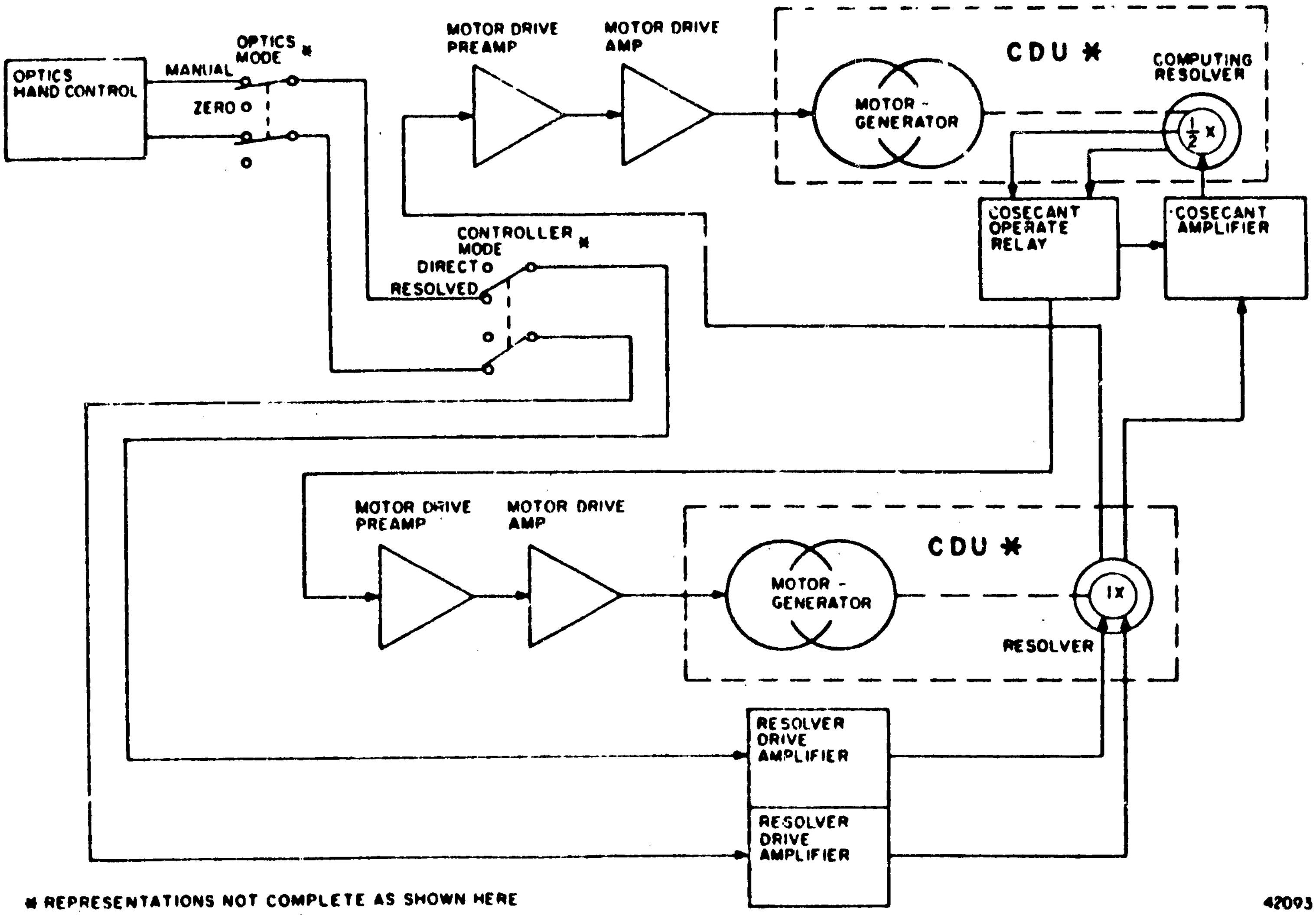


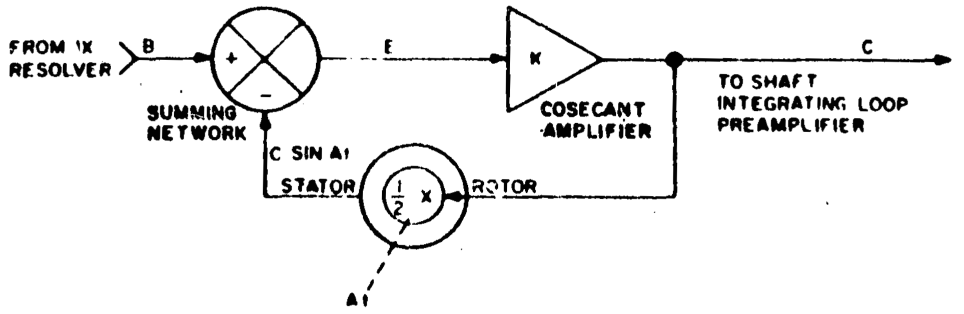

Figure 3-14. Integrating Loop, Manual Resolved Mode

When the drive signal from the cosecant amplifier is applied to the shaft integrating loop motor drive preamplifier, the loop operates in a manner similar to that described for direct mode.

### 3.6.4 Zero Optics Operation

The zero optics mode of operation is established by the astronaut prior to making an optical sighting. In zero optics, the CDU servo loops are driven to electrical zero and the shaft and trunnion axes of the sextant follow to an optical zero based on the coarse resolver only.

Zero optics mode is initiated when the astronaut moves the optics mode switch on the G & N indicator control panel to the zero optics position. 28 volts 800 cps is then applied to the CDU motor-tachometer set. The tachometer feedback voltage is removed by relay action from the motor drive preamplifier that has been used in operate and applied to the other motor drive preamplifier (refer to figure 3-16). The motor drive preamplifier also receives an input voltage through a two-speed switch. The two-speed switch is an electronic switching device which uses diodes to allow the coarse resolver output to drive the loop close to zero and then to switch to the fine resolver output to refine the position to the zero point. Another set of relays, one in the trunnion loop and one in the shaft loop, is energized in the zero optics mode. These relays provide a reference voltage to the fine resolvers for zero positioning of the sextant trunnion and shaft CDU's. The sextant position coarse servo loops drive the sextant optics to an optical zero position.




$B = A^{\circ}_s \text{ SIN } A_s - A^{\circ}_t \text{ COS } A_s$

$E = B - C \text{ SIN } A_t$

$C = KE$

$C = K(B - C \text{ SIN } A_t) = KB - KC \text{ SIN } A_t$

$C + KC \text{ SIN } A_t = KB$

$C(1 + K \text{ SIN } A_t) = KB$

$C = \frac{KB}{1 + K \text{ SIN } A_t}$

$C = \frac{B}{1/K + \text{SIN } A_t} \quad (K \rightarrow \infty)$

$C = \frac{B}{\text{SIN } A_t} = \frac{A^{\circ}_t \text{ SIN } A_s - A^{\circ}_t \text{ COS } A_s}{\text{SIN } A_t}$

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Figure 3-15. Gain Variation Circuit, Simplified Diagram

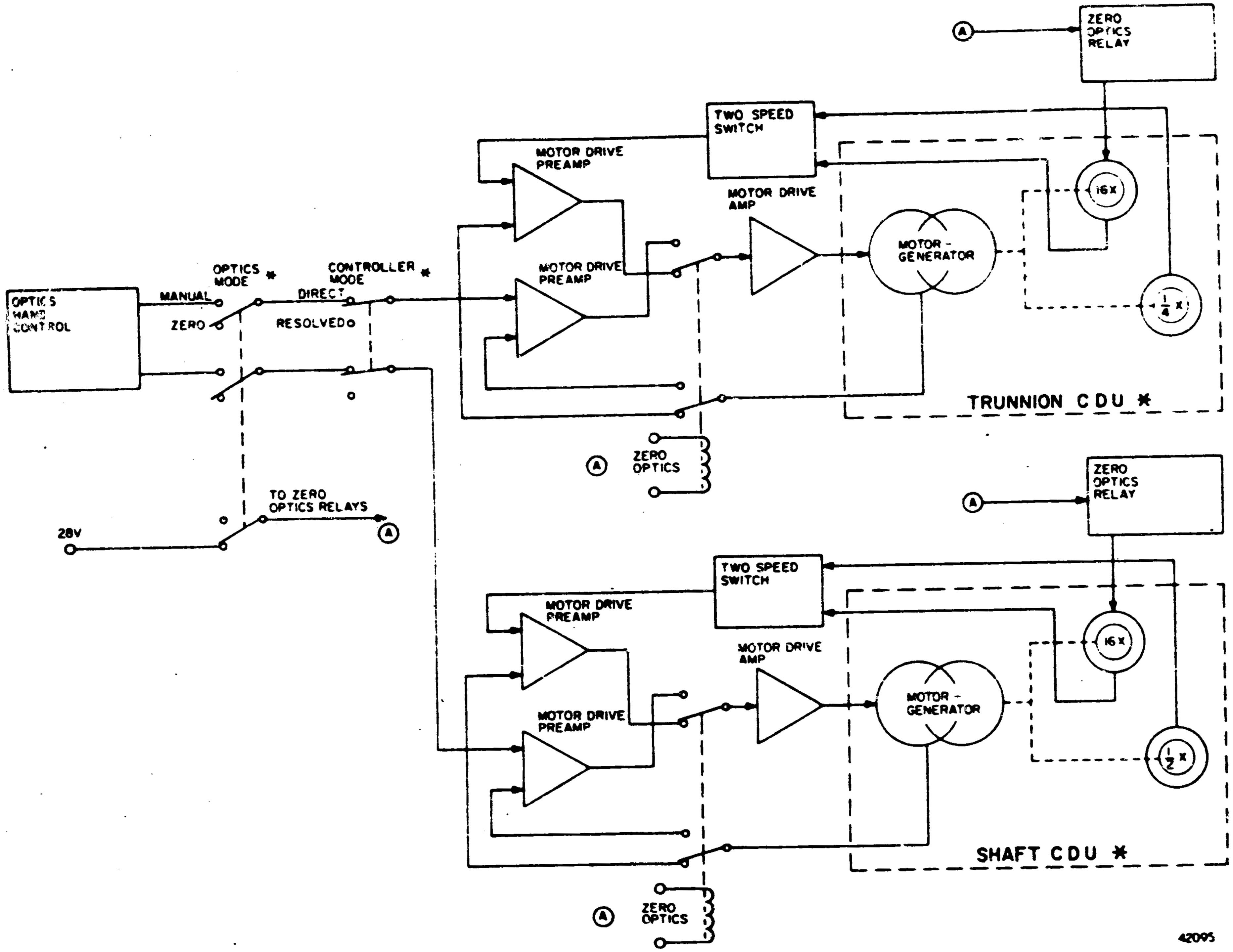


Figure 3-16. Zero Optics Mode

## 3.7 POSITION SERVO LOOPS

The position servo loops position the optics trunnion and shaft in accordance with position information transmitted from the integrating servo loops.

### 3.7.1 Sextant Position Servo Loop Operation

The sextant trunnion and shaft position loops (Figure 3-17) are two-speed (coarse-fine) loops. Each trunnion loop uses a 1X resolver to receive the coarse $A_t$ position signal from the 1/4X resolver transmitter in the trunnion integrating loop. The coarse $A_t$ signal is compared with the value of $A_t$ existing in the position loop. If the $\Delta$ signal magnitudes are large enough, the two-speed switch routes it through the motor drive preamplifier to the motor drive amplifier. The amplifier output drives the motor-tachometer. When the coarse $\Delta A_t$ signal magnitude becomes too small to pass through the two-speed switch, the fine $\Delta A_t$ signal is switched into the circuit to refine the trunnion position.

The position loop fine $A_t$ is developed in a 64X resolver and transmitted back to the 16X resolver receiver in the trunnion integrating loop. At this point, a fine $\Delta A_t$ signal is developed and sent to the two-speed switch to eventually drive the trunnion position loop as described previously.

The sextant shaft position loop operates in the same manner as the trunnion position loop except that a 1/2X resolver is used for coarse positioning and a 16X resolver is used for fine positioning.

### 3.7.2 Telescope Position Servo Loop Operation

The telescope position servo loops (Figure 3-18) differ from the sextant position loops in that they are single-speed servo loops (coarse only). The trunnion loop also utilizes two relays for 25-degree and zero-degree offset operation.

The telescope trunnion position loop receives $A_t$ command signals from the 1/4X resolver transmitter in the trunnion integrating loop. The $A_t$ signal is sent to the 25-degree offset relay and the zero-degree offset relay. If the astronaut has not selected either offset the relays will be deenergized and will route $A_t$ to the 1X resolver receiver in the position loop. The resolver receiver compares the values of integrating loop $A_t$ and position loop $A_t$ to develop a $\Delta A_t$ signal is applied to the motor drive preamplifier. The preamplifier output drives the motor-tachometer until $\Delta A_t$ is cancelled.

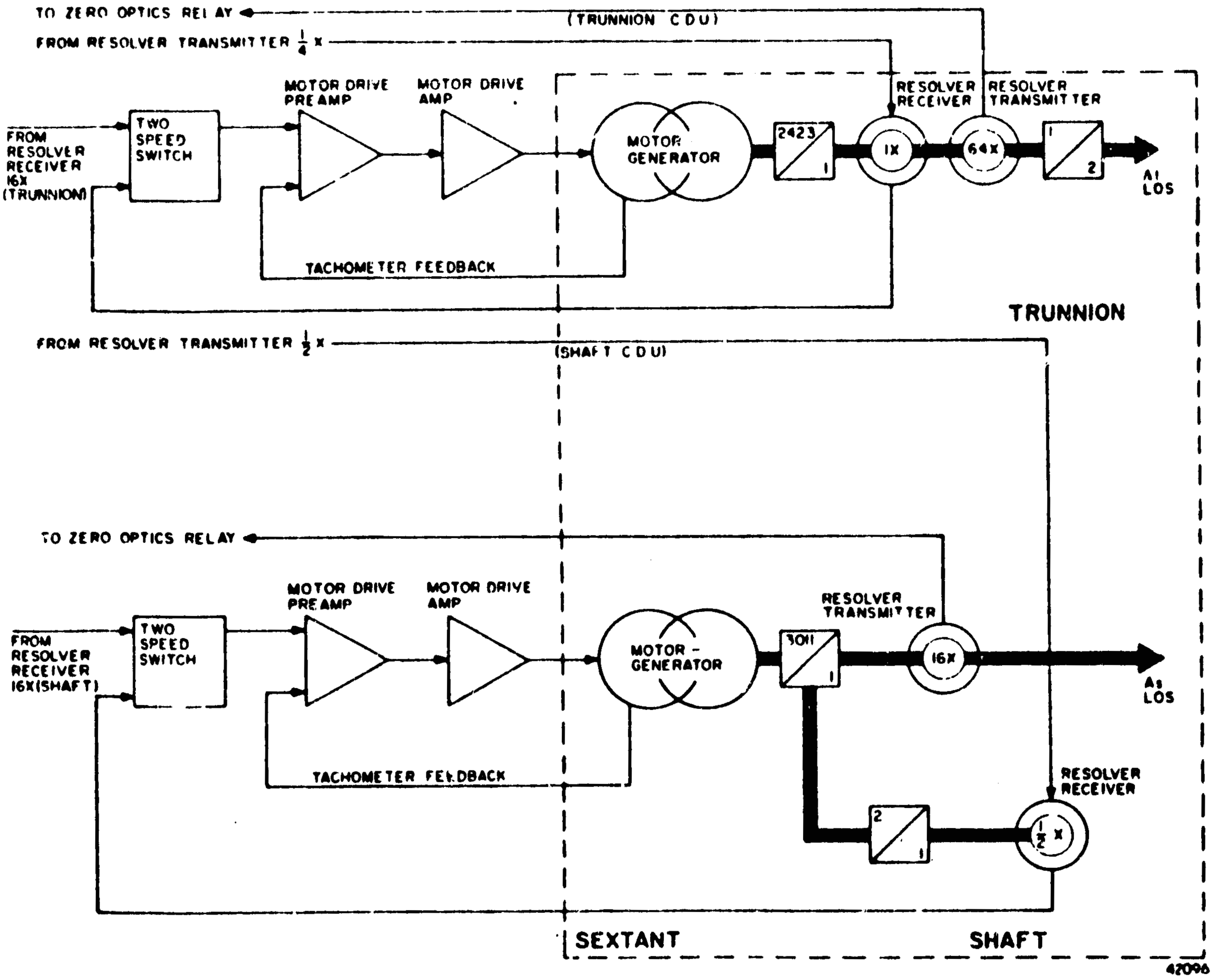


Figure 3-17. Sextant Position Loop

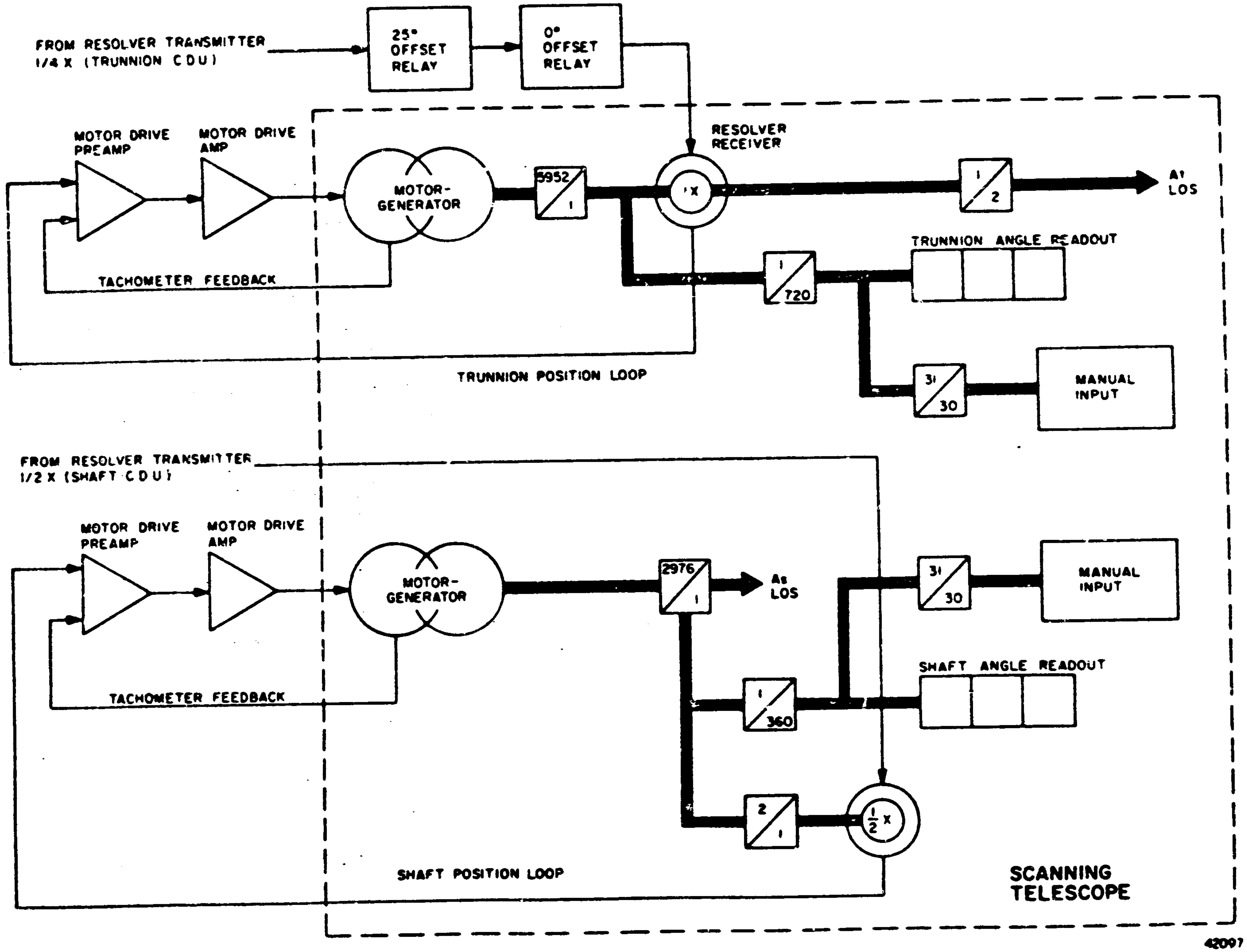


Figure 3-18. Telescope Position Loop

When $\Delta A_t$ is cancelled the telescope trunnion is positioned at the proper value of $A_t$. If the astronaut has selected either the 25-degree offset or zero-degree offset for the optics, the respective relay will be energized and will replace the $A_t$ signal from the integrating loop with a voltage to drive the telescope trunnion to the desired offset position.

The telescope shaft position loop does not have the offset relays in its circuitry. The $A_s$ signal is transmitted from the 1/2X resolver transmitter in the shaft integrating loop directly to a 1/2X resolver receiver in the shaft position loop. The resolver receiver compares the integratingloop $A_s$ with the position loop $A_s$ to develop a $\Delta A_s$ signal. The $\Delta A_s$ signal is sent to the motor-drive preamplifier. The preamplifier output drives the motor-tachometer to cancel the $\Delta A_s$ signal. When $\Delta A_s$ is cancelled, the telescope shaft is positioned at the desired angle.

The telescope position servo loops have a manual input device and are provided with readout counters for $A_t$ and $A_s$. The sextant position loops do not have manual inputs or readout counters.

## 3.8 POWER SUPPLIES

The 28-volt dc prime power for the optical subsystem is provided by the spacecraft +28-volt dc fuel cells or batteries and is routed through the dc bus to the optical subsystem power supplies, panels, and relays. The ac voltage inputs are supplied as 5-volt signal pulses to the optical subsystem power supplies from the AGC scaler.

### 3.8.1 Optics 800-CPS Power Supply

The two optics 800-cps power supplies are located in the CDU PSA tray 6. They are identical to the 800-cps supplies of the inertial subsystem. The output from the 800-cps, 1-percent supply is used for CDU tachometer and resolver excitation. The output of the 800-cps, 5-percent supply is used for CDU servomotor excitation and for sextant power.

### 3.8.2 Optics 25.6 KC Power Supply

The optics 26.6-kc power supply is located in PSA tray 2. It is identical to the inertial 25.6-kc power supply. The output of the optics 25.6-kc power supply is used to provide optics encoder excitation.

## 3.9 DISPLAY AND CONTROL PANELS

The lower display and control panels provide the navigator with a means of manually controlling and monitoring G & N system operation. The lower display and control panels contain the panels required to monitor and control the optical subsystem. These panels are the G & N indicator control panel, the optical panel, and the map and data viewer.

### 3.9.1 G and N Indicator Control Panel

The G & N indicator control panel (Figure 3-19) contains the controls used to operate the optical subsystem. These controls are the optics hand controller, sextant power switch, optics mode control selector, tracker button, direct-resolved switch, slave telescope switch, mark button, and optics speed switch. The panel also contains photometer controls to be utilized in future systems.

The optics hand controller positions the sextant and telescope about the optics trunnion and shaft axes. The control stick can be moved up or down and left or right. The angular rate of travel of the optical line-of-sight is proportional to the stick position. A switch dead zone prevents the optics servo loops from moving the optics when the control stick is at center position.

The sextant power switch is a toggle switch that applies power to the sextant. The sextant power is separate from the rest of the optics subsystem. A signal indicating operation of the sextant power switch is sent to the AGC and to the decoder to change the trunnion "bits per tooth".

The optics mode control selector is a position rotary switch which selects three optic modes of operation: zero optics, manual, and computer.

In the zero optics mode, the CDU resolver feedback loop is closed and excitation is applied to the CDU tachometer to drive the CDU resolvers to electrical zero.

In the manual mode the sextant and telescope can be controlled by the optics hand controller for normal operations.

The computer mode is not used in the present G & N system but is included for use in the future. The tracker button is a push-button switch which controls application of power to the optical tracker for automatic tracking of a star or other light source.

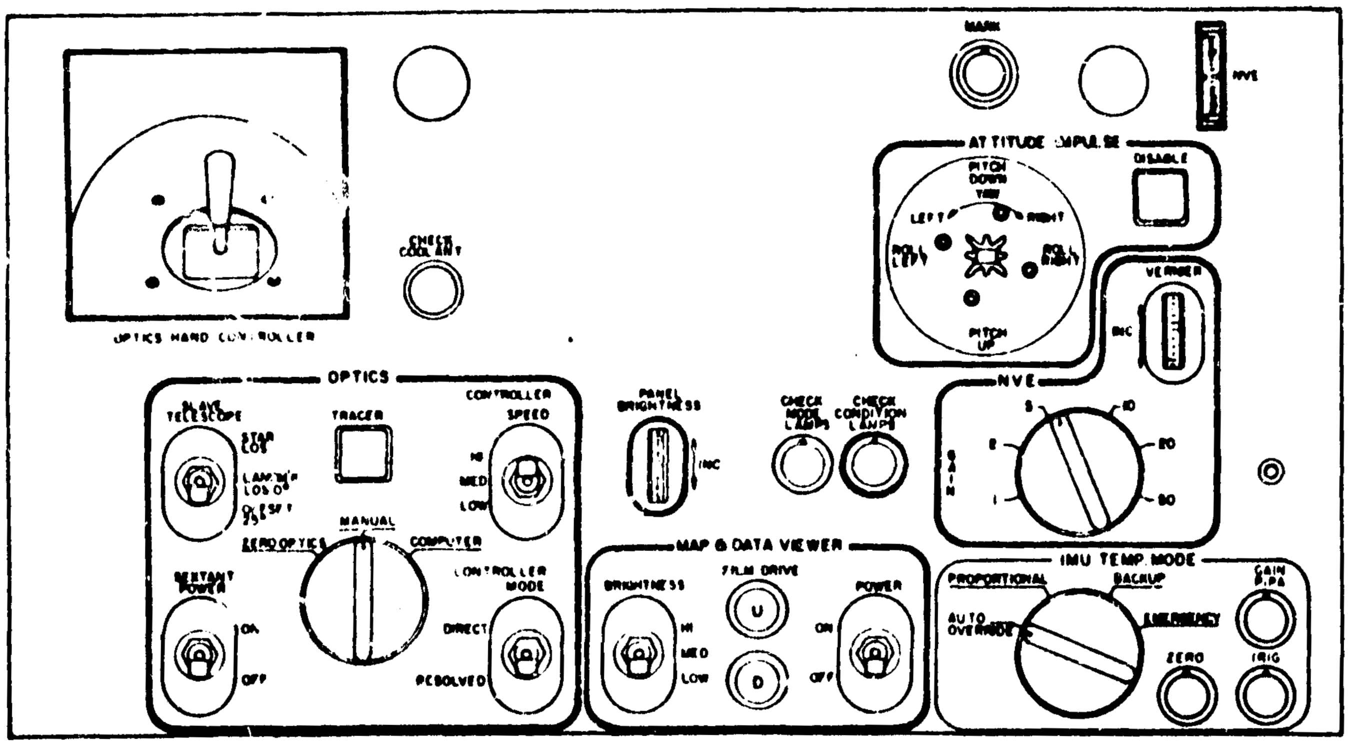


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Figure 3-19. G & N Indicator Control Panel, Optical Subsystem

The direct-resolved switch is a two-position toggle switch (direct and resolved) which provides LOS movement in the RM coordinate system and XY coordinate system, respectively. See Figure 3-11.

With the direct-resolved switch in direct position the shaft and trunnion axis servos are commanded directly by the optics hand controller stick. Right-left motion of the stick controls negative-positive shaft rotation; up-down motion of the stick controls the increase or decrease of the trunnion angle.

With the direct-resolved switch in the resolved position, the inputs to the shaft and trunnion axes command servo are resolved. Right-left and up-down movements of the optics hand controller stick result in right-left and up-down motions of the fields of view.

The slave telescope switch is a three-position toggle switch which is used to align the telescope trunnion axis for navigation fixes. When the slave telescope switch is at the landmark LOS zero-degree setting, the telescope trunnion is driven to zero. At the offset 25-degree position of the switch, the telescope trunnion is driven to a 25-degree offset from the shaft axis. With the telescope trunnion offset 25 degrees, the landmark can be held in the 2-degree circle and the shaft axis is rotated to acquire to a target star. When the target star has been acquired, the star LOS position of the slave telescope switch is selected. When the slave telescope switch is at the star LOS position the telescope trunnion axis is slaved to the sextant line-of-sight.

The mark button is a momentary contact pushbutton switch which supplies an interrupt signal to the AGC to permit insertion of optical angles, time of measurement, and if the IMU is operating, the IMU gimbal angles.

The optics speed switch is a three-position toggle switch which selects three ranges of speed control for the optics hand controller.

The attitude impulse controls are used to control the attitude of the spacecraft. These controls are the attitude impulse disable button and the attitude impulse control. The attitude impulse disable button transfers spacecraft attitude control to the minimum impulse controller. The attitude impulse control is a three-degree-of-freedom, pencil-type controller used to control spacecraft attitude with the attitude impulse jets. This control can apply individual or any combination of roll, yaw, and pitch impulses. The attitude impulse control holds spacecraft drift to a minimum when optical measurements are made.

### 3.9.2 Optical Panel

The optical panel contains the eyepieces for the telescope and sextant and also contains fittings and readouts used during positioning of the telescope. It is located in the center of the lower display and control panel.

The telescope is a single line-of-sight instrument used to make navigational measurements during earth or lunar orbit. It also is used to acquire landmarks or stars for navigational fixes. The telescope is located on the right side of the optical panel. The navigator can position the eyepiece to use either of two lens assemblies for viewing a target. One lens assembly provides a 60-degree field of view, the other lens assembly provides a 3X, 20-degree field of view.

The sextant is a precision, dual line-of-sight instrument used to make angular measurement between star and landmark or to make single star sightings. A 28X, 1.8-degree field of view is provided for each sextant LOS. The sextant contains only one eyepiece and is located on the left side of the optical panel.

The telescope manual control allows the navigator to operate the telescope manually when servo control is not possible. The manual controls consists of allen-head fittings recessed in the optics panel. Manipulation of one allen-head fitting positions the telescope trunnion angle. Another allen-head fitting positions the telescope shaft angle. The telescope shaft and trunnion axes angles are displayed by counters on the optics panel. These counters are accurate within 0.02 degree.

3.10 MAP AND DATA VIEWER

The map and data viewer provides visual display of pertinent data for astronaut orientation and also contains 11 lamps which indicate the status of critical G & N system circuits. (See Figure 3-20)

Information, such as navigation charts, computer settings, flight instructions, etc., is contained on 16-millimeter film and stored in mechanized cartridges. Each cartridge holds sufficient film to catalogue 2,000 separate frames of data. The data is projected onto the rear of a screen and is viewed from the front of the map and data viewer panel.

The 11 condition lamps are mounted vertically on the map and data viewer front panel. When lit, each lamp indicates a G & N circuit malfunction.

3.10.1 Functional and Operational Description

Pertinent information, stored on individual film frames, is selected by the astromaut in much the same manner employed for projecting standard microfilm pictures on a screen. A specially built projection lamp illuminates the selected frame. The frame image is projected onto beryllium mirrors within the map and data viewer, and reflected onto the back of a translucent screen (See Figure 3-21). Screen displays are viewed through a 6-inch by 8-inch opening in the front panel.

Map and data viewer controls are located on two individual panels. Manual operating and adjustment controls are in the map and data viewer front panel assembly: other operating controls are located on the G & N panel. The controls and their respective functions are as follows:

1. Focus adjustment - manual, provides adjustment of projector lens to allow alignment of projected film image size with viewing screen.

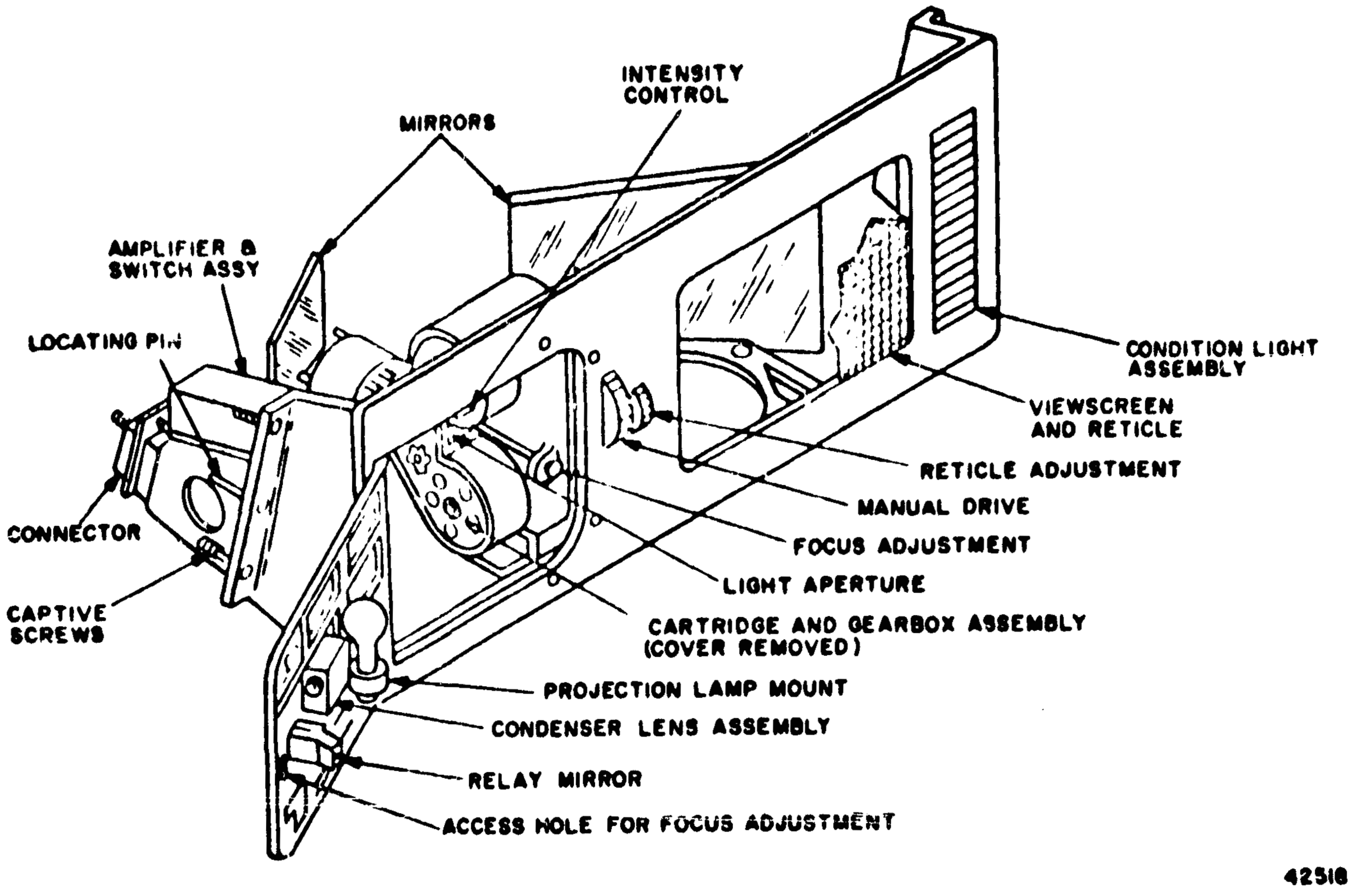



Figure 3-20. Map and Data Viewer

2. Reticle adjustment - manual, provides lateral adjustment of viewing screen to enable the astronaut to align the projected image with reticle indices on the screen face, thus providing measurement of coordinate positions on projected maps.

3. Manual frame selectro, provides manual handwheel control for vernier adjustment of projected image. Also, serves as standby film frame selector in the event of remote control malfunction.

4. Step silm control, provides remote operating control for transferring film in single frame increments.

5. Slew film control, provides remote operating control for driving film at speed from 0 to 20 frames per second.

The map and data viewer consists of the following major functional components: cartridge, gear box, panel and door, optics, and electronics assemblies. Descriptive and functional information on these assemblies is provided in the following paragraphs. Most structural parts of the components are fabricated from beryllium. Overall physical dimensions of the map and data viewer are: height, 9 inches; length, 24 inches; and width, 9 inches.

3.10.2 Description of Optics

Map and data viewer optical components consist of condensing lenses, a dichroic mirror, focusing lens, and two polished, nickel-coated beryllium mirrors. (See Figure 3-21)

The optical system is designed to provide maximum possible resolution and magnification. The optics deliver 18.5:1 minimum magnification with a resolution of 7 lines per millimeter.

Light from the projection lamp is transmitted through the condensing lens onto a dichroic mirror. The mirror reflects light and also transfers thermal energy from the projector lamp to a heat sink assembly. Reflected light from the dichroic mirror is then brought into the cartridge film gate. From the film gate, the image is projected to a pair of beryllium mirrors and focused on the back of the viewing screen.

3.10.3 Cartridge and Gear Box Assembly

The cartridge assembly is an interchangeable film storage container. (See Figure 3-22) Each cartridge assembly is preloaded with approximately 50 feet of 16-millimeter color film.

The assembly comprises a housing, two spools, film gate, drive sprockets, and gears. Gears (A, Figure 3-22) and (b) of the installed cartridge extend beyond the aluminum housing to engage driving components of the gear box assembly. Cartridge gear assembly (C) is a specially designed drive gear arrangement. Incorporation of the drive assembly (C) provides angular correlation between drive sprockets (D) and the external gear assembly.

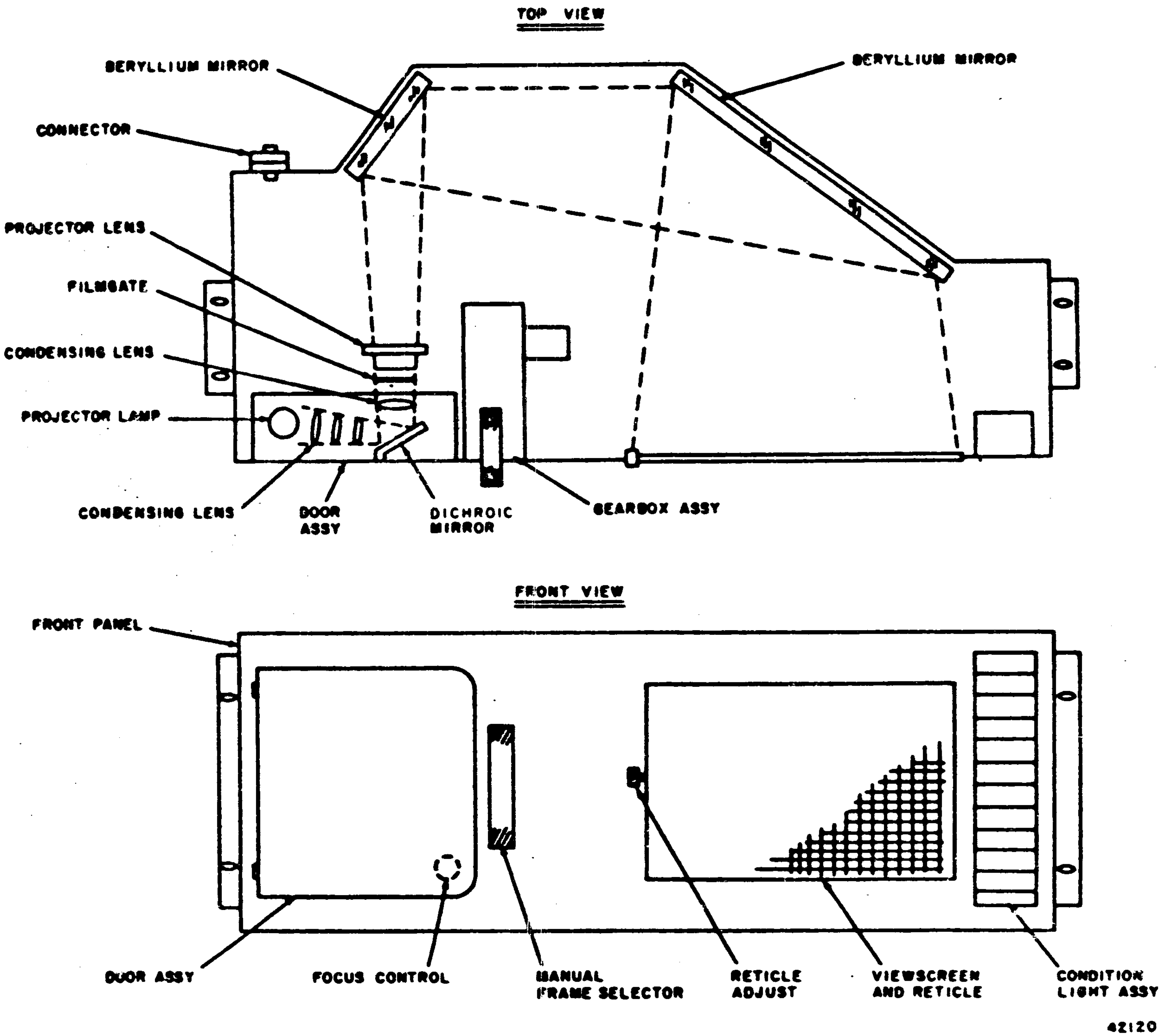



Figure 3-21. Map and Data Viewer Component Arrangement

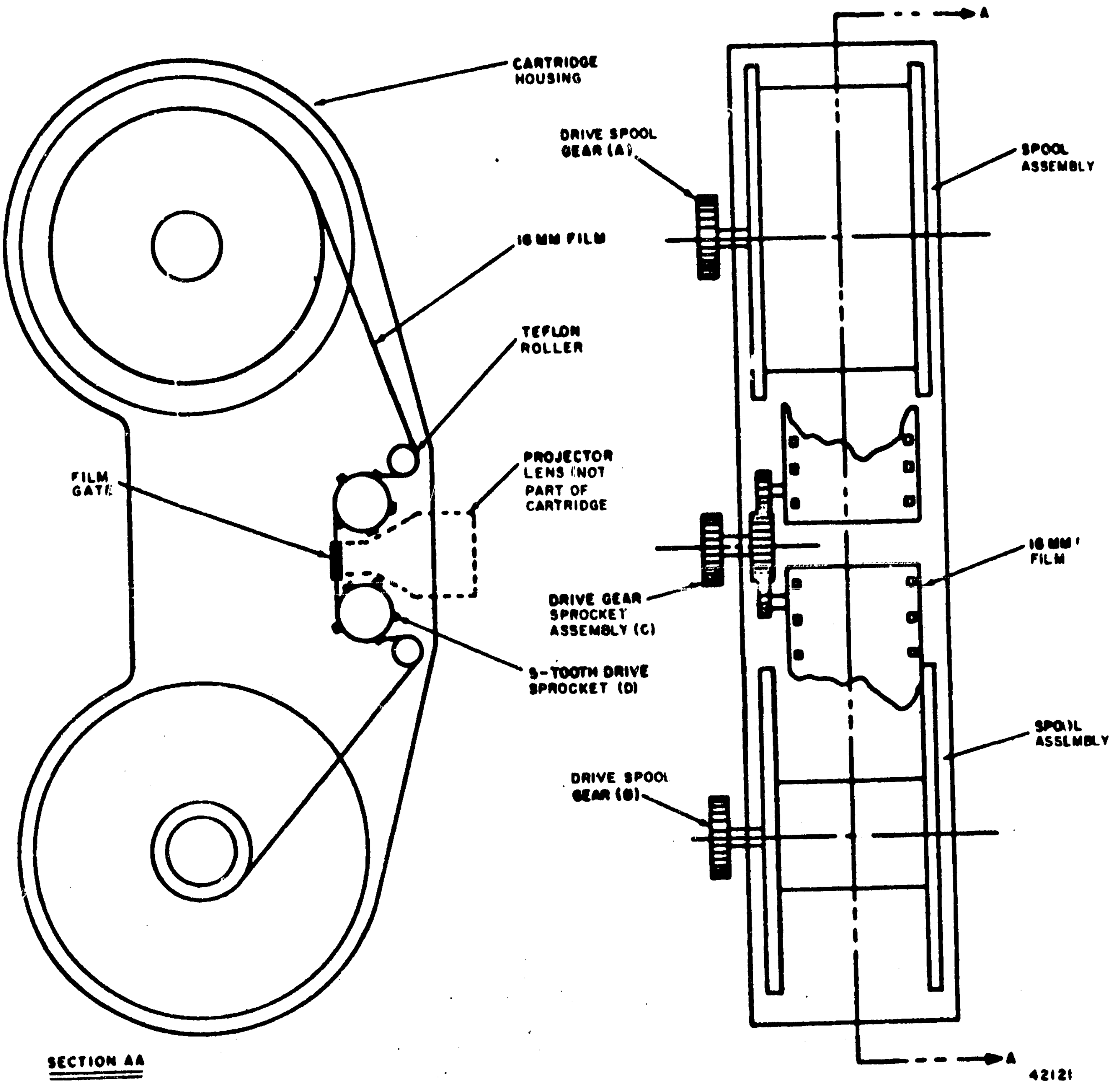



Figure 3-22. Map and Data Viewer Cartridge Assembly

Gear box components include housing, drive motor, resolver, clutch, and gear assemblies. Slip clutch and override clutch assemblies are installed between the sprocket drive shaft and spool drives. During operation, reduction gear drive shaft velocity remains constant; however, film speed can vary according to the radius change resulting from spool take-up. The slip clutch arrangement allows the feed-out spool to unwind uniformly regardless of film speed changes.

### 3.10.4 Panel and Door Assembly

The panel is a rigid structure fabricated from 1-inch beryllium The bottom and sides are permanently fastened at the edges and corners.

Access to the map and data viewer components is gained by use of a swingout door mounted on the map and data viewer panel. Components of the door assembly include projection lamp and mount, dichroic mirror, condensing lens, and heat sink (See Figures 3-20 and 3-21). When necessary, cartridge change, focus adjustment, and map and data viewer component may be replaced. The design of the door assembly facilitates these operations.

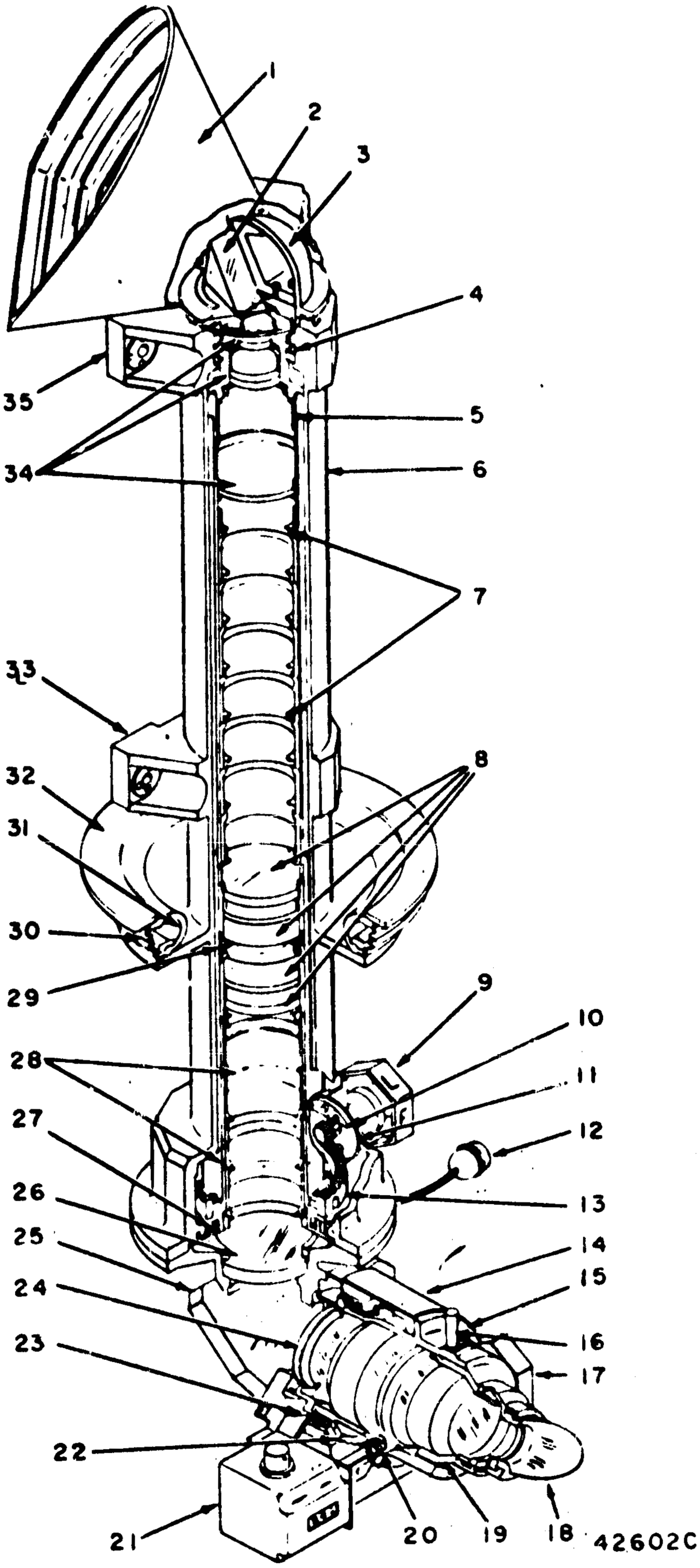
### 3.10.5 Electronics Package

The map and data viewer electronics assembly comprises a welded module including four relays and transistorized components. The circuitry incorporates necessary switching and amplification functions to provide remote stepping or slewing operations.

## 3.11 ALIGNMENT OPTICAL TELESCOPE

The AOT (Figure 3-23) is a manually operated, periscopic, optical instrument located in the forward structure of the LM. It is mounted on the nav base with the shaft axis parallel to the LM X axis, and the upper portion of the shaft protruding from the top of the LM.

Physically, the AOT is an L-shaped structure formed by the perpendicular intersection of two major assemblies. These assemblies are the telescope shaft and the telescope eyepiece. The major assemblies are jointed by a horizontal flange joint at the base of the telescope shaft assembly. In general, structural components such as housings and mounts are machined beryllium, spacers are aluminum, and threaded parts that engage beryllium are made of corrosion resistant steel. On AOT 6011000-041 and above, a radar shield is mounted on the prism shield plate to keep light reflected




1. Sunshade
2. Head prism
3. Head prism housing cover assembly (GSE)
4. Ball bearings
5. Inner housing assembly
6. Outer housing assembly
7. Light baffles (7)
8. Relay lenses
9. Shaft positioning knob
10. Shaft positioning gear
11. Detent disc spring
12. P1 connector to CCRD
13. Shaft gear and slotted detent
14. Heater protective cover
15. Worm and gear housing assembly
16. Focus control handle
17. Reticle positioning knob
18. Rubber eyeguard
19. Eyepiece lens assembly
20. Reticle drive worm gear
21. Angle counter and cover
22. Reticle drive gear
23. Ball bearings
24. Reticle and cover ring
25. Mirror
26. Pressure sealing window
27. Ball bearing
28. Light baffles (4)
29. Aperture
30. Flameguard bellows
31. Rubber pressure seal
32. Pressure sealing vehicle mount
33. Nav base and ASA mounting pads (2)
34. Objective lenses
35. Nav base and ASA mounting pads (2)

Figure 3-23. AOT Cutaway View

by the rendezvous radar antenna from entering the AOT optical system. On AOT's 6011000-073 and -091, the prism shield and radar shield are removed and replaced with the conical sunshade and radar shield assembly 1, Figure 3-23) which is attached to the inner housing assembly. All current operational AOT's conform to the configuration shown in Figure 3-23.

### 3.11.1 Telescope Shaft Assembly

The telescope shaft assembly consists of a stationary outer housing assembly and a rotatable inner housing assembly. It contains the shaft positioning mechanism assembly, most of the AOT optics, and a prism shield.

The inner housing assembly is bearing mounted within the outer housing assembly with the vertical axes of both assemblies coincident. This mounting permits the inner housing assembly to be rotated through 360 degrees about the shaft axis. Six detent positions are provided to lock the shaft at each 60 degrees of rotation. Orientation of the inner housing assembly is accomplished by manually turning the shaft positioning knob (Figure 3-24). By positioning the shaft, the head prism (mounted in a fixed position to the inner housing assembly) is positioned to the desired field of view.

#### 3.11.1.1 Outer Housing Assembly

The outer housing assembly is a beryllium cylinder approximately 27 inches with a 3-inch bore diameter and a wall thickness of about 0.100 inch. It houses the shaft positioning mechanism and shaft bearings. The outer wall of the cylinder is flanged to accept the rubber pressure seal and flame guard bellows that interface with the outer wall of the LM bulkhead. Four machined mounting pads, which are used to mount the AOT to the nav base, extend at right angles from the outer wall of the cylinder.

The shaft positioning mechanism consists of hexagon knob and bevel gear mounted on a common shaft with a pressure seal interposed between them, and a cantilevered detent disc spring with a ball bearing welded on the free end. The shaft positioning mechanism mates with a bevel gear and slotted detent mounted around the outer periphery of the inner housing assembly. The purpose of the shaft positioning mechanism is to provide a means of manually positioning the optics head prism, attached to the inner housing assembly, to each of six viewing positions, left (L), forward (F), right (R), are set 60 degrees from each other while the prism protective position, closed (CL), is set 180 degrees from the forward position. Two additional positions, $L_R$ and $R_R$, which are not used, are located at 60 degrees on either side of the CL position. A lock is provided at each position by the welded ball bearing as it slides into the 60 degree spaced grooves of the inner housing assembly slotted detent. For AOT's 6011000-073 and -091, the prism shield is removed and all six viewing positions are utilized for sightings.

The prism shield is attached to the upper end of the outer housing assembly by two bolts on AOT's 6011000-081, 072, and below. All units above the 6011000-081 configuration utilize prism shields furnished as GSE. This provides the required protection against damage whenever the conical sunshade and radar shield assembly is not installed. The GSE prism shields, together with the transparent prism and head protection cover, comprise the AOT protective cover set, part number 6014329. This unit primarily functions as a

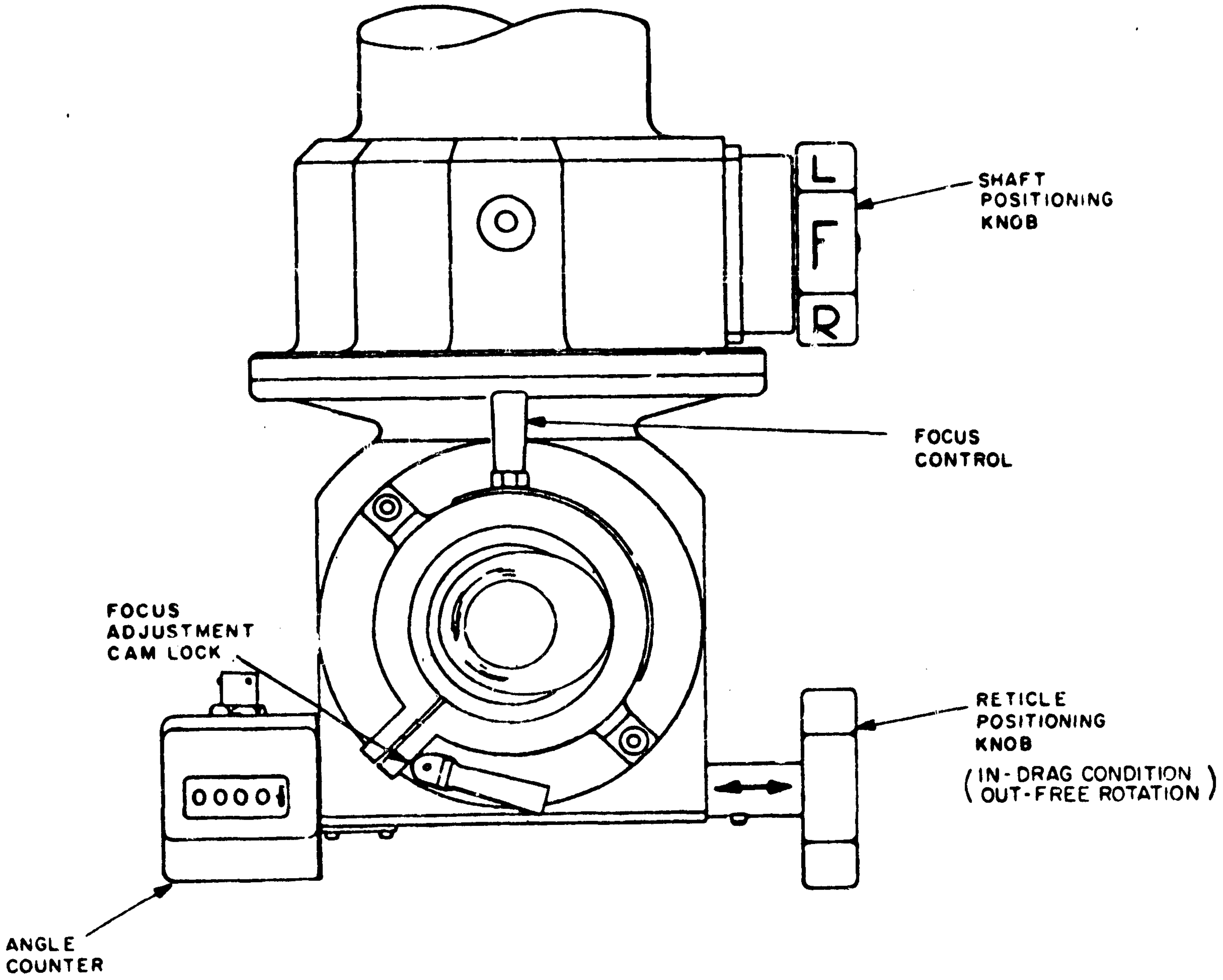



Figure 3-24. AOT Controls

protective shield for the optics head prism against such hazards as dust, etc. The prism shield also acts as part of a labyrinth seal that aids in reducing the evaporation of the shaft ball bearing lubricant. With the head prism facing the rear of the LM, the shaft closed (CL) position, the prism is completely enclosed by the prism shield. A spacer is mounted between the prism shield and outer housing assembly. This spacer is machined to allow a clearance of only 0.0035 (±0.0015) inch between the inner wall of the prism shield and the head prism mount.

3.11.1.2 Inner Housing Assembly

The inner housing assembly is a beryllium cylinder which is stepped externally to provide seating and retaining surfaces for the shaft ball bearings and internally for seating some of the shaft optics. A bevel gear and slotted detent, used in positioning the inner housing assembly in the previously described viewing and protective positions, is mounted about the lower periphery of the cylinder. Most of the AOT optics are contained within or mounted atop the inner housing assembly. The optics consist of the head prism, objective lenses, relay lenses, and two sets of light baffles. All of the optics are centrally aligned, axially located, and carried in azimuth rotation about the shaft axis with the cylinder. A special wave washer at the lower end of the shaft provides a predetermined load on the shaft ball bearings.

The head prism housing assembly, consists of the head prism, prism housing, and prism mount. It is mounted to the objective lens housing assembly on top of the inner housing assembly. The prism housing and mount are machined beryllium and are held to each other by three bolts. The prism, which is inserted between the housing and mount at a 45 degree angle, is held firmly in place by the adjustable force of a leaf spring and epoxy. The leaf spring, located in a recess in the prism housing, is forced to bear down on the rear (hypotenuse) surface of the prism. A U-shaped element, extending upward from the prism mount along the lower face of the prism, acts as a forward retaining surface for the prism. The element also serves as an aperture defining the optics lower field of view. The purpose of the head prism housing assembly is to gather the impinging light rays of the 60 degree field of view. The prism then refracts these rays through a circular passage in the prism mount, concentric with the optical centerline, to impinge on the first element of the objective lens housing assembly.

The objective lens housing assembly, to which the head prism housing assembly is mounted, is mounted to the upper end of the inner housing assembly cylinder by six bolts. The assembly consists of two doublet lenses, the aspherical field lens, spacers, and retaining rings. The retaining rings hold these optics in radial and axial position. The purpose of the objective lens housing assembly is to minify the light rays received from the head prism by 5 power, and focus these rays at the first focal plane of the AOT. The first focal plane is at the exit side of the aspheric field lens.

The relay lens housing assembly is precisely positioned axially inside the stepped lower portion of the inner housing assembly cylinder. The relay lens housing assembly is held in place by a spacer retained against the stepped inner surface of the cylinder above the assembly and below, by a long spacer and a threaded retainer which mates with the lower end of the cylinder. The assembly consists of two identical lens cells and a spacer held together by a threaded coupling ring. The lens cells are power matched and mutually focused. The purpose of the relay lens housing assembly is to collect the minified image light rays from the objective lens housing assembly and focus them at the second AOT focal plane. This focal plane is coincident with the telescope eyepiece assembly reticle in a vacuum environment for AOT 6011000-021 and above, and in an air environment for AOT 6011000-000 and 6011000-011.

The conical sunshade and radar shield assembly is supplied for installation on AOT's 6011000-073 and 6011000-091. The assembly consists of sunshade and radar shield, clamps, shims, and attaching **hardware** (1, Figure 3-23) for attachment to the inner housing assembly. The assembly is shipped and stored in its own shipping container for installation on the AOT after it has been installed on the spacecraft. The function of the assembly is to prevent stray light which is reflected off the skin of the spacecraft and other reflecting surfaces from entering the optics of the AOT. The assembly makes it possible for the astronaut to perform star sightings without having the reflected light blanking out the light emitted fromthe stars.

### 3.11.2 Telescope Eyepiece Assembly

Mounted on the lower end of the telescope shaft assembly, the telescope eyepiece assembly is the reticle positioning, angle readout, and target-reticle image viewing portion of the AOT. The assembly consists of a mirror and window housing assembly, a worm and gear housing assembly, and a lens housing and eyeguard assembly.

#### 3.11.2.1 Mirror and Window Housing Assembly

The mirror and window housing assembly is a beryllium, 90 degree elbow with two cylindrically flanged ends. It contains an image deflecting mirror and pressure sealing window.

The mirror is machined from 1/2 inch beryllium, heat treated, nickel plated, aluminized, and optically polished. It is mounted in the elbow at 45 degrees to the horizontal eyepiece. This unit provides a means of diverting the target image from the vertical optical centerline of the shaft optics to the horizontal optical centerline of the eyepiece optics.

The window is mounted in a packing ring which is seated in a groove inside the upper portion of the assembly. This unit acts as a seal between the upper AOT components, exposed to the environmental conditions outside the LM, and the eyepiece optics. Having no optical qualities, the window transmits the target image without change from the relay lens housing assembly directly to the mirror.

3.11.2.2 Worm and Gear Housing Assembly

The worm and gear housing assembly is a beryllium casing containing the reticle and counter drive gear mechanism. AOT reticle, and angle counter. This assembly is mounted to the pressurized end of the mirror and window housing assembly and serves as a mounting receptacle for the eyepiece lens assembly.

The reticle and angle counter drive gear mechanism consists of a transverse worm shaft connected at one end to the angle counter and at the opposite end to the manually operated hexagon control knob. On AOT 6011000-062 and above, the reticle positioning knob has been equipped with a drag mechanism to prevent free rotation of angle counter when hand is removed. (See Figure 3-24) The worm shaft meshes with the reticle drive gear. This mechanism provides a means of manually positioning the reticle and transmitting that position to the counter where it is read out in terms of angular displacement.

The counter is a continuous readout counter. The counter provides angular readouts from 000.00 degrees to 359.99 degrees. The resolution of the counter is ± 0.01 degree (equivalent to ± 36 arc seconds). To preclude the possibility of fogging and corrosion, AOT 6011000-062 and above include a hermetically sealed counter with wedge lighting for ease in viewing.

The reticle is positioned at the second focal plane between two plano-plano (glass) discs. The reticle pattern is etched on the surface of one disc and covered by the other disc for protection. The reticle discs are secured with epoxy in a cover ring which is then clamped at three points in the drive gear for planar adjustment. The reticle drive gear, mounted on ball bearings in the housing assembly, provides precision positioning of the reticle in coincidence with the angle counter readout.

In AOT 6011000-021 and above the reticle is positioned so it is in focus under vacuum conditions. The difference in indices of refraction for vacuum and air under normal conditions causes the target to focus at a plane that is not coincident with the reticle when the AOT is used in an earth environment. When in an earth environment, either target or reticle can be brought into focus with the eyepiece, but both cannot be brought into focus simultaneously.

Ten miniature lamps are mounted about the periphery of the reticle to supply the reticle with edge lighting. For AOT 6011000-062 and above, the ten miniature lamps have been painted red to preclude false star indications caused by imperfections in the reticle. A star appears white, while reticle imperfections appear red. To preclude the possibility of fogging because of the presence of moisture and low temperatures, AOT 6011000-021 and above include an electrical heater on the eyepiece assembly. On AOT's 6011000-081 and above, a heater protective cover and reticle lamp protective cover have been installed.

3.11.2.3 Lens Housing and Eyeguard Assembly

The lens housing and eyeguard assembly is a beryllium cylinder containing the eyepiece lens assembly and focusing mechanism, and a rotatable rubber eyeguard. The assembly is inserted into and attached to the worm and gear housing assembly. This assembly is the image exit portion of the AOT.

The eyepiece lens assembly consists of three lens doublets of 5 power. This power is matched to the objective lens power providing an image exit power of unity. The eyepiece lenses are contained in a cylindrical aluminum adapter that is attached to the movable focus control handle. The aluminum adapter moves the eyepiece lenses axially in the housing when driven by the manually operated focus control handle. It thus focuses the viewed image to the exit pupil. The focus control handle protrudes from a helical slot in the lens housing. In AOT 6011000-021 and above, a focus adjustment cam lock (located below and to the left of the eyepiece) can be swiveled, rotating a cam to lock the focus adjustment in a selected position. When the handle is returned to the in-line position, the cam lock is released.

A rotatable eyeguard is fastened to the end of the eyepiece lens assembly. It is made of non-toxic synthetic rubber and is a axially adjustable for head position. The adjustment allows for differences in facial contours. The rotatable eyeguard is used when the astronaut takes sightings through the AOT with his face mask opened.

A fixed eyeguard is cemented to the image exit end of the long eye relief (LER) eyepiece lens assembly (Figure 3-25) in AOT 6011000-041 and above. It is made of non-toxic synthetic rubber in an annular shape. The rotatable eyeguard is removed from the AOT when the astronaut takes sightings with his face mask closed. During these sightings, the fixed eyeguard prevents marring of the face mask when pressed against the eyepiece lens assembly.

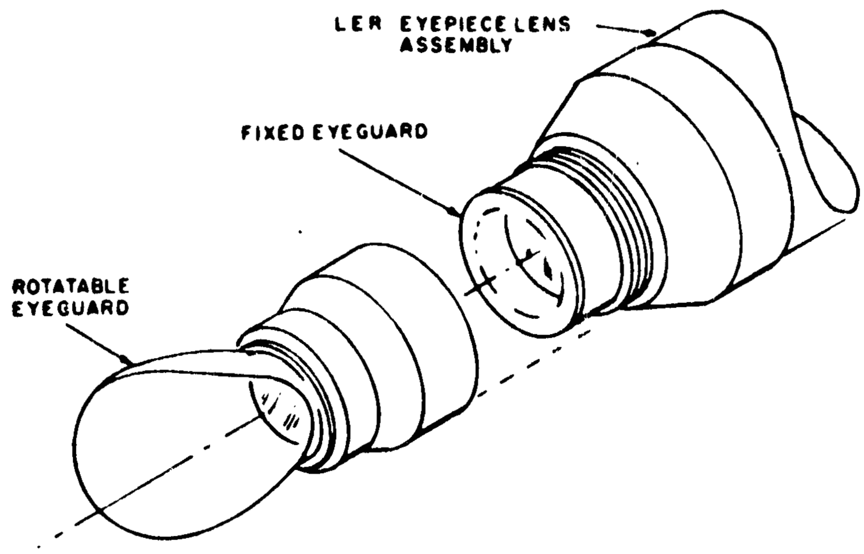



Figure 3-25. AOT Eyeguard Assemblies

### 3.11.2.4 AOT High Density Filter Assembly

The AOT high density filter assembly (Figure 3-26) is supplied as a piece of auxiliary equipment to be used in the Apollo mission. The assembly consists of a retainer assembly and high density filter. The retainer assembly contains two lever assemblies mounted on a flexible pivot. The lever assemblies grip the threaded portion of the fixed eyeguard when installed in place of the rotatable eyeguard. (See Figure 3-25). The function of the assembly is to prevent damage to the astronaut's eyes by accidental direct viewing of the sun.

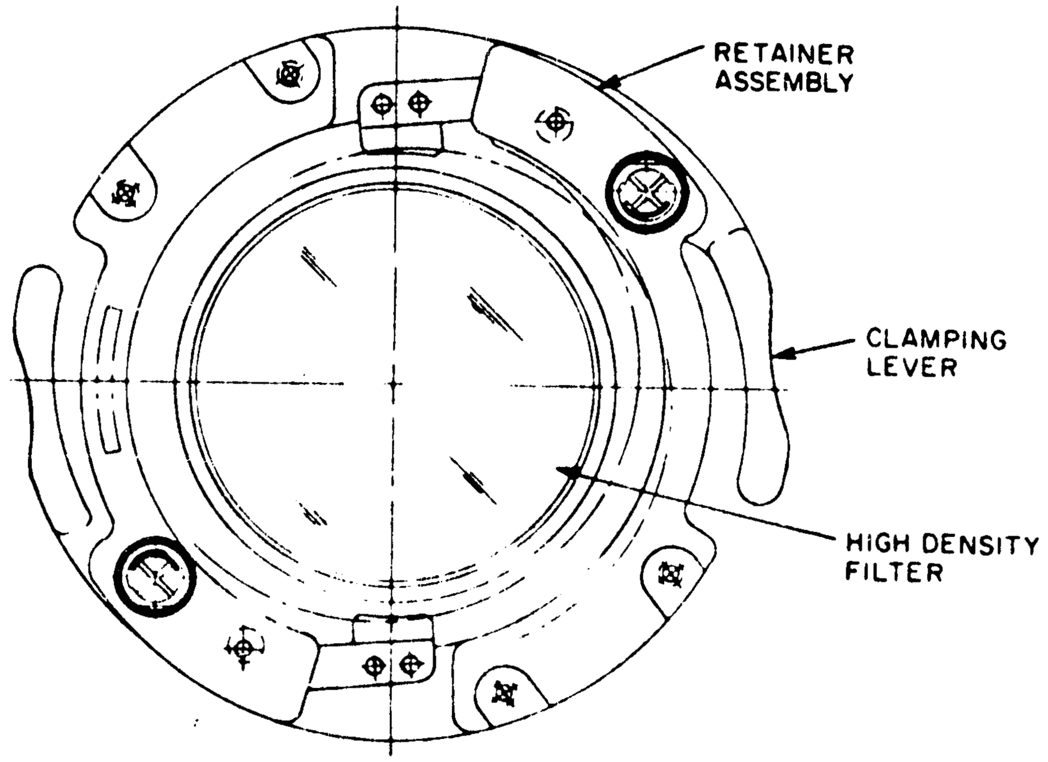



Figure 3-26. AOT High Density Filter Assembly

# SECTION 4

# ENGINEERING

In order to best support the design and fabrication phases of the Apollo prime equipment Kollsman Instrument engineering was broken into two categories: External Engineering and Internal Engineering.

The prime objective of external engineering was to interface with MIT/IL during the early design stages to ensure the establishment of close communication and liaison between the design area and KI, itself. Further, external engineering being knowledgeable and conversant in the field of opto-mechanical systems, was able to contribute constructively to the design discussions, detail design, and recommended changes. Such changes were recommended on the basis of post-engineering and manufacturing experience.

Toward this end, external engineering was assigned resident positions at the MIT location. The relationship and interface between this group of Kollsman engineers with MIT and with Kollsman internal engineering contributed greatly to the end result of producing sophisticated Apollo program equipment on a timely and high quality level basis.

Internal engineering represented the in-house engineers who had the prime responsibility of ensuring that the flight equipment would be manufactured at a high reliability level, and to provide the tools, test equipment, plans, and technical knowledge so this could be achieved on a timely and expeditious basis.

Internal engineering's interface with external engineering kept them abreast of all design developments and projected milestones. This allowed them to move out judiciously in many areas, even during the early design phases. This arrangement proved most effective throughout the early design phases of the Apollo Program, not only for Kollsman, but for the total program itself as it provided the necessary impetus for the program "kickoff".

## 4.1 ENGINEERING - PERIOD ENDING 31 DECEMBER 1962

### 4.1.1 External Engineering

In the beginning, the External Engineering group effort at MIT/IL was mainly confined to the execution of the Sextant and

Scanning Telescope designs. The execution of the Data Display Unit design was entirely in MIT/IL hands.

The sextant design, itself, was formulated in its main outline by MIT before Kollsman participation began, except for the eyepieces and portions on the astronaut's side of the bulkhead; whereas, the Scanning Telescope design was in Kollsman's hand since the formulation of requirements.

The MIT designs, as they initially existed, were examined and proposals for improvements were discussed. Action was deferred on most changes until a redesign phase was feasible without endangering the schedule. From the beginning, the following tasks were accomplished for the period ending 31 December 1962.

1. The scale reading optical and mechanical design was worked out with improvement to provide simultaneous readout of star and landmark scales.

2. The mounting of the double dove scanning prisms for the telescope was completed and released. A rough draft report on the manufacture and mounting problems was completed.

3. The Scanning Telescope Shaft and Trunnion Axis gearboxes were well along in detailing and Kollsman manufacturing review when this effort was laid aside for redesign resulting from the elimination of hand cranks for manual shaft and trunnion inputs. The redesign resulted in substantial design simplification and weight saving. The long lead item - the optical base - was affected but by careful coordination, the delay was held to acceptable limits.

4. The Scanning Telescope eyepieces were in mechanical design, based on tentative optical information.

5. The Sextant head was 75% through a mechanical design refinement stage. Detailing of the Telescope was a major portion of the effort during December and the internal review of the final package of drawings was completed.

6. The layout of the flexible wiring arrangement for accommodating shaft rotation was completed.

7. Final optical design of the Sextant eyepiece system, in effect a "telemicroscope" available at the end of December, permitted completion of this phase of the Sextant Design.

8. The Optical Base layout, and detailing was proceeding concurrently with frequent liaison between Kollsman engineering and manufacturing personnel and the Beryllium fabrication vendors.

Unresolved questions of basic approach and lack of data on ambient high level slowed the design somewhat. Steps were taken to resolve these questions which permitted a firm design course during early 1963.

Kollsman participation in the design of the Map and Visual Data Display unit was begun at this time, December 1962.

4.1.2 Internal Engineering

One of internal engineering's first efforts was the preparation of a Development Plan (T.D. K-2) which consisted of general planning familiarization studies and training, and required facilities rearrangement. Design was initiated on fixtures and test devices for the Optical Subsystems Factory Test Equipment (T.D. K-10). Design and preparation for manufacturing was started on Ground Support Equipment for Optical Instruments (T.D. K-15) consisting of the Precision Test Fixture, Adapter and Control Unit, Alignment Mirror Assembly, Alignment Periscopes, Optical Target (Laser), and Autocollimator Eyepieces.

The following are specific tasks that were accomplished up to the end of 31 December 1962.

SCT and SXT Design layouts were the basis for design reviews, familiarization studies and the preparation of preliminary Weight, Center of Gravity and Moment of Inertia calculations.

1. The preliminary detail drawings of the SCT optics were used to determine the amounts of each type of optical glass required, and orders for all long lead glass was initiated.

2. Detail drawings of the SCT were reviewed for producibility, reliability and quality assurance, and the design review reports forwarded to Kollsman External Engineering at MIT.

3. Kollsman received a preliminary Optical Laboratory layout for both the NAA and AMR locations from MIT. Engineering reviewed the layout and submitted recommendations to MIT.

4. The Internal Engineering Group further prepared Family Trees for the SXT and SCT. These family trees were

transformed into fabrication/assembly/test flow diagrams for use in the detailed preparation of test specifications, test equipment utilization requirements and subassembly performance specifications.

5. A preliminary detailed description of the design parameters and theory of operation of the SXT and Telescope was prepared. This information was applicable to the Familiarization Manual.

In addition to the foregoing, the Internal Engineering Group also supported the effort required in the following Technical Directives.

1. Apollo Project Engineering Support (T.D. K-12) - Establish and operate a project engineering office to provide internal engineering support.

2. Breadboard Instrument Effort (T.D. K-13) - Preparation for support of design and fabrication of the Sextant (SXT) Scanning Telescope (SCT) and Map and Data Viewer (MDV) breadboard and preproduction models.

3. Planning for Manufacturing (T.D. K-14) - Establishment of procedures and personnel familiarization in preparation of manufacturing.

4. Familiarization Manual Information (T.D. K-27) - Provide information to assist MIT in preparing a Familiarization Manual.

During this period, Internal Engineering also received a Technical Directive for Breadboard Manufacturing (T.D. K-19) which authorized the manufacture of six breadboard Optical Subsystems to various degrees of completion.

4.1.3 Study Analysis

Concurrent with the above tasks, a comprehensive study analysis was started in accordance with T.D. K-18. This required a familiarization in detail of the existing status of Apollo design and navigation theory. Technical notes and charts integrating this information and defining potentially important analytical tasks were generated and discussed with MIT/IL technical management. Three separate tasks were defined under Technical Directive K-18:

1. Apollo Ascent Abort

2. Apollo Injection Model

3. Optical Models

The objective of the Ascent Abort task was to study the ascent trajectories to an earth parking orbit and to determine their suitability in those situations where the flight must be aborted. The results of this study were useful in the determination of any necessary modification of the proposed ascent trajectories required to meet constraints implied by safe abort capability during all portions of the ascent.

The objective of the Injection Model study was the determination of the effects that launch perturbations have on the parking orbit. The results provided input data for an already existing digital simulation of the injection guidance problem.

The objectives of the Optical Model Study were:

a. The generation of error models for the sextant and scanning telescope, and related optical instrumentation.

b. Determination of the static, dynamic and noise performance of the optical system.

c. Determination of the inaccuracies introduced in the optical system by the astronaut, movement of field of view, and methods for the elimination of bias errors (ASK-KI No Computer Navigation Study).

The accomplishments in the above areas are listed below:

4.1.3.1 Ascent Abort

An initial condition generating program was assembled and run. The main program for the Ascent Abort study was also prepared. This information was combined with a modified version of MIT data on establishment of safe corridors for re-entry flight, to obtain curves of forbidden regions in velocity, altitude and flight path angle for the ascent.

4.1.3.2 Injection Model

An earlier analysis of the propagation of circular parking orbit errors[1] was reviewed, and this positional and velocity error data was presented in a cylindrical coordinate system moving with the orbiting vehicle.

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[1] "Error Analysis Considerations for a Satellite Rendezvous" Duke, Goldbert & Pfeffer, ARS Journal, April 1961, p. 505.

Considering that the point of injection into a translunar orbit is fixed in an inertial frame, and that the earth continues to rotate about the polar axis, a delay in launch time requires a different inclination of the parking orbit. An analysis utilizing orthogonal coordinate transformations is being conducted to determine the velocity difference between two parking orbits that have the same radius and period, but different inclinations.

4.1.3.3 Optical Models

The major mechanical and optical errors of the sextant and scanning telescope were determined and a tentative error model constructed. The model also incorporated the electrical read-out errors that are encountered. The optical model was predominantly useful when the sextant and telescope are operated in a mid-course star-landmark measuring mode.

Provisions were made to extend the validity of the model when the sextant is operated in other modes, such as the theodolite mode, etc.

## 4.2 ENGINEERING - PERIOD ENDING 31 DECEMBER 1963

### 4.2.1 External Engineering

In addition to providing the continuing support to MIT on the design and development of the optical unit and the Map and Data Viewer, external engineering made several personnel additions in accordance with TDK directives. These personnel changes served to maximize the KI resident support effort in view of the increasing and expanding tasks that were rapidly developing. The following lists these changes:

1. External Project Engineering (T.D. K-5) - directed the transfer of a Project Engineer and two Senior Engineers to MIT/IL.

2. Design Personnel Resident at MIT (T.D. K-8) - authorized the transfer of four Mechanical Designers, three Detailers, and three Checkers to MIT/IL.

3. Display and Control (T.D. K-32) - directed the transfer of one design engineer to assist in identifying and solving lighting problems associated with the Display and Control Subsystem.

4. Design of Map and Data Viewer (T.D. K-35) - Directed the transfer of a Project Engineer to MIT/IL to participate in the design and development of the Map and Data Viewer.

5. Resident Effort (T.D. K-106) - Provided resident effort at MIT/IL for an Engineer, Mechanical Designer, and one Draftsman for the accomplishment of design changes for the Optical Subsystem and the Map and Data Viewer.

At this time, TDK-22 also authorized the fabrication and procurement of models of parts or subassemblies for use in support of design studies and formulation of equipment designs.

During this year, much of external engineering's efforts were concentrated on originating and processing engineering changes and incorporating new design requirements to facilitate manufacture, test and shipment of the Optical Unit.

All of the design work, except for the Map and Data Viewer and the final details of the Scanning Telescope eyepiece lens mountings were completed, including the final configuration of all the lenses. The long eye relief requirement moved a long step toward solution with the favorable reaction at the NASA Design review toward a new proposal for long eye relief provision. Work proceeded in optimizing the proposed solution on compromising on magnification to obtain 2-3/8 inch eye relief with an enlarged exit pupil and lightweight.

4.2.1.1 Eyepiece Detail

The Sextant and Scanning Telescope Eyepieces were subjected to design revisions centering on the provision of Eyeguards, the Polaroid Analyzer for relative brightness control on the LLOS and STLOS of the Sextant, and refinement of the SXT Eyepiece lenses resulting in the elimination of one lens.

The completion of the emergency Eyepiece design resulted in a weight decrease from 2.3 to 1.5 pounds. Design and weight calculations on the Eyepieces resulted in refinements which pared the weight from five pounds to slightly under four pounds in spite of the addition of an adjustable Eyeguard to each of the three normal Eyepieces.

The design of storage provision for the Eyepiece, which must be detached from the panel during certain phases of the mission, was completed and readied for submission to MIT for transmittal to North American.

4.2.1.2 Eyepiece Detail (3X)

In regards to the 3X eyepiece elimination, tests were made on the SCT to verify the approach taken.* The SCT Block I Optics were assembled on the bench and with the 1X eyepiece designed to fit on a turret with a 3X eyepiece, the resolution was barely adequate at the mid-portion of the field and unsatisfactory in the outer half due to astigmatism which could not be corrected. Use of the 3X eyepiece did not add significantly to the telescope effectivity. For a useful 3X system, the dimensions would necessarily be so large as to be prohibitive, from a weight and space consideration, or the system would have to be designed exclusively for the 3X eyepiece. Another test was made with a second set of objective lens components assembled as an eyepiece. Although this unit was not optimized for this purpose, the results indicated that it could be redesigned readily to serve as a satisfactory 1X eyepiece. However, this 1X eyepiece could not be mounted in a shared turret with a 3X eyepiece without compromising the design to an objectionable degree. The recommended solution was to use an optimized 1X eyepiece for Block II Optics and supply the 1X and 3X combination as is with the optimized 1X eyepiece. This new 1X eyepiece accompanied the delivery of the optical unit.

The change to a new 1X eyepiece was advanced from Block II to Block I hardware and was being incorporated on the first breadboard units.

4.2.1.3 MDV Detail

The Map and Data Viewer design proceeded according to schedule, including detailing of three subassemblies and layouts of two major subassemblies. Experimental models of the Cartridge and Gearbox assemblies were completed and the electronic system was evaluated.

A problem was encountered in fabrication of the MDV Housing Assembly, 1011439. It was found that the brazing technique proposed for joining the parts of this assembly was inadequate, and an alternative joining technique, consisting of cementing with an epoxy cement, in conjunction with the use of screws and dowel pins, was therefore adopted. This technique has proven to be satisfactory. New drawings, reflecting the revised technique were generated and released. The superceded drawings were obsoleted. This

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*Designing the 1X and 3X eyepieces to have the same eyepoint location compromised the 1X eyepiece design to an extent where it was unsatisfactory.

necessitated some slippage due to resultant drawing changes as well as changes in procedures that had to be adopted for assembly of the Map and Data Viewer.

4.2.1.4 Drawing Detail - OUA

A change handling procedure was established and approximately 30 changes were processed, about one third of which were Class One, requiring Design Review Board approval.

Detailed part drawings were completed and submitted to the design review board action for release to the change control board.

The Class A release of all remaining detail parts and specification control drawings were complete for the SXT, SCT and Optical Base Assemblies. Assembly drawings were 95% completed and ready for review and checking.

The status of drawings at that time for the Optical Unit is shown in Table 4-1. This tabulation includes the drawings required to implement the Auxiliary Long Eye Relief Eyepiece and the Revised SCT Eyepiece which replaced the turret design.

Table 4-1

OPTICAL UNIT, DRAWING STATUS

| DRAWING | QUANTITY REQUIRED | DWGS COMPLETED QUANTITY | DWGS COMPLETED PERCENT | DWGS RELEASED CLASS "A" QUANTITY | DWGS RELEASED CLASS "A" PERCENT |
|---|---|---|---|---|---|
| Assys | 101 | 101 | 100% | 101 | 100% |
| Details | 352 | 352 | 100% | 352 | 100% |
| S.C.D.'s | 49 | 48 | 98% | 41 | 84% |

4.2.1.5 Drawing Detail - MDV

The detailing of the Map and Data Viewer begun during the last report period, now resulted in the Class A release of 24 detailed drawings and 8 SCD's, which included virtually all of the long lead items.

The status of drawings for the Map and Data Viewer at that time is shown in Table 4-2.

Table 4-2

MAP AND DATA VIEWER DRAWING STATUS

| Drawing | QUANTITY REQUIRED | DWGS COMPLETED QUANTITY | DWGS COMPLETED PERCENT | DWGS RELEASED CLASS "A" QUANTITY | DWGS RELEASED CLASS "A" PERCENT |
|---|---|---|---|---|---|
| Assys | 24 | 24 | 100% | 24 | 100% |
| Details | 9 | 91 | 100% | 91 | 100% |
| S.C.D.'s | 29 | 28 | 96% | 28% | 96% |

In addition to the emphasis on the OUA and MDV, external engineering haddactively engaged in the design and development of Block II revision of the Optical Unit which was a redesign of Block I hardware incorporating new concepts in CDU's, SCT optics and the addition of photoelectric devices for star and horizon tracking.

In regards to the Block II effort for the SCT and SXT, without the photoelectric devices, the following tasks were accomplished:

4.2.1.6 Scanning Telescope

A. Elimination of the three power eyepiece which required a redesign of the eyepiece assembly.

B. Discontinuance of the addition of digita' unters to the SCT gearboxes due to the system rev: s.

C. The design of a SCT eliminating the Trunnion Axis continued as a backup design. This telescope operated similar to the LEM telescope in that a rotatable spiral reticle was used to determine star reference angle. This redesign was not used.

4.2.1.7 Sextant

(No design work for Block II was initiated although modifications were approved in the following areas):

A. A new and larger motor for the Trunnion Drive and increased gear ratio in the Trunnion Drive gearbox.

B. Additional 2X resolvers were added to both Trunnion and Shaft Servo Systems due to the change in system expansion eliminating CDU gearboxes.

4.2.1.8 Block II Electronics

Parallel with the Block II effort on the optical unit, external engineering was intimately involved with a Block II design which would incorporate photoelectric features for star acquisition and tracking.

In the sextant, considerable design work was accomplished on the photoelectric features to provide a semi-automatic photoelectric device capable of replacing the need for visual observation. A very satisfactory concept was developed. This design, which resulted in simple packaging and maximum utilization of the existing design, encompassed both the star tracker and the horizon photometer functions. A two-axis compact star tracker and a similarly designed horizon photometer formed an integral unit which was mounted on the SXT head. This device was rotated using the scanning motion of the head by simple extension of the indexing mirror.

During October layouts for the redesign of the SXT trunnion drive gearbox was completed. This design used a new motor and also incorporated a higher gear ratio. Redesign of the SXT shaft gearbox incorporating a 1X resolver was also completed. A new design incorporating a 64X resolver on the SXT shaft was near completion. This design was reviewed and detailed by KI ex ernal engineering.

Provisions were also made for the design of additional electrical connections between the SXT head and the Optical Base.

During the latter part of this period, the star tracker and horizon photometer package detailing was 75% complete. Design reviews were held periodically to simplify production. The preliminary lens design was detailed and submitted for optical design review and checking by the Internal Project Group at Kollsman.

During the same period, additional engineering support activities by Kollsman residents at MIT/IL included thermal analyses, star tracking parameter analyses and image dissector tube star tracking system studies.

In the administration area, the Kollsman project office established a procedure for handling documentation drawings and changes, which facilitated a more systematic and efficient liaison between external and internal project engineering.

4.2.2 External Engineering - LM

The above accomplishments describe in detail the tasks performed for external engineering during this critical phase. All of the effort described, however, is relative to the OUA and MDV. During the latter part of this same period, external engineering began design discussions and exercises relative to the Alignment Optical Telescope, a periscopic device to be used aboard the moon lander, the LM vehicle.

4.2.2.1 LM Program Planning

During this period, Kollsman was notified that the design concept phase had been extended from 30 September to 30 November 1963. As a result of this extension, the program was reviewed and new manloading requirements were incorporated as suggested at the NASA review held at MIT/IL.

In accordance with the requirements of the Design Concept Statement of Work, Kollsman submitted to NASA/MSC a proposed LM Program including a detailed cost breakdown. In addition, in accordance with the Design Concept Statement of Work, Kollsman submitted a preliminary study report comparing the LM and CM design. The final report was deferred to 30 November 1963.

Extensive effort was conducted during this quarter on the LM planning. Preliminary manloading charts were developed and submitted with the proposed LEM Statement of Work to NASA/MSC. In developing the manloading charts, the entire program requirements were carefully reviewed. Only a 24-man month Field Operations effort was suggested in the LM Statement of Work due to lack of firm information on starting dates in the field. For study purposes, starting dates were assumed and a Field Operations manloading requirement was developed.

4.2.2.2 Ground Support Equipment

In line with the planning aspects, external engineering studied the requirements for LM GSE and determined that a family of devices similar to that supplied for the optical unit would be adequate.

4.2.2.3 Documentation

The requirements of Documentation for the Apollo LM program were reviewed with a view toward establishing similar controls for this effort as were being used for the Command Module. Preliminary outlines were being formulated for preparation of the Documentation Plan, Reliability Plan, Progress Reports and other documents that were required early in the program.

4.2.2.4 LM AOT Description

The LM telescope is a wide-angle unit-power telescope used to measure angles between stars and a set of reference axes for aligning the IMU.

Since the configuration of the LM capsule differs considerably from that of the CM capsule, the scanning telescope as designed for the Command Module cannot be adapted to LM Thus, the LM telescope was of a completely new design.

The design philosophy was to simplify the mechanical construction to the ultimate degree. The proposed construction for utmost simplicity employed an all manual polar coordinate system of measuring star polar and declination angles. This was done sequentially by rotation of a reticle carrying a polar angle cursor and a declination scale consisting of an Archimedean spiral with its origin at the center of the field. In this system, the same means of rotation and the same scale served for both measurements.

The further objective of placing the controls directly at the operator's hand and wholly within the controlled environment dictated that the measuring reticle be at the instruments second focal plane, that is, adjacent to the eyepiece.

The original objective of having an instrument capable of making all necessary measurements from a fixed orientation of the front optics had to be compromised because of the practical limitations on field size. The compromise chosen was to provide three positions of the optics. This was done by rotations of the headend about the polar axis which are secured by a precise detent means. The suggested method was an adaptation of a well known principle applied to precision rotary tables. Matched crown gears with a suitable number of teeth are engaged face to face under spring load as the detent. It is possible for such a device to provide all the restraints to align the optics in each position, buththe intention as used on the LM Telescope is to provide the axial direction by a conventional ball bearing arrangement. The axial freedom needed to disengage the crown gears, was provided by mounting one of the pair concentrically on a large bellows which will permit axial disengagement but still provide the necessarily rigid torsional coupling. The portion of the optics to be rotated by this arrangement will depend on details of the optical design.

The telescope extends down into the occupied area of the vehicle in such a way as to impede entry and egress. This unavoidable invasion of space had led to a decision that the lower end of the telescope be made removable. Since this portion carries the measurement device, its mounting must be precisely repeatable and sufficiently strong to resist deflections arising from the physical contact with the astronaut.

#### 4.2.2.5 Design Considerations

Design effort on the LM telescope was continued as this effort had been extended through 31 January 1964. The primary approach for the telescope design established during this time will be briefly described and then alternatives that were under consideration will be noted.

A significant design hurdle was the astigmatism that was associated with the optical train and which limited pointing accuracy. External engineering studied several approaches to ameliorate this problem and contributed much to the final design change which was most satisfactory.

Design of the mechanism used for actuating and rotating the telescope for the multi-positioning of the telescope field was challenging and actively participated in by engineering. Design effort was also concentrated on the enclosure around the deviation (objective) prism. A design was required which would prevent moondust from contaminating and obscuring the objective prism and lens surfaces. The use of a metal housing around the dove prism with a single circular aperture was considered. A spherically surfaced spring-loaded cover would close the referenced single aperture hole when the telescope is rotated to the "close" position.

#### 4.2.2.6 Problem Areas

With the completion of design effort, it was apparent that changes recommended by many different groups would be difficult to reconcile in time to meet production schedules. Because of this, Kollsman recommended that there be a modification of the definition of changes requiring NASA/MIT Design Review Board approval, so that only changes that were actually different design concepts, substitution of materials or methods outside of established documentation would require this review.

### 4.2.3 Internal Engineering

In conjunction with external engineering efforts at MIT, external engineering continued to expand and directed their efforts toward the implementation stages of the program. T.D.'s were received calling for the specific following efforts:

1. Manufacture five subsystems for Block I and assemble.
2. Manufacture five MDV's.
3. Fabricate a wooden OUA mock-up.
4. Fabricate an MDV simulator.
5. Fabricate OUA breadboard parts.
6. Fabricate LER eyepieces.
7. Design and manufacture GSE for OUA.
8. Design and manufacture GSE for MDV.

During this period, internal engineering was faced with a dual task of getting the manufacturing personnel started by providing them with the tools, equipment and know-how and, at the same time, monitoring design changes, drawing releases and cut-in's to minimize schedule and cost impact.

To accomplish a cut-in and design control, engineering established a Design Review Board. The board, attended by cognizant disciplines became the controlling instrument through which a most effective coordination was achieved and which enabled many design changes of Class I and Class II nature to be smoothly cranked into the production cycle with minimum schedule and cost impact.

Additionally, engineering reviewed all the prime equipment assembly and test flow charts to ensure they were compatible with the factory test equipment. Manloading and test equipment loading charts were prepared and given to Manufacturing.

Concurrent with this design and fabrication of required factory test equipment and tooling was accomplished. In this area, internal engineering actually simulated the optical parts of the SXT and telescope. These simulated optical assemblies were utilized in laboratory tests to verify that the design parameters of the FTE, especially the precision test fixture were compatible with the design of the OUA.

A specific accomplishment during this period was the preparation and submittal to MIT of all existing and new process specifications considered applicable to the fabrication of Apollo equipment. In this area, engineering also provided additional information that was required to support the delivery of an optical subsystem.

1. Weight, Center of Gravity and Moment of Inertia reports.

2. Purchase specifications.

3. Material specifications.

4. Guidance and Navigation interface specification.

The design section of internal engineering had achieved a major effort during this period also. They developed an outline drawing covering the purchase and installation of a dual environmental chamber. The design criteria included viewing parts, alignment target parts, sun simulator parts and cyrogenic shield arrangements. Preliminary engineering was performed in developing design specs for vibration and shock fixtures also.

As indicated in the preceding paragraphs, internal engineering was continually monitoring and controlling design changes and the issuance of release drawings. Design review board periodically met and achieved a high degree of performance in not only releasing drawings but on making review comments on Class B drawings which were forwarded back to MIT.

With many drawings released, procurement and vendor problems started to mount and in this area, engineering performed a KI/vendor/MIT liaison and succeeded, even in those areas where the "state of the art" was being taxed, to get acceptable material and parts fabrication. Some significant vendor problems that threatened schedules were as follows:

1. Beam splitter

2. Reticles

3. Worm shaft

4. 64X resolver

5. Optical base

6. Projection lamp

Due to the concentrated efforts of KI's internal engineering group, all of these problems were solved without undue schedule slippage.

4.2.2.1 Optical Unit Assembly Status

Changes in disposition of the first three Optical Units were made at this time. Instead of furnishing "parts only" on AGE 1, 2 and 3, assembly of these systems was accomplished at Kollsman at MIT's request. Upon completion, these units were furnished to Reliability for Thermal Integrity and Structural Integrity tests. These three systems did not require the accuracy that was to be maintained on AGE 4 but rather were built to specific parameters.

At this time, major emphasis was concentrated on the fabrication and procurement of detailed parts for all systems. Expediting and engineering liaison both with vendors and in-house received special attention to facilitate the earliest possible receipt of parts. This effort continued until all the necessary components were available.

4.2.2.2 MDV Status

Also at this time, family trees for the Map and Data Viewer were updated and furnished to MIT. The process chart was also reviewed and released. A procedure was started during this period wherein the status of parts that were crucial for conforming to schedule requirements was furnished to MIT by TWX. Extremely close supervision was maintained on critical parts to remove obstacles as they occurred.

Release of the projection lamp was a problem. Samples of the MIT X1 configuration were received from Sylvania but preliminary tests revealed that these samples were unsuitable. The lamp developed by GE suffered a setback which was attributed to filament coil design. The new filament coil design was formulated and assembly procedures were developed for the mounting of filaments to stems and of stems to bases.

Preliminary samples of new projection lamps were received from GE and evaluation tests performed at MIT/IL. Results of the tests indicated that GE was proceeding satisfactorily with their development program -- color temperature filament separation and power consumption of these samples were close to design requirements. GE was proceeding with refinements of these parameters, as well as investigating the possibility of applying a silver coating and a dichroic coating to the bulb. The location of the filaments in the sample lamps was 0.125 inch closer to the socket than originally intended. As a result, the insulation ring which holds the lamp required changes to build up the lamp socket by a corresponding 0.125 inch.

4.2.2.3 Laboratory Investigation

Optics - A precise method for measuring the test plates for all lenses was established. The test plates were manufactured and calibrated using the Watts Spherometer to measure the critical radii of curvature. The relay lenses and the objective lenses were completed.

An engineering evaluation was made of fabrication, mounting and cementing of the dove prism assembly. This investigation showed that a method of air curing, to avoid extreme strain and stress and maintain resolution criteria, was successful for the dove prism. This method was employed in production of these prisms. A process of grooving the dove prism (for free aperture) was also successfully demonstrated during this engineering evaluation.

Deviations from the specifications on the drawings of both the polaroid filter and SXT beam splitter were analyzed with the appropriate vendors considering the requirements of the program and the capabilities of the vendors. Criteria for these items were established for mutual benefit and firm orders were placed during this quarter.

Electronics - During the reporting period, a breadboard-type amplifier and a solder-type amplifier were fabricated to investigate the electronics for the Map and Data Viewer. These two units were tested for gain and stability characteristics in the laboratory.

4.2.2.4 AOT Status

1. LEM Internal Project Engineering Assignments - Effort continued in establishment of Internal Engineering (T.D. K-2L) and Project Management (T.D. K-3L)

2. LEM Documentation Assignments - Effort continued under the authorization of a technical directive for Documentation (T.D. K-4L)

3. LEM External Project Engineering Assignments - Effort continued to be expended on the Resident Effort (T.D. K-1L) and Design Analysis (T.D. K-5L).

This period proved to be highly charged and volatile and presented a unique challenge to internal engineering. In summation, engineering handled all facets in a most admirable manner. They had successfully accomplished the following:

1. FTE task, fixtures (Block I) had been designed and were in fabrication.

2. Actual manufacture of Block I subassemblies had begun.

3. Process and material specs were in the process of being finalized.

4. Parts problems, just begun, were closely monitored and controlled.

5. Knowledge and understanding of the optical unit, in terms of its high reliability requirements, had been successfully disseminated.

6. Reliability fixtures and equipment for environmental testing had been designed and were in fabrication.

7. Analyses were proceeding on all drawings and recommendations consistently submitted to MIT.

8. Design changes and new releases were smoothly being fed into the production cycle.

## 4.3 ENGINEERING - PERIOD ENDING 31 DECEMBER 1964

### 4.3.1 External Engineering

During the early part of this period, external engineering again increased its personnel to support the Block II phase of the program. As per T.D. K-133 and T.D. K-149, the following changes were made:

1. T.D. K-133 Block II Resident Effort - This effort was for the accomplishment of detailed design of the Block II Optical Subsystem and the Map and Data Viewer including engineering support for the star tracker/horizon photometer design, GSE design and thermal/vacuum design evaluation.

2. T.D. K-149 Block II Resident Effort - Provided for one resident electrical technician to MIT for three months to become familiar with troubleshooting procedures and aid in testing of the star tracker/photometer electronics.

The external engineering work during this period, although much harder in scope, supported effectively the following areas:

1. Balance of Block I design and changes
2. Block II
3. Block II, with electronics
4. MDV design
5. AOT (LEM)
6. Eyepieces, SXT and SCT
7. Varied Analyses

The following enumerates some of the significant accomplishments during this period:

4.3.1.1 Block II Design Status

The Block II design status was completed and detailed. The design was an adaptation of a Kollsman design used previously for phototracking.

Redesign of SXT Head Assembly - Redesign of all major components was completed with the exception of the electronic package. The design detailing was approximately 90% complete. Checking was pending completion of the electronic package design and interface.

Redesign of SCT panel - A redesign for a clearance cut to accommodate a resolver change in the SCT shaft gearbox was initiated.

Redesign of Optical base assembly - Changes in this area consisted of addition of one tapped hole for additional connector mounting plates.

Redesign of the Block II sextant shaft gearbox was planned in order to eliminate the anti-backlash windup spring. Among the proposed methods to be explored is the introduction of split backlash gears. Although gear ratios and servo component speeds were not affected by this change, it necessitated redesign of gearbox plates and housing. When this redesign was completed, detailing was initiated by Kollsman resident engineer.

Redesign of SCT shaft drive gearbox - This design and detailing was completed and checked.

Additional Flexprints - Design of two new flexprints was completed.

4.3.1.2 SXT Eyepiece Details

A minor redesign was made in the sextant eyepiece casting to eliminate the requirement for two separate castings for regular eyepiece and long eye relief assemblies. The sextant long eye-relief eyepiece design has been definitized for a distribution of the five-diopter focusing range. Now focusing will cover the range of from +1 to -4 diopters in air.

The problem of focusing the sextant under space vacuum conditions was resolved by the expedient of incorporating two reticles in the optical system. One reticle is at the focus of the objective under space conditions and the second reticle is in focus under terrestrial atmospheric conditions. The utilization of a temporary shim provided focusing for ground test (air) purposes. The shim was removed for flight (vacuum) use.

A full scale wooden mockup of the MIT/IL design for a scanning telescope, long eye-relief, full field-of-view eyepiece revealed that incorporation of this MIT/IL design would create both mounting and storage problems. Kollsman was nearing completion of a design for a full field, long eye-relief eyepiece for the LEM telescope which would result in some reduction in size and weight by comparison with the aforementioned MIT/IL eyepiece. The possible inclusion of this Kollsman designed eyepiece into the OUA awaited a NASA decision to require full field capability in both Sextant and Scanning Telescope with long eye-relief eyepieces.

Parallel with this effort, investigations were proceeding as to the type of heaters that would be incorporated into the eyepiece.

MIT/IL followed up on its lead for a supplier of sprayed-on heaters for eyepieces. Techniques for use of this material to meet the particular requirements was evaluated prior to incorporating the heaters into the eyepiece design.

Eyepiece heaters of a formed blanket type was finally selected and epoxy-cemented to the eyepieces. Electrical leads and connectors were provided for hookup of the eyepiece heaters while in launch or storage position. A set of prototype heaters for the first test OUA were made up and testing would determine the required output in wattage of the final design of the heaters.

4.3.1.3 OUA - SXT Details

A redesign of the Sextant reticle assembly was made at MIT/IL to separate the adjusting and clamping functions of components within the assembly. The present design utilized tapered clamps bearing against the reticle housing and glass reticle. The basic change in the new design incorporated a reticle mount which was adjusted by clamping tapered wedges as in the current design; however, the wedges in this design bear against metal and not against glass. The reticle itself was held in its mount by cement. After the reticle housing has been adjusted for centering, it is clamped by tightening three screws. The three adjusting wedges and their respective screws are removed after the clamping screws have been tightened.

4.3.1.4 Block II - Electronics

Design in the area of electronic interconnection had established the location of the connector which couples the Tracker electronic packages to the shielded lead flexible conductor. This shielded lead is the counterpart of the flexprint used in the interconnection of the servo systems.

It was decided that the interconnection of the tracker modules within themselves would be accomplished by the use of a terminal board. The connection of the terminal board of the flexible conductor connector would be accomplished by the use of an intermediary harness. Design effort was directed toward optimizing the shape, layout and mechanical attachment of this terminal board to the related assembly.

A fixture to mount a Block II Star Tracker Unit onto a Wild T-3 Theodolite was designed by Kollsman resident effort. This fixture was used for MIT/IL evaluation of a tracker assembly. The fixture provided alignment of the Tracker to the theodolite line of sight.

Design studies were planned for the following areas:

1. A sun protection device and associated mechanics for the Star Tracker and Horizon Photometer.

2. A light shield assembly within the outer cover of the Scanning Telescope to reduce or minimize stray light from entering the Scanning Telescope optical system through the dove prism.

Error analyses were performed on the Precision Test Fixture, Short Periscope, Alignment Mirror Assembly, and Optical Laboratory Targets. Accordingly, reports were published presenting the detailed results of each analysis.

A vibration analysis was performed and a report was published on various types of optical holding stands for supporting the Laboratory Targets. The effort yielded conceptual design of an optimized holding stand (in terms of resonant frequency) weighing 1,200 pounds and with a natural frequency of approximately 288 cps.

#### 4.3.1.5 Drawing Status

OPTICAL UNIT - BLOCK I - The status of drawings, at that time, for Optical Unit is shown in Table 4-3. This tabulation includes the drawings required to implement the Auxiliary Long Eye-Relief eyepiece and the revised SCT eyepiece which replaced the turret design. These figures do not include Block II Optical Unit redesign.

Table 4-3

OPTICAL UNIT
BLOCK I, DRAWING STATUS

| DRAWING | QUANTITY REQUIRED | DWGS COMPLETED QUANTITY | DWGS COMPLETED PERCENT | DWGS RELEASED CLASS "A" QUANTITY | DWGS RELEASED CLASS "A" PERCENT |
|---|---|---|---|---|---|
| Assys | 102 | 102 | 100% | 101 | 99% |
| Details | 357 | 357 | 100% | 355 | 99% |
| S.C.D.'s | 53 | 51 | 96% | 44 | 83% |

OPTICAL UNIT - BLOCK II - The status of drawings at that time for the Optical Unit is presented in Table 4-4.

Table 4-4

OPTICAL UNIT
BLOCK II, DRAWING STATUS*

| DRAWING | QUANTITY REQUIRED | DWGS COMPLETED QUANTITY | DWGS COMPLETED PERCENT | DWGS RELEASED CLASS "A" QUANTITY | DWGS RELEASED CLASS "A" PERCENT |
|---|---|---|---|---|---|
| Assys | 131 | 131 | 100% | 131 | 100% |
| Details | 413 | 405 | 98% | 405 | 98% |
| S.C.D.'s | 93 | 90 | 97% | 67 | 72% |

*Not including electronics

MAP AND DATA VIEWER - The status of drawings at that time for the Map and Data Viewer is shown in Table 4-5.

Table 4-5

BLOCK I,
MAP AND DATA VIEWER DRAWING STATUS
(INCLUDING RECENT DESIGN CHANGES)

| DRAWING | QUANTITY REQUIRED | DWGS COMPLETED QUANTITY | PERCENT | DWGS RELEASED CLASS "A" QUANTITY | PERCENT |
|---|---|---|---|---|---|
| Assys | 60 | 60 | 100% | 60 | 100% |
| Details | 95 | 95 | 100% | 95 | 100% |
| S.C.D.'s | 35 | 35 | 100% | 34 | 99% |

LUNAR MODULE - The external engineering effort continued at MIT/IL in these specific areas:

1. Resident Effort
2. Design Analysis
3. Project Office

At this time, the LM telescope design was approximately 95% complete. The upper or telescope design layout was approved by the Design Review Board and was pending release for detailing. The lower or eyepiece unit design layout was completed except for design study concerning a flexible shaft coupled to the reticle knob. The optical design data was completed except for information regarding the spiral reticle from MIT/IL.

### 4.3.2 Internal Engineering

This was a very significant period in that actual hardware deliveries were scheduled to begin. Internal engineering's support rate, although still continuing in an overall mode, had to shift heavily to the support of manufacturing and vendors. During this phase, much of the previous planning and peripheral support began to bear results. In effect, internal engineering concentrated on ensuring a smooth mesh and marriage of the Program's hardware and software into a well integrated manufacuring flow.

The work completed during this period resulted in many refinements to the testing and assembly procedures in both the SXT and SCT areas. The most significant improvements were in the procedures of setting up shaft bearings, matching sensitive optical components for enhanced resolution and elimination of parallax, closer control of setting of trim pots and SCT Resolvers to eliminate bias errors over the complete angular range. Generally, all of the inspection methods to eliminate human error, whenever possible, were improved.

As was anticipated, problems arose in the vendor and manufacturing areas. The solving of these problems on an expeditious basis was the highlight of this period. The following outlines some of these difficulties:

4.3.2.1 Optical Unit Assemblies - Sextant

VENDOR PROBLEM AREAS - Polaroid filters to-date had been supplied by repeated rework and reselection from reworked lots. Under these conditions, results were marginal and unsatisfactory.

The problem was that Polaroid had experienced difficulty in maintaining tight flatness requirements of two light fringes. Changes were processed to remove the coating. Polaroid was then able to successfully rework four units and proceeded with the rework of the additional parts.

Bendix was experiencing difficulties in the area of accuracy, insulation resistance, and mechanical tolerances in regards to the 64X resolver. KI Engineering and Quality Control kept in close liaison with Bendix which culminated in a change to the Procurement Specification which relaxed several troublesome requirements. As a result, vendor promises were more realistic.

Delivery on reticles from D. Mann was extremely slow, but through personal engineering visits and phone liaison, the rate of production improved sufficiently to cover fabrication through optical unit 6.

The suppliers of the 1010610 motor generator were having difficulty delivering the required quantity of motors because of the axis error specification. Kearfott found that after burn-in only 35% of the units passed this requirement and they requested a change to 4 mv. Investigation of the possible effect on system accuracy was made by MIT. Table 4-6 shows the results obtained at MIT.

Table 4-6

MOTOR GENERATOR AXIS ERROR

| ANGLE | ERROR SENSITIVITY | MECH. ERROR FOR 4 mv. TACH. |
|---|---|---|
| SXT AT | 3.4 mv/sec. | 1.2 sec. |
| SXT AS | 9.6 mv/sec. | .4 sec. |
| SCT AT | .25 mv/sec. | 16 sec. |
| SCT AS | .25 mv/sec. | 16 sec. |

From this data, it was decided to purchase two different motors against the drawing 1010610-1 with 2 mv axis error and 1010610-2 with 4 mv axis error. The 1010610-2 would be used in the less critical applications and not in the Sextant Trunnion.

The delivery of relays were a critical item in that the vendor was able to deliver only small quantities at a time in conformance to all requirements of the drawing. Kollsman ordered additional units from a second qualified vendor (the only other qualified source) and sufficient units were in-house and on route to Kollsman to satisfy requirements through AGE's 6, 7, 8, and 20.

MANUFACTURING PROBLEM AREAS - Engineering effort was also concentrated on investigations for solutions to recurring problems that had either retarded production or resulted in conditional acceptance (via waivers). Among the problems worked on were the following:

SXT Shaft Perpendicularity - The consistent perpendicularity discrepancy between vertical and horizontal optical unit orientation was investigated. It had become apparent that the discrepancy was not attributable to the Optical Unit, but rather to the PTF's references and the technique for their setting. The investigation resulted in all existing PTF's being examined and establishing the necessary revisions to certification equipment and procedures to eliminate or substantially reduce this discrepancy.

SXT Reticle Eccentricity - Manufacturing had a problem of securing the reticle and objective lens against shifting under vibration. Engineering investigations resulted in the submission of changes to MIT which were subsequently incorporated in Block II systems.

Specks on Reticles - Microscopic examinations had indicated that the light baffling spring washers above the SXT and SCT reticles tended to shed their optical black coating under stress and strain. While alternate finishes and altered baffle designs were investigated for Block II, special brushing and cleaning techniques were employed on the remainder of Block I.

SXT Reticle Lamp Failures - It was concluded, through engineering experimentation, that lamp envelope fractures were attributable to the rigidity of the bonding agent used to retain the lamps in their cavities. A change request was pursued which substitutes RTV 881 encapsulant for the Eccobond 45 adhesive presently being specified.

Double Dove Prisms - The double dove prisms were a recurring manufacturing and quality control problem in spite of extra effort to improve quality. Careful investigation showed that theoretical resolution values were closely approached but that the theoretical resolution was itself marginal from the SCT functional requirements. The prisms were a problem in mounting because of their small size, delicate sensitivity to strain and large leverage on the final accuracy. Progress was made in solving these problems by intimate liaison with KI optical department and manufacturing personnel.

SCT Trunnion Stiction - The combination of worm drive and the high speed differential were proving to be the source of repeated failures for manufacturing to meet the specified friction level on the SCT Trunnion. A recommendation was made after investigation to reduce the stiffness of the anti-backlash spring and maintain closer control of bearing end play in the gearbox.

SCT Shaft and Trunnion Accuracies - Research into the characteristics of the Block I Optical Units assembled and gear train analysis of the gearboxes involved indicated that the tendency to exceed accuracies was inherent in the design. Two approaches were taken to remedy the condition. One approach initiated was a request for a design change in which anti-backlash gears were utilized at the critical mesh in each gearbox. The other approach involved a change in the criteria for acceptance of gearboxes at the subassembly level to insure improved accuracy characteristics at final assembly. The criteria for acceptance of the final assembly was reviewed for the purpose of substituting a mean accuracy requirement over the excursion range of the SCT instead of a point-to-point accuracy requirement. The mean accuracy requirement was found more useful than the former point-to-point technique.

Silicon Exudate - Preliminary tests had indicated that the moisture which appeared between the optical unit panels and base, when the unit was opened, exuded from the pores of the beryllium surfaces under the clamping pressure of the panel mounting screws. Results of high temperature, high vacuum bake-out tests had been encouraging and this technique employed to condition the remainder of Block I bases and panels.

Leakage Rate Through Optical Unit - An internal operation sheet controlled the leakage testing of the Optical Unit. A more formalized test with improved fixturization was submitted for MIT/IL approval as an addition to the FTM.

4.3.3 <u>Internal Engineering - Block II (with electronics)</u>

4.3.3.1 Block I (100 Series)/Block II Design

Initial engineering investigation of the Block I (100 Series)/ Block II design incorporating the Horizon Sensor and Star Tracker was in progress also at the time.

The three tuning fork oscillators manufactured under the amendment to T.D.-119 were delivered to MIT and worked satisfactorily. The remaining modules (2 power supplies and 2 photodetectors and preamplifiers) were delivered by June 30. Originals of sketches, which were used to manufacture these modules, were delivered to MIT. Kollsman investigated the feasibility of incorporating the complete electronics for the tracker and horizon photometer in the Sextant head. Several alternate design approaches appeared feasible for incorporating these modules in the Sextant head.

A wooden mockup of the Sextant Head, incorporating the Star Tracker and Horizon Photometer, was manufactured for the investigation of assembly and interconnection problems associated with the electronic modules.

A laboratory darkroom was set up, including an optical bench and simulacrum, for engineering evaluation and checkout of the electronic modules.

4.3.3.2 OUA Environment Testing

THERMAL - Concurrent with the above effort, the Reliability segment of internal engineering carried out intensive analyses on the OUA relative to Thermal and mechanical integrity. These were accomplished in accordance with T.D. K-61, 60, and 98.

The thermal analysis, conducted in our new environmental space chamber, resulted in specific and significant contributions to confirming the integrity of the design. Engineering took the test data on the solar simulator cycle and electrical power dissipation and converted it into computer input data. A computer run was performed and the data was plotted. Comparison with the test results showed exceptionally good correlation, with only minor adjustments required in the analysis model.

MECHANICAL INTEGRITY - OUA vibration tests were conducted in accordance with the hard mount vibration specification for launch and entry at the 1/3 level along each of the three axes. The following discrepancies were noted:

1. The SCT panel eyepiece window loosened (Failure Report 2951).

2. The SXT reticle eccentricity shifted 9 seconds from the baseline data.

3. Bolts were scored due to apparent relative motion between the Optical Base and the vibration fixture (Belleville washer compression).

Using new mounting hardware, and after tightening the loose window, vibration tests were conducted in accordance with the hard mount vibration specification for High "Q" Abort, at the 1/3 level, along each of the three axes. The following discrepancies were noted:

1. The SXT reticle shifted 14 seconds from the position following the launch and entry test.

2. The bolts were scored as above, indicating a definite compression of the Belleville washers.

The SXT reticle was readjusted and a baseline FTM was performed in preparation for the shock tests.

Shock tests were performed at 15g, 20g, 25g, and 30g, 6 millisecond terminal peak sawtooth pulse, along the $\pm X_{cm}$, $\pm Y_{cm}$, and $\pm Z_{cm}$ directions, two (2) drops per level, per direction.

Acceleration tests were performed at 20g, 25g, 30g, 35g, and 40g along the $\pm X_{cm}$, $\pm Y_{cm}$, and $\pm Z_{cm}$ directions for five minutes per direction.

Acoustic tests were performed for five minutes in accordance with the spectrum specified in the test procedure.

An FTM was performed following these tests and showed no degradation of the OUA.

STRESS ANALYSIS - A vibration analysis of the OUA was now performed to determine the dynamic behavior of selected elements of the assembly. In addition, evaluation of unusual and excessive shock loading on the OUA, imposed during earthlanding was conducted specifically in terms of crew safety requirements. These analyses were used to determine critical areas and were very helpful in determining points of measurement for the AGE 2 mechanical integrity tests (T.D. K-61).

The final report on this analysis effort was completed and issued.

With the conclusion of the above testing, a review and study analysis was made of all testing performed to-date and conclusions were derived therefrom. All data was transmitted to MIT.

A brief report was also published containing information derived from the AGE 1 test cycles I, II and III. The specific data (requested by the Apollo Reliability Group) pertained to minimum and maximum temperatures in the vicinity of the proposed location, in the Block II configuration, of the photo tube and optical errors in the precision angle observed in the test cycles mentioned above.

In accordance with various conclusions drawn from several meetings held between MIT/IL and Kollsman, evaluation group locations for three thermocouples were chosen for the AGE 20 unit. The locations were chosen so that North American Aviation could maintain the proper thermal input to the structural interface between the Command Module structure and the Optical Unit.

### 4.3.4 Internal Engineering - MDV

#### 4.3.4.1 Design Analysis Conference

A meeting was held among cognizant Kollsman MDV Project Engineers to discuss design problems needing immediate and/or long range rectification by MIT and Kollsman.

The design problem areas listed below were discovered during fabrication and design evaluation vibration of the first Map and Data Viewer:

RELAY SWITCHING - The four latching relays used for film direction control were not switching in the correct sequence in one module. Initial breadboard testing of switch network indicated an interdependence between relays, relay inductances, relay position and C8, C9 capacitance values. The present design of the relay circuit used for film direction control utilized the inductance of the relay coil in an LC circuit to effect switching. Inductance of the relay coil was not a controlled parameter of the relay 1006772-2 and in fact, varied approximately 3:1 between two approved manufacturers. In addition, one manufacturer indicated that his relays in any batch could vary as much as 30%. Breadboard testing of the relay switching circuit indicated that it was necessary to match capacitors with relays to obtain a correctly operating circuit. Further breadboard testing was under way as this problem required immediate attention.

MODULE ENCAPSULATION - Immediate investigation was required on the material being used as an encapsulant for the welded module as the present material was unduly heavy. E & C Stycast #1090 (1010305) and Catalyst #11 (1010306) per ND 1002036 were recommended in place of the clear encapsulant in current use.

TRIMPOTS - To effect improved reliability the trimpots were removed. The trimpot function should be replaced with fixed resistors selected at assembly to give equal slew rates in both directions, or should be completely eliminated. Initial tests of breadboard units indicated that the latter path gave satisfactory operation with very much improved reliability.

AMPLIFIER ASSEMBLY - It was recommended that long range consideration be given to redesign of the amplifier assembly into a more compact unit. During the design study, a possible new location for the welded module within the amplifier assembly was investigated.

LAMP INTENSITY SWITCH - Shrink sleeving currently used for protecting the switch contacts was inadequate as it was by necessity too large for the wire. Therefore, it was recommended that the switch terminals be potted and the shrink sleeving be used for the wire only.

CABLE CLAMP - An additional clamp was required for the harness although, for temporary purposes, lacing tape was used.

RESOLVER WIRE SLEEVING - The sleeving on P/N 1011471 was too rigid and impared the required flexibility of the harness, therefore, necessitating a change.

CLUTCHES - For reasons of reducing subsystem complexity and thus increasing reliability, it was recommended that engineering consideration be given to combining the slip and overrunning clutch assemblies into a single unit. It was further recommended that slip clutch torque be increased to overcome film stiffness and thereby ensure optimum windup of film on spools.

CLUTCH ENGAGEMENT - Investigation was needed for improving design of overrunning clutch engagement. A method was needed whereby positive clutch engagement may be implemented.

FILM DRIVE STOP - To prevent inadvertent wrong direction film slewing, there was need for a film drive stop in the gearbox. For example, if most of the 50 feet of film were on one spool of the film cartridge and if the film was driven in a direction to continue takeup on this spool, the other end might be torn or disconnected from the feed spool.

SERVO MOTOR - There was indication that a stop motor drive in lieu of a servo motor may substantially reduce subsystem design complexity and it was therefore, recommended that a design study be instituted in this area.

HANDWHEEL - On the present MDV's, the handwheel turns opposite to the direction that a projected image moves. From a human factors standpoint, this direction of the handwheel and image should be the same.

VIEW SCREEN RETICLE - The reticle component did not impose a design problem but was classified as a general problem due to lack of reticle design requirement data from MIT.

The bearing blocks and adjustment screw assemblies needed careful redesign study as the bearing blocks were inadequately aligned, resulting in excessive friction on the adjusting screw and the adjustment screw did not clear the manual drive knob at the extreme left end of its travel.

It was recommended that redesign of the view-screen support be considered, as the leaf spring assembly did not provide positive support.

As presently designed, the door assembly fit was not adequate since interference at the corners was noted. Hence, a dimensional analysis was recommended with appropriate tightening of tolerances where required.

A light baffle was needed for the door assembly to adequately preclude the exit of light into the spacecraft. Internal light baffles were also required to limit stray or scatter light within the MDV.

A lightweight dust cover was needed for containing the entire MDV. This cover, to encompass all the unit behind the front panel, would prevent contamination of the internal mirrors and optics and would also serve as a light stop.

A gasket was required for the MDV front panel interface with the G&N Control Panel.

The bracket, and the support between the bracket and the holding structure for the small mirror, although not critical, would be revised to provide a more adequate arrangement.

Maximum stress area on the upper panel occurred near the connector, at which point two holes would be removed, and this particular area strengthened by increasing the section. In addition, if a dust cover was provided for the MDV, this would add to the stiffness of the front panel.

If the film was not wound completely on one spool, the film would wind until it touched the case. This resulted in increased film drag and possible film scratching. It was recommended that a device be incorporated in the cartridge to prevent unwinding when the cartridge was removed from the gearbox.

It was recommended that the film wrap further around the sprocket so as to engage tw teeth rather than the present one.

A shipment of 100 pre-production samples of Projection Lamp (P/N 1011413) was received at MIT in June 1964. These lamps were currently undergoing evaluation and appeared to satisfy requirements of filament location, luminous output and color temperatures to a greater degree than had been achieved in earlier samples. Several of these samples had been consigned to KI by MIT, and would be delivered with forthcoming AGE units.

Six Condition Light Assemblies (1011375) units were received from Penn Keystone. The problem of reversal of pin polarity encountered in earlier units had been eliminated. Fourteen units, which were on hold, were currently being fabricated for TDRR 08480.

All other problem areas including magazine retention, magazine loading and film transport, optical deficiencies and housing/door interferences, had been resolved by virtur of redesign. The new manufacturing releases and new drawings presented a partial picture of the results of these design investigations.

4.3.4.2 Status of Equipment, Map and Data Viewer

The Map and Data Viewers AGE's 1, 2 and 4 were completed and accepted by NASA.

The first Map and Data Viewer, AGE 1, was subjected to a preliminary vibration test.

### 4.3.5 Internal Engineering - AOT

The AOT effort, at this time, was also beginning to move forward with a rapidly increasing work-load.

Operations were initiated for requisitioning raw glass for the LM AOT breadboard model. Additional effort in this regard was underway for finalizing tooling requirements. Preliminary "make or buy" meetings were held for the purpose of determining the feasibility of fabricating all or part of the AOT beryllium components at the Kollsman facility. A LM AOT family tree was prepared to facilitate this effort.

A LM GSE Development Plan was being formulated. No work at this time was started on the LM GSE Shipping Containers TD due to the lack of necessary information. A study design layout was prepared for the Telescope Alignment Fixture.

#### 4.3.5.1 Drawing Status

Three design review meetings were held and full time design checking of detail drawings was undertaken during the period.

The project management effort included extension of staffing for the LM AOT program.

Documentation effort was concerned with preparation of a familiarization manual for the AOT and a development plan for the overall program.

### 4.3.6 Internal Engineering - FTE/GSE

The support effort rendered by internal engineering to the design and fabrication of FTE, during this period, was of phenomenal note. Not only were there pressing in-house problems to solve in this area, but equipment scheduled for delivery to AC, Milwaukee had to be accelerated for their test uses.

In this area, engineering not only succeeded in maintaining production, using interim jury rigs where required, but they simultaneously performed the debugging on these completed items, coordinating changes with in-house documents and specs. All of this was achieved with minimal impact to manufacturing.

There were countless discrete problems that were solved relative to each of the many and complex pieces of equipment. Again, the knowledge and perseverance of this group served to maintain the program momentum that they initially helped to get started three years before.

## 4.4 ENGINEERING - PERIOD ENDING 31 DECEMBER 1965

### 4.4.1 External Engineering

The requirement for design effort TD K-133, Block II Resident Effort at MIT/IL on the CM/LM optical systems was completed as of 28 October 1965. The design and drafting team returned to Kollsman while the resident group engaged in CM/LM liaison, electronic and systems engineering problems pertaining to the guidance and navigation systems for the CM and LM. The Kollsman Resident Group also worked on design of the environmental test fixtures for the LM to be used by MIT/IL at Cambridge.

#### 4.4.1.1 Command Module Engineering:

Finalization of Block II Resident Effort was accomplished as follows:

(1) The redesign of SXT reticle assembly was completed in detail and incorporated into the OUA by means of TDRR's for both the Block I-100 and Block II series.

(2) The design of a light shield assembly for the outer cover of the SCT, to minimize stray light within the SCT optics, was completed in detail. This design was checked by Resident Effort before submittal to the DRB at Kollsman for inclusion in Block I-100 and Block II OUA systems.

(3) A light shield for the Star Tracker assembly was designed and detailed to eliminate light leaks around the reduction mirrors and Tuning Fork housing. This light shield was incorporated into the OUA by means of TDRR's.

(4) Resident effort at MIT/IL designed and built the fixture for mounting a Block II Star Tracker unit onto a Wild T-3 theodolite. The fixture was assembled, checked and prepared for photomultiplier tube studies.

(5) The outline drawings were completed on eyepieces for Block I-100 and Block II for the stowage compartment design in the space vehicle manufactured by North American Aircraft Co.

(6) General test equipment was designed for use by MIT/IL in both environmental and component testing.

(7) Design studies were continued on repackaging of the Star Tracker-Horizon Photometer high voltage (HV) power supply to incorporate improved quality filter condensers.

(8) A sun-protective device for the phototube was designed for incorporation into the Star Tracker Assembly. The design was based on a commercially available rotary solenoid. The size of the unit was well suited to the design. Incorporation of this sun-protective device into the tracking system required study by MIT/IL and Kollsman resident engineers to determine the best means of obtaining the operation signal for the sun-protective device.

(9) Design of the new SXT eyepiece, including heater and quick disconnect features was completed. Included in the design is the normal eye relief eyepiece with a new mirror housing incorporating a heater, thermostat and thermal insulation blanket. The mirror housing also incorporated the quick-disconnect feature.

(10) Both normal and LER eyepieces were retained for the SCT. The new casting for these SCT eyepieces was required to incorporate the thermostat heater and thermal insulation blanket.

(11) An alternate design for the SCT eyepiece providing approximately ±4 diopters focusing range was completed, detailed and checked.

(12) The prism housing for the SCT eyepiece was redesigned to incorporate the quick-disconnect feature. The SCT prism housing also included a thermal insulation blanket.

(13) The in-flight cleaning kit was resolved by inclusion of books of plain and silicone treated, lens-cleaning tissues and one cotton handkerchief. These items are readily available and are covered under FED Specifications, therefore, no SCD drawing release was required. The only item which is not definitely specified is the container or pouch for the cleaning kit elements. A commercially-available polyethylene envelope with a molded-in plastic zipper was under evaluation.

(14) The Tracker HVPS was modified to eliminate component problems associated with the Star Presence Indicator circuitry.

### 4.4.2 LM External Engineering

A design study was completed to incorporate the new eyepiece into the Alignment Optical Telescope (AOT) configuration.

A change was generated to replace the teflon packing used in the AOT rotating knob shaft with an "O" ring seal.

The design of the new reticle element, which incorporated an aspheric surface, presented a requirement for redesign of the reticle assembly, its mounting and adjustment.

Rework of at least one major component was required to adapt the new eyepiece to the AOT.

Continued support to Manufacturing was provided for purposes of developing improved manufacturing assembly alignment, and test procedures to facilitate delivery of the AOT breadboard, pre-production and production models. As a result of such efforts, two AOT breadboards were delivered and one production model was assembled and tested. Qualification testing of the AOT Shipping Container was completed and delivery of the first production container was accomplished.

Procurement of all parts and assemblies necessary to fabricate and ship the AOT Learner Model, Thermal Breadboard, Mechanical Breadboard and Trainer Simulator was completed. However, it was necessary to ship the first three units less the Strain Isolation Pressure Seal (PN 6011096) because of vendor difficulties in fabricating this part.

Fixturization was designed for thermal-vacuum and vibration acceptance testing of the AOT and fabrication was completed. Fixtures for AOT leakage tests were also completed.

Several design recommendations on the reticle drawing and the drawing of the rubber interface seal between the AOT and the LM spacecraft were forwarded to MIT/IL. The rubber seal was undergoing further evaluation and some changes were anticipated.

Functional evaluation of the AOT breadboard optics was continued. Seven aspherics were fabricated in the course of development of methods for producing the AOT aspheric lens.

Analytical design efforts concerned with developing wooden mockups of the AOT were completed. Analytical work was moving toward mockup design simulating the body geometry, weight and c.g. A Fabrication and Test specification was prepared for this type of mockup.

The Internal Engineering Staff assisted the Documentation Staff with development of assembly and test procedures for the AOT. Other work in this area included development of assembly test and flow charts.

LM engineering provided support to the fabrication and test of the Learner Model AOT. Several potential design problem areas were noted and discussed with MIT/IL. During testing of the Objective Assembly (P/N 6011809), the centration and axial alignment control of the first two lenses were not adequately controlled.

Subsequent meetings with MIT/IL resulted in an agreement to redesign this portion of the assembly and the effort was in progress. Kollsman recommended retrofit of the redesigned lens cell into the Thermal and Mechanical breadboards and MIT/IL considered this action. Several alternative procedures and tests for calibrating the AOT power under operational vacuum conditions were developed. These tests and procedures were submitted to MIT/IL for consideration.

Change Control recorded completion of seven outstanding TDRR actions in May and six in June. (See Table 4-7.)

Table 4-7

FINALIZED TDRR ACTIONS

| Request No. | TDRR No. | Summary of Changes |
|---|---|---|
| K-2056 | 20025 | Modification for addition of adapter. |
| K-5023 | 19850 | To correct drafting error. |
| K-5026 | 19840 | To increase tolerances. |
| K-5029 | 19842 | To correct drafting error. |
| K-5034 | 19849 | To assure mechanical compliance and reliability. |
| K-5035 | 19841 | To correct drafting error. |

Design studies were continued on fixturization to test AOT leakage. A fixture designed to test the overall instrument leakage was released to manufacture. A fixture for isolating and testing each leakage source was developed. Five leakage sources included: the rubber seal, packing at the eyepiece and upper section interface, the gas ejection valve, the positioning mechanism seal and defects (perforations) in the various mechanical components.

LM Engineering extended support to Space Division Manufacturing. The objective was to develop and refine AOT assembly, alignment and test techniques. As a result of these efforts, six AOT's were shipped. One unit (Simulator I) met all Procurement Specification requirements, with the exception of excessive bias error shift in the Lead prism during exposure to acceptance level violation. This was evaluated by Kollsman and MIT/IL, and resolved by securing the prism with epoxy, effective AOT 601.

A written formal request was submitted to MIT/IL recommending that the TDRR Proposal K-2092 (CRN MK-267) modifying the LEM Procurement Specification 6011000 be cancelled and replaced with new TDRR Proposal K-5069.

It should be noted that both TDRR Proposals similarly described changes to PS 6011000 for the performance of specific functional tests on the AOT under space vacuum conditions per MIT/IL design requirement. Within the new TDRR Proposal, however, the changes in functional testing under vacuum environment were based upon a test adapter to present FTE and GSE configurations. This adapter, with associated vacuum pump, vacuum gauge, etc., was easier and more economical to fabricate and use than the more elaborate and costlier replacement vacuum test fixture previously planned.

This test adapter consists of a windowed hemisphere which was placed over the head prism section of the AOT instrument so that it then sealed the head prism from ambient pressure conditions. Because the spacing between the telescope hood and prism mount forms a labyrinth seal and because the instrument is sealed at its lower internal end, evacuation may be readily accomplished by this method. Vacuum measurements would be accomplished through the "purge valve". Vacuum conditions within the telescope (space side) will be $1 \times 10^{-2}$mm Hg. or less which is an adequate vacuum for simulating space conditions with regard to expected change in index of refraction. The hemisphere has two plano-plano windows strategically placed so that target collimators used on FTE and GSE may be utilized. The hemisphere can also be rotated on an axis parallel to the instrument shaft axis so that refraction errors due to prism window alignment may be negated.

The new TDRR proposed K5069 was incorporated as part of Kollsman's revised Engineering Revision Plan (ERP K76R1), and submitted to AC Electronics for approval. The proposed production effectivity would be incorporated on the first AOT and GSE units, three and one-half months after receipt of authorization to "go-ahead". All production AOT units delivered as air-focused units were recommended for retrofit at KI.

Other accomplishments included improvement of AOT power match test techniques both at the objective assembly level and at the end-item level. Also, vibration, leak test and thermal-vacuum test procedures on the AOT at assembly and end-item levels were successfully developed. All of these tests were performed on the AOT Simulator No. 1 without difficulty.

KPS 11K 6011829 and KPS 11K 6011807 were utilized for preliminary test on the Mechanical Positioning Assembly, and Mirror Housing and Window Assembly, respectively. Both test procedures, although requiring minor modifications such as adjustment of torque values and addition of helium concentration to test data sheets, proved adequate. Both assemblies exhibited leak rates which were well within the limits specified by their respective procedures. The test of the Mirror Housing and Window Assembly, PN 6011807 uncovered the need for a torque requirement for tightening of the Locking Ring, PN 6011030.

The Mechanical Positioning Assembly was also tested against a 15-psi pressure differential and still exhibited a leak rate which was well under the limit imposed by KPS 11K 6011829. In addition, a test fixture was improvised for dynamic leak testing of the Mechanical Positioning Assembly, PN 6011829 during rotation of the positioning knob. During this test, the Mechanical Positioning Assembly, PN 6011829, still exhibited a leak rate which was below the limit allowed by KPS 11K 6011829.

#### 4.4.2.1 Problem Areas

(1) Strain Isolation Pressure Seal, PN 6011096

LEM Project Engineering performed leak tests on an engineering sample of the pressure seal NASA PN 6011096. The purpose of the tests was to obtain definition of an acceptable procedure for testing compliance with the maximum leak rate required by Note 6B of NASA PN 6011096. Early results were obscured by rapid, high-level permeation of helium through the large area silicone rubber surface of the seal. Further experiments indicated that a procedure which allowed pulsing helium into a backfill chamber delayed the onset of helium permeation for a sufficient time to allow discrimination between actual leakage and helium permeation. Delivery of Class A pressure seals were tested for compliance in accordance with the acceptance and qualification requirements (Notes 6B, 7 and 8) of NASA PN 6011096.

(a) Leak and Deflection Tests - Each of the pressure seals was subjected to leak test and deflection test in accordance to Note 6B, PN 6011096. All seals were found to exhibit leak rates well below $3 \times 10^{-5}$ lb. $(O_2)$/hr. defined by the drawing leak requirement. In addition, all seals tested for diametral deflection exhibited deflections of less than 1/2 inch. This was below the 9/16 inch allowed by Note 6B and remained uniform within the 1/16 inch requirement.

(b) Thermal Leak Test - The seal (SN 8) was selected for leak testing over the -45°F to 160°F range as specified by Note 7, NASA PN 6011096. The seal exhibited a leak rate well below $3 \times 10^{-5}$ lb. $(O_2)$/hr. allowed by the drawing.

(c) Rupture Test - The same seal (SN 8) was tested in accordance with Note 7 of NASA PN 6011096 to obtain the diametral deflection versus the pressure differential curve. The seal ruptured at a pressure differential of 60 psi, which was well above the 30 psi failure point specified by the drawing requirement.

Vibration Test - One seal (SN 4) was selected for testing in accordance with the vibration leak test required by Note 8 of NASA PN 6011096. The vibration input was a ±1/8-inch displacement for $1 \times 10^6$ cycles at a vibration frequency of 25 cps. Leak rates were measured after $3 \times 10^3$, $2.5 \times 10^5$, $5 \times 10^5$, $7.5 \times 10^5$ and $1 \times 10^6$ cycles. The maximum leak rate recorded was well below the leak rate of $3 \times 10^{-5}$ lb. $(O_2)$/hr. allowed by Note 8.

Conclusion - Based upon the above test results, it was concluded that all seals tested were found to be in Class "A" compliance with the drawing requirements.

(2) Addition of new Thermostat Switch to AOT Eyepiece Heater Design Change.

(a) The addition of a new thermostat, PN 1012548, to the present AOT configuration 6011000-000 by MIT/IL revised the original Change Request MK 262 to MK 281 and MK 262B. MK 262 included addition of heater and insulators to the AOT Eyepiece. The addition of a thermostat required remachining of the existing "Housing, PN 6011106", for proper installation. The requirement to rework "Housing, PN 6011106", to accommodate the thermostat results in a part non-interchangeable feature and thus changed the original configuration to 6011000-011. It should be noted that new assembly drawings had been created as a result of the revised change request.

(b) A design review was conducted at KI to evaluate all drawing affected by the MK 262A and MK 281. Several comments and recommendations which related to the thermostat, heater, and potting materials were made by the Design Review Board. All comments and suggestions were submitted to MIT/IL for evaluation and implementation of change to the drawings.

(3) Prism, PN 6011427 - Interference between the prism and the Prism Mount, PN 6011017, was detected at assembly, and verified by dimensional analysis. The chamfer on the prism edge was increased to eliminate this problem. Simultaneously, the Luxorb was replaced by 3M coating and clear areas were located on the prism base, to permit sealing of the prism directly on the three flat pads on the Prism Mount, PN 6011017. These changes were telecon-approved by MIT/IL prior to the rework of the parts.

(4) Housing and Spring Positioning Mechanism Assembly, PN 6011823 - The inability to hold the O.D. of the PN 6011822 to .7615 maximum after spotwelding the PN 6011026 to PN 6011027 caused interference at the PN 6011823 level. An engineering proposal has been submitted to MIT/IL to allow machining of PN 6011822 to a 1.750 O.D. after spotwelding.

(5) Lens Spacers, PN 6011000 - Based on the vertex-to-vertex lens separations required by the optical design of the AOT, a dimensional analysis was performed on the seven lens spacers used in the

AOT optical system. The analysis indicated that all spacer dimensions were adequate except the PN 6011013 which was almost 0.20 oversize. The width of this spacer was reduced from 0.620 ± .005 to 0.600 ± .001. This change was telecon-approved by MIT/IL.

(6) Counter Window, PN 6011122 - The counter window interfered with the shade of the counter during assembly. Consequently, an additional slot was added to the window to correct the above interference. A telecon-approval was received from MIT/IL to implement this change.

(7) The reticle control knob on the Learner Model AOT appeared to be exceptionally free in rotation. Since this may cause problems in the stability of measurement exercises under orbital dynamic conditions, suggestions were forwarded to MIT/IL concerning an increase of torque on this device.

(8) Design Recommendations - As a result of assembly-level testing on the AOT Learners Model, Thermal Breadboard, and Mechanical Breadboard, centration and axial orientation control of the first two objective lenses were found to be inadequate. Subsequently, at a meeting with MIT/IL, design change recommendations were presented and were currently being considered.

(9) Ball-to-disc welding problems were encountered on the Spring and Disc Assembly (PN 6011822). The problem was corrected by an alternative brazing process.

4.4.2.2 Ground Support Equipment (GSE)

(1) TDK-14L-LM Shipping Container (PN 6014000). The shipping container was subjected to Qualification Tests and a report was prepared. The container successfully passed the qualification tests after having its suspension system revised to eliminate a previous deficiency. Delivery of the first production container was effected.

(2) TDK-15L-LM Alignment Optical Telescope Tester (AOTT), PN 6014003. A First Article Test (FAT) to demonstrate field site capabilities was planned for accomplishment at GAEC. A FAT Development Plan, dated 29 November 1965, was issued in Apollo format. Recent development however, required revision of the AOTT mounting base requiring that the overall height and weight of the fixture be reduced to acceptable limits. A revised Mechanization Drawing, replaced the original version which was pending review by MIT/IL prior to altering the already completed fixture. A new hoisting sling was to be supplied so that the existing hoist at all sites under consideration could be used. An ERP was in preparation, describing the additional effort to be expended in the performance of FAT. This included baseline AOT calibration using Factory Test Equipment (FTE) (on the Learner Model AOT) and the preparation and performance of tests at GAEC, including procedures and other documentation.

(3) LM Optics Cleaning Kit - This item was shipped.

(4) Vacuum Test Adapter-ERP-K-76 Revision 1 was distributed revising the AOT Procurement Specification 6011000 to include testing under simulated vacuum environment. This specification revision necessitated design modifications to the existing AOT Final Test Fixture (FTE) and AOT Tester (GSE). A mechanization drawing, assembly and detail drawings for the added vacuum test adapter were completed for both FTE and GSE with production break-in effectivity three and one-half months after go-ahead. No authorization to manufacture was received.

### 4.4.3 Internal Engineering

#### 4.4.3.1 OUA Fabrication

BLOCK I - The OUA Block I fabrication effort was highlighted by the completion and delivery of AGE 17 and AGE 12, as well as the spare (formerly AGE 10) OUA.

The AGE 17 was shipped to AC two days ahead of scheduled delivery date, despite a last-minute design change which entailed the replacement of the trimming module with a newly designed breadboard module requiring realignment of the OUA and further testing after installation. AGE 17 also represented the successful culmination action which considerably improved the OUA.

Experience with AGE 12 proved fairly similar to AGE 17. However, a new problem became evident in the tendency for some motor-generators to develop over-limit stictional characteristics which necessitated their replacement. AGE 12 also represents the first Optical Unit Assembly (OUA) with built-in, vacuum-defocus compensation. The SXT eyepiece was focused intermediately on the reticle for ground testing. By removal of a spacer, sandwiched between the SXT Panel and the eyepiece, the SXT was optimally focused for remote targets in space. This change was received only a few days before the unit was shipped and it was incorporated immediately.

Seven Block I-100 OUA's and two Block I-100 retrofits were accomplished. In addition two Block I-50 retrofits were completed.

AGE 121 was completed and shipped to AC. AGE 121 represented the first unit built and tested to meet the full requirements of the Block II OUA Procurement Specification PS 2011000. Acceptance testing was conducted in accordance with KPS 11K-2011000-1, Revision C. The buildup and testing history for this unit is documented in Acceptance Data Package (ADP) No. 38.

AGE 102 was completed and delivered to KI Apollo Analysis and Evaluation for thermal analysis. This unit was built and tested to meet modified requirements of PS 2011000. These modifications were authorized by AC Directive KD-2105. Acceptance testing was conducted in accordance with KPS 11K 2011000-1 AGE 101/102 Revision I. The buildup and testing history for this unit is documented in ADP, No. 45.

AGE 17, previously shipped to AC, represents the first of the Block I-50 OUA's returned to Kollsman for retrofitting of stray light suppression features and a double SXT reticle. This rework, involving approximately 50 percent teardown, was completed and the unit reshipped to AC. The unit was acceptance tested to Block I OUA requirements in accordance with FTM 1011000, Revision F. The history of this retrofit is documented in ADP No. 19, Revision A.

AGE 121 was returned to KI in September for retrofit of stray light suppression features, electronics ground isolation, and installation of antibacklash gears in accordance with RIB 0106011 and KD's 2190 and 2194. This work, involving approximately 40 percent teardown, was completed and the unit returned to AC. The unit was acceptance tested in accordance with PS 2011000 Revision C, KPS 11K 2011000-1, 001, and Waiver No. KI C-95 which deleted tracker and photometer operation as a selloff requirement. The history of this retrofit is documented in ADP No. 38, Revision A.

AGE 20 was the second of the Block I-50 OUA's returned to KI for retrofitting of stray light suppression features and the air/vacuum SXT reticle in accordance with RIB's 0106011 and 0106012. This work, involving approximately 50 percent teardown, was completed and the unit returned to AC. The OUA was acceptance tested in accordance with FTM 1011000, Revision F. The history of this retrofit is documented in ADP No. 16, Revision A.

AGE 110 was diverted from KI Qualification Testing for repairs and retrofit of electronics ground isolation. This work, involving approximately 25 percent teardown, was completed and the unit sent to AC. This OUA was acceptance tested in accordance with PS 2011000, Revision D, KPS 11K 2011000-1, Revision L, and Waiver No. KI-C-107 which deleted tracker and photometer operation as a selloff requirement. The history of this retrofit is documented in ADP No. 46, Revision A.

AGE 122 was completed and shipped to AC. This unit was built with a functioning but untested tracker and photometer. The OUA was acceptance tested in accordance with PS 2011000, Revision D, KPS 11K 2011000-1, Revision L, and Waiver No. KI-C-96 which deleted the tracker and photometer testing. The buildup and testing history of this unit is documented in ADP No. 63.

AGE 109 was completed and shipped to AC. This unit was also built with functioning but untested tracker and photometer. The OUA was acceptance tested in accordance with PS 2011000, Revision D, KPS 11K 2011000-1, Revision L, and Waiver No. KI-C-105 which deleted the tracker and photometer testing. The buildup and testing history of this unit is documented in ADP No. 64.

AGE 123 was completed and shipped to AC. The electronics module associated with the tracker and photometer functions were deleted from this unit and a compensating weight was substituted to maintain SXT shaft balance. The OUA was acceptance tested in accordance with PS 2011000, Revision E, KPS 11K 2011000-1, Revision P and Waiver No. KI-C-139 which deleted the tracker and photometer functions and substituted the balance weight. The buildup and testing history of this unit is documented in ADP No. 62.

BLOCK II - Redesign of Tracker and Photometer Electronics (Block II) was applied to a single OUA, AGE 200, SN 010. This OUA was delivered to MIT/IL as an evaluation unit. The new design involved revision at the module assembly level. (reference Table 4-8)

The Block II Learner Model (LM) and AGE 101, as well as the electronic breadboards, were assembled and tested. The LM, AGE 101 and Breadboards No. 1 and No. 2 were completed. Concurrent with fabrication and test, the Block II OUA procurement specification, PS 2011000, was finalized. In addition, test techniques specified in the sub and final assembly test procedures were refined. Four versions of the final OUA test were generated for the following applications:

BLOCK II LM FINAL TESTING - A composite OUA KPS consisting of modified Block I and interim Block II JDC's (JDQ's). This procedure permitted testing the LM with the Block I Position Test Fixture (PTF), the Functional Tester, and temporary equipment for tracker and photometer test configurations.

EVALUATION UNIT FINAL TESTING - An interim Block II OUA KPS consisting of Block II procedures modified to reflect the subprocurement specification standards to which AGE 101 and AGE 102 were being built. This KPS incorporates the Block II PTF and Functional Tester, yet reflects the use of interim equipment for tracker and photometer configurations.

STANDARD OUA FINAL TESTING - A KPS incorporating procedures and FTE for Block II production OUA's to substantiate their conformance to the Procurement Specification was completed.

FIRST ARTICLE TEST (FAT) COMPATIBILITY - An abbreviated version of the Standard Optical Unit Final Test KPS designated to verify compatibility between GSE and FTE.

SYSTEM DATA - A KPS was issued to perform alignment tests on the SXT Index Head, PN 2011701, and OUA subassembly stage 2, PN 2011890, with interim and final test equipment. Method books to accomplish these tests were released. The focusing fixture (FTE) to set Tracker and Horizon Sensor Optics was complete and operational. The potting specifications for Phototube fabrication was revised to 120°F at longer cure times to eliminate high temperature tube problems.

Table 4-8

MODULE ASSEMBLY REVISIONS

| Title | Block I (100) Dwg No. | Block II Redesign Dwg. No. |
|---|---|---|
| High Voltage Power Supply | 2007030 | 2007030-011 |
| Tuning Fork Assembly | 2007023 | No Redesign |
| Head Electronics Assembly (Tracker) | 2007024 | 2007176 |
| Head Electronics Assembly (Photometer) | 2007025 | 2007179 |

4.4.3.2 Test Equipment

GROUND SUPPORT EQUIPMENT (GSE)

BLOCK I

1. TD K-74 Five-inch Autocollimator - The last unit was delivered and the TD completed.

2. TD K-92 Two and one-half inch Autocollimator (SCT) - The last unit was delivered and the TD completed.

3. TD K-86 G and N Installation Qualification Fixture - Three units were completed and delivered.

4. TD K-86 Azimuth Reference Fixture - Three units were completed and delivered. The last two units were in the final assembly stage.

5. TD K-86 Certification Fixture (for 3. and 4. above) - Three units were completed and delivered.

6. TD K-107 Theodolites and Supporting Equipment - The reticle retrofit was performed on four units. The final three reticles were faulty and were rejected. The vendor manufactured new reticles.

7. TD K-108 Two and one-half inch Autocollimator (SXT) - The last units have been delivered and the TD is now completed.

8. TD K-132 Retroreflecting Prism - One prism has been delivered. The second unit had indications of an internal fault and was returned to the vendor. The first prism certification fixture was accepted and delivered.

## FACTORY TEST EQUIPMENT (FTE)

## BLOCK II

1. SXT - SCT Transmission Tester
2. Eight-inch reflecting Collimator
3. Dual Preamplifier Tester
4. Trunnion Mirror Flatness Tester
5. Precision Balls
6. Dual Photodector and Preamplifier Assembly Tester
7. Dual High Voltage Power Supply Tester
8. Dual Tuning Fork Oscillator Tester
9. Electronics Assembly Tester
10. Stiction Tester
11. Narrowband Amplifier Simulator
12. Tracker-Photometer Focusing Fixture
13. Phototube Peaking Fixture (PTF)
14. PTF Modification
15. Functional Tester Modification
16. Star-Horizon Simulator
17. Star-Horizon Certification Fixture
18. Auxiliary PTF
19. Narrowband Simulator (Photometer)
20. SXT Mirror Interferometer
21. Phototube Tester
22. Horizon Calibration Unit

GROUND SUPPORT EQUIPMENT (GSE)
BLOCK II

| | | |
|---|---|---|
| 1. | Functional Tester (FT) | |
| 2. | Variable Deviation Wedge | three units |
| 3. | Portable Light Assembly | four units |
| 4. | Shaft Accuracy Tester | one unit |
| 5. | Yoke Position Fixture | two units |
| 6. | Alignment Mirror Assembly | one unit |
| 7. | Autocollimator Plate Assembly (0°) | five units |
| 8. | Autocollimator Plate Assembly (45°) | three units |
| 9. | Star Horizon Simulator Certification Fixture (SHSCF) | five units |
| 10. | G and N Fixture Stand | nine units |

SXT HEAD MIRROR INTERFEROMETER - Kollsman received a Perkin-Elmer Modified Twyman Green Interferometer. This instrument applies the Michaelson interferometer to the precise evaluation of optical systems. As the instrument is used on the Apollo SXT, it supplements the data obtained on the flatness of mirrors obtained individually in the Davidson Fizeau Interferometer.

This instrument enables much more precise evaluation than was possible by calculation from the individual mirror reports because the addition is automatic and has double sensitivity. This is due to the configuration which caused the beam of light to traverse the mirror assembly twice.

The results of this technique confirmed the work done prior to acquisition of the instrument, in cases where the mirrors used had regular contours. However, with mirrors having irregular departures from flatness, only the new technique is reliable. The technique has also shown that the mounting design and practice has maintained the expected mirror performance.

Kollsman planned to conduct tests using this new instrument to determine how the mirrors perform under varying temperatures, thereby enhancing means to improve thermal stability.

4.4.3.3 Problem and Study Analyses

COATED MIRRORS - Initial difficulties were experienced by the vendors in supplying Kollsman with SXT Head Mirrors. The surface flatness requirement of 1/8 $\lambda$ proved difficult to maintain throughout the reflection enhancement coating operation. A joint investigation, initiated by KI with the mirror vendor and conducted at the latter's facility, proved that control of flatness was lost when the mirror was subjected to the high coating temperatures required for enhanced reflection. Stress relief at a higher temperature and careful regulation of heating and cooling rates brought the problem under control.

MOTOR GENERATORS - Excessive starting voltage values were registered when the motor was energized in a vacuum of $10^{-4}$ torr or higher. Investigation disclosed a high temperature gradient between the motor housing and the rotor. Binding resulted when this gradient, transmitted through the bearing, caused the inner race to expand at a higher rate than the outer race, thereby removing the allowable radial play. Corrective action was taken by authorizing a drawing change to permit the use of larger radial play bearings.

TUNING FORKS - KI revised the electrical data on the SCD to comply with parameters noted in repetitive testing of production units of the Tuning Fork. Materials Review Board (MRB) action on Beryllium housing discrepancies was studied and a complete delivery of parts was made to American Time Products for rework to incorporate the necessary changes. Dual tracker forks were installed in the laboratory tracker housing for experimental purposes. Production problems caused by the use of 32-gauge wire were solved by changing to 26-gauge wire, thus minimizing lead breakage.

Failure reports were requested on two tuning fork units for tracker use. A coil circuit failure was discovered on one Engineering Evaluation (serial number EE-1) unit after delivery to KI and a pinched lead was noted on a second unit. Corrective action was accomplished on both units. The vendor submitted a procedure to measure tuning fork imbalance, SP01563A, which was approved after minor correction.

PHOTOMULTIPLIER TUBES - Proposed and/or completed changes to the Photomultiplier Tube SCD included:

(1) deletion of Figure I and Figure II (Time resolution and typical anode characteristics.)

(2) relocation of anode rise time and electron transit time from Table II to paragraph 3, Design Requirements,

(3) tightening envelope dimensions of the Photomultiplier tube,

(4) provision of an alignment hole in the tube base.

A request was issued to remove paragraph 5, Special Conditioning and to downgrade QC provisions from Class 2 to Class 3. The request was not approved by KI, due to the condition of the photomultiplier tubes inspected and delivered. Meetings at RCA and KI to discuss bent leads and distorted tube envelopes resulted in a program which got under way to eliminate these defects. As agreed with the vendor, three class A tubes, which had off center cathodes, were returned.

Approximately thirty-five photomultiplier tubes were delivered, completion of a total order of sixty tubes was anticipated. A reorder of one hundred twenty photomultiplier tubes was forwarded to the vendor. Twelve tube module failures occurred in-house during various phases of manufacture.

HEAD ELECTRONICS - The preamplifiers exhibited inconsistent gain from unit to unit as well as a tendency to oscillate.

The inconsistent gain resulted from allowable parameter tolerances on the input Field Effect Transistor (FET) which caused some units to operate in their saturation regions. This problem was corrected by changing the value of a bias resistor.

Elimination of the oscillations was achieved by adding a capacitor to reduce high frequency and by shielding the high impedance input FET. The shield prevents feedback from the output stage which is adjacent to the input. A new layout was designed and the unit performed well without the need for any shielding. The layout was reviewed by MIL/IL.

Nonalignment of the photomultiplier tube to the optics can produce physical tolerance buildups in an assembly. A tester was built to adjust this position and check the resultant operation. However, the mechanical configuration did not permit the necessary tube rotation. Kollsman designed a rotatable configuration which was reviewed by MIT/IL.

HIGH VOLTAGE POWER SUPPLY (HVPS) MODULES - HVPS breadboards were built and tested exhaustively. Several changes in component values and minor circuit configurations were suggested and incorporated into the welded modules. These changes improved operating points, optimized scale factors, and reduced component power dissipation.

OSCILLATOR MODULES - The tracker fork drives did not activate the forks to the proper drive amplitude and lacked the proper phase relationship for the reference output. Circuit changes were implemented and several welded units were built which proved satisfactory.

BLOCK II FUNCTIONAL TESTER - A Fine Indicator Receiver was incorporated in the Block II Functional Tester to permit precise positioning of the Shaft and Trunnion. The size 11, two-minute receiver acts as a load on the 64X resolver transmitter on the Sextant Trunnion. A series of tests for accuracy were conducted to determine the amount of error introduced into the 64X resolver output angle with the receiver as a load. Using two receivers, SN 6384 and SN 6388, two accuracy tests were performed every one degree from zero to 30 degrees of mechanical rotation. See Figure 4-1. Two additional accuracy tests were made to compare the peak-to-peak errors. (See Figure 4-1.) One test was made in accordance with the PS 1012065 procedure and the other under no load with output windings floating. The insignificant effect exerted by the Fine Indicator Receiver on the 64X resolver transmitter readout is clearly indicated in the following data and associated Figures 4-1 and 4-2.

| | | |
|---|---|---|
| p-p error | (per PS 1012065) | 6.7 sec. |
| p-p error | (unloaded) | 7.3 sec. |
| p-p error | (SN 6384) | 6.5 sec. |
| p-p error | (SN 6388) | 6.8 sec. |

RESOLVERS - The availability and delivery of all high precision resolvers (64X and 16X) was ahead of scheduled requirements. The delivery of 1X receivers and transmitters was also meeting required schedules. A change to the accuracy requirements was under consideration to insure uninterrupted delivery while remaining compatible with the new Block II OUA specifications.

(a) 64X Resolver - A review of all the documented discrepancies did not disclose any problems directly attributable to the 64X Resolver. However, in order to insure that a sufficient amount of data was available in the event of a deviation or failure, the JDQ's associated with the SXT Trunnion Accuracy and zero were expanded to include information on the 1X and 2X resolvers.

(b) 16X Resolver - The SXT Shaft Drive Axis (SDA) exhibited an unusually large number of deviations before and after environmental exposures.

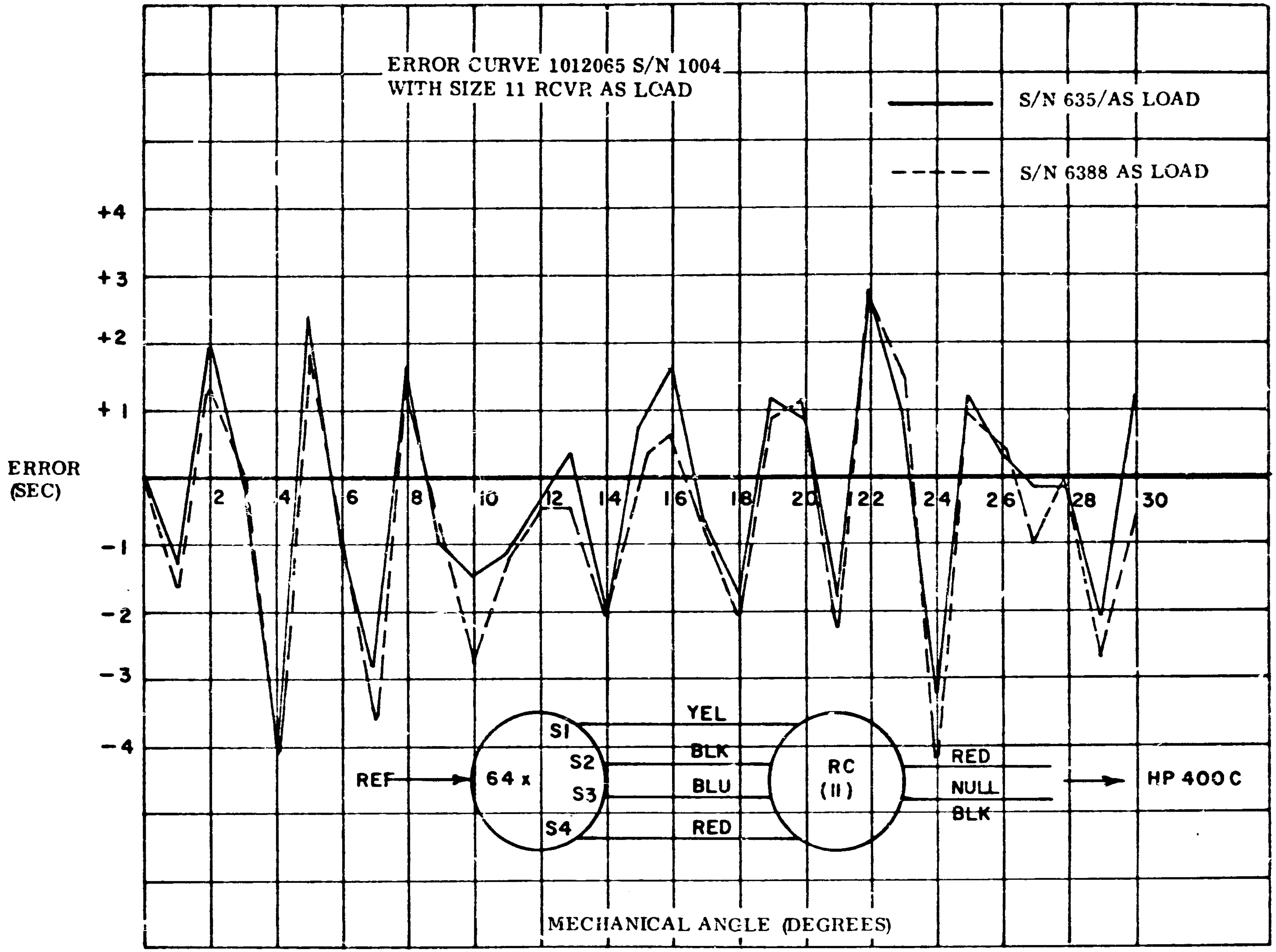



Figure 4-1 Accuracy Test Data With Fine Indicator Receiver as Load

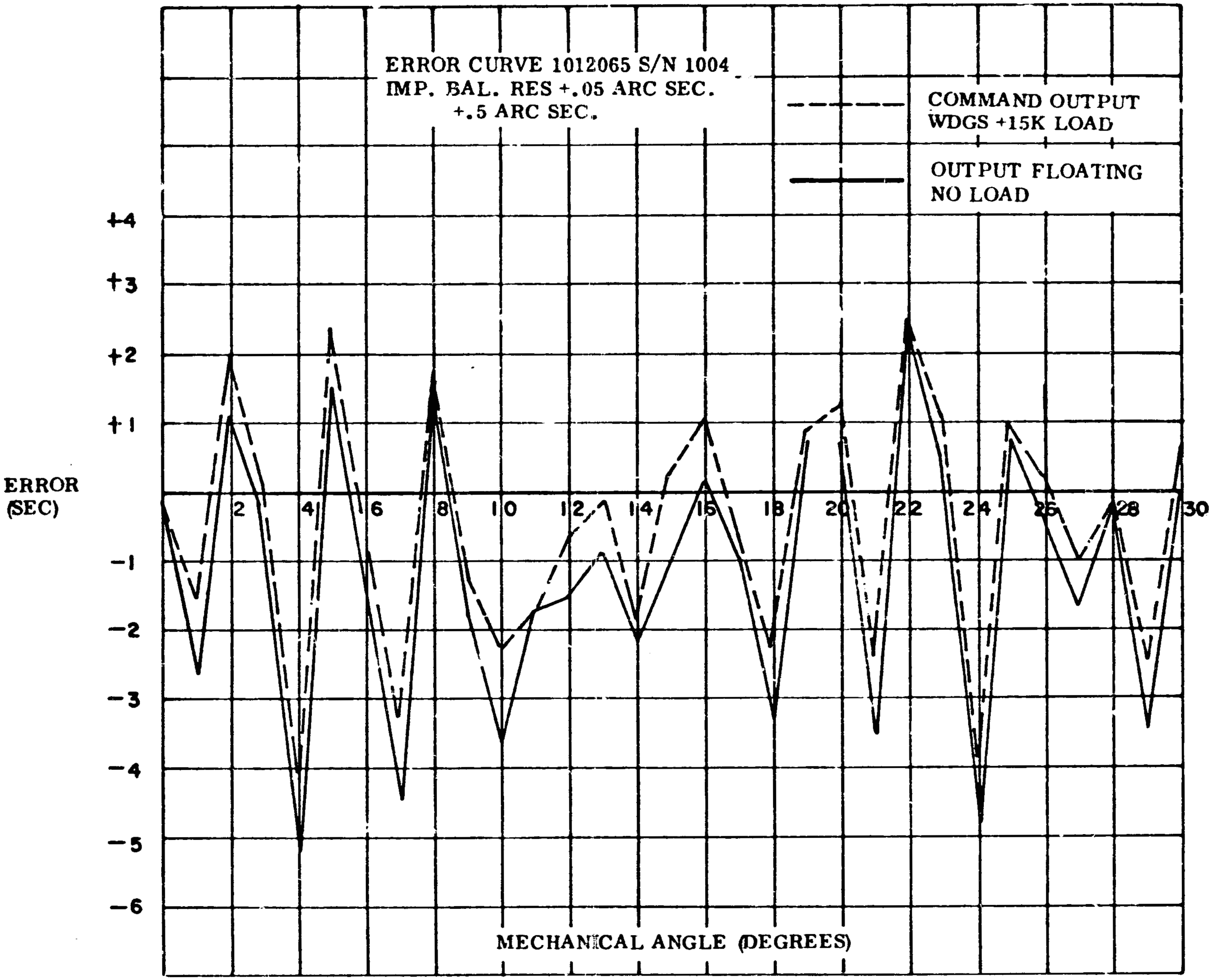



Figure 4-2 Accuracy Test Data Without Receiver as Load

(c) The majority of the deviations occurred as an out-of-specification condition at optical zero. The resolver seemed to shift mechanically since an in-specification measurement at zero moves to an out-of-specification condition after exposure to environment. The peak-to-peak results of the JDQ's show that the resolver maintained its basic harmonics and peaks and valleys. Although the zero seemed to move, a plot of the error data indicated that the resolvers maintained their characteristic shape. The graphs in Figures 4-3 and 4-4 show a plot of the errors, recorded at four different times for the first 22 degrees of rotation on AGE 110 and AGE 123. The peak-to-peak values for the four curves are tabulated as follows:

| AGE 123 (ADU reading x $10^{-3}$) | AGE 110 (ADU reading x $10^{-3}$) |
|---|---|
| 4.6 | 6.7 |
| 5.2 | 5.8 |
| 5.1 | 6.3 |
| 4.6 | 6.7 |
| Max. diff. = .6 x $10^{-3}$ = 2.16" | Max. diff. = .9 = 3.24" |

NOTE

The large peak recorded on one of the curves for AGE 123 at 1° was ignored in the preceding tables since it was subsequently found to be in error.

(d) The maximum differences noted in the preceding tables amount to about 10 percent of the allowable peak-to-peak tolerance (44 sec.). This same variation was noted in both published and unpublished data on AGE 121, AGE 111, and AGE 122. The zero shift phenomenon results in changes that amount to several seconds where the allowable error is 10 seconds. This is equivalent to variations of 25 percent and higher.

(e) An investigation into the effect produced by the trim module indicated that for AGE 123 the trim module was performing in accordance with the theoretical calculations. Calculated gradient for the trim module is

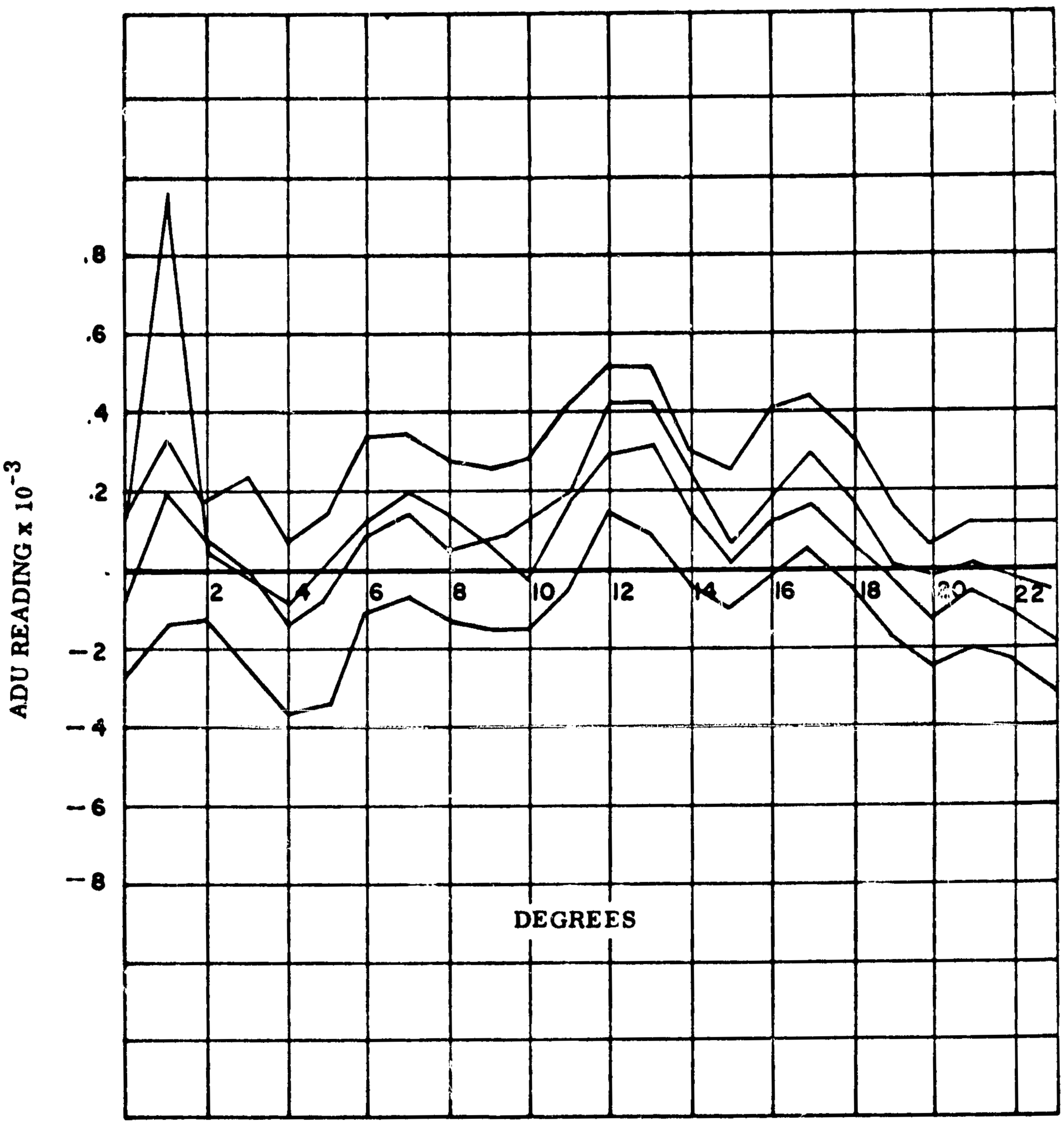



Figure 4-3. JDQ 03004, AGE-123

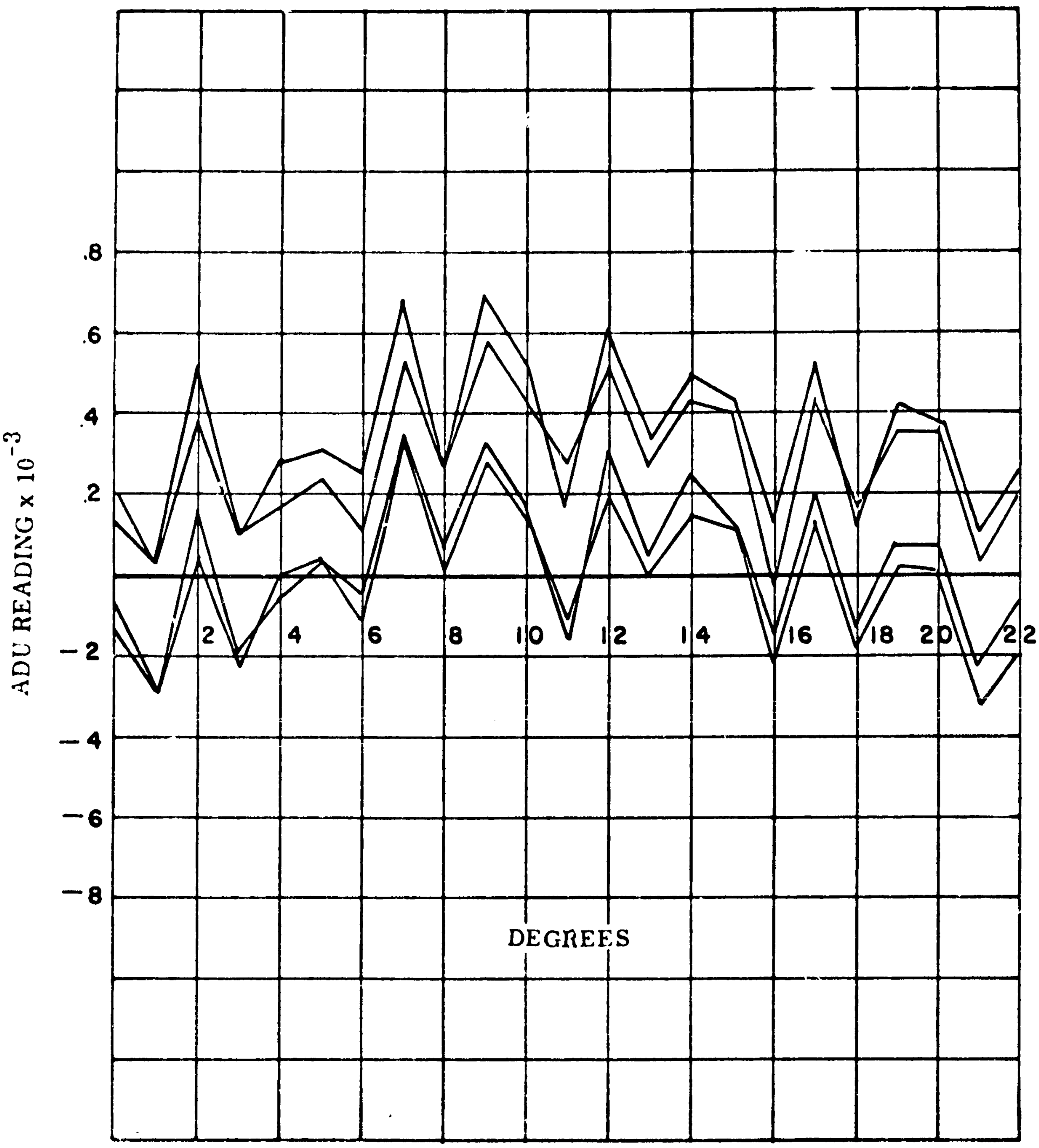



Figure 4-4 JDQ 03004, AGE 110

15 mv/turn of the potentiometer which is equivalent to 6.25 seconds/turn. On AGE 123 the voltage on the trim was measured at 76 mv equals 32 seconds. The zero was measured at 47 without the trim module and 14 seconds with the trim module. The difference of 33 seconds is contributed by the trim module. The trim module obviously was not causing this type of trouble.

(f) The result of further analysis of this problem indicated that a physical movement of either of the two parts of this resolver would result in a zero shift while still maintaining peak-to-peak accuracy within readable limits. Since complete data on the 1X resolver associated with this unit was not available, changes were incorporated into the JDQ's.

MOTOR GENERATOR - The six sample servomotors, with the blackened drag cups, were delivered and tested at KI under the proposed special conditioning (+ 150°F and -40°F). All servomotors performed satisfactorily and the qualification to the drag cups was incorporated into all servomotors in process and at Solvere. In addition, the motors were returned to Solvere for incorporation of ribbon retainer bearings and the new drag cup design.

PHOTOMULTIPLIER TUBES - Considerable progress was made in upgrading the quality of the tube leads. Difficulty in devising a quantitative criteria of lead acceptability prevented resolution of the problem. To alleviate this problem, KI and the vendor selected a single tube, SN 900, as representative of the minimum acceptance criteria for lead quality. Acceptable leads are those equal to or better than the criteria of the sample tube. The relationship between tube noise, dark currents and mode sensitivities were investigated. Results indicated that the relationship between tube noise and mode sensitivity was not clearly defined or readily predictable and that tubes rejected on the basis of poor signal-to-noise ratio (ratio measured at sensitivities of 100 amps/lumen) may perform satisfactorily at the lower sensitivity levels used in the Tracker. Phototube studies continued in the foregoing areas, and additional tests were made to determine photocathode quality and predictability of response.

ZENER DIODES INVESTIGATION - As a result of extended performance testing at KI, the reliability of the 1010830-11 zener diode (tracker preamp star presence circuit) was questionable. Tests indicated that a large percentage of KI stock failed to meet the moisture leak requirements (ND 1002054). Follow through investigation at the vendor's facility revealed that the vendor was aware of the noncompliance, but neglected to recall the units in question. Suitable documentation and assurances were furnished to KI indicating that the problem would be eliminated in future shipments.

BEAMSPLITTER, P/N 2012222 - In the first lot of beamsplitters obtained from the vendor, acceptance was based on the evaluation of spectrophotometric curves of two samples in the lot. Subsequent system tests indicated that some of these filters did not meet the latest part specification.

Spectrophotometric checks on the second lot of 12 beamsplitters indicated that they satisfied conditions required by Revision D. However, further check on flatness requirements rejected all but SN's 1015, 1017, and 1019. SN 1016 was retained for engineering evaluation.

The vendor indicated difficulty in maintaining the flatness of the blanks through its coating process. A closer liaison with the vendor together with change to a more stable substrate (PN 2012222, Revision G) increased the number of acceptable parts.

One lot of four beamsplitters were coated with the new substrate. In view of the critical nature of these parts, KI engineering continued to monitor their progress.

Additional procedures for inspection were instituted which included 100 percent spectro-transmittance measurements by the vendor to insure final qualification. A test procedure was set up by KI Quality Control with the vendor for a step-by-step inspection.

In measuring the transmittance of a beamsplitter in a spectrophotometer at 45° incidence, the measurement beam deviated from the center of the photometer sensor by the thickness of substrate. To compensate this beam deviation, the spectro-transmittance of the beamsplitters was measured two at a time. The resulting spectrocurve represents the product at the two spectro-transmittances. Should the transmittances of the two beamsplitters tested prove identical, then their individual transmittance is the square root of the aforementioned curve. However, this does not always apply.

To ensure that the spectro-curve obtained by the spectrophotometer represents a single beamsplitter, an uncoated substrate was used with the beamsplitter to compensate for measurement beam deviation. Since the attenuation of the uncoated substrate is easily determined, the spectro-transmittance of the beamsplitter along can be factored out.

SXT HEAD MIRRORS (BERYLLIUM) - The production facilities of the Star Line of Sight (SLOS) mirrors were increased. The control procedures were reviewed and updated with the various vendors involved. Technical coordination affecting all vendors improved. All parts in process at coating were heat-treated in accordance with the latest revisions. These mirrors were lapped more to the concave side of the tolerance. It was anticipated that these revisions would produce more stable mirrors as the result of the coating process, which causes the mirrors to move in a convex direction. A material reduction in the percentage of parts requiring rework to meet the drawing requirements became evident.

Anodized Beryllium Components - KI, MIT/IL and AC met to implement NASA's request to improve the corrosion resisting characteristics of the OUA. At this meeting it was determined that the exposed beryllium components, i.e. optical base, SXT and SCT panels and their seal gasket frames, should be black anodized. Minimum requirements were established for anodize characteristics and areas to be anodized. A target for implementation of the anodize requirements was set at AGE 203 and a team was selected to make inquiry and visit potential vendors for the anodize finish. It was further agreed that, based on the findings of the team, AC would authorize KI via TWX to proceed with placement of an order for anodizing based on a budgetary estimate.

The team contacted and visited several vendors and concluded that Brush Beryllium of Cleveland, Ohio was the best suited to the task. On the basis of the bid from Brush, a TWX was sent to AC with the estimate and a request for approval to anodize the AGE 1 optical base for MIT/IL's evaluation. AC refused approval on the grounds that MIT/IL could handle the anodizing more efficiently. AC further indicated that the urgency of implementing the anodizing requirement by AGE 203 was superseded by the more radical design revisions (Tracker and Photometer deletion).

The Photometer HVPS was manufactured without difficulty. Test cables and terminal boards were prepared and used to select the high voltage (HV) level for proper Photometer output. Special handling reduced lead breakage and an SCD was submitted to MIT/IL for more flexible wire to further reduce the breakage.

The Tracker HVPS was a continuing problem. Units which fell within specification requirements were assembled by selecting a resistor, a zener diode and a transistor. These components were difficult to obtain, as the manufacturers would not provide components in the narrow range of the parameters needed. In addition, the HV and Star Presence outputs drifted for approximately one-half hour after the unit was in operation. KI prepared and tested several alternate circuits. These circuits were submitted to MIT/IL for evaluation and development of a new design for Block II. Tests, performed due to initial difficulties in adjusting prototype models of the supply, indicated that, while the design is operable, an improvement in the adjustment provisions of the supply was highly desirable and could be effected with a relatively small modification. See KI publication AA-65-260, "Report of Assembly High Voltage Power Supply Star Tracker PN 2007175" dated 16 December 1965.

FOCUSING AND PEAKING (HS and ST) - Positioning of the objective lens on the Horizon Sensor (HS) and Star Tracker (ST) for optimum focus at 350 and 400 microns respectively were performed at FTE level. To reduce operator error due to readout ambiguity, a narrow-band pass green, filter was added to visual readouts. This permitted more accurate observer's setting for visual focus which is then corrected for the 350 and 400 micron positions.

In addition, the peaking fixture was re-oriented to vertical position to eliminate the inherent error due to sag or fixture imbalance. Vertical reposition required rework of the peaking fixture.

ST peaking at the component level was introduced to account for vertical position of peak photocathode output. The existing FTE fixture for Head electronics was being modified and corresponding revisions to the appropriate KPS to permit photocathode survey in the vertical position for peak response were in effect. Suitable spacers were installed at the assembly level to locate this position with respect to STLOS.

RESOLVER ZEROING AND ACCURACIES - A proposal to increase the allowable angular error of Resolver PN 1012157 from 2 minutes to 2.5 miniutes was rejected. This resolver affects performance of the Scanning Telescope (SCT) shaft and trunnion. It was expected that the increase from 2 to 2.5 minutes would not affect the overall performance of the OUA, which is 4 minutes maximum for shaft and 8 minutes maximum for trunnion. Out of 30 received, nine resolvers with angular error above the specification of 2 minutes were accepted. Insufficient system test data was available on the use of these resolvers to indicate their effect on the overall accuracy of the OUA. In AGE 121, SN 1012 (JDQ 3006) produced a maximum error of 2 minutes which is half of the maximum allowable for the Shaft Drive Axis (SDA). In addition, a change to the gearbox was implemented, incorporating an antibacklash gear on the resolver shaft to facilitate the zeroing procedure.

SXT INDEX MIRROR BALANCING - Static balancing of the SXT Indexing Mirror and Mount Assembly, PN 2011712, about its trunnion axis could not be accomplished on SN 10, SN 11, and SN 12, due to an apparent lack of weight on the counterweight side of the assembly.

The additional weight required to balance SN 11 was obtained by manufacturing a left-hand counterweight, PN 2012457, and a right-hand counterweight, PN 2012456, to the "high limits" of the dimensional tolerances specified on the counterweight detail drawings.

In order to balance SN 10 and SN 12, new, heavier, left-hand and right-hand counterweights were required. The additional weight was obtained by increasing the thickness of the counterweight, and by reducing the total tolerance limits of certain appropriate dimensions. The dimensional changes as outlined increased the weight of each counterweight by approximately 18 percent of the original weight.

Scanning Telescope (SCT) Trunnion Drive Axis (TDA) Assembly Technique - Assembly methods used for the SCT TDA, PN 2011215, were reviewed and revised to improve the repeatability of SCT TDA accuracy after vibration. The improvement was accomplished by ensuring that the bearings in the SCT TDA assembly were properly seated.

The telescope Trunnion Axis Assembly PN 2011215, required seating of the bearings into a blind hole of the housing, and a close tolerance fit on the worm-shaft, PN 2011198. Failure of these bearings to seat in either the housing or the shaft, resulted in shaft end play, indicated as non-repeatability, or accuracy problems in the SCT Trunnion Drive Shaft. The revised methods incorporated additional techniques and tooling to prefit and pressfit the bearings into the housing and shaft without damaging the bearings. A dimensional check of the individual parts in the assembly, versus the overall assembly dimension, after the parts were assembled, was also referenced as an added check to assure proper seating of these bearings.

SCT OBJECTIVE ASSEMBLY TECHNIQUE - An SCT accuracy failure on AGE 122 was caused by a loose objective lens. Consequently, a revised Route and Tool (R and T) procedure was developed to ensure proper seating and locking of the assembly. The new technique uses dimensional and locking torque measurements to ensure proper assembly.

SCANNING TELESCOPE (SCT) OBJECTIVE AND RETICLE REDESIGN - During this report period, failure of the SCT LOS to maintain alignment through mechanical integrity became chronic. The first diagnosis was that the SCT reticle had shifted. However, retightening of the reticle changes failed to prevent another shift during a repetition of the mechanical integrity vibrations. Further investigation disclosed that the cause of the failure lay in the objective lens system. It was determined that the design was susceptible to failure for several reasons: Cocked or canted lenses and/or spacers caused an unstable assembled condition upset by vibration; air cushions prevented the lens stack from bottoming completely; the "O" ring that should provide vibration-proofing either failed in this function or acted to bind the lockring before it was bottomed.

The assembly requirement for minimum lens strain would act in concert with the aforementioned possibilities in causing the failures that were experienced. The immediate remedy that permitted continuation of production was a change in assembly techniques. The shafts that had failed were reassembled under controlled conditions, the vibration-proofing "O" ring was lightly lubricated to prevent binding, and a maximum torque commensurate with the mechanical strength of the assembled components was applied to ensure that the "O" ring and air cushion resistance were overcome. The stacked weight was also compared to the sum of the individual element weights to ensure that the assembly was completely compressed. As these precautions proved successful on the reworked units, they became standards for all follow-on shaft assemblies. As a result of the foregoing experience in production, a design study of the shaft assembly was conducted. This study yielded two design improvements as follows which submitted to MIT/IL for incorporation.

The first redesign was prompted when the initial failure occurred in the SCT reticle mount. The present design approximated the Block I SXT reticle design which had failed on several occasions in Block I production. That SXT was redesigned for Block II and has proven very successful. It therefore appeared logical that reliability and prolonged precision alignment would be enhanced by utilizing the same reticle mounting arrangement for the SCT. Figure 4-5 demonstrates how to accomplish this with minimum rework or scrapping of parts. A modification at the Outer Telescope Tube Assembly (PN 2011722) level is required, involving five new parts and no change to the main beryllium telescope tube or the SCT reticle. This new design duplicates the cemented reticle flange, removable positioning cams, and positive locking features of the Block II SXT reticle mounting arrangement.

The second redesign involves an improvement to the mounting of the SCT Objective lens elements in the SCT shaft and is illustrated in Figure 4-6. In this redesign, a positive banking surface is provided for the third objective doublet, PN 2011709. The first two doublets, PN 2011709 and PN 2011708 are mounted and locked into place with the first locking ring which threads into the main beryllium telescope tube. The third doublet is then clamped against the first locking ring by a second locking ring that threads into the first. The third doublet is then secured, independent of the first two. This modification requires no changes to the optics or telescope tube and only requires two new mounting rings.

SXT INDEX HEAD BALANCE - Initial design and fabrication of the counterweight to replace Head Electronics was completed. Redesign of this unit to provide a more rigid lug is in work. Installation of this counterweight will be arranged by ECO to expedite manufacture. Drawing No. 2012723 was assigned to this part.

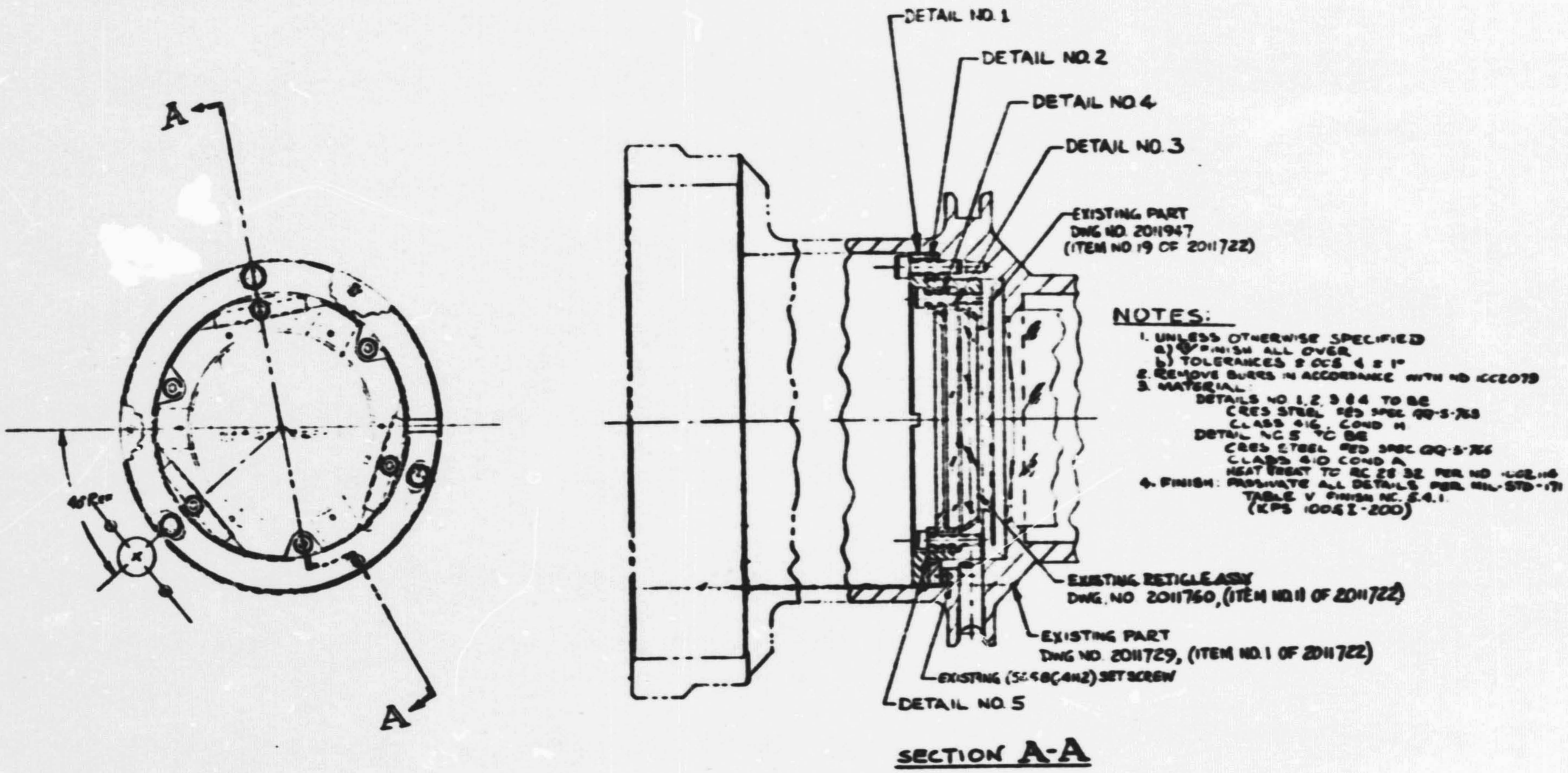



Figure 4-5. Adjustable Reticle Assembly - SCT (Sheet 1 of 3)

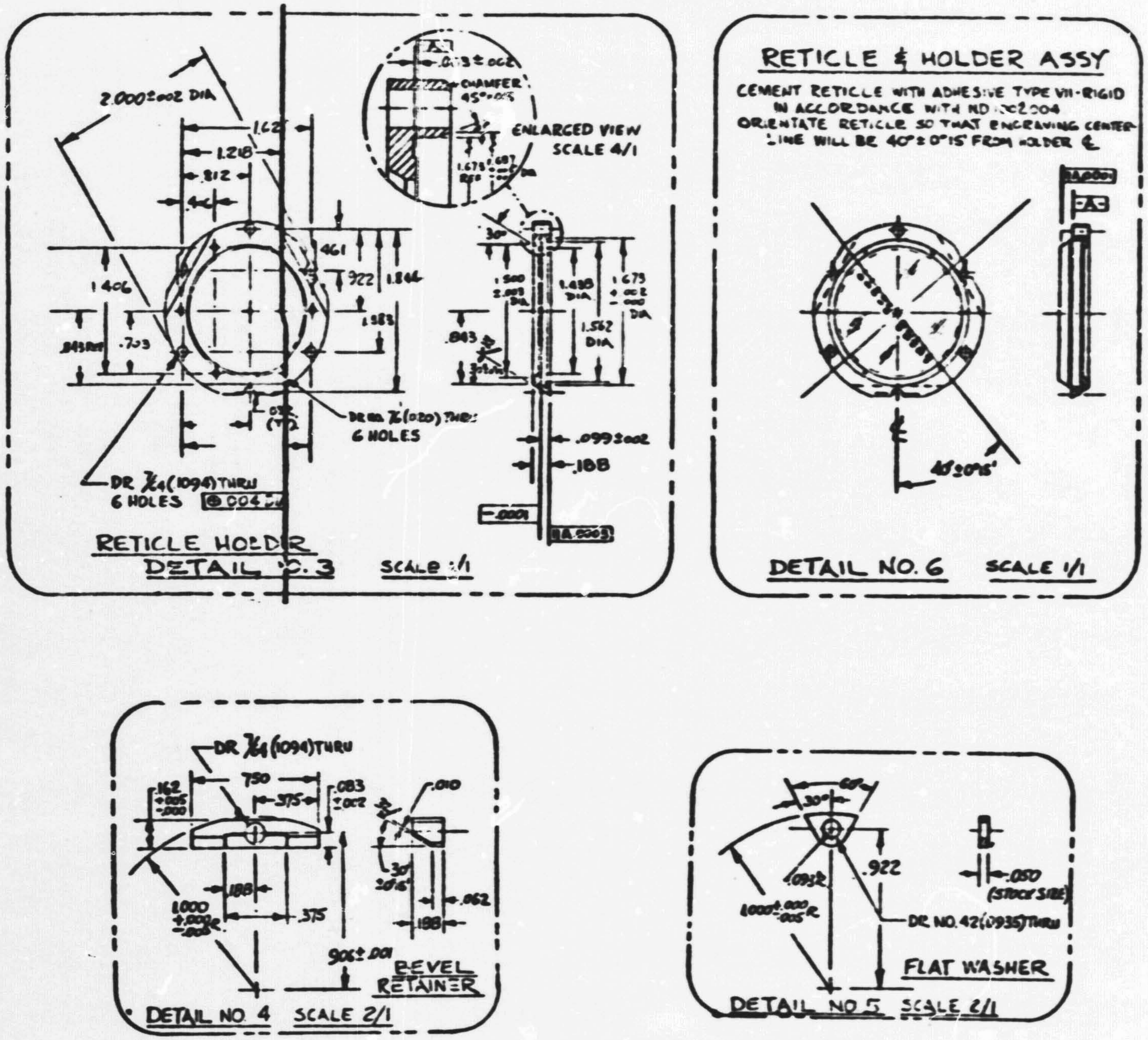
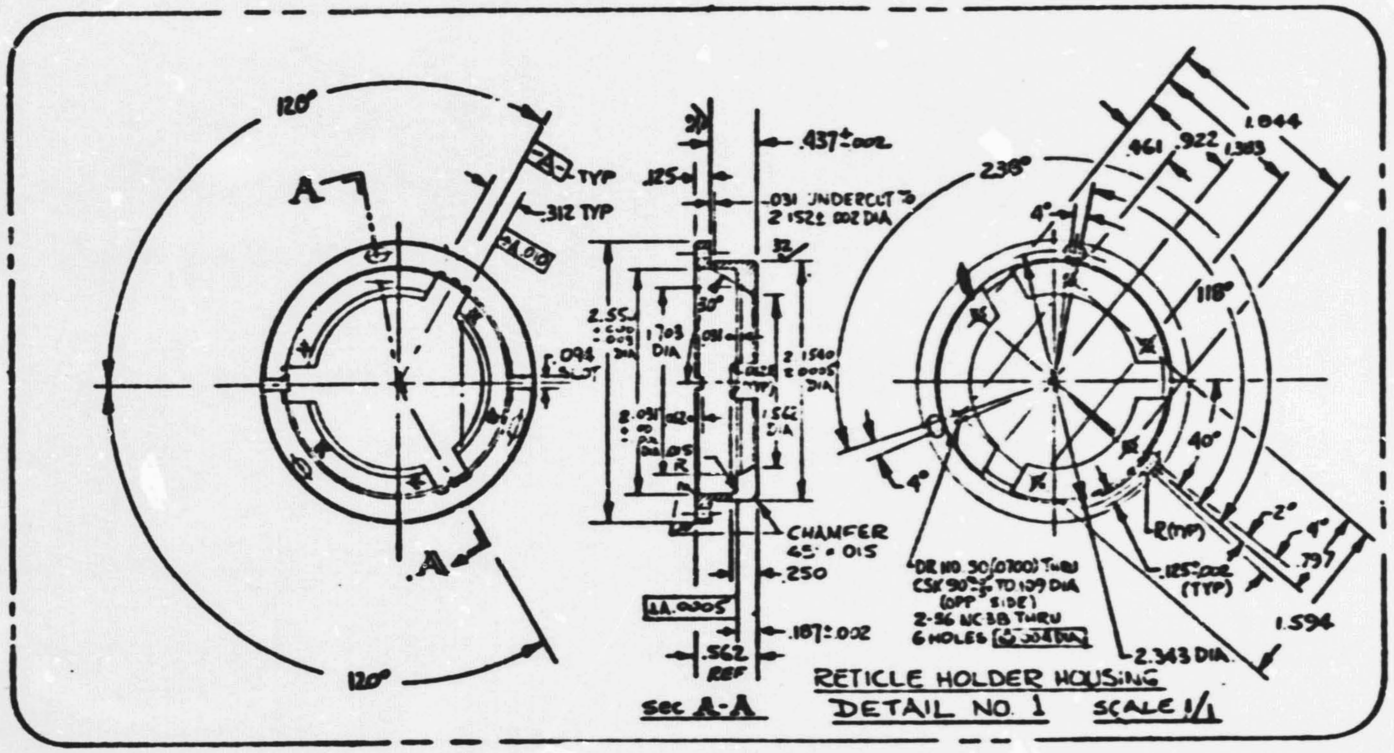



Figure 4-5. Adjustable Reticle Assembly - SCT (Sheet 2 of 3)



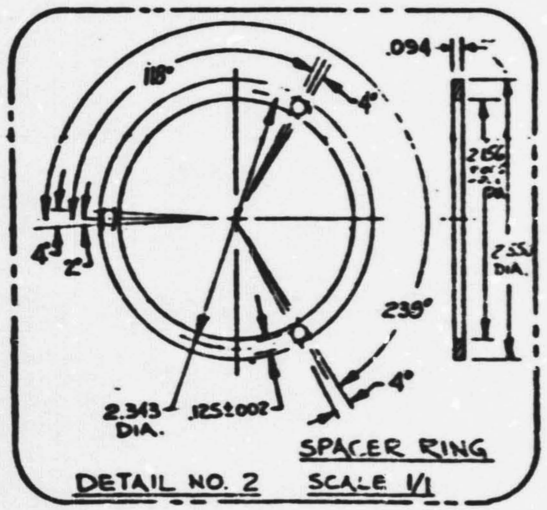




Figure 4-5. Adjustable Reticle Assembly - SCT (Sheet 3 of 3)

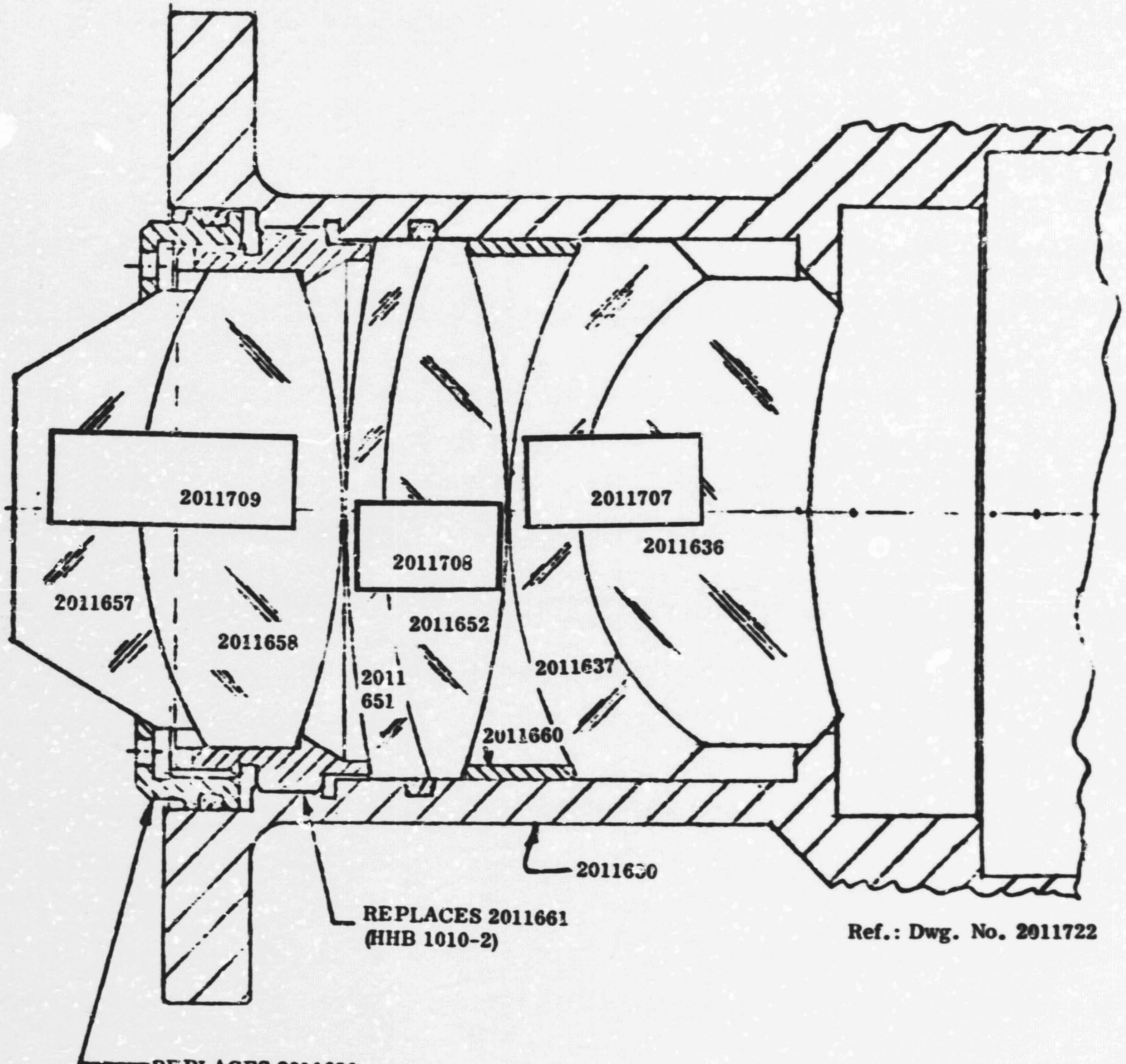



Figure 4-6. New Mounting of SCT Objective Lens Elements

LUMINOUS TRANSMITTANCE - Both AGE 110 and AGE 111 required sell-off waivers when they were found to be nonconforming by failing a portion of a luminous transmittance acceptance test. The requirement for transmittance through the SXT LLOS is 4 percent. Both units measured approximately 3 percent for this parameter. Investigation and analysis pinpointed the Beamsplitter, PN 2012222 as responsible for this failure. AGE 121 met luminous transmittance requirements but contained a non-Class A Beamsplitter. AGE 110 and AGE 111 contained Class A Beamsplitters. A series of transmittance tests with samples of both categories of Beamsplitters from stock verified that the difference in transmittance between the two categories of Beamsplitters corresponded to the difference between the acceptable AGE 121 and the out-of-specification AGE 110 and AGE 111. See Table

(a) Luminous Transmittance Investigation - The problems encountered in qualification of OU Luminous Transmittance have been twofold. One is the inability to obtain a sufficiently accurate reading of the LLOS Luminous Transmittance. Second, is the acquisition of Beamsplitters which consistently meet the part specification.

(b) Pritchard Photometer Calibration - The Pritchard Photometer has been analyzed and found to be "red deficient" (e.g. it is not as sensitive to the longer wavelength of the visible spectrum as it should be). In the search of a method to extract meaningful data from the Pritchard, short of elaborate spectrophotometric calibration at a standards laboratory, an expedient method was developed in which a correction factor was derived for the Pritchard when measuring the LLOS.

In such a calibration, a source with monochrometer and a calibrated thermocouple must be used. The thermocouple gives the absolute energy emitted by the monochrometer while the photometer gives the response to this emitted energy. By taking the readings at regular intervals of the wavelength region a spectral sensitivity curve of the photometer can be obtained. This curve will be similar but certainly not identical to the ideal standard luminosity curve. There is insufficient data at this point to ascertain the retention of this calibration.

After such a calibration is made, a correction factor will still be necessary, should there be a deficiency in its red region sensitivity.

The correction factor is the ratio of the theoretical and the measured luminous transmittances of a specific "CF" filter. The assumption is that this filter has essentially the same spectral-transmittance as the SXT LLOS and, by determining a correction factor for it, a correction factor usable for measuring for the LLOS is also determined.

For this specific CF filter, an actual beamsplitter has been utilized. Its spectral-transmittance $F(\lambda)$ was measured accurately on a spectrophotometer. The energy of the illuminant "C", required for the test, through the CF filter as sensed by an eye of standard luminosity $S(\lambda)$ was obtained by the following equation:

$$\int_{4000}^{7000} B(\lambda)\ O(\lambda)^2\ C(\lambda)\ S(\lambda)\ F(\lambda)\ d\lambda$$

Where $B(\lambda)$ = spectral radiance of tungsten lamp at 2854°K

$O(\lambda)$ = spectral transmittance of opal glass used as diffuser

$C(\lambda)$ = spectral transmittance of Corning C-1-71 filter used to correct 2854°K black body to illuminant C.

The theoretical luminous transmittance of the CF filter is then given by:

$$T_t = \frac{\int_{4000}^{7000} B(\lambda)\ O(\lambda)^2\ C(\lambda)\ S(\lambda)\ F(\lambda)\ d\lambda}{\int_{4000}^{7000} B(\lambda)\ O(\lambda)^2\ C(\lambda)\ S(\lambda)\ d\lambda}$$

In actually measuring this quantity, the Pritchard photometer is substituted for S and the integrals are replaced by the output of the photometer. However, each item under the integral are physically present and pertinent.

$$T_m = \frac{\text{Pritchard output with CF filter}}{\text{Pritchard output of illuminant C only}}$$

The correction factor CF is then simply:

$$CF = \frac{T_t}{T_m}$$

In the long run a certified spectrophotometric calibration on a Pritchard photometer may still be made at a standards laboratory.

To facilitate better alignment of the photometer line of sight with that of the SXT alignment fixtures are under consideration. One of them is an inclined mirror to be attached to the photometer lens used to aid the positioning of the photometer.

Fixtures to insure the stability of the test configuration are also under consideration. These fixtures would retain a degree of freedom in the vertical direction for the peaking of the photometer.

HORIZON SENSOR OUTPUT PROBLEMS - The Horizon Sensor (HS) output problem was due to light level changes and Auxiliary Precision Test Fixture (APTF) calibration problems.

(a) An extensive investigation by KI, which included sky measurements in optimum sky condition areas, consultations with the National Bureau of Standards (NBS) and conferences with MIT/IL, were completed, and the certification equipment recalibrated.

(b) In order to determine the light losses due to use of the APTF, KI measured, and had other optical manufacturers measure the reflection factors of the Deflection Mirrors. In addition, a Normal Probe Mounting Probe was designed to allow direct measurement of simulator light as it enters the OUA.

HORIZON SENSOR (HS) ALIGNMENT PROBLEMS - In view of variations in Photometer LOS alignment (PLOS) to LLOS, an error analysis due to tolerance buildup was investigated. This review showed that the PLOS was offset by .014 inches and, for the optical characteristics of the photometer lens, .014 inches corresponded to 15 arc-minutes. As a result, adjustments to this LOS were investigated. Two methods for adjustment were available. One method readjusted the objective lens with respect to the objective lens. In both cases, the PLOS was adjusted with respect to the LLOS.

STAR TRACKER SIGNAL GRADIENT PROBLEMS - The Star Tracker signal gradient was above specification requirements in each system produced to date. Calculations showed that, within the tolerance limits of all components as specified, the signal gradient could vary from slightly below to more than ten times above the specification requirements. KI proposed one resistor, to be mounted on the terminal board, to be selected as a HV adjustment at the OUA level to set the gradient. MIT/IL rejected this approach, and would rather adjust the gain of the Tracker Head Electronics module at the subassembly level. Tests were developed at KI which determined reliable subassembly test parameters, that would assure OUA signal gradients which meet specification requirements.

## COMPARISON OF BEAMSPLITTER TRANSMITTANCE
SN 103 - PN 2012222
31 AUGUST 1965

| Filter Type | Source Intensity | Beamsplitter Intensity | Percent Transmission |
|---|---|---|---|
| No filter, different source | 30.0 | 3.6 | 12 |
| CS-1-71 (Sq) | 4.2 | .44 | 10.4 |
| CS-1-71 (Rd) | 4.0 | .44 | 11 |
| CS-1-72 | 13.3 | 1.60 | 12 |
| Corning No. 5900 | 2.0 | .19 | 9.5 |

SN 104 - PN 2012222
31 AUGUST 1965

| Filter Type | Source Intensity | Beamsplitter Intensity | Percent Transmission |
|---|---|---|---|
| No filter, different source | 30.0 | 3.3 | 11 |
| CS-1-71 (Sq) | 4.2 | .41 | 9.8 |
| CS-1-71 (Rd) | 4.0 | .41 | 10.3 |
| CS-1-72 | 13.3 | 1.50 | 11.2 |
| Corning No. 5900 | 2.0 | .185 | 9.3 |

SN 1005 - 1 SEPTEMBER 1965

| Filter Type | Source Intensity | Beamsplitter Intensity | Percent Transmission |
|---|---|---|---|
| No filter | 29.0 | 1.7 | 5.9 |
| CS-1-71 (sq) | 4.2 | .175 | 4.17 |
| CS-1-72 | 13.2 | .73 | 5.4 |
| Corning No. 5900 | 2.0 | .078 | 3.9 |

STAR TRACKER ALIGNMENT PROBLEMS - Final tests on Star Tracker (ST) alignment indicated that the trunnion axis had in-specification and out-of-specification tolerances on repetitive tests. This condition was resolved when such variations on the earlier OUA were attributed to operator technique and readouts.

Holding twenty-second accuracy in Trunnion Axis as a requirement has been defined as a two-step operation. Basic alignment is performed at the 2011701 assembly level by setting the fork housing, and final alignment is completed at the 2011890 assembly level by adjusting one Tracker Mirror. The ability to perform basic alignment at the 2011701 assembly level with FTE or with an optical base has been included in the KPS to allow uninterrupted fabrication depending upon completion of subassemblies.

Consistent readout of Trunnion Asix accuracy for the STLOS before and after vibration tests was noted during OUA tests. Familiarization of APTF setup for such tests is one of the important factors in maintaining in-specification conditions.

STICTION PROBLEMS DURING THERMAL VACUUM TESTING - The high stiction problems that were exhibited by Servomotor, PN 1012156, during thermal vacuum testing have been solved by increasing the radial and end play specifications.

A proposed change to the special conditioning was under consideration, changing the room temperature requirements to a hot (+150°F) and a cold (-40°F) cycle.

At the end of August, two Solvere servomotors were subjected to the proposed special conditioning. The results of these tests were presented to Solvere engineering. The tests were not 100 percent conclusive in favor of the Solvere design and a simple modification to the present design was recommended. Since the problem exists only at the cold temperature (where maximum temperature gradient occurs from rotor to case), a method of removing the heat from the rotor had to be found. At present, heat is conducted from rotor through the bearings. Solvers proposed to blacken the tachometer drag cup in accordance with MIL-F-495, thereby increasing the heat transfer through radiation. Six sample servomotors were manufactured with the new drag cup and delivered to KI for test and evaluation.

LEAKAGE TESTING PROBLEMS - During manufacture of the Block I-100 series of OUA's, a problem was encountered in the use of Block I Optical Bases (PN 1011631) used in the earlier AGE. In this design the bellows mounting studs are epoxied in to form a vacuum seal. In-process testing and environmental conditioning of the units necessitates the assembly and removal of leak test caps and bellows. The units on these bolts are torqued in accordance with the requirements specified for assembling the bellows to the OUA in the field. Leak testing disclosed that, after several of these assembly and removal cycles, minute leaks developed in the studs, requiring rework. The Block I-100 Optical Bases do not have this problem because of a design change incorporating blind holes for the studs. This problem was not noticed on Block I units because of the method of leak testing and the allowable leak rate. These minute leaks were not of sufficient magnitude to cause rejection of a Block I unit, but would be cause for rejection of a Block I-100 unit which has a leak rate 10,000 times lower than a Block I unit.

This problem also became apparent in the environmental testing of SN 10 OUA after retrofit. This is a Block I unit and met the Block I leak rate requirements, which are incompatible with the pumping capabilities of the vacuum chambers used for thermal vacuum testing, thus preventing the chamber from reaching the required level of pressure. KI requested that the seal lubricant used on Block I-100 units be incorporated in the Block I retrofit units in the form of a TDRR. This would help alleviate, but not completely eliminate, the problem.

OUA MOUNTING TECHNIQUES - Information was added to JDQ 03016 covering the technique and tools to be used in mounting the OUA unit to the vibration fixture. This information shall prevent damage to the high precision ball mounts and maintain the repeatability of the OUA alignments.

CLARIFICATION OF THERMAL VACUUM TEST REQUIREMENTS - Information was added to JDQ 03017 covering the technique and tools to be used in mounting the OUA unit to the vacuum chamber bulkhead to prevent damage to the ball mounts and maintain the repeatability of the OUA alignments.

The "Procedure" section was revised for clarification and a specific voltage was added for excitation of the OUA during the test and shutdown of test equipment between runs. The "Profile Chart" was revised for clearer definition of the pumpdown phase, test run starting requirements, and the duration of test.

Technical Directives TDK-60 AND TDK-92 authorized the performance of thermal analyses of the OUA and Map Data Viewer (MDV) to determine temperature conditions of selected critical elements for hot and cold orbits. Both the final MDV thermal analysis report and the OUA thermal analysis final report were issued, thereby completing the final effort.

Technical Directive TDK-61 authorized mechanical integrity tests of the AGE 2 OUA. Specifically, the work consisted of preparation of a test plan, design and fabrication of test fixtures, performance of tests and recording of analysis of data. Following the tests specified below, a final report was issued, thus completing the authorized effort.

Vibration overstress tests were begun. Initial exposure to the 125 percent level gave rise to repeated impact within the OUA. This problem has been investigated and SXT and SCT shaft axes bearing preloads were established at 120 pounds each.

Sinusoidal vibration testing was performed at 45 cps, and at increasing levels up to a 6g peak. At this level, repeated impact was evident. The Belleville washers were then flattened, and the test was repeated. No impact occurred for levels up to a peak of 8g's. It was concluded that the OUA had not been secured properly, and that the Belleville washers were being compressed. The remainder of the overstress tests (random vibration) were conducted with flattened Belleville washers.

A full FTM was performed prior to the start of the 125 percent level tests. Vibration tests were conducted along the three (3) C/M axes. An FTM performed following these tests showed no degradation of the assembly. However, a slight shift in the optical axis alignment (2 seconds of arc) was measured.

Vibration tests were conducted at the 150 percent level along the three C/M axes. Tests were completed along the $X_{cm}$ and $Y_{cm}$ axes with no apparent malfunctions. Immediately after the start of $Z_{cm}$ vibration, failure occurred on the four (4) shoulder posts, PN 1011323 (support for the Flexprint connector in the SXT head). The test was completed without making a repair. An FTM performed following these tests showed an optical axis alignment shift of two (2) seconds of arc. No other degradation in performance of the unit occurred, except for loss in electrical continuity in the Flexprint. This was attributed to the failure of the posts. The Flexprint was reworked by resoldering the connectors to their respective leads and repotting with a conformal coating. The posts were replaced.

Testing was performed at the 175 percent level along the $X_{cm}$ axis. Degradation in performance was noted, since there was no gear drive to the SXT Index Mirror. Investigation of this problem showed that approximately five (5) teeth of gear, PN 1011346, had been stripped. Since this gear is used over only one-quarter of its circumference, the repair was performed by repositioning the gear on the assembly. Testing was continued along the $Y_{cm}$ and $Z_{cm}$ axes of the C/M. An FTM following these tests showed no additional degradation in performance of the unit, except for the shift of an optical axis alignment of about two (2) seconds of arc.

The oxygen overpressure test was completed. The OUA functioned properly during exposure to this environment. The explosion test was completed. The OUA functioned properly during exposure to this environment.

The earthlanding shock test was completed. After this test, the following discrepancies were noted:

(1) SXT Telescope Tube, PN 1011293, was broken into two pieces.

(2) Black pasty residue had accumulated at the interfaces of the Sextant shaft bearing retainer, PN 1011316, and the inner race of the bearing, PN 1011607-2.

(3) The glass envelope of one of the Sextant reticle lamps, PN MS 24367, was broken.

Each of the above discrepancies was considered to be unimportant inasmuch as crew safety, the only requirement for the earthlanding shock test, was not affected.

The final report was issued by 30 June 1965, thus completing the authorized effort.

Technical Directive TDK-83 authorized design evaluation testing of the AGE 1 OUA which included thermal vacuum and humidity exposure. Following the tests specified below, a final report was issued, thus completing the authorized effort.

The OUA was prepared for further thermal vacuum testing. The SXT reticle was replaced and clamped with 15 ounce-inches of torque equally applied to the three (3) clamping screws, in accordance with the approved Assembly Test Procedure. New covers for the SXT and SCT were obtained and painted in the manner outlined and with the materials specified in Figure 3-3 of the Command Module Quarterly Technical Progress Report, No. 10. The SXT shaft axis bearings were preloaded to 75 pounds, in accordance with the latest Assembly Test procedure. Thermocouples were mounted at locations assigned by MIT/IL.

Evaluation of the SCT was performed by MIT/IL personnel at KI , with KIC assistance. Continued investigation of the SXT error was performed by MIT/IL personnel at KI , with KI assistance.

Intermittent cycling of the OUA under nominal thermal vacuum conditions and typical operating conditions was begun. The first ten (10) days of the 30 day cycle was completed. Evaluation of the data shows SXT angular measurements (electrical versus optical) to be within 32 seconds of arc. In general, operation of the unit was satisfactory.

1. Completed intermittent cycling test - the unit functioned satisfactorily.

2. Leakage test - no measurable leak rate was determined.

3. Ground temperature test - the unit functioned satisfactorily.

4. Thermal vacuum overstress test - the unit functioned satisfactorily.

5. Humidity test - formation of a corrosive-like substance was observed on the beryllium (Be) surfaces of the Optical Base. Chemical analysis of this substance was being performed.

## 4.5 ENGINEERING - PERIOD ENDING 31 DECEMBER 1966

### 4.5.1 Command Module Engineering

The following Block II OUA's were completed. In addition, a Block I-50 retrofit was accomplished and a Block II SXT Head Assembly (MIT/IL) evaluation was completed:

1. AGE 124
2. AGE 12, S/N 11
3. AGE 201 S/N 012
4. AGE 202, S/N 013
5. AGE 1-201 S/N 014
6. AGE 203 S/N 015
7. AGE 204 S/N 016
8. AGE 205 S/N 017
9. AGE 206 S/N 018
10. AGE 208 S/N 020
11. SXT Head Assembly S/N 040

The major part of Engineering's effort during this period was spent on vendor and in-house technical problems. At this point in time, enough engineering and manufacturing experience had been gained so that time could more gainfully be spent on solving the more subtle and design related problems. The following is a review of this action.

### 4.5.2 OUA Components and Subassembly Performance

#### 4.5.2.1 Solvere Motors

Kollsman, per TDRR 30916, performed all special conditioning (thermal vacuum) tests on Solvere Motors prior to final acceptance. To insure proper operation during these tests, Solvere incorporated a .004 minimum end play (in-house) specification, since previous data indicated units with lower end play became marginal.

As a result of failures experienced in the qualification system (OUA 124) several meetings were held at AC Electronics on failure analysis with KI, and Solvere personnel in attendance. One of the areas of investigation, and results of these studies are presented in the following paragraphs.

As a result of the special conditioning tests performed by KI, the maximum temperature of the generator output winding was found to exceed the specified value by approximately ten degrees. A request was forwarded to MIT/IL to lower the control thermocouple temperature to 140°F from 150°F thereby lowering the maximum generator temperature. The graph in Figure 4-7 indicates temperature on the right are calculated from the measured resistance values on the left, using the following formula.

$$T_h = \frac{R_h - R_o}{R_o} (234.5 + T_o)$$

$R_h$ = Measure resistance (hot) ohms

$R_o$ = Measure resistance (ambient temp.) ohms

$T_o$ = Ambient Temp. °C

$T_h$ = Temperature rise °C

$T_h$ is then corrected to °F and added to the ambient temperature in °F.

At the suggestion of Solvere, the drag cup was dyed black to meet the new requirements presented by Kollsman engineering. Calculations leading to this suggestion are presented in Table 4-9.

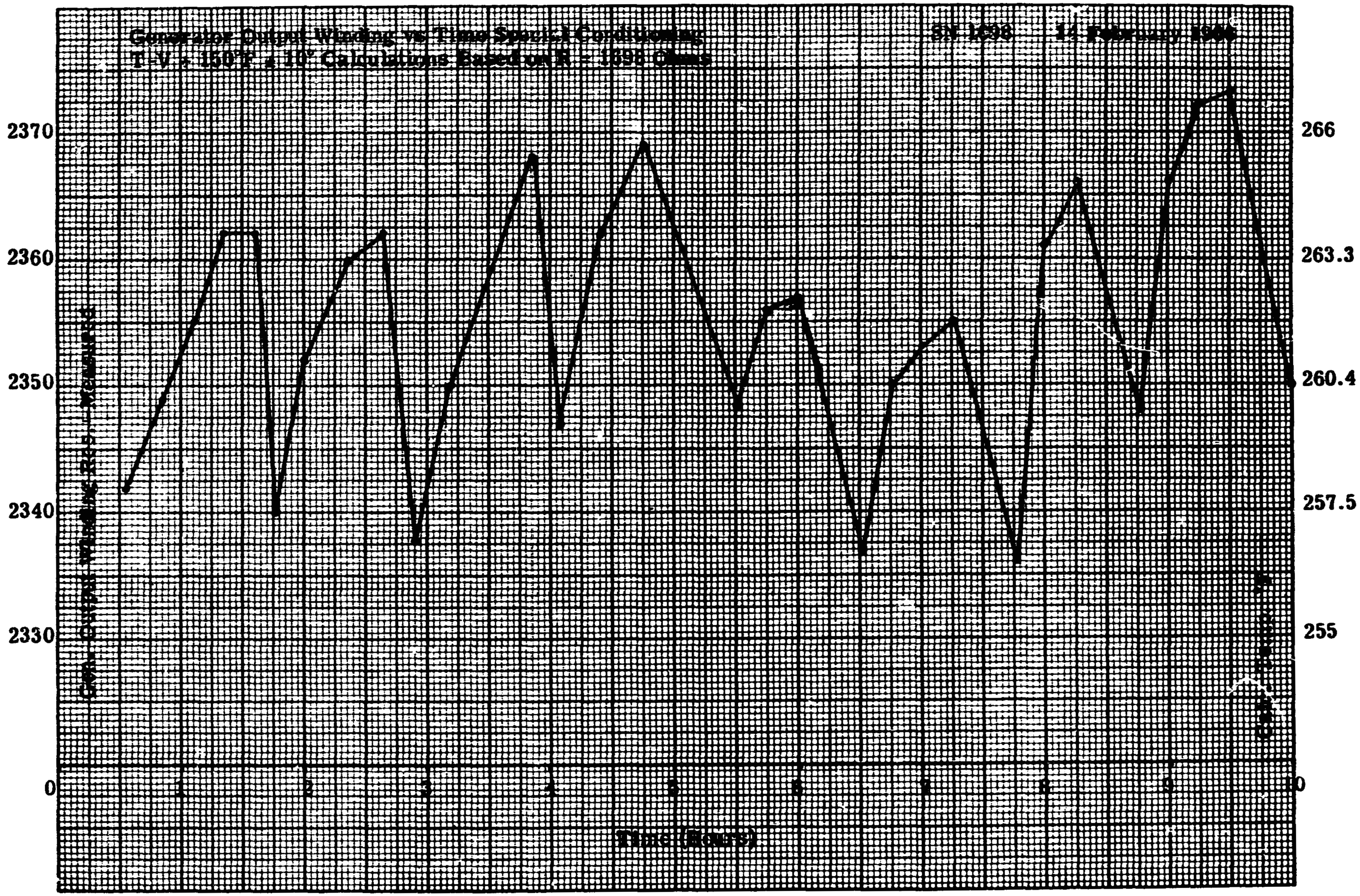



Figure 4-7. Solvere Motor Thermal Vacuum Test

## TABLE 4-9

### CALCULATION OF RADIATED HEAT TRANSFER FROM ROTOR TO STATOR

Parameters:

| | |
|---|---|
| Motor Stator Temperature | 10°C |
| Motor Rotor Temperature | 100°C |
| Motor Rotor Emissivity Constant (e) | 0.3 |
| Motor Rotor Area | 0.47 $in^2$ |
| Drag Cup Temperature | 100°C |
| Drag Cup Emissivity Constant | 0.66 |
| Drag Cup Area | 4.9 $in^2$ |
| Dyed Drag Cup Emissivity Constant | 0.87 |
| Outer Stator Temperature | -8°C |
| Inner Stator Temperature | 8°C |
| Power Input to Rotor | 1.7 watts |

Power transferred to motor stator:

$$W = e\ (3.68)\ (t_R^4 - t_S^4)\ 10^{-11}\ A$$

$$= (0.3)\ (3.68)\ (373^4 - 283^4)\ 10^{-11}\ (0.47 = 0.067 \text{ watts}$$

| | |
|---|---|
| Power transferred to outer stator | = 0.859 watts |
| Power transferred to inner stator | = 0.781 watts |
| Total power transfer | 1.707 watts |

Power transferred via drag cup = 1.640 watts

To dissipate 1.640 watts using e = 0.87, a new drag cup temperature was found which satisfied the power transfer equations. This value was 78°C, showing the rotor-stator temperature gradient to be 22°C less if the drag cup were dyed black. Note also that 95 percent of the heat transfer was from the drag cup.

Solvere experienced an increase in starting voltage failures, due to the rotors which were purchased from Chase Electronics, New York. Kollsman Engineering and Reliability visited the vendor to verify the manufacture and processing of the rotors. Investigation at Solvere revealed that during the machining of the stator I.D., the lamination did not clean up. An internal dimensional change was made to ensure proper clean of the stator I.D.

MOTOR TACHOMETER RECYCLING - On 11 November 1966, AC K-D2353 directed the cessation of production activities on AGE 207 and AGE 209. The directive also limited activity on units following those portions of the OUA not associated with motors.

A joint meeting of Kollsman, AC and Solvere was held during November 1966, to disassemble eight motor tachometers.

Visual and photographic inspection revealed a high degree of manufacturing Control and Quality Control. Contamination was found to be the result of the disassembly process. Kollsman and AC met for a bearing analysis at the vendor's (NHBB) facilities December 1966.

The basic Motor tachometer problem was inadequate lubrication quantity of lubricant. Kollsman provided the bearing lubrication procedure. Kollsman also provided detail procedures for disassembly, cleaning and assembly of motor tachometers recycled to Solvere. End play settings procedure was recommended. Kollsman provided and performed a review of the telescope assembly as well as others to determine possible elements contributing to motor-tachometers stiction. Reference report AE-66-028.

To further expedite the motor recycling, three Kollsman personnel were assigned to Solvere on a full-time residence basis.

4.5.2.2 Resolvers

1X RECEIVER - Clifton Precision experienced a high percentage of rejects after the temperature cycling procedure. A change to PS 1012157 was submitted to MIT/IL to give relief in the area of high rejection rate. This change increased the maximum allowable error to 2.5 minutes and added a peak-to-peak error requirement of 3.5 minutes which was in accordance with the new OUA test procedures.

64X RESOLVER ERRORS - It was noted that the peak-to-peak errors on the 64X Resolver at the 2012736 level of assembly exceeded the allowable specification. The units were within the final sell-off specification. Since a high percentage of 64X Resolvers purchased were at or near the maximum allowable tolerance (10 sec. p-p equivalent to 20 sec. p-p LOS), a study of resolver errors versus SXT TDA errors was performed. Tables 4-10 and 4-11 show the peak-to-peak data for each Resolver manufacturer. Figure 4-8 shows the TDA errors and resolver errors plotted for OUA 200, 201 and 203. Except for a bias error (to be expected) it appeared that the harmonic content of the error curves repeated satisfactorily, indicating no changes in the resolvers. In addition, comparison of KI final data on OUA 205 and tests performed at AC on OUA 205 indicated the same type of repeatability. Checks of in-process data show that the peak errors always occur at the same points, further substantiating the integrity of the resolvers.

TABLE 4-10

64X RESOLVERS
REEVES

| OUA | Resolver S/N | P-P Error at Source (X2) Sec | TDA Measured P-P Sec |
|---|---|---|---|
| 111 | 1006 | 14 | 12.6 |
| 109 | 1007 | 18.6 | 21.9 |
| 123 | 1001 | 17.2 | 9.7 |
| 200 | 1003 | 20.8 | 19.8 |
| 124 | 1002 | 13 | 15.8 |
| 201 | 1005 | 16.4 | 20.9 |
| 202 | 1004 | 17.2 | 20.2 |

TABLE 4-11

64X RESOLVERS
CLIFTON

| OUA | Resolver S/N | P-P Error at Source (X2) Sec | TDA Measured P-P Sec |
|---|---|---|---|
| 121 | 1502 | 16.4 | 13.3 |
| 102 | 1501 | 12.4 | 18 |
| 110 | 1503 | 16.0 | 8.65 |
| 122 | 1504 | 13.8 | 10.9 |
| 1-201 | 1517 | 18.6 | 21.2 |
| 203 | 1518 | 19.6 | 21.9 |
| 204 | 1513 | 15 | 12.6 |
| 205 | 1510 | 18.8 | 25.9 |

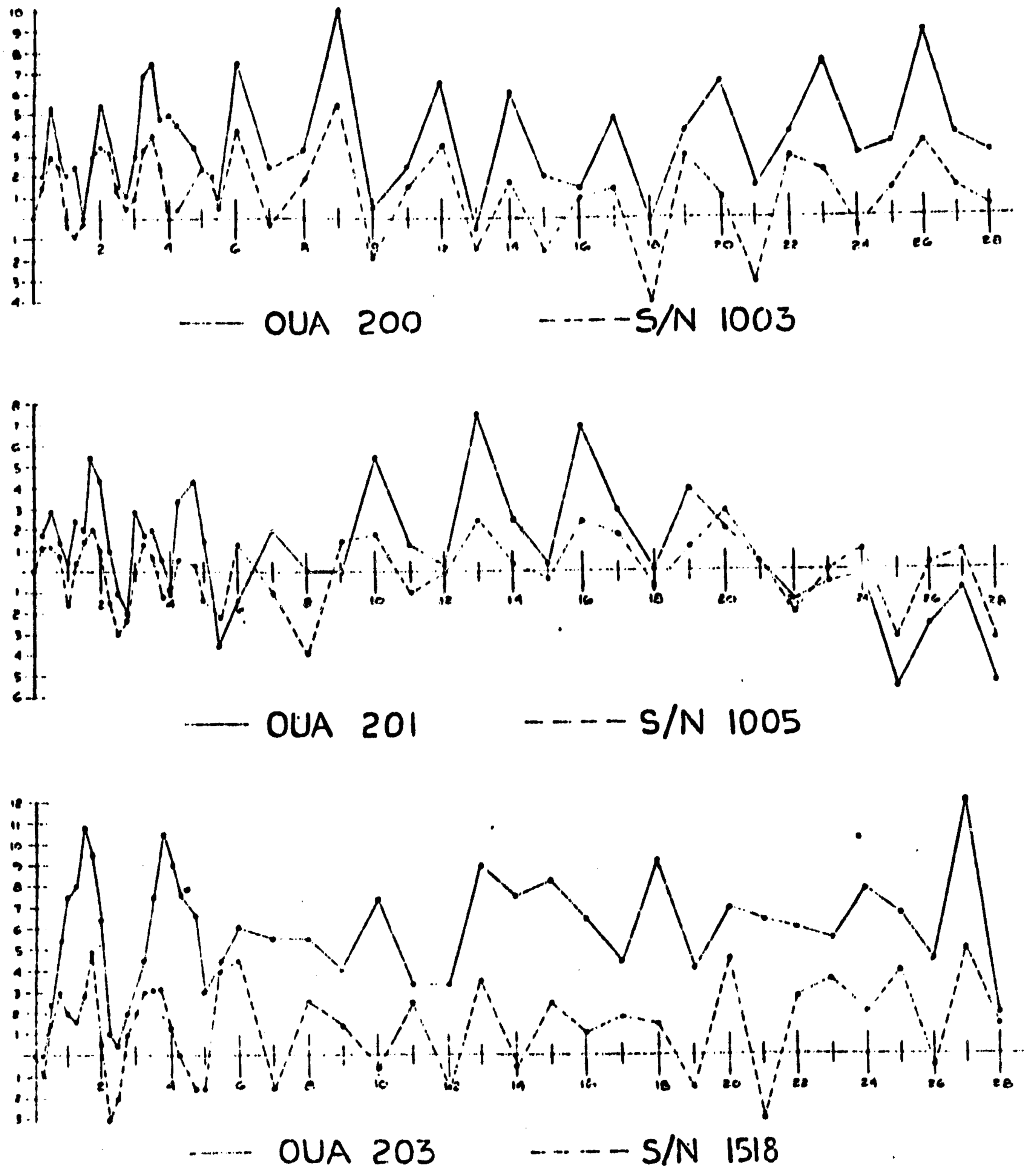



**Figure 4-8. TDA Vs 64X Resolver Accuracy**

4.5.2.3 Eyepieces (SCT and SXT)

DESIGN - Several significant changes were made on the SXT and SCT eyepiees during the reporting period.

The fixed focus SCT eyepiece, PN 2012693, was replaced with an adjustable eyepiece, PN 2012719. To avoid a schedule impact, modification of the SCT LER design allowed common use of casting, PN 2012670, and insulating blanket, PN 2012714 and PN 2012715, for both PN 2012719 and PN 2012691.

Modification of the Prism Housing Assembly, PN 2012667 assured interchangeability of this assembly as a module. The original design concept required OUA adjustments to accomplish field retrofit. It was expected that these modifications were incorporated with no impact on the original schedule set for in-line and retrofit activities. ERP 108 was updated to include these modifications.

A special provision had to be made for Block I-50 in the form of a modified P/N 2012667 released as a new assembly, P/N 1013010. This new assembly may be used in Block I-100 and Block II units with shim, PN 1013015 attached. For use on Block I-50 units the new configuration shall be assembled without shim PN 1013015 and in accordance with special field instructions. Figure 4-9 illustrates the application of these assemblies to units in the field. The size of spacer, PN 2012712-2 or PN 1013014 is determined from the field measurement described in paragraph 3.2.13.6. Spacers PN 2012750 and PN 1013015 are set up in production to provide the Prism Housing Air Equivalent of 3.835 ±0.003 inches.

A change in the main housing of the SCT Long Eye Relief, (LER) P/N 2012691 became necessary to assure that all units would meet specification, regardless of tolerance accumulation.

PROCUREMENT - End item procurement philosophy was finalized to reflect the following end item configurations:

2012699 - SXT Mirror Housing and Air Focus Shim Assembly

2012700 - SXT Standard Eyepiece

2012667 - SCT Prism Housing and Insulation Assembly (Block I-100 and Block II)

1013010 - SCT Prism Housing and Insulation Assembly (Block I-50)

2012719 - SCT Standard Eyepiece (Adj.)

2012691 - SCT Long Eye Relief Eyepiece

2012748 - SXT Long Eye Relief Eyepiece

2011000 - OUA (without eyepieces)

1011000 - OUA (without eyepieces)

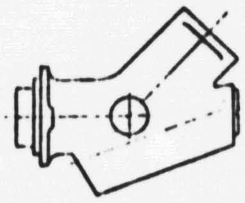
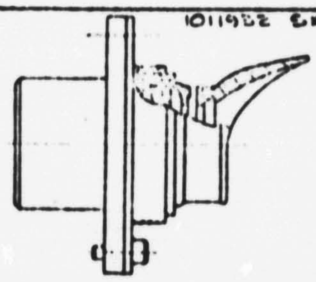
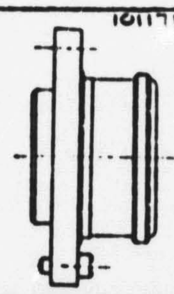
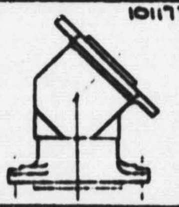
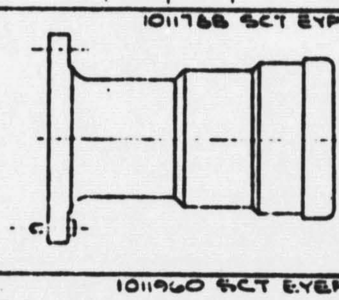
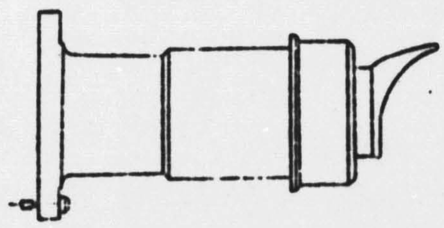
| | | BLOCK I CONFIGURATION | |
|---|---|---|---|
| SXT | MIRROR HOUSING | 1011786 SXT MIRROR HOUSING ASSEMBLY<br> | MAJOR PARTS<br>1011640 HOUSING<br>1011781 LENS<br>1011780 LENS<br>1012162 MIRROR (2) |
| SXT | REGULAR EYEPIECE | 1011982 SXT EYEPIECE, REGULAR<br> | MAJOR PARTS<br>1011676 HOUSING<br>1011782 LENS<br>1011860 LENS<br>1011783 LENS<br>1011872 HOLDER, FILTER & EYEGUARD |
| SXT | LER EYEPIECE | 1011787 SXT EYEPIECE, LONG EYE RELIEF<br> | MAJOR PARTS<br>1011926 HOUSING<br>1011922 LENS<br>1011921 LENS<br>THREE (3) WERE BUILT ON TDK-100 |
| SCT | PRISM HOUSING | 1011734 HOUSING SCT PRISM ASSEMBLY OF<br> | MAJOR PARTS<br>1011257 HOUSING, PRISM<br>1011269 PRISM, SMALL<br>1011270 PRISM, LARGE |
| SCT | LER EYEPIECE | 1011768 SCT EYPIECE ASSEMBLY, LONG EYE RELIEF<br> | MAJOR PARTS<br>1011915 HOUSING<br>1011730 LENS<br>1011824 LENS<br>THREE (3) WERE BUILT ON TDK-100 |
| SCT | REGULAR EYEPIECE | 1011960 SCT EYEPIECE, REGULAR<br> | MAJOR PARTS<br>1011961 HOUSING<br>1011707 LENS<br>1011708 LENS<br>1011967 LENS |

Figure 4-9. OUA Eyepiece (Sheet 1 of 3)

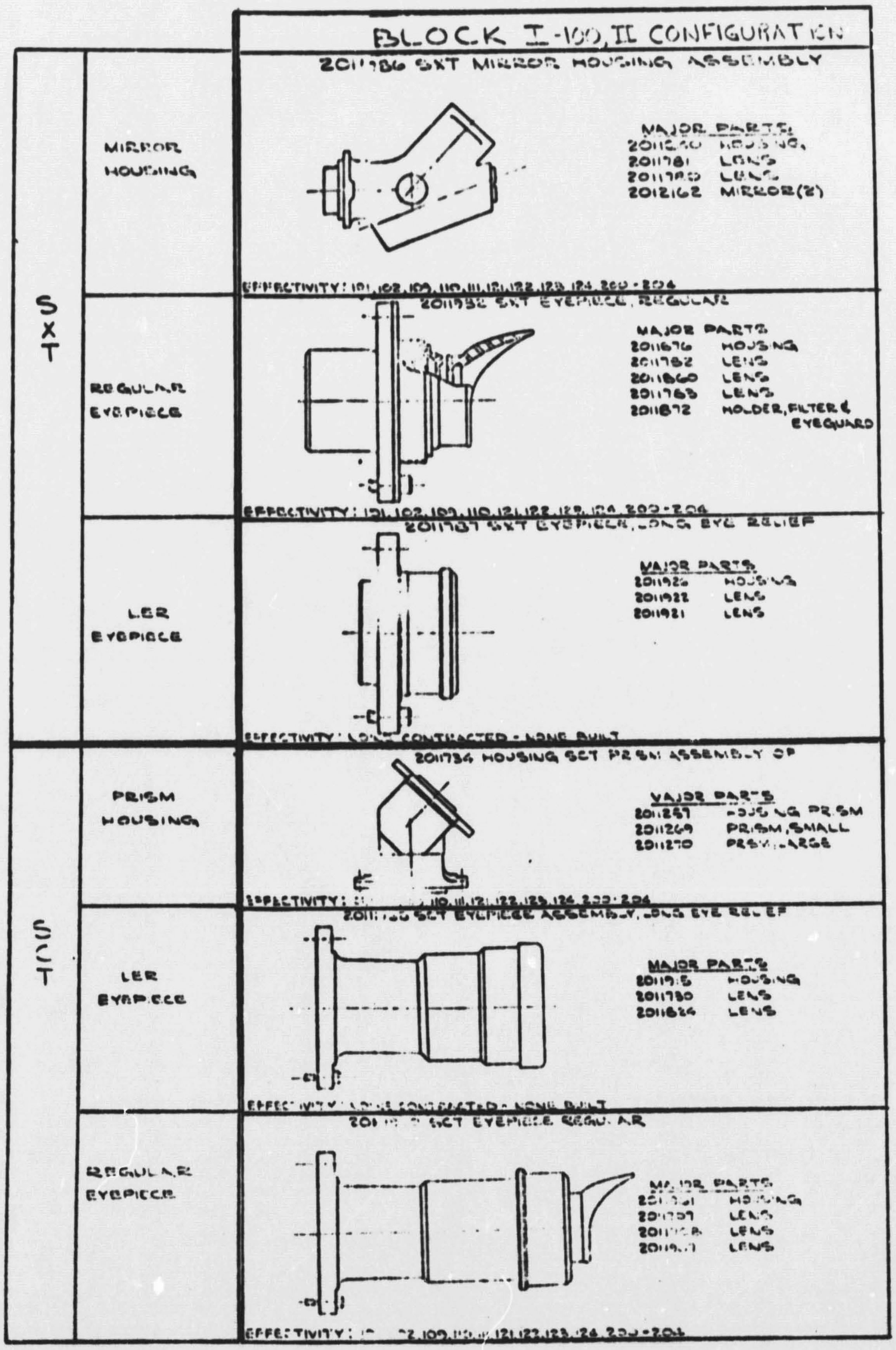



**Figure 4-9. OUA Eyepiece (Sheet 2 of 3)**

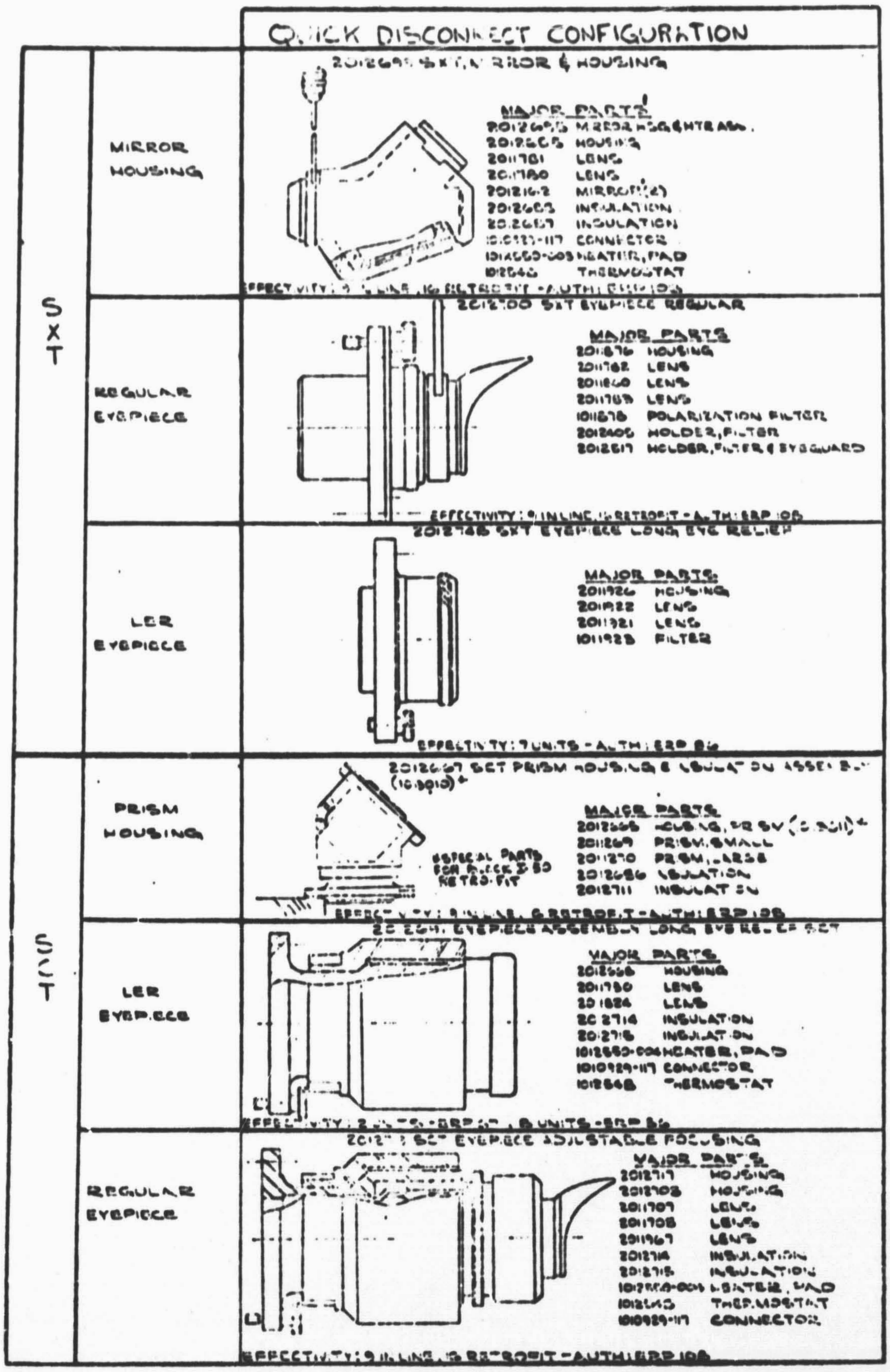



Figure 4-9. OUA Eyepiece (Sheet 3 of 3)

The previous scheme, although not finalized, did not include provisions for 2012700 and 1013010. See Figure 4-10 for illustration of configurations.

MANUFACTURING - Engineering changes, especially new releases reduced the lead time to a minimum although no schedule slippage occurred.

TESTING - Optical Unit AGE 102, was supplied as a test vehicle for eyepieces in accordance with Apollo Memorandum Ap-M-12383. The original scheme for testing was revised to incorporate the Optical Unit in lieu of test equipment which was not available during this reporting period.

FAILURES - A single electrical failure took place in September 1966, (FR9873) in which an eyepiece cable broke away at the eyepiece solder joint. Upon study of the assembly, the current method of strain relief was adjudged to be inadequate. A layout was generated for a technique of strain relief which was applied in the field and involved no factory alteration to existing hardware.

A steel wire, slightly shorter than the electrical conductors runs parallel to the conductors. The wire is firmly anchored to the cable connector at one end, and to the eyepiece housing at the other end, by means of wraparound clamps.

Assembly number 2012700, SN 2002, was returned from the field. Focus adjustment was not attainable due to a jammed assembly. Analysis at KI indicated damage to Key number 2012882 and slight galling of adjustment thread. The probable cause was misassembly in the field. The air focus shim may have been reversed, eliminating necessary Key clearance which led to subsequent jamming. A caution note was added to ADP's concerning this assembly.

#### 4.5.2.4 Connectors

PROBLEM - An investigation was initiated by Kollsman, following a failure report indicating grooving of OUA bulkhead connectors, gold flaking causing contamination of the connector interface, and failures on the Functional Tester cables attributable to excessive wear on the aluminum coupling ring, caused by the scored steel balls.

INVESTIGATION RESULTS - Investigation and examination of failed connectors by Engineering and Reliability indicated that the grooving of the shell and the gold flaking contamination of connector interface were caused by constant mating and unmating of connectors during test cycles.

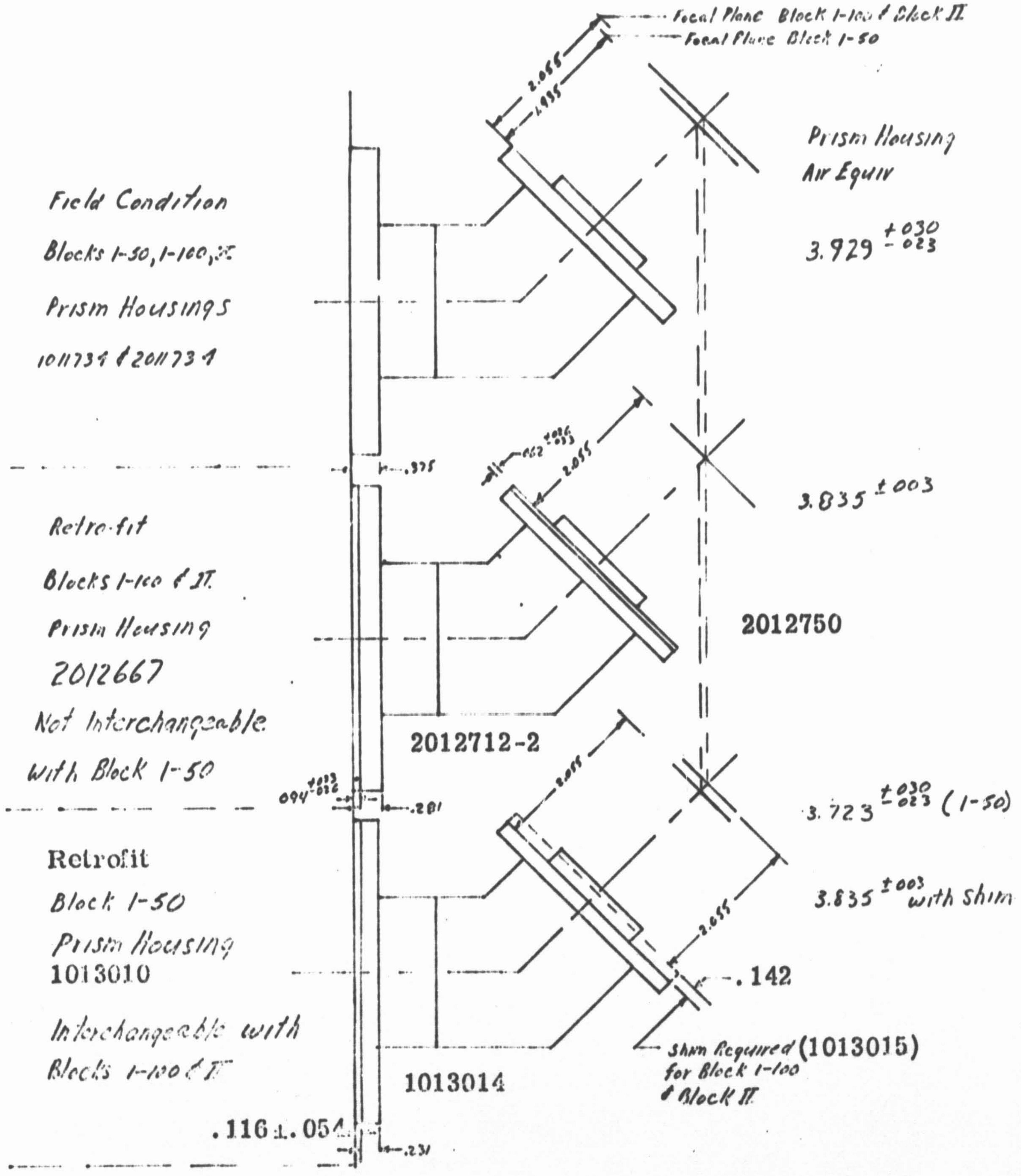



Figure 4-10. Prism Housing Assemblies

Representatives of KI Engineering and Reliability and AC Electronics component parts group met at Deutsch Electronic Components Division, Banning, California, on 12 and 13 May 1966, to discuss the aforementioned problems.

The following items were discussed:

a. Grooves on shell due to steel balls on mating plug

b. Removal of gold plating on pins

c. Building of excessive gold fillings upon interface, creating possible shorting path

d. Ruptured shell liner

e. Burrs around detent holes

f. Rough and irregular interior of socket contours

g. Irregular or high spots on wall of shell liner

h. Cracked plastic insert of Base Harness Plug.

As a result of this discussion, a test plan was formulated by which a failure analysis was conducted by Deutsch Reliability Group on each of the items listed.

An ERP was submitted to AC Electronics for the design and manufacture of short adapter cables (6 inches long). These cables were attached to the OUA bulkhead connectors. They remained on the OUA during the production test cycle, thus avoiding grooving and gold flaking contamination of connector interface.

Kollsman Engineering investigated the difficulties of bonding to Teflon (wire insulation). A report of test results was prepared which reflected an increase in holding power of two times with the application of a new primer P/N 1010900. The results of these pull tests are shown in Figure 4-11.

4.5.2.5 Flexprints

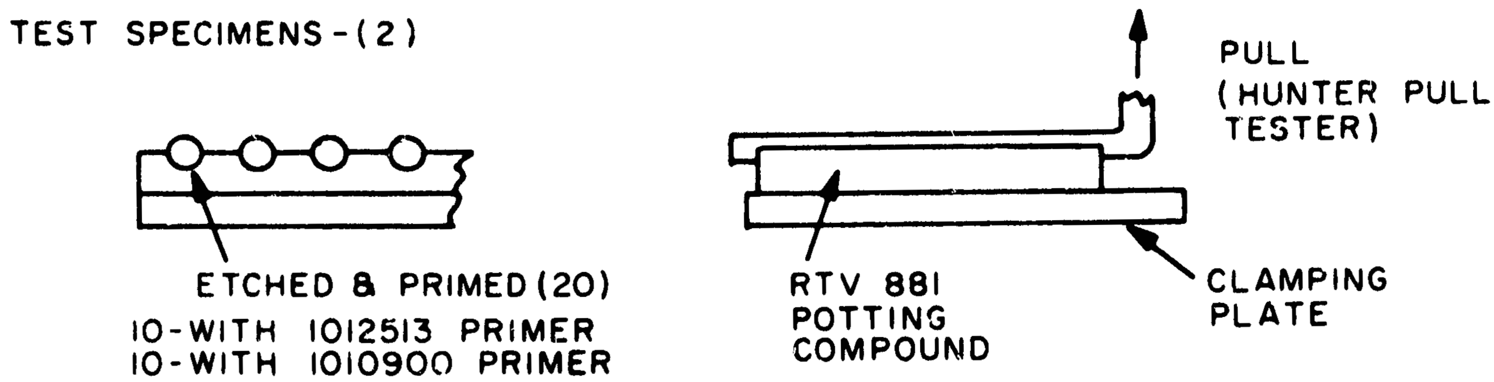
PROBLEM - Flexprint parts (PN 1012519 and PN 1012520) at KI were at a low level continually due to a high rejection rate based upon inspection rejects. All accepted flexprints required MRB action with resulting "Use as is" disposition.

The major reasons for the rejects were:

1. Contamination between flexprint layers

2. Undercutting, pinholes, scratches and nicks on conductors

3. Nonadherance of potting to FEP (Teflon) insulating material.




| WIRE # | PRIMER # | AVG. TEST READING LBS |
|---|---|---|
| 1010789-001 (24 AWG) | 1010900 | 1.5 |
| 1010789-001 | 1012513 | 0.7 |
| 1010416-10 (28 AWG) | 1010900 | 2.7 |
| 1010416-10 | 1012513 | 1.2 |

Figure 4-11. Primer Pull Test

APPROACH TO SOLUTION - In order to correct this situation, KI had taken the following steps:

1. Study of manufacturing operations, and suggestions to vendors how to improve methods.
2. Development of detailed visual inspection criteria by KI Engineering, Reliability and QC. These criteria were then submitted to the vendors for comment and approval.
3. Review of Kollsman Inspection procedures to assure that quality is at the required high level, and to eliminate the possibility of undue rejects, due to misinterpretation of the written procedures.
4. Frequent visits to the vendors by representatives of KI Engineering, Reliability, QC and Purchasing, as required, to resolve any differences and to lend technical support to improve the finished product.
5. Survey and evaluation of other vendors in an attempt to develop additional and superior sources.

ACTION

1. Visits were made to Flexible Circuits, Inc., Hatboro, Pennsylvania, and Sanders Associates, Nashua, New Hampshire, to discuss the overall problem, observe and review their manufacturing and inspection procedures and develop more definitive visual inspection criteria.
2. KI investigated several areas, and submitted suggestions for changes in the cleaning, etching and potting procedures. These recommendations were accepted by both vendors and were implemented.
3. The humidity requirements were removed from both SCD's (TDRR 27259 and 27260). Although the flexprints failed the humidity portion of their qualification tests, they are not subject to such extremes in actual use.
4. KI developed and evaluated a pull test to check potting adherence. This pull test was accepted by both vendors, and the process was added to the purchase orders. The following paragraphs discuss the calculations of force on connectors and description of pull test setup.
5. KI developed a group of visual inspection criteria that were satisfactory to Engineering, Reliability and QC. These were submitted to the vendors for review and comment.

6. KI established a procedure whereby KI inspectors source-inspected the flexprints after soldering and after potting. This is to verify that in-process manufacturing provides a satisfactory product for end use. Previously, these parts were fully completed, then inspected and invariably rejected due to in-process workmanship. This revised inspection procedure called out those units that indicated substandard workmanship, early in production to avoid additional effort.

RESULTS - The effort mentioned in the above paragraphs resulted in improved workmanship and quality of recent flexprints reviewed at KI and in work at the vendors. Contamination between FEP layers was reduced in number and size whereby foreign particles may not bridge conductors. Also, digs, scratches, and nicks in or around conductors or insulation were reduced to a minimum and undercutting of conductors or pinholes in conductors due to etching were substantially decreased and held to an acceptable level necessary for OUA use.

PULL TEST

KI requested that current flexprint vendors perform a pull test between connector and ribbon. This test should verify potting adherence for improved reliability and quality. KI flexprint vendors indicated concern in meeting this pull test.

Herewith is a review of the loads OUA flexprints may encounter based on vibration requirements in PS 2016206.

Paragraph 3.3.2 of PS 2016206 for the OUA states vibration in each axis shall be as follows:

".0054g $\frac{2}{cps}$ at 20 cps increasing to .02g $\frac{2}{cps}$ at 70 cps and constant to 1000 cps. Then, decrease to .004g $\frac{2}{cps}$ at 200 cps with a -3db limit (for the entire profile)."

Graphically, the vibration profile appears in Figure 4-12.

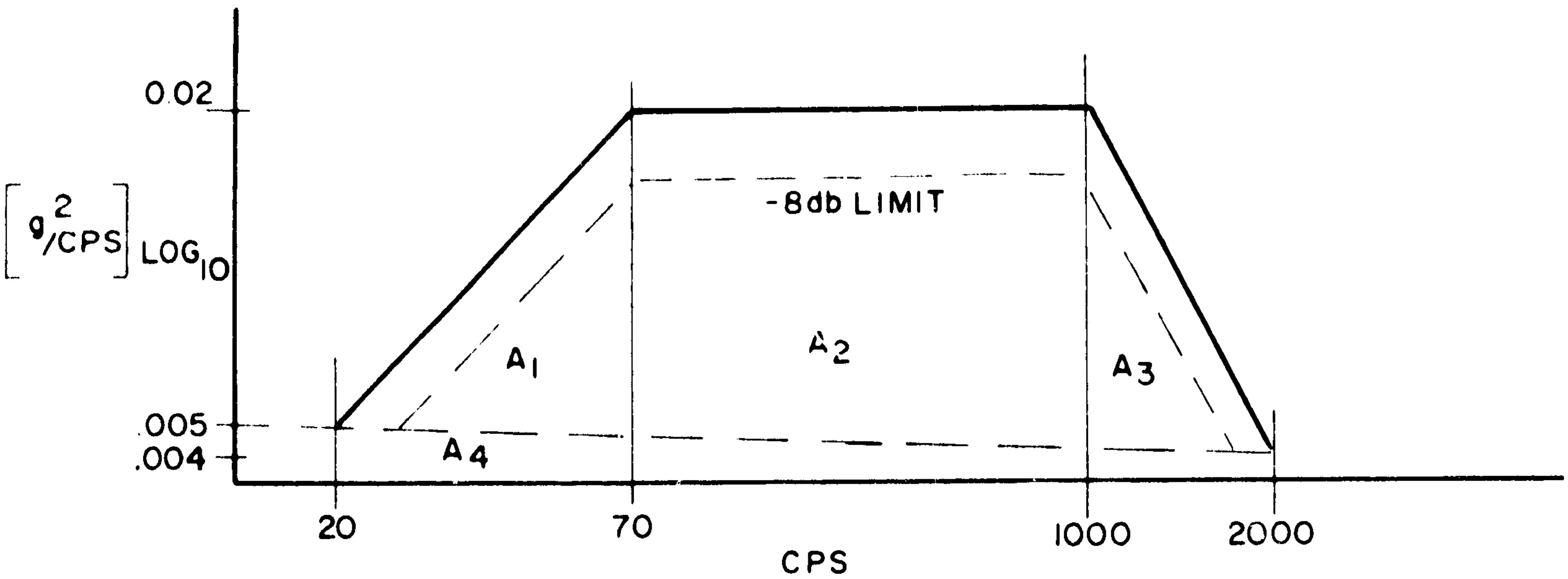



Figure 4-12. Vibration Profile

Converting the energy under the entire cu.ve into gravitational units provides a maximum force of approximately 5-1/2$g^2$. This is obtained as follows:

$A_1$ = 1/2bh = 1/2 70-02(.02-005$g \frac{2}{cps}$) = 1/2 50 x .015$g^2$ = .275$g^2$

$A_2$ = bh = 1000-70(.02-005) = 930 x .015$g^2$ = 13.75$g^2$

$A_3$ = 1/2bh = 1/2 1000(.02 x 004) = 1/2 1000 x .016$g^2$ = 16$g^2$

$A_4$ = bh = 2000-20(.0045) = 1980 (.0045$g^2$) = 8.4$g^2$

g = 6.2 38.53$g^2$

The flexprint area under concern is at the receptacle or connector which is fastened to the SXT Index Head. The Connector experiences local vibrations similar to the index head. For a random input of 5-1/2g's to the OUA, the connector or Index Head may encounter harmonics (due to flexibility) as high as 16 g's per Report AA-66-307. The weight of potting compound and ribbon with respect to connector is two ounces. For a 15g load, the force that tends to separate ribbon from potting compound or ribbon and potting compound from connector is 15 x 2 or 30 ounces (2 pounds) (reference Figure 4-13).

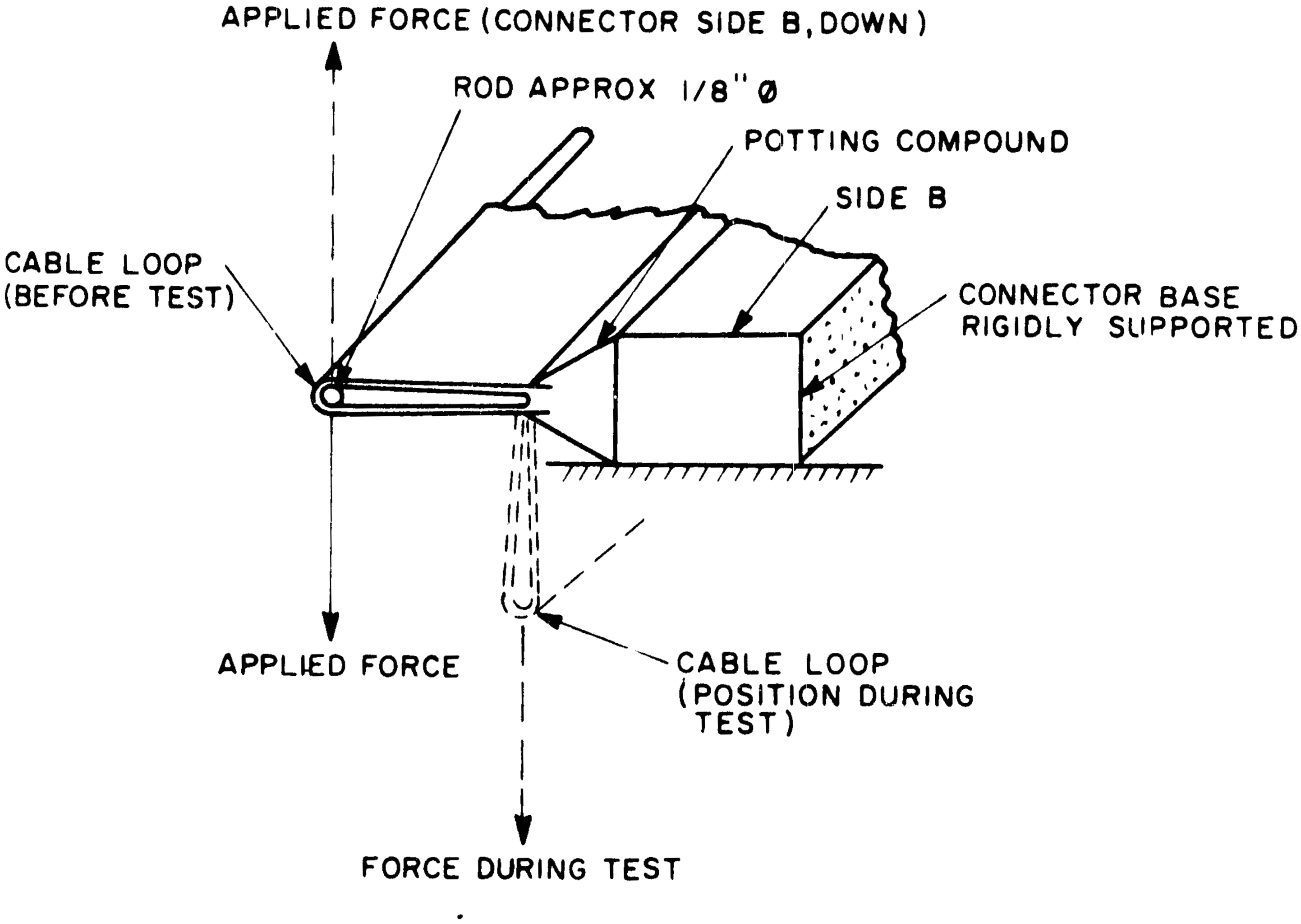



Figure 4-13. Pull Test Set-Up OUA Flexprints

## VISUAL INSPECTION CRITERIA

Inspection Requirements for KIC Part Numbers 1012519, 1012520-1 and 1012520-2:

1. Inspection is to be performed under 5x magnification. Greater magnification may be employed only to verify seemingly suspected conditions.

2. A minimum of .010 separation shall be maintained between conductors, and between any conductor and any edge.

3. Slivers and/or burrs emanating from conductors shall not extend beyond 10% of the minimum conductor separation width. Conductor edges shall be reasonably straight, however, irregularities due to burrs, nicks and etc. that do not violate minimum space or conductor width, shall not be cause for rejection.

4. Black oxide coating of conductors shall be generally free from copper exposed areas resulting from scratches, rubs, or undercutting from etching. However, their presence shall not be cause for rejection if those conditions extend less than 20% of the conductor width. Total conductor width must still meet the .025 minimum requirement.

5. Contamination held to a minimum, and shall not, in any case, bridge conductors. Its presence shall not be cause for rejection, except where cable fails 1500 VDC high potential test. Where contamination exists, and tests are performed, Flexible Circuits, Inc. will certify that the cable has passed this test.

6. Surface of the teflon shall be smooth, continuous, and generally free of imperfections. There shall be no dielectric breakdown, and the test method shall not introduce surface imperfections.

7. Connector body (except base) jack screws and the exposed pins of the connector shall be clean and free of potting compound, mold release, and/or other foreign material.

8. Nothing herein shall be construed as a deviation/variation of the blueprint and/or applicable specification requirements.

9. Flexible Circuits, Inc. will maintain in-house procedures per manufacturing and inspection flow chart dated

10. Pinholes shall not be cause for rejection except when total conductor width across pinhole is less than .025". In addition, two or more pinholes located within any 3 inch length of conductor shall be cause for rejection.

NOTE: When 1500 V high potential test is required, it shall be applied only across those conductors in question.

11. A pull test shall be performed in each flexprint to verify potting adherence in accordance with the following procedure:

a. Rigidly support the connector body making certain the connector is not damaged.

b. Apply a force of 3.5 pounds as follows:

(1) Uniform force to the calbe via a smooth rod inserted through the cable loop.

(2) Force applied perpendicular to the face of the connector.

(3) Apply and remove force 5 times in each of the two directions.

c. Any separation between cable insulation and potting compound visible during or after these tests under 5x magnification shall be cause for rejection.

4.5.2.6 Purge Valves

PROBLEM - Difficulties had been encountered with the purge valves (see Figure 4-14) in seal failures and flow stoppage.

ACTION AND RESULTS - KI now opens and closes each valve five times at the panel assembly level and final OUA level. The valves are leak checked and checked for flow stoppage at the two assembly levels. In addition, a gas injection valve (Figure 4-15) was installed in the purge valve and shipped with the units. KI also recommended the addition of a flowmeter (see Figure 4-16) to the field purge kit. This will readily disclose whether there was any flow stoppage and the amount of flow during purging.

4.5.2.7 Manual Adjust Knobs

PROBLEM - The "pop-out" feature of the Manual Adjust knob was occasionally sluggish and, at times, inoperative. The radial operation of the knob was tight. Beryllium and rubber particles were noted in the shaft threads.

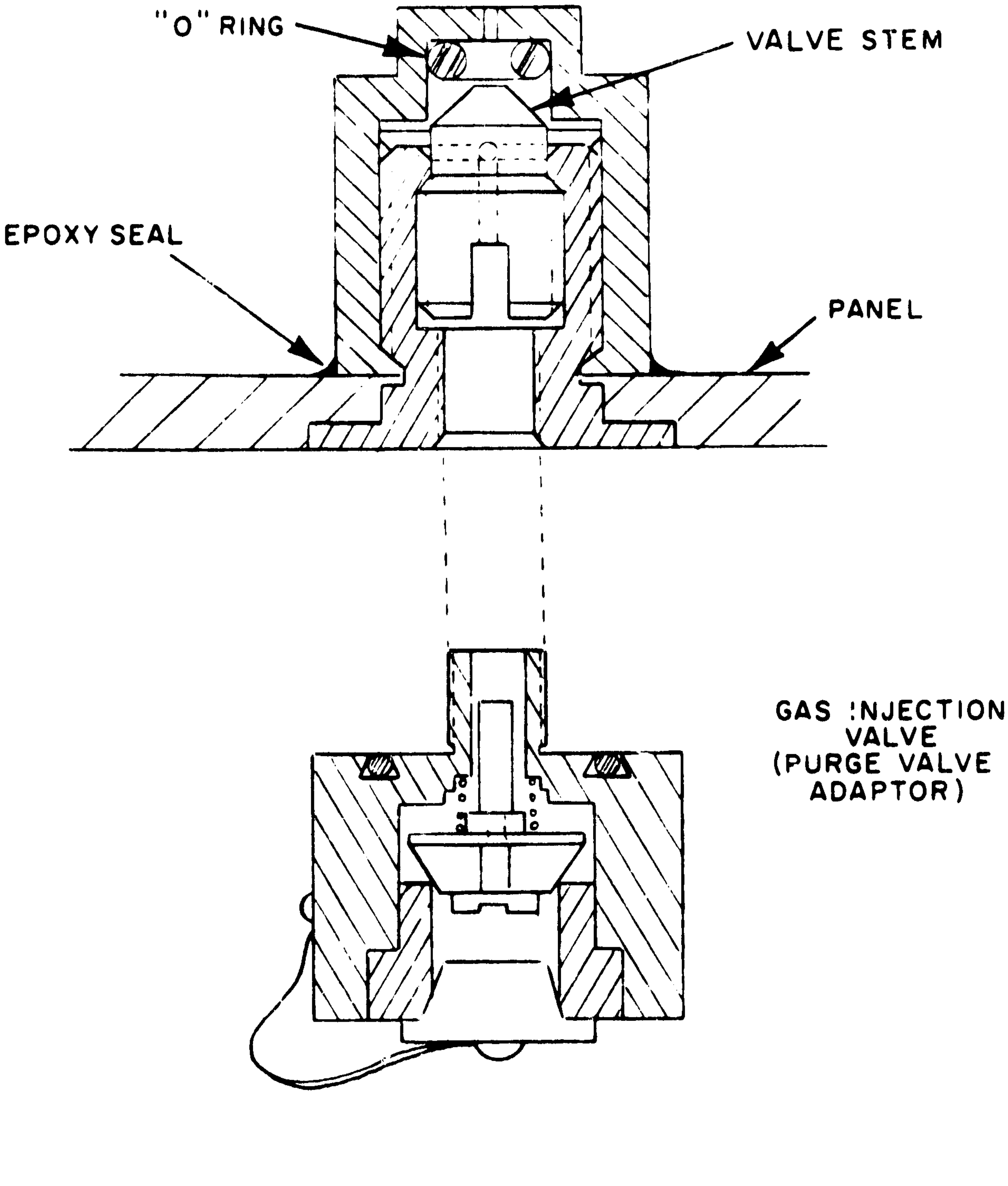



Figure 4-14. Purge Valve

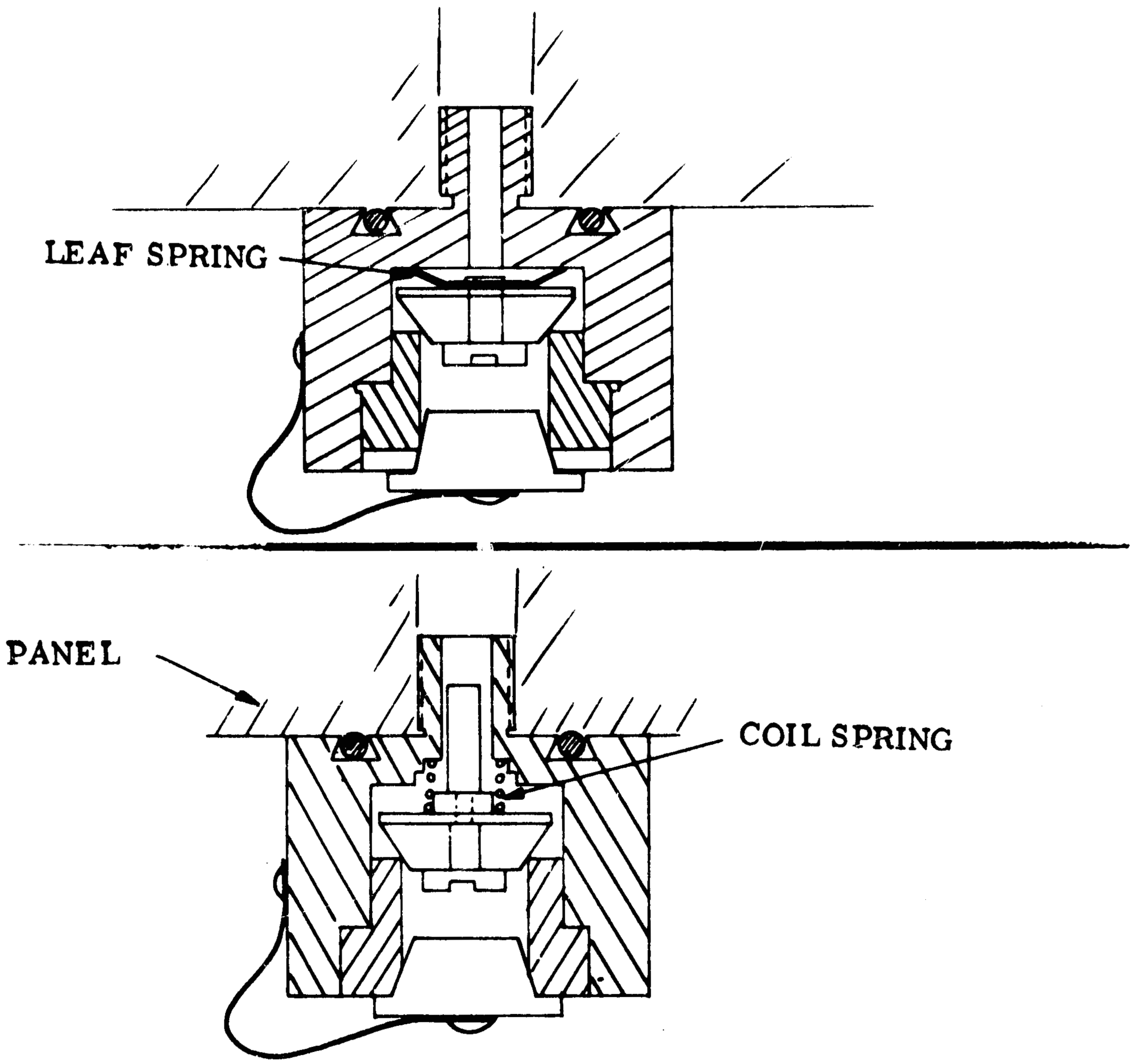



Figure 4-15. Gas Injection Valve

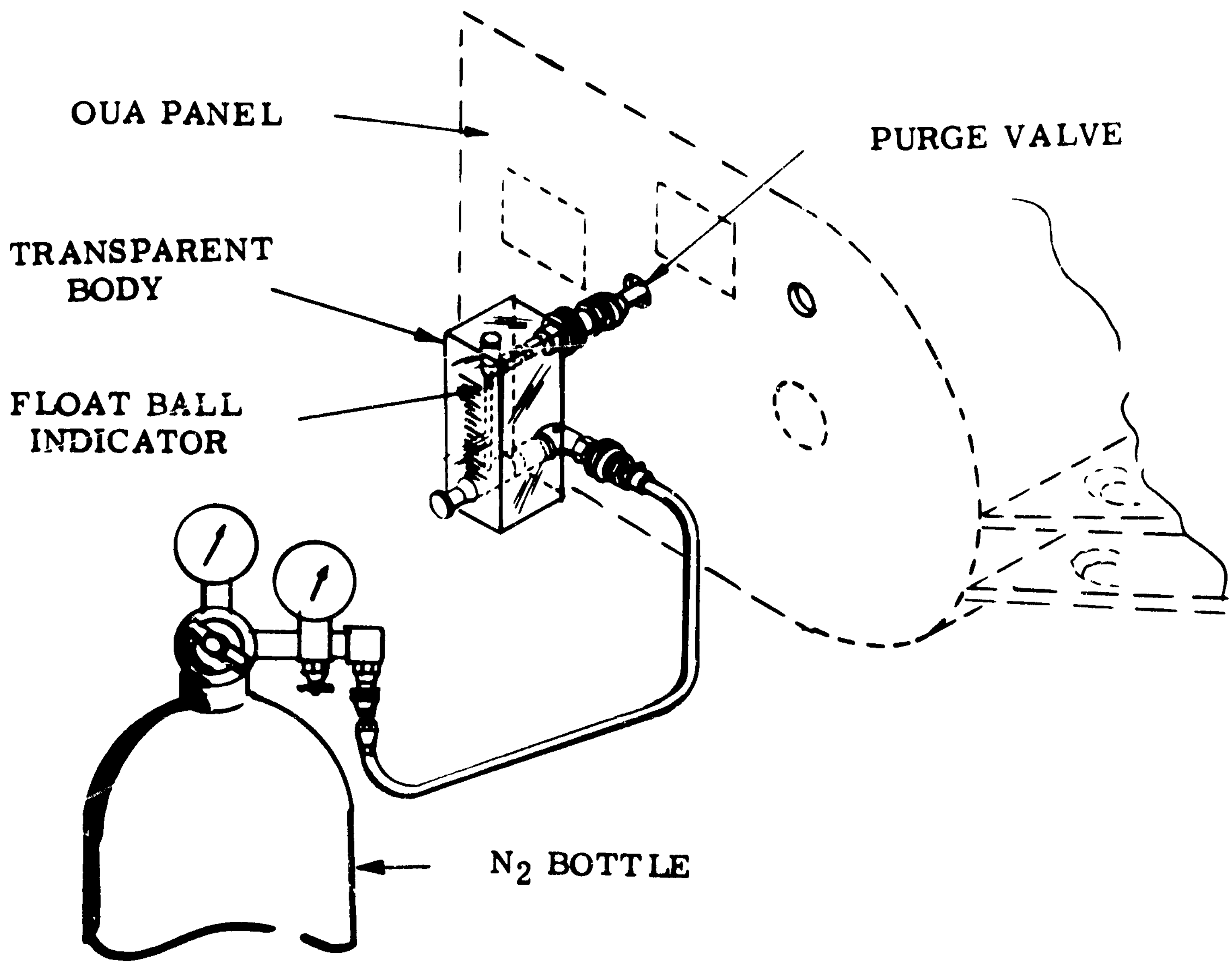



Figure 4-16. Flowmeter

INVESTIGATION SUMMARY - Results of tests performed, using a Beryllium test block simulating the front panel and production Manual Adjust Knob assemblies, was determined to be a lack of "O" ring lubrication, and contamination by "O" ring particles and Be material particles.

RECOMMENDATIONS - As a result of investigation, several proposals were submitted as corrective action. Figure 4-17 shows design revision.

1. (K753) - Remove sharp edge from beginning and end of shaft thread; polish shaft thread.

2. (K780) - Revise lubrication note on panel assembly.

3. (K1471)- Remove burrs and sharp corners from spring.

4. K731 - SCT Panel 2012728. Lead-in chamfer for large "O" ring to reduce number of rubber particles.

5. K732 - 2011784 Panel Assembly. Add spacer between spring and spring seat.

4.5.2.8 Luxorb

PROBLEM - A Luxorb failure (Failure Report 4476, dated 28 March 1965) was observed on the Block I spare, SN 12. The OUA was examined after thermal-vacuum and solar exposure. It was discovered that the Luxorb in the lens assembly had bubbled and run onto areas other than were it had been applied originally.

Some difficulty was also experienced by KI Manufacturing when the Luxorb would be slightly dissolved during the usual lens cleaning operations.

The Luxorb on the lens of AGE 201A failed during qualification testing where bubbling was observed after exposure to thermal-vacuum and solar radiation (Failure Report 9685, dated 20 April 1966).

INVESTIGATION - In May 1965, KI Reliability prepared several samples coated with Luxorb and exposed them to severe solar radiation with resultant bubbling, flaking and loss of material. MIT/IL was informed of these results.

KI then prepared a TDRR proposal (K694 dated 11 March 1966) for replacing the Luxorb on the lens assembly with 3M Black Velvet paint. A proposal to remove the Luxorb from the prism assembly was not submitted at that time, as no failures had been found on the prisms and Luxorb is more desirable than the 3M paint, from an optical point of view, on the prism assembly.

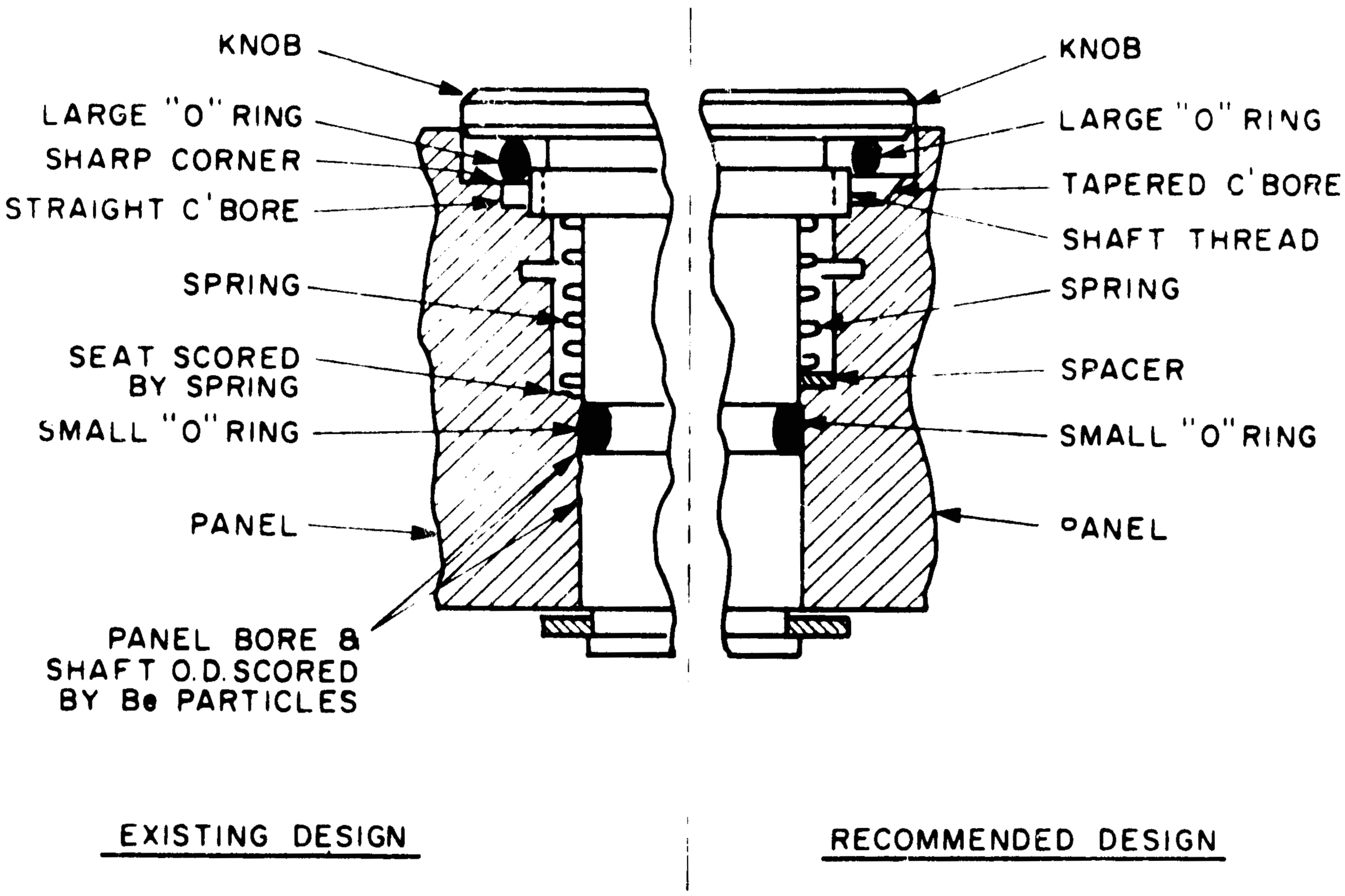



Figure 4-17. SCT Manual Adjust Knob

MIT/IL responded to further KI questioning the use of Luxorb by approving the TDRR (No. 28691 approved 11 May 1966) on the basis that KI had difficulty in applying the Luxorb properly.

AC''.JN - The KI manufacturing change to 3M Black Velvet on the ] - : was effective on AGE 213 a~ per ECO 116963, dated 23 May 1966.

4.5.2.9 Optical Measurement of Mirror Mounting Surfaces

PROBLEM - A study was conducted to provide information concerning the condition of mirror mounting surfaces on OUA Sextants in connection with a separately conducted investigation of TDA shifts.

The study directed toward accomplishment of the following objectives:

a. Establishment of criteria for interpretation of interference fringe patterns obtained when an optical flat is placed in contact with three mounting pads simultaneously.

b. Empirical verification of theoretical criteria using laboratory test setup.

c. Photographic recording, and interpretation of patterns obtained with available production test equipment from mirror-mounting surfaces of OUA Sextant AGE's 205 and 206 (after lapping of surfaces for optical alignment), and of AGE's 210 and 211 (at subassembly levels prior to lapping).

ACTION AND RESULTS - The results obtained indicate that a significant degradation of flatness and coplanarity of mirror mounting surfaces can occur when the surfaces are lapped for optical alignment. While no attempt was made here to evaluate the impact of these findings on Sextant TDA shifts, the results did point up the necessity for closer control of flatness and coplanarity of mirror-mounting surfaces during the lapping procedure. Accordingly, in-process monitoring of these parameters on current and future production units will be accomplished by introduction of the requirement for the performance of the above described checks into the appropriate assembly alignment procedures.

For complete details of this study, reference Project Engineering Report, AE-66-013, "Interferometric Measurement of Flatness and Coplanarity of SXT Mirror Mounting Surfaces", dated 6 June 1966.

4.5.2.10 LOS Shift in Thermal-Vacuum Tests

PROBLEM - The precision angle measurement, SXT SLOS/LLOS, has been observed to change during the OUA exposure to thermal-vacuum-solar radiation. This change was first observed during the Block I qualification tests (report AA-65-232, dated 31 July 1965). The same shift was observed again during the Block II qualification tests (reports AA-65-245, 250 and 258).

This problem is not apparent on all OUA's as the precision angle measurement is made before and after, but not during thermal-vacuum exposure, and the angle returns to the preexposure, exposure value after room ambient temperature is restored. A setup was then prepared to monitor the performance of a regular production unit during final testing. The results of this test (see Figure 4-18), as well as the past qualification tests, indicate a shift of approximately 25 arc-seconds.

ACTION AND RESULTS - It was empirically discovered that a 20-pound preload on the trunnion axis bearings will cause a 25 arc-second offset. It is also known that the length and diameter of the trunnion drive shaft increase with higher temperature, see Figure 4-19, and that both these increases will tend to raise the preload on the bearings with a resulting change in the mirror mounting plane. A layout was then prepared, see Figure 4-20, using flanged bearings arranged so that an increase in shaft diameter will raise the preload, and an increase in shaft length will lower the preload. The contact angle will be selected (calculations shown approximately 17°) so that the two effects will offset each other, thereby eliminating this source of shift.

Additional testing was indicated before any change was implemented. Another OUA test, run with temperature and strain monitoring, was performed to assure that there were no causes of shift other than the bearing load. The flanged bearing configuration should be checked to optimize the cancellation effect of bearing load increase and decrease.

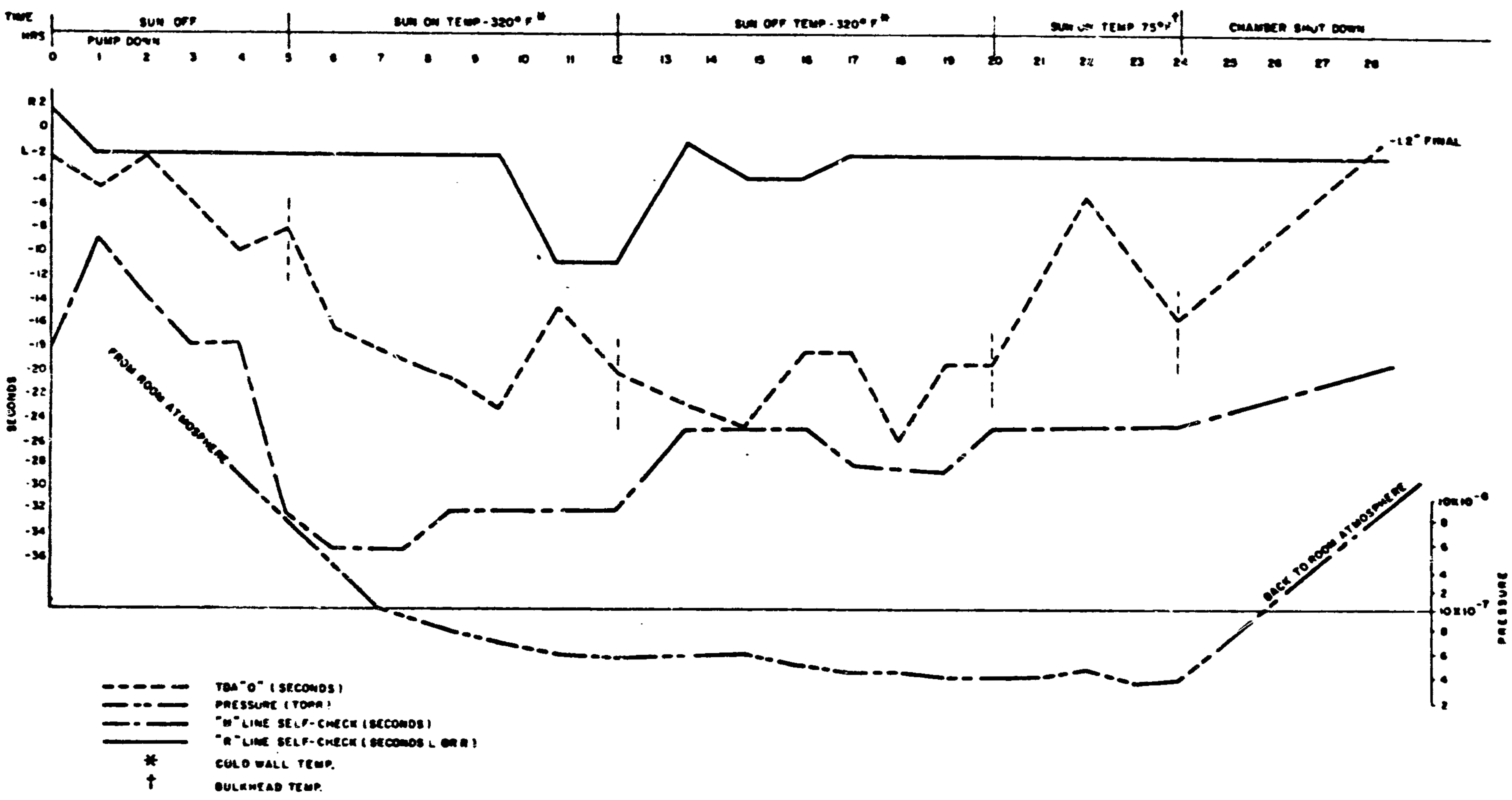
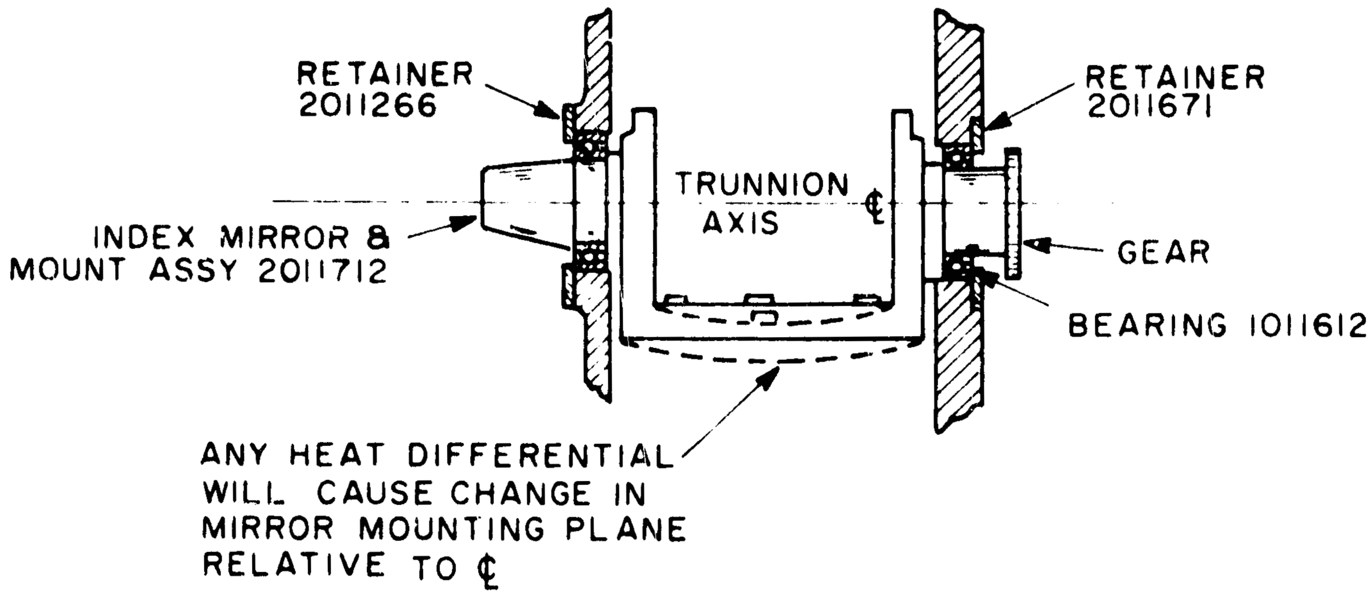



Figure 4-18. LOS Measurements During Thermal-Vacuum Exposure (AGE 204, SN 16 June 2, 1966)



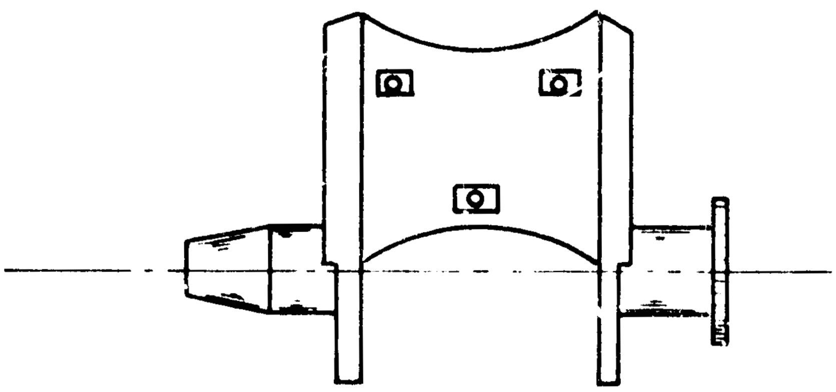



Figure 4-19. Sextant TDA Assembly

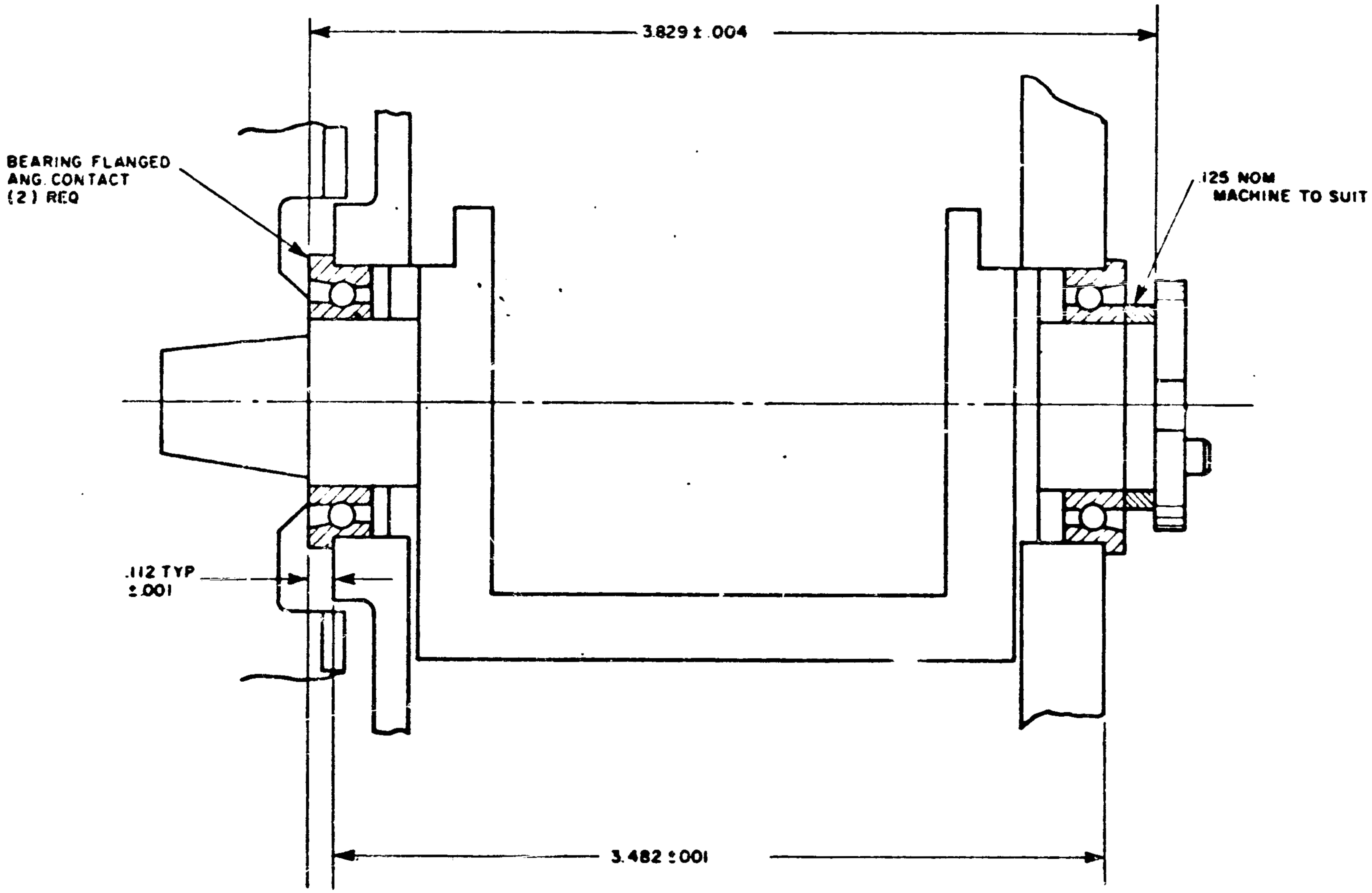



Figure 4-20. Proposed SXT TDA Bearing

4.5.2.11 Functional Tester Compatibility and MDA Tuning

PROBLEM - The compatibility of data between Functional Testers in the telescope shaft and trunnion axes has been a source of error in OUA testing.

ACTION AND RESULTS - Unlike the Sextant (SXT), the Scanning Telescope (SCT) accuracy depends on the response of the Motor Drive Amplifier (MDA). See Figures 4-21 and 4-22.

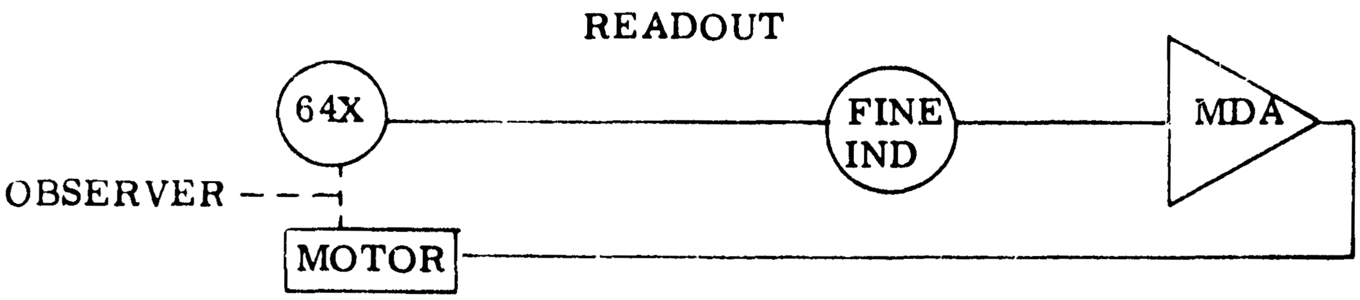



Figure 4-21. SXT Readout Loop

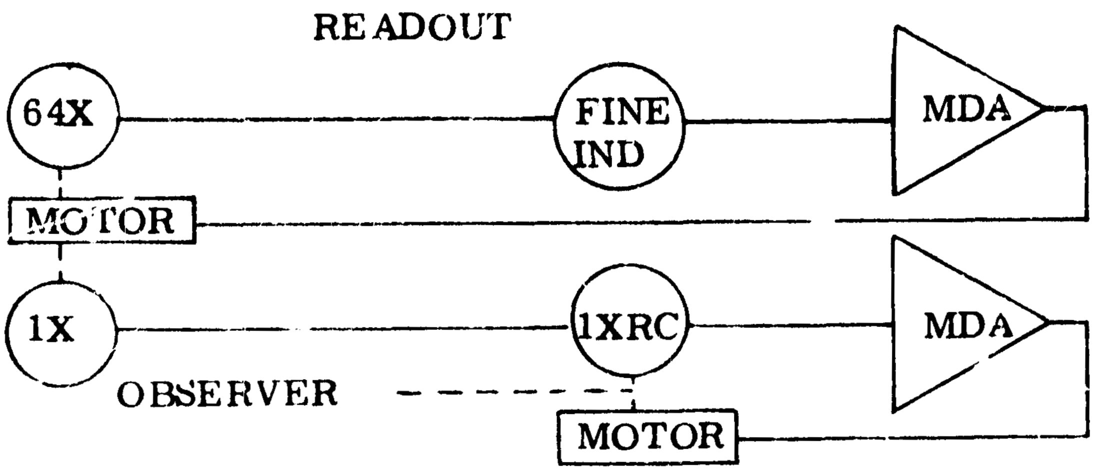



Figure 4-22. SCT Readout Loop

In Figure 4-21 the readout is taken from the same shaft that is being observed by the operator. In Figure 4-22, the SCT readout comes from the SXT shaft while the operator is observing the telescope shaft (Slave Mode). A modified method of tuning the MDA has been developed to make the response more nearly identical between amplifiers. The new procedure incorporates these basic criteria.

a. Overall in-phase gain approximately equal to 6000

b. Gain to quadrature adjusted to approximately equal to 500 and balance for 0 and π phase within 20 percent.

The data is presented in Table 4-12 indicate the improvement in compatibility achieved with the modified method of tuning.

Table 4-12

FUNCTIONAL TESTER COMPATIBILITY

| Original Amplifiers | SCT TDA Zero Error | Retuned Amplifiers | SCT TDA Zero Error |
|---|---|---|---|
| GSE No. 2 | .010 | FTE 103 | .0646 |
| GSE No. 3 | .044 | FTE 104 | .0569 |
| Max. Diff. | .034 Deg. | GSE No. 2 | .054 |
| | | GSE No. 3 | .060 |
| | | Max. Diff. | .0106 |

4.5.2.12 Anodize/Reanodize of Beryllium

PROBLEM - The anodizing of beryllium parts continues to present problmes. A tendency exists for some portions of almost any part that is black anodized to remain gray in color. This gray condition has been most troublesome on Eyepiece Housing 2012708, but has been less pronounced on the SXT and SCT Panels.

ACTION AND RESULTS - The degree of corrosive protection provided by a gray anodize was known with certainty at this time. Checks made by measuring the thickness of the gray areas show them to be within the requirements of the anodizing specification.

The standard test samples used for measuring thickness and salt-spray durability were not adequate to measure gray area performance, since the samples have not had the gray condition. Since the graying is believed to be due to tooling problems of configuratioon and wear, a special sample has been made up to reflect these problems as do the panels and the eyepiece housing. This sample was subjected to salt-spray, with special attention being given to the gray portions.

Uncertainty as to the feasibility of reanodizing beryllium parts has been largely resolved. Three SXT Panels that were rejected for inadequate anodize coverage (as measured by very light gray in some areas) have been reanodized, and the result is a better than average anodize condition. These panels were reworked by stripping off the original oxide coating and reanodizing on bare metal. Dimensional changes are less than 0.001 inch per surface.

Based on the results of this rework, that reanodizing of beryllium appears to be a practical process.

4.5.2.13 Sextant Index Head Assembly

The final design of counterweight PN 2012723 was established as described in Engineering Report AE-66-001. This part is of fixed size and shape requiring no special balancing procedures for installation. It was satisfactorily shown on AGE 124 and AGE 201 to compensate the imbalance created by the deletion of electronics.

4.5.2.14 Thermal Protective Shields (Contamination Prevention)

PROBLEM - Design and Evaluation of Astrosextant Passive Thermal Protective Shields.

BACKGROUND - KI was directed per KD-2319 to implement the following effort on protective covers for the OUA. (These covers are interfaced with the ablative covers, and provide protection from reaction control system contamination.)

a. Evaluate a design previously generated by MIT/IL.
b. Develop alternate design solutions.
c. Provide estimates of cost and schedule impact for each of the aforementioned designs.

ACTION AND RESULTS- An engineering review of the MIT/IL design was held 9 September 1966, and Design Review Report No. 29 was issued summarizing the comments on the review.

Apollo Project Design personnel undertook the development of alternate protective cover proposals. One of these proposals was reviewed 15 September 1966, and Design Review Report No. 30 was issued accordingly. Two other concepts of protective covers were also developed to the level of proposal layouts.

Flip charts were made up for each of the design approaches, presenting a sketch of the design and a summary of the advantages and disadvantages of each. These charts were used in the Quarterly Presentation at AC Electronics.

Estimates of cost and schedule impact were generated at KI for each of the proposed designs. A comprehensive report, "Contamination Protection Study - Ablative Parts", AE-66-021, was written to present a complete comparative picture of all the designs. For further details on the relative merits of the various designs, reference AE-66-021.

4.5.2.15 Bearings and Lubrication

Test performance of the ball bearings and lubricant used in the OUA has not demonstrated a need for periodic maintenance or other special procedures. However, there have not been any life tests to provide data on performance after extended periods (two years or more) in a static condition of storage, either before or after assembly. Despite favorable performance to date, storage life tests should be performed to dispel all reasonable doubt concerning lubricant and bearing life.

BACKGROUND-Due to the finite life of the bearing lubricant and to the relative delicacy and criticality of the ball bearinggs, KI Engineering is aware of the possible need for some form of periodic maintenance to prevent bearing failures in the OUA. In order to predict the life of the ball bearings, study was made of the bearings themselves, the lubricant properties, and the performance of the lubricated bearing in actual application. Relevant information was presented in each of these areas.

LUBRICANT PROPERTIES-The ball bearing lubricant is a mixture of two General Electric components: G.E. Silicone Oil, Type F-50, 1012050, and G.E. Silicone Grease, Type G-300, 1012051.

Properties of the oil that might result in lubricant failure are as follows:

a. Life - 5-year shelf life

b. Temperature range - from -100°F to + 450°F

c. Vacuum durability -0.34% weight loss in 114 hours at 150°F and $10^{-5}$mm Hg.

These performance levels are fully adequate for OUA requirements, especially since the vendor had expressed confidence that the useful life of the oil was considerably greater than the five years stated on the drawing. The only OUA application that might constitute a significant test of lubricant performance is the relatively high speed of the bearings in the 1012156 motor-tachometers. Actual performance of the lubricant motor special conditioning has been free of failures, despite the fact that estimated lubricant temperatures over 300°F are reached during these runs. It must also be recognized that these tests are of short duration, some 23 hours.

Thermal tests run on OUA's have shown that in operation the bearing (lubricant) temperatures do not approach the +450°F ceiling specified on the 1012050 silicone oil drawing. No deterioration of the oil was noted, either through breakdown of bearing performance or other evidence. These tests involved severe conditions (36 days total exposure to thermal-vacuum cycling), but do not provide a measure of passive life durability.

Lubricant in storage at KI, due to the continuing manufacturing activity, has not been left undisturbed for sufficiently long periods of time to provide meaningful test results of lubricant life.

The 1012051 Silicone Grease, General Electric Type G-300, might be subject to failure in the following areas:

a. Vacuum weight loss: 3% weight loss after 100 hours at 150°F and pressure of $10^{-5}$mm Hg.

b. Temperature range: -100°F to +450°F.

c. Life: One year shelf life; 3 years functional after use.

Test performance of the OUA showed no evidence of failure of the grease, as in the case of the silicone oil. However, there have been no test conditions that provide a measure of life of the grease under long term storage.

Since the grease exhibits a tendency to separate when not in a state of movement or agitation, its life under static conditions (shelf life) is shorter than life in use. However, this can be corrected through the simple expedient of stirring or shaking before application.

The principal function of the 1012051 grease in the grease-mixture is to provide a barrier to excessive creep of the 1012050 oil. Since creep is a function of time, the most effective test of the results of creep is to observe the bearing over a long period of time and check for the remaining oil film. Combined times of bearing storage at KI, followed by the build cycle and by field testing have resulted in some total bearing life times up to two years. Although tests of bearing performance per se have not been run on these units, bearing and lubricant performance as determined by general OUA testing has been satisfactory.

BALL BEARINGS(EXCLUSIVE OF LUBRICANT CONSIDERATIONS) - The actual applied bearing loads in the OUA are well within recommended dynamic load ratings. The only recorded bearing failures to date have been caused by the presence of foreign matter in the bearing, or by failure of the wrong type of retainer. Due to the safe ratio of actual loading to permissible load, the OUA bearings performance becomes wholly dependent upon cleanliness and the adequacy of the lubricant.

There is one area in which long term storage conditions could prove to be critical-namely, the high axial loads applied to the large shaft axis bearings. The durability of these bearings in terms of possible brinelling of the balls and races due to axial loads (although within bearing manufacturers' recommended levels) can only be finally determined by storage life testing.

CONCLUSIONS - Since no conclusive tests of lubricant and bearing life over long storage periods have been performed, it was recommended that these tests be initiated immediately. The results of performance under operating conditions are known to be satisfactory but, due to aging considerations for the lubricant and to the separation tendency of the grease, a long period of two years or more could prove to be the critical condition. Use of an OUA that has been in storage for some time could provide an advantage in that storage time to date may cover several months of the proposed two year period. Such a test, however, would render the OUA involved unavailable for any functional application during the test period.

It was recommended that two gearbox assemblies be tested and set aside to provide a means of submitting bearings and lubricant to storage conditions and testing performance after one or two years. This approach is more feasible and economical than use of an OUA, but provides no check of the larger, axially loaded shaft bearings. These could be checked by use of a fixture, or of scrap parts needed to make up a shaft bearing and telescope tube subassembly.

Aside from existing controls of storage conditions, no maintenance procedures are recommended. Since the principal causes of bearing failure are believed to be grease separation, oil creep, and brinelling of balls or races, the only recommended procedure would be periodic operation of the OUA. This would serve to mix the lubricant and redistribute the bearing loads that might cause brinelling. None of the OUA's delivered have experienced an extended period of storage not interrupted by operating time.

4.5.2.16 SXT Vibration Shifts

There were numerous factors which potentially contributed to SXT Vibration Shifts. The following areas were investigated to determine the source of "shift" problem.

1. Resolvers
2. SXT Head Mirrors
3. Trim Module
4. SXT Head Mounting
5. OUA Mounting on PTF
6. PTF Repeatability
7. Functional Tester
8. Operator Repeatability

One of the requirements for the Apollo OUA is that the Sextant (SXT) shaft axis (SDA) resolver be aligned to the Star Line of Sight (STLOS) with a ± 10-second maximum error at zero degrees of shaft angle. Kollsman has complied with this requirement on all systems shipped. However, repeated tests of the SXT SDA resolver alignments on the same OUA have indicated repeatability variations as high as ten seconds of arc.

Additional testing of OUA's and checking of Factory Test Equipment (FTE) has not provided a conclusive answer as to the source of this apparent shift. Therefore, sources of possible shifts have been examined in detail to pinpoint areas for further tests and evaluations.

In the Apollo Command Module (CM), the OUA will be used to provide STLOS information to the Guidance Computer. The operator will adjust a hand controller until the navigational star in question is centered in a reticle pattern. The information concerning the angle between a reference position on the CM and the star is then supplied to the Guidance Computer by means of a precision, multispeed resolver mounted on the OUA SXT shaft. Figure 4-23 describes this operation.

DESCRIPTION OF TEST - The SXT SDA resolver alignment is tested by using the Precision Test Fixture (PTF) as a positional reference, and by reading the resolver position via a commercial resolver bridge located in the Functional Tester.

More precisely, the rotary table on the PTF is set to zero. The SXT is then autocollimated off the 57° azimuth mirror on the rotary table. This is accomplished by backlighting the SXT reticle, and projecting the reticle on the 57° PTF mirror. When the inspector sees that the reticle and the reflected reticle image coincide the SXT SDA is correctly positiioned. The SXT SDA 16X resolver position is then determined by balancing the resolver output against a Decade Resolver Bridge (DRB), observing the null on a Phase Angle Voltmeter (PAV), and reading the resultant angle on an Angular Display Unit (ADU). The three pieces of resolver test equipment are located in the Functional Tester. Figure 4-24 describes the test setup.

RESOLVER SHIFTS - The SXT SDA resolver is a multispeed (1X and 16X) precision unit manufactured by Clifton Precision Products of Clifton Heights, Pa., NASA PN 1012066.

The specifications for this resolver are contained in PS 1012066B. The angular error of the 16X winding is required to be within 20 seconds of the 1X mechanical shaft. More significantly, from the point of view of the subject shift problem, the specification contains requirements for angular repeatability after the resolver is subjected to various environmental stresses. These requirements are summarized in Table 4-13.

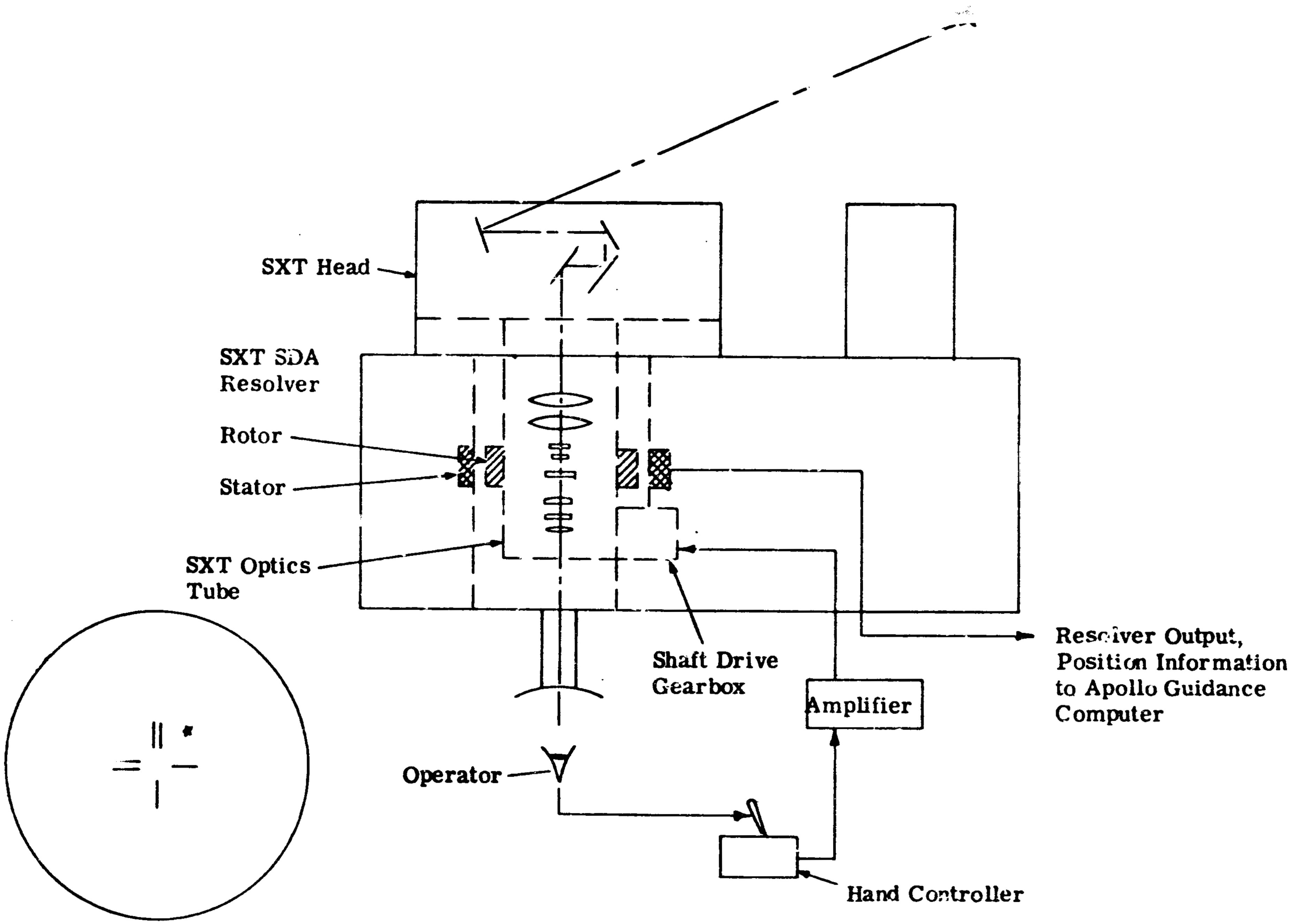



Figure 4-23. Operation of OUA

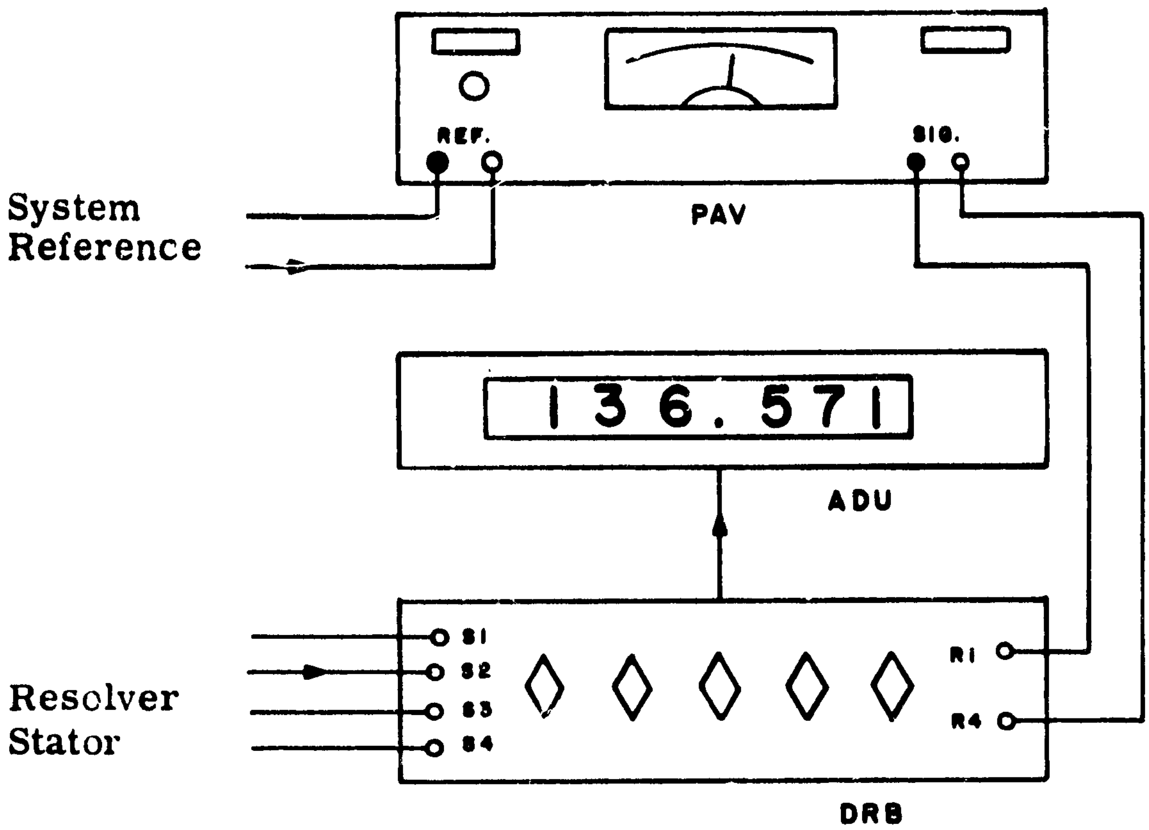



Figure 4-24. Resolver Test Setup

Table 4-13

ANGULAR REPEATABILITY REQUIREMENTS

| Environment | 16X Repeatability |
|---|---|
| Vibration, 10 cps to 2000 cps, profile range from .008 $g^2$/cps at 10 cps to .06$g^2$/cps at 70 cps through 420 cps, reducing to .013$g^2$/cps at 2000 cps. | 2 arc seconds |
| Shock 50g, 12 shocks, 6 milliseconds. | 2 arc seconds |
| Low temperature -45.5°C, 48 hours | 5 arc seconds |
| High temperature +93.3°C, 48 hours | 5 arc seconds |
| 52°C Temperature, 4 hours | 4 arc seconds |
| Humidity, 95%, 68°F to 160°F cycles, 7 cycles, 168 hours | 5 arc seconds |
| Thermal Vacuum, $10^{-7}$mm Hg at -45.5°C and + 93.3°C | no repeatability requirement |
| Endurance, 464 hours cycling from +37.8°F to -34.5°F | no repeatability requirement. |

At the conclusion of the testing, listed in Table 4-13, the angular error of the 16X resolver must remain within 20 seconds of the 1X resolver shaft.

These qualification tests are presently in process at Kollsman but no test cycles have been completed to date. The vibration levels required for qualification are approximately three times greater than those required for OUA sell-off.

MIT/IL has performed vibration tests, during the week of 14 March 1966, on one of the subject resolvers using vibration levels that were twice the levels required for the optical unit. There was no shift in the resolver electrical angle as a result of this vibration. Vibration tests at MIT/IL on a completed OUA have produced shifts.

RESOLVER MOUNTING-The resolver rotor is mounted to the telescope tube assembly by means of the rotor locking nut, PN 2011311 which is torqued to 100 in-lbs and then cemented with Loctite as per route and tool book 2012736. See Figures 4-25 and 4-26 for rotor and stator mounting details.

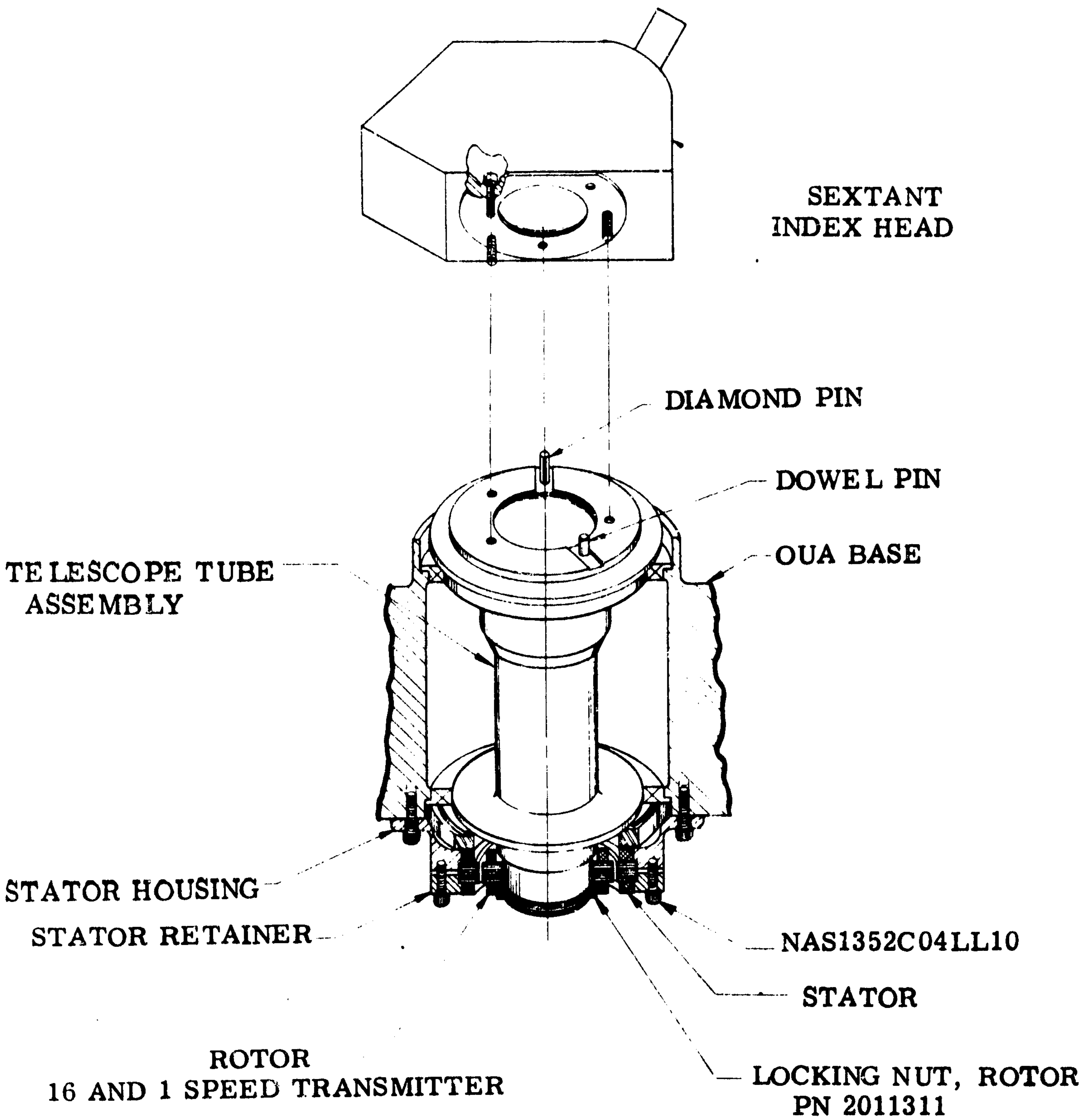



Figure 4-25. SXT Design Features Affecting SXT SDA Alignment

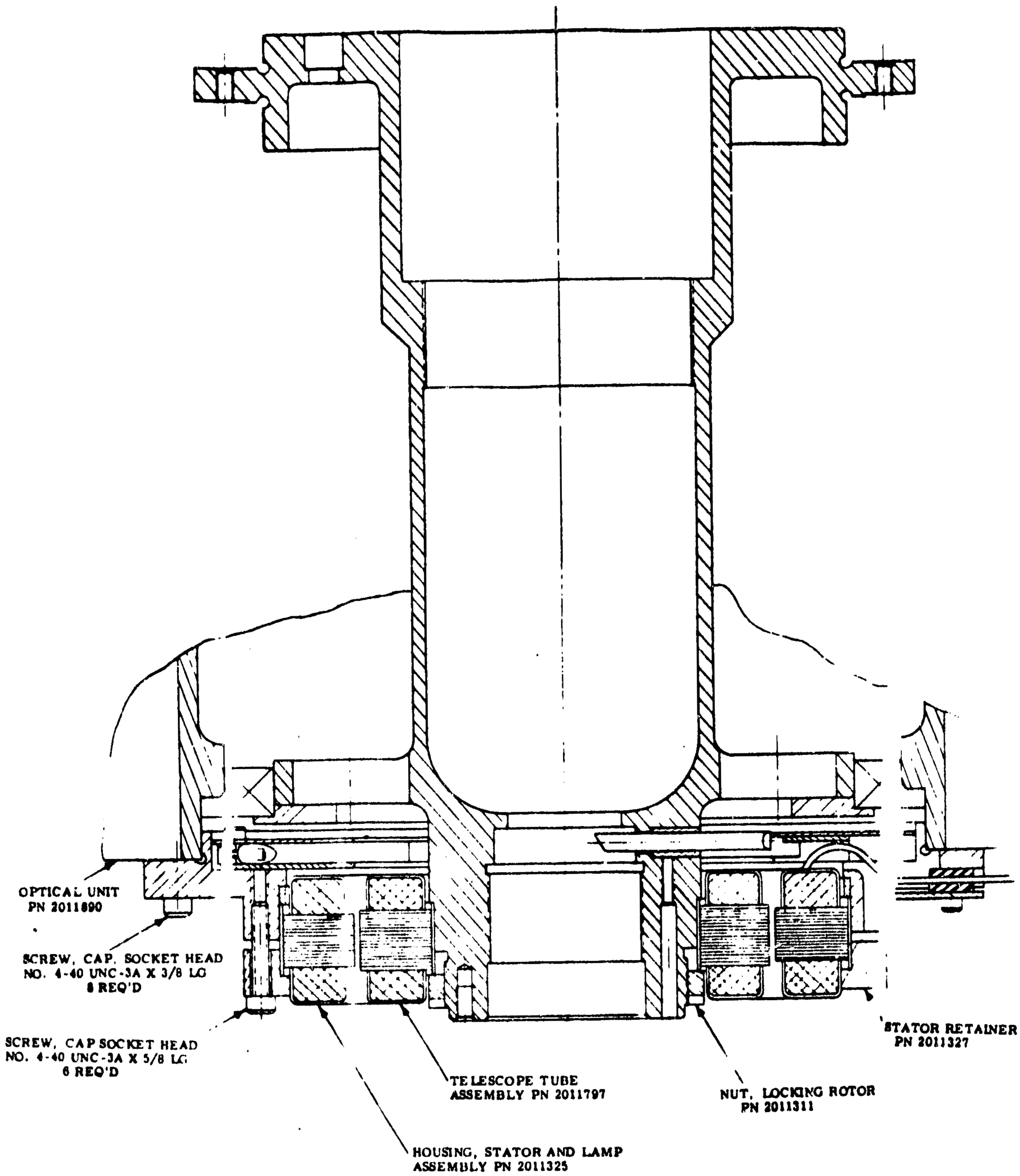



Figure 4-26. SXT SDA Resolver Mounting

The resolver stator is mounted to the stator housing, PN 2011325, by clamping it with the stator retainer, PN 2011327, which is held by six No. 4 long lock screws.

The stator housing is fastened to the OUA base by eight No. 4 long lock screws.

The three interfaces discussed in the previous paragraphs are possible sources of shift.

A joint NASA, KI, AC and MIT/IL meeting at MIT resulted in the release of official TDRR's plus additional proposed changes (all MIT generated) to change resolver mounting hardware and to raise the torque on resolver mounting screws to high values in order to reduce the possibility of resolver shifts during vibrations. Review of these actions by KI revealed technical and configuration errors on both the official and preliminary documents. Counter-proposals by KI resolved the problems.

Proposal No. K-1445-2 covers a request for changing the resolver mounting screws and increasing the torque on these screws in order to reduce the possibility of resolver shifts during vibration. See Figure 4-27 for details of resolver mounting hardware changes.

SXT HEAD MIRROR SHIFTS - (Figure 4-28) - Actually, this change started in February 1966 when Manufacturing experienced a "screw" bottoming condition" at the 2011712 assembly. The three screws (NAS1352CO4LL6) which hold Index Mirror, PN 2011259, was found to botton on the back of the relief slot in the mirror. This caused mirror strain. Engineering study confirmed that tolerance buildup could result in an interference condition.

TDRR proposals were sent to MIT/IL to correct the condition by lengthening the Mirror Bushing. This particular approach was chosen (as opposed to special screws or a special washer under the screw head) because the investigation also revealed that the Wave Washer, PN 2011213, was being substantially overstressed. Changing specific bushing dimensions would then change the available space for the Wave Washer at assembly and optimize "load" conditions.

Also transmitted to MIT/IL was a TDRR proposal to change the Wave Washer drawing, PN 2011213, which was found to be in error. Calculations indicated that load requirements were incorrect. Tests were run which verified the calculations and also confirmed that a new value for the Wave Washer compressed height at assembly (per aforementioned bushing change) was desirable.

SXT HEAD MIRROR MOUNTING - Proposal No. K-769 covers a request for changing the configuration of the mirror bushing on the 2011712 assembly to eliminate an interference between the end of the mounting screw and the back of the relief slot in the Index Mirror, PN 2011259, and an enlargement of the bushing O.D. to reduce the amount of potential mirror shift during vibration.

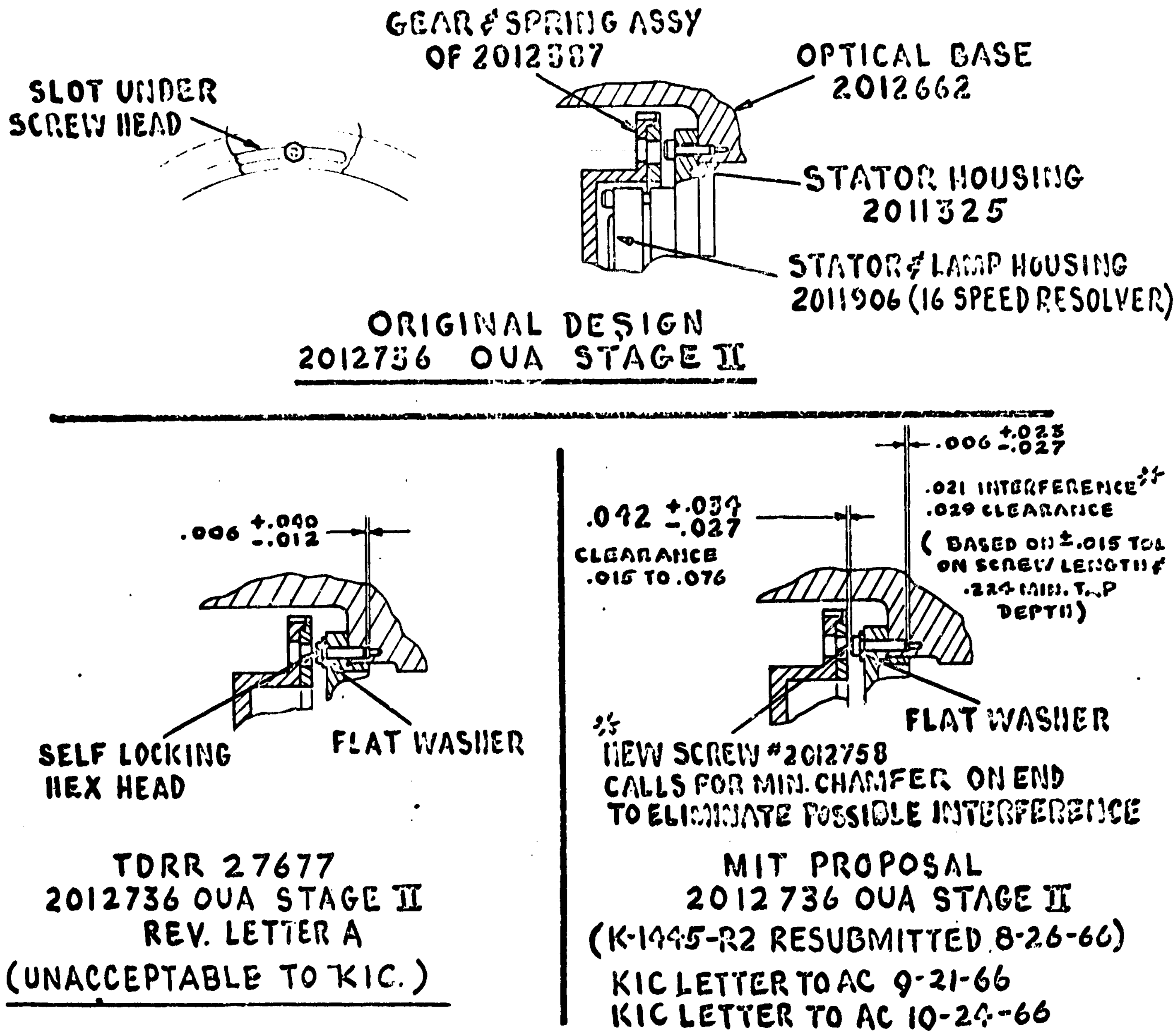



Figure 4-27. Mounting of 16 Speed Resolver at 2012736 Stage

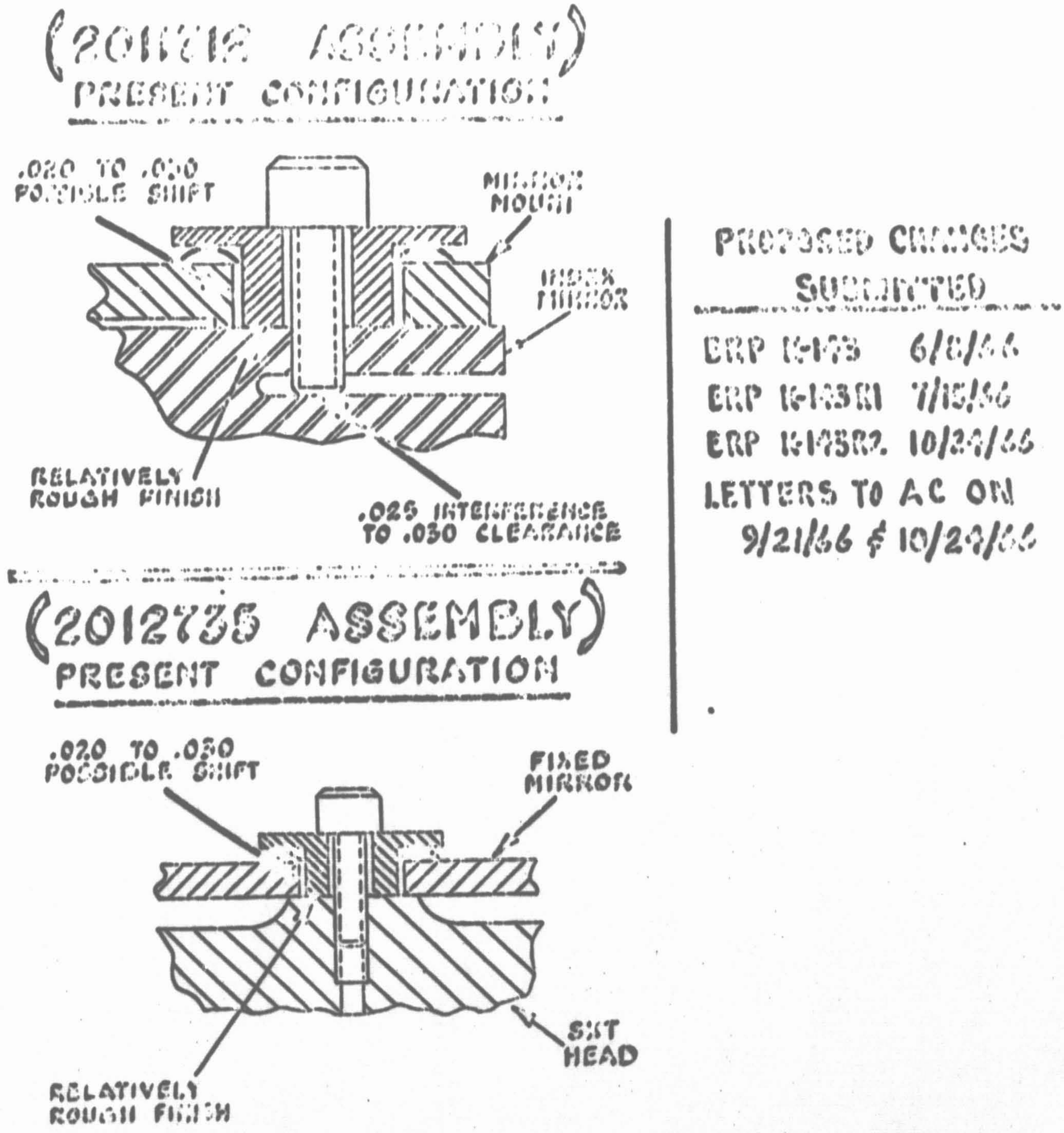
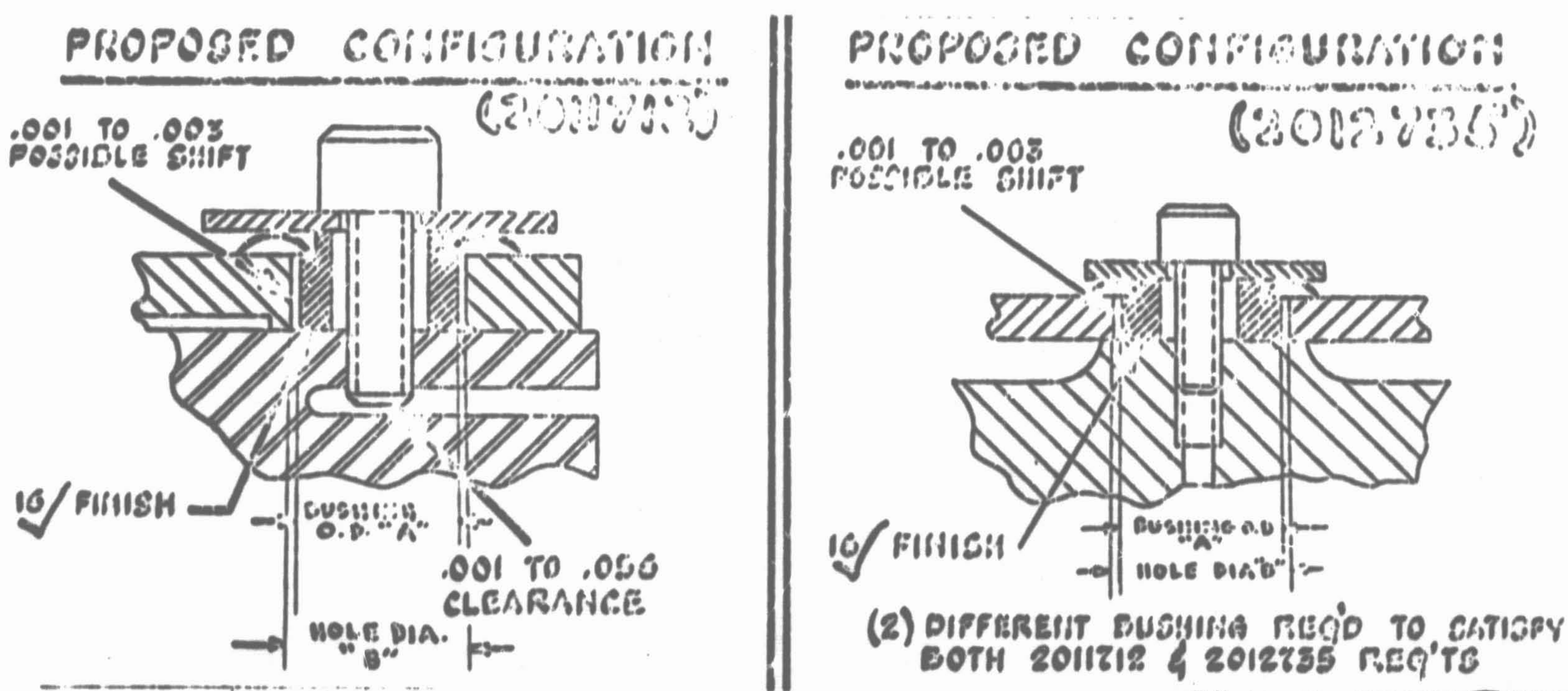



Figure 4-28. SXT Head Mirror Mounting (Sheet 1 of 2)




APPLICABLE TO BOTH 2011712 & 2012735 ASS'YS

| BUSHING O.D. "A" | HOLE DIA "B" | RESULTANT CLEARANCE |
|---|---|---|
| .214 / .213 | .216 / .215 | .001 / .003 |
| .213 / .212 | .215 / .214 | .001 / .003 |
| .212 / .211 | .214 / .213 | .001 / .003 |
| .211 / .210 | .213 / .212 | .001 / .003 |
| .210 / .209 | .212 / .211 | .001 / .003 |

Figure 4-28. SXT Head
Mirror Mounting (Sheet 2 of 2)

Proposal No. K-770 covers a request for changing the configuration of the mirror bushing on the 2012735 assembly to enlarge the O.D. of the bushing thus reducing the amount of potential mirror shift during vibration.

Proposal No. K-681-1 covers a request for changing the Wave Washer drawing, PN 2011213, which was found to be in error.

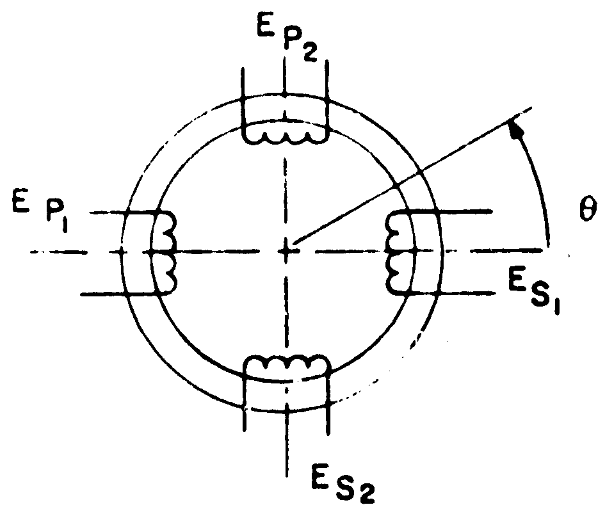
TRIM MODULE - The resolver trim module assembly, PN 2011946, has been subjected to the following environmental tests to determine whether the module is a source of resolver zero shift. The module was subjected to random vibration along the three mutually perpendicular axes at levels called for in the acceptance test procedure in JDQ 03016, Rev. B. During vibration, the module was functionally tested with the outputs to equivalent resistive loads, continually monitored.

The trim module was then exposed to a thermal vacuum cycle simulating optical base conditions which would be experienced by the module, (see Figure 4-29) and the module outputs were continuously monitored.

Finally, the module was exposed to a second series of random vibrations. The three axes along which the module was vibrated were those called for in JDQ 03016, Rev. B, for the OUA. The test fixture in this case simulated the actual mounting position of the trim module on the OUA. The module outputs were continually monitored during this vibration.

The first vibration caused the 16X output of the module to vary ± 1 millivolt (mv) about the 50 mv initial setting. The same magnitude of change was observed during the thermal vacuum test. The second vibration resulted in variations of ± 0.5 mv. In all cases the trim module output was within one mv of the initial setting after exposure to the environment.

To calculate the angular error caused by a one millivolt variation, proceed as outlined in following paragraphs.




where

| | | |
|---|---|---|
| $Ep_1$ | = | Reference input |
| $Ep_2$ | = | Trim module input |
| $Es_1$ | = | Cos output winding |
| $Es_2$ | = | Sin output winding |
| $\theta$ | = | Resolver angle |
| N | = | Resolver speed (16) |
| K | = | Resolver transformation ratio |

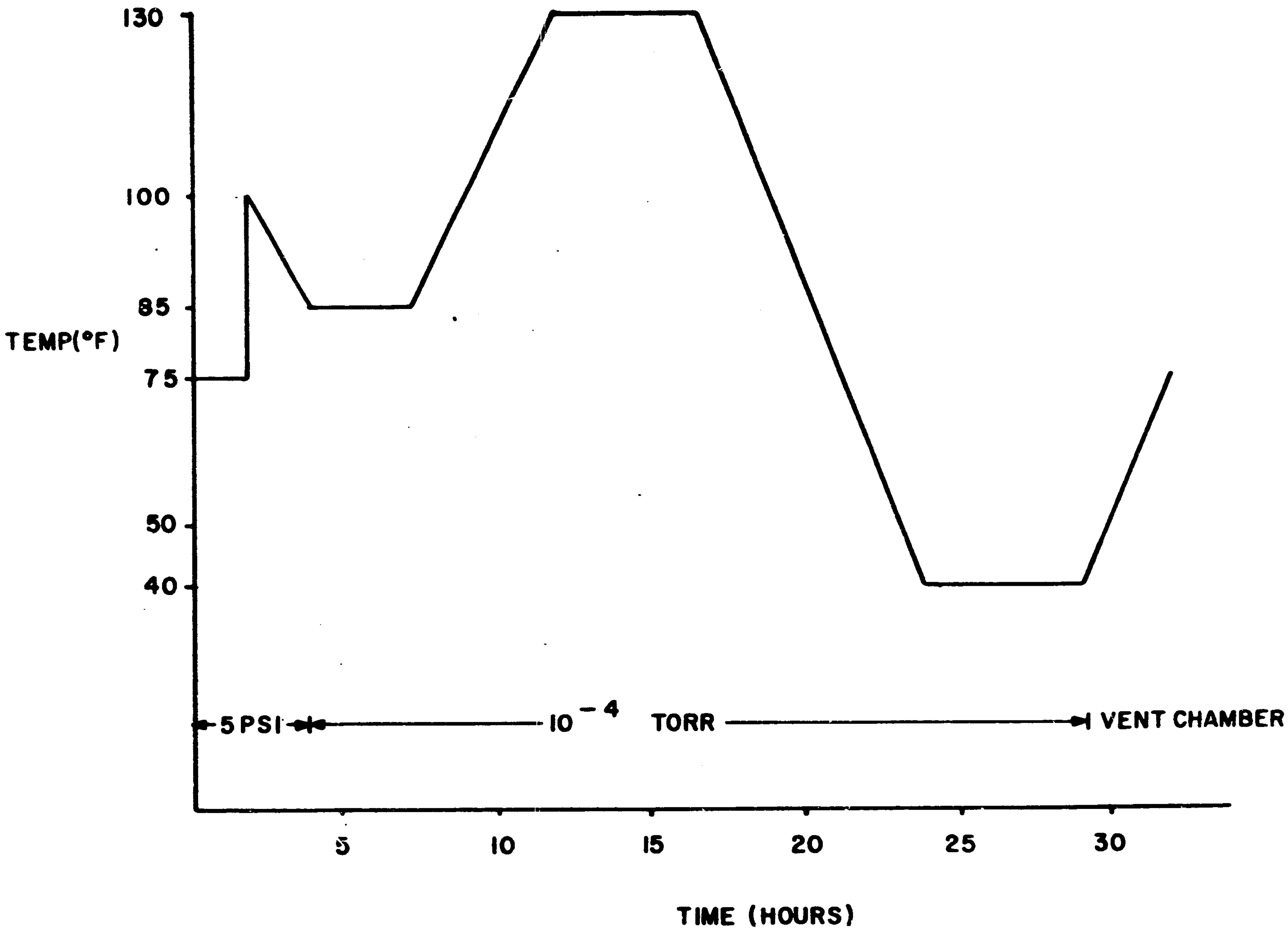



Figure 4-29. Thermal Vacuum Test Schedule

$$Es_2 = K(Ep_1 \cos\theta + Ep_2 \sin\theta)$$

$$Es_1 = K(Ep_2 \cos\theta - Ep_1 \sin\theta)$$

at electrical zero, $Es_1 = 0$

therefore $Ep_2 \cos\theta - Ep_1 \sin\theta = 0$

and $$\frac{Ep_2}{Ep_1} = \frac{\sin\theta}{\cos\theta} = \tan\theta$$

For resolver shaft motion of one second from electrical zero, $\theta$ = 16 seconds for the 16-speed resolver windings. For $\theta$ less than 10°, $\tan\theta \approx \theta$ radians. Therefore

$$\frac{Ep_2}{Ep_1} = \tan 16 \text{ sec} = 0.0775 \times 10^{-3}$$

When $Ep_1$ = 28 volts, $Ep_2 = 2.2 \times 10^{-3}$ volts. Therefore a one-millivolt change in $Ep_2$, the trim module voltage, will cause a 0.45 second angular change.

SXT HEAD MOUNTING The SXT head is secured by three screws and two pins to the telescope tube, which is mounted through bearings to the optical base. Two pins, a diamond and dowel, are pressed into the mounting surface of the tube. These pins locate the SXT head on the tube and are the sole means of preventing rotational shift, other than the screw tension.

The dowel pinhole in the SXT head, PN 2011252, is bored 0.1882 to 0.1887 inch. The dowel pin, MS 16555 can vary from 0.1876 to 0.1878 inch which leaves a maximum clearance of 0.0011 inch.

The diamond pinhole is bored at 0.2497 to 0.2499 inch. The diamond pin, PN 1011769, long-axis is 0.2490 to 0.2493 inch, which leaves a maximum possible clearance of 0.0009 inch.

The nominal distance between the two pins is 2.778 inches. The maximum radial freedom which could exist between the SXT head and its mount is approximately the angle having the radian:

$$\frac{0.0011}{11 \times 2.778} — 2.91 \times 10^{-4} \frac{\text{rad}}{\text{min.}} \quad \text{or } 2.48 \text{ arc min.}$$

Therefore, if the three screws do not hold the SXT head securely to the telescope, there can be a maximum shift of 2.48 minutes before the pins will stop the rotation. See Figure 4-30.

TORQUING OF LONG LOCK SCREWS - On AGE 202, the torque on the three SXT head mounting screws, No. 10-32, was increased from 24.7 to 40 inch-pounds. Before using this torque value, six sample tapped holes in beryllium were tested by simulating the physical design. Long lock screws were inserted in each hole successively and torqued to the 40 inch-pound value. The tapped holes were examined for damage and none was found. Two long lock screws were tehn successively torqued to increasingly higher values in steps of 5 inch-pounds, until the screws broke at 95 inch-pounds torque. No damage to the beryllium tapped holes was observed. These tests provided assurance that the three screws could be safely torqued to 40 inch-pounds. The 14 4-40 screws locating the 16X resolver stator were torqued to 10 inch-pounds.

The lockring for the rotor which had been torqued to 100 inch-pounds and four drops of Loctite used, required a breakaway torque of 240 inch-pounds. This ring and mating thread was cleaned and retorqued to 100 inch-pounds and eight drops of Loctite used.

The trim pots were reset and the unit was vibrated. After this vibration the SXT SDA reading was 15 seconds in error. The previous error was 23 seconds. After the next vibration, the shift was 2.9 seconds. After the subsequent vibration, no shift was observed.

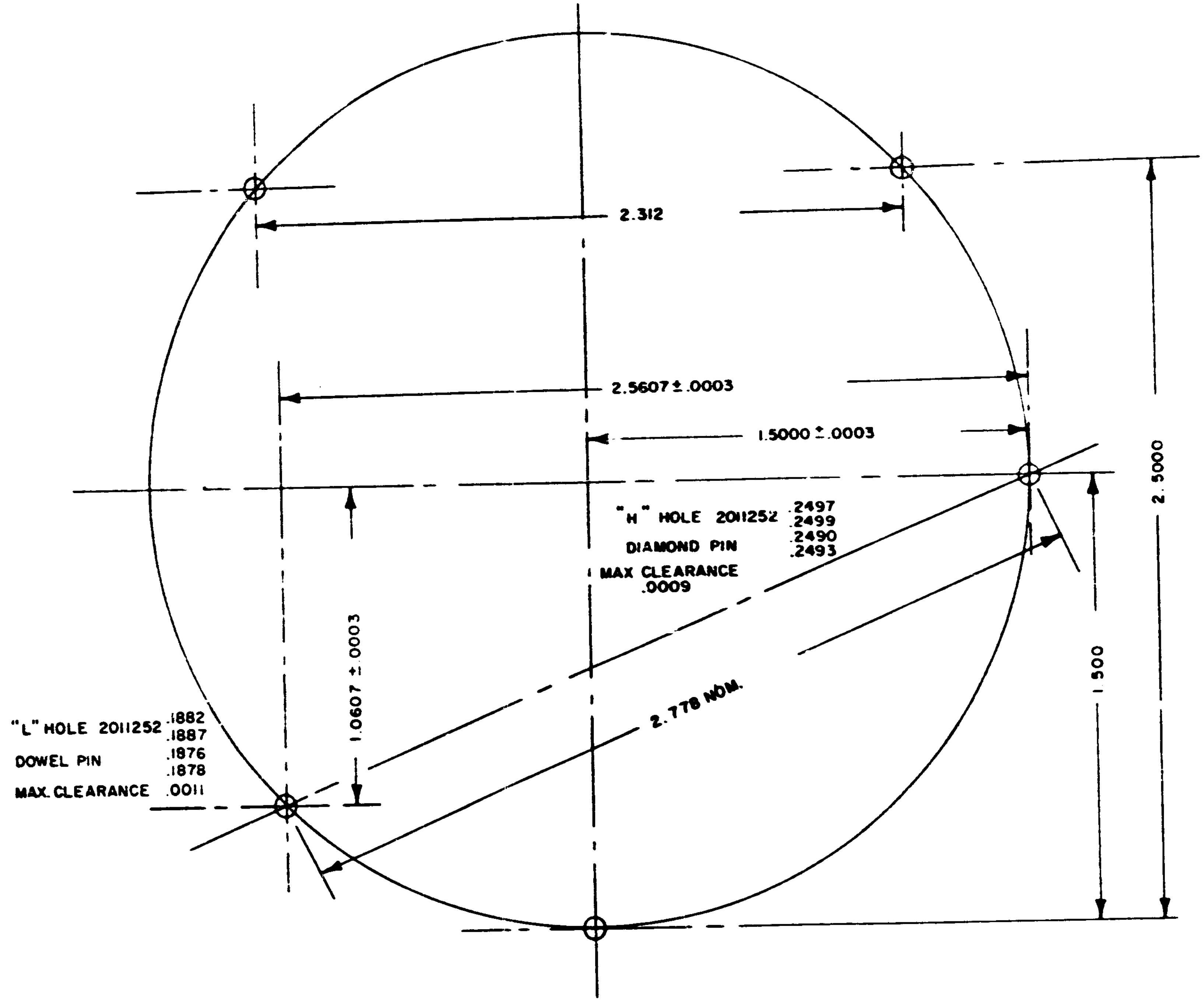
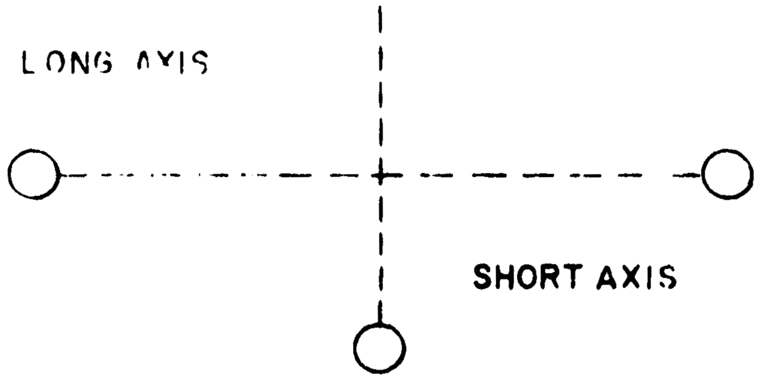



Figure 4-30. SXT Head Alignment Pins

OUA MOUNTING ON PTF - The Optical Unit is mounted on the PTF by supporting the OUA on three precision balls, PN 1019156. The following analysis will indicate whether switching the locations of the precision balls will cause any variation in the SXT SDA Zero reading.

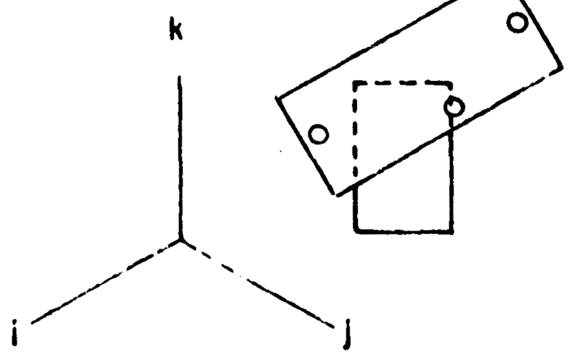
For purposes of this discussion, reference the OUA in resolver zero test position on the PTF. The line joining two of the ball mounts will be designated as the long axis and the line perpendicular to the long axis and intersecting the third ball mount will be called the short axis.

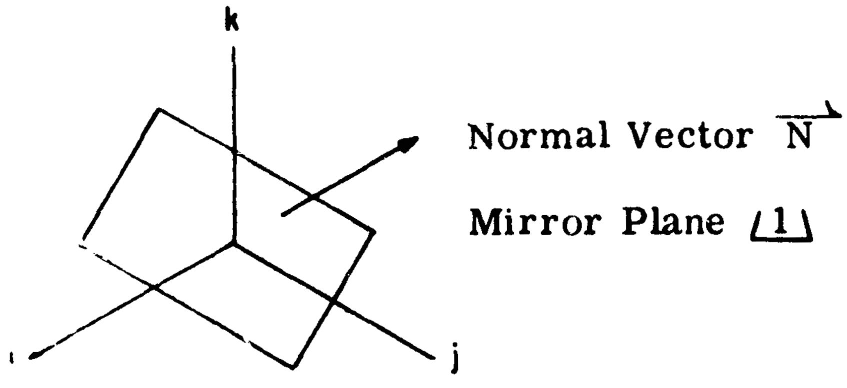



Any rotation about the long axis due to ball tolerance will induce a direct error in TDA which will not influence the SDA zero position. Errors that tend to cause rotation about the short axis (or other parallel axes) will affect both SDA and TDA angles. To demonstrate this effect, vector methods will be used to compute the general solution to this problem.

Consider three mutually orthogonal axes oriented in such a way that the k axis is parallel to the SDA, the i axis is parallel to the TDA (and therefore the long axis), and the j axis is parallel to the short axis.

The trunnion mirror plane will be parallel to the PTF autocollimator mirror plane and oriented about the i axis making an angle of 33° with the j axis.



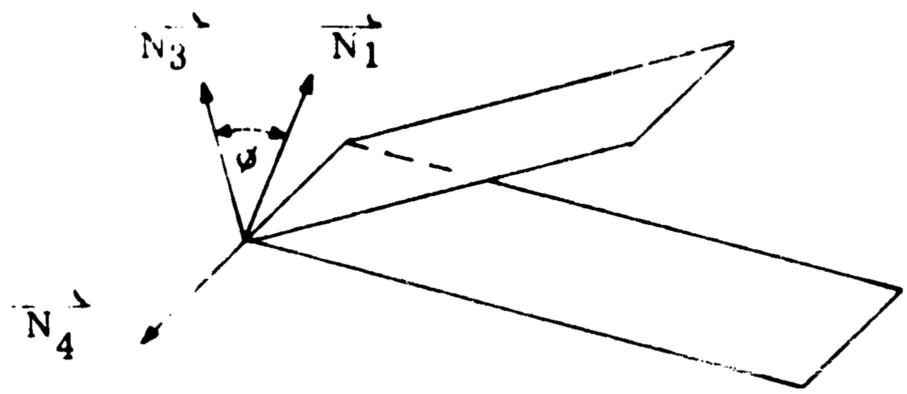
A unit normal vector to 1 can now be drawn. For simplicity, the mirror angle will be assumed as 30°.

$$\text{so } N_1 = 1/2 \text{ j} + \frac{3}{2} \text{ k.}$$

Since for autocollimation, the OUA mirror plane 2 will be parallel to 1 , $N_1 \times N_2 = 0$. A ball mount diameter error in the long axis (i) will cause a rotation, $\phi$, about the short (j) axis, changing the orientation of the OUA mirror plane and thus establish 3 with unit normal vector.

$N_3 = \frac{3}{2} \sin \phi \text{ i} + 1/2 \text{ j} + \frac{3}{2} \cos \phi \text{ k}$ where $N_3$ is $N_2$ rotated about the j axis in the positive i direction.

The angle between two planes is the same as that between their normal vectors.




hence $$\phi_{13} = \cos^{-1} \frac{N_1 \quad N_3}{N \quad N_3}$$

The j axis rotation of the trunnion mirror plane must be resolved into SDA-coupled and TDA-coupled components. This is accomplished by first rotating $N_3$ into the j-k plane about the k (SDA) axis so that $N_4$ i = 0. Therefore,

$$N_4 = \frac{3}{4} \sin^2 \phi + \frac{1}{4} \text{ j} + \frac{3}{2} \cos \phi \text{ k}$$

and $\phi_s = \cos^{-1} \dfrac{N_4 \quad N_3}{N_4 \quad N_3}$

$$\phi_s = \cos^{-1} N_4 \quad N_3 = \frac{3}{2} \sin \phi + \frac{\frac{3}{4} \sin^2 \phi + \frac{1}{4}}{2} + \frac{3}{4} \cos^2 \phi$$

for small $\phi_s$, $\sin^2 \phi \approx 0$

therefore $\phi_s = \cos^{-1} \quad \frac{3}{4} \cos^2 \phi + \frac{1/4}{2}$

$$\phi_s = \cos^{-1} \quad \frac{1}{4} + \frac{3}{4} \cos^2 \phi$$

since $\cos^2 \phi = \frac{1}{2} \quad 1 + \cos 2\phi$

$$\cos \phi_s = \frac{5}{8} + \frac{3}{8} \cos 2\phi$$

It becomes evident that as $\phi$ approaches zero, $\phi_s$ also approaches zero but at a faster rate, which means that only a small fraction of the ball mount induced error appears as SDA zero error.

Trunnion-coupled error can be found by taking $N_4$ and noting what the rotation of $N_4$ about the i (TDA) axis will restore $N_4$ to the or ginal position of $N_1$, hence,

$$\phi_t = \cos^{-1} \frac{N_4 \cdot N_1}{N_4 \cdot N_1} = N_4 \cdot N_1$$

$$\phi_t = \cos^{-1} \frac{\frac{3}{4} \sin^2 \phi + \frac{1}{4}}{2} + \frac{3}{4} \cos \phi$$

for small angles of $\phi$, $\sin^2 \phi \approx 0$

and $\cos \phi_t = \frac{1}{4} + \frac{3}{4} \cos \phi$

From the preceding equations, it is shown that only a small percentage of ball mount error propagates into the TDA. The mounting balls are checked, as part of the PTF cerfitication, using JDQ 03042 which requires sphericity and equal diameters within 0.000010 inch. The worst case analysis of ball mount tolerance yields a $\phi$ of 0.21 arc second, with a resulting $\theta_s$ and $\theta_t$ of less than 0.21 sec.

PTF REPEATABILITY - The Precision Test Fixture (PTF), PN 1016910, is a massive, precision fixture for testing the OUA. The OUA is mounted to the fixture by means of three precision balls. It has been proven in the previous paragraphs that the mounting balls do not affect repeatability.

The portions of the PTF directly involved with the SXT SDA measurement are the Azimuth Mirror Assembly, PN 1016920, and the rotary table, PN 1017438, see Figures 4-31 and 4-32.

The Azimuth Mirror is checked as per JDQ 03047, KPS 11K 10169 0, and the angle of the mirror is checked to within one arc second. The rotary table is checked and calibrated as per JDQ 03051 of the same KPS, and the zero position is calibrated to within one second of arc.

Reviews of Test Equipment records indicate that neither the Azimuth Mirror nor the turntable require frequent adjustment or recalibration. They are checked each time an optical unit undergoes final testing. In addition, all tests on any single OUA are performed on the same PTF so that variations between PTF's need not be considered at this point.

The procedure for measuring the SXT SDA zero requires that the rotary table be adjusted clockwise to the desired position. If the desired position is passed, the table must be rotated counter-clockwise at least 5 degrees past the position, and the desired setting approached from the clockwise direction. This eliminates any errors of repeatability due to backlash in the rotary table mechanism.

Therefore, it is possible that the PTF can cause an uncertainty of two seconds in the worst case.

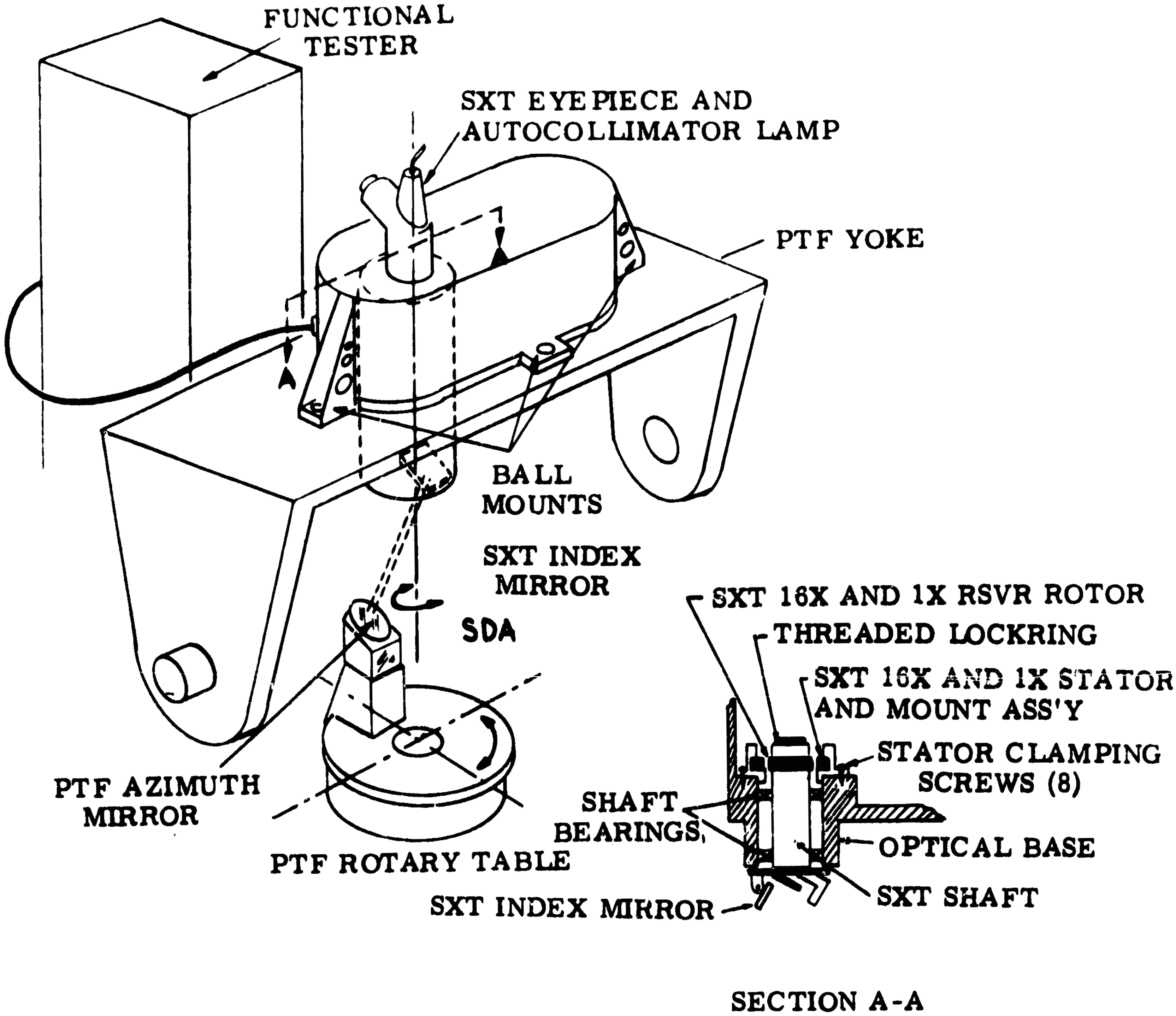



Figure 4-31. SXT SDA Resolver Alignment Relationships

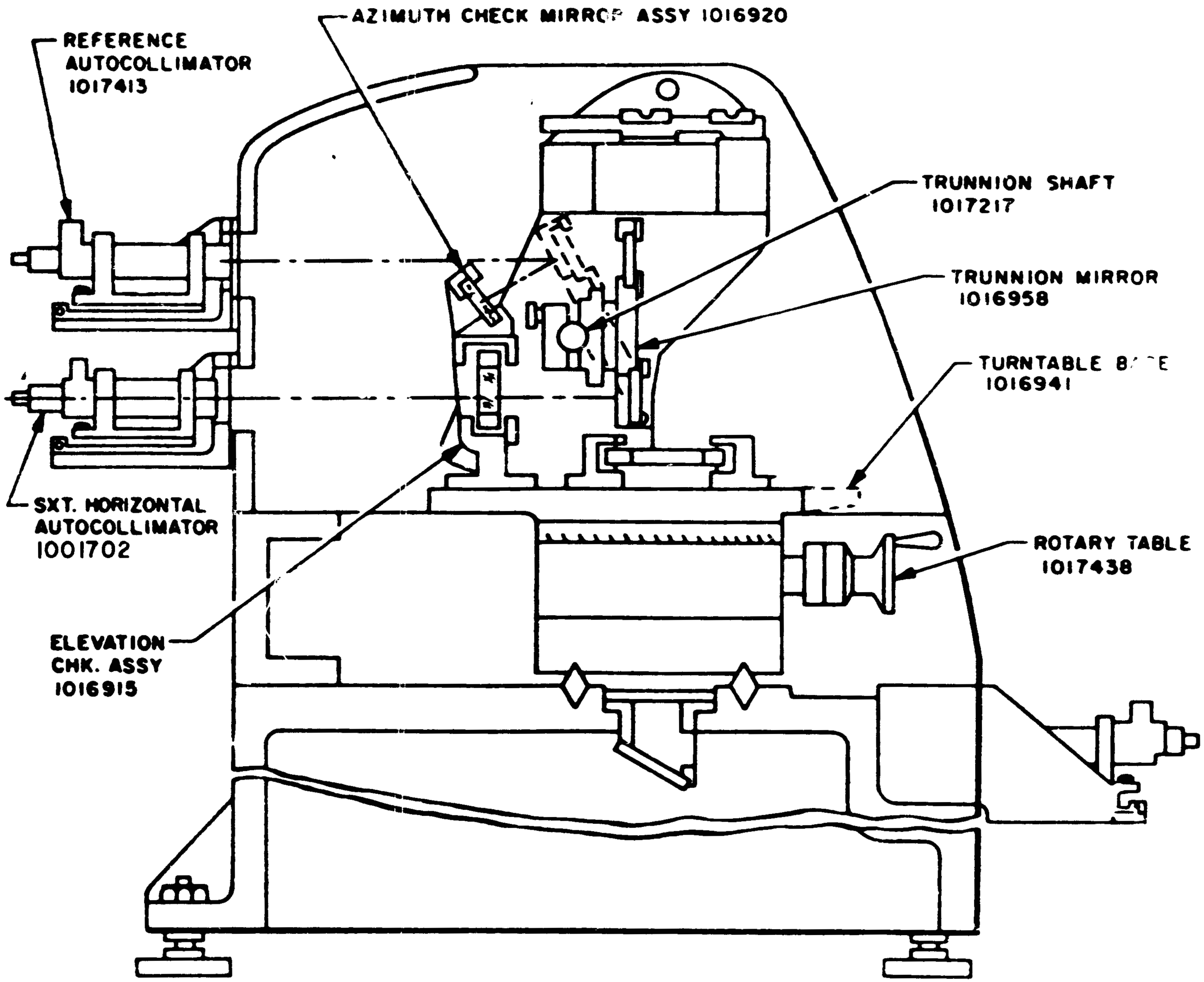



Figure 4-32. Precision Test Fixture, Left Side

FUNCTIONAL TESTER - The Functional Tester contains the following resolver test equipment, manufactured by Gertsch Products, Inc. of Los Angeles, California:

Phase Angle Voltmeter (PAV)
Gertsch desig. 1586R, NASA Dwg. 1017451

Decade Resolver Bridge (DRB)
Gertsch desig. 1587R, NASA Dwg. 1017452

Angular Display Unit (ADU)
Gertsch desig. 1588R, NASA Dwg. 1017453

The Decade Resolver Bridge (DRB) is a precision transformer instrument which produces an output, or error, voltage when set to an angular position which differs from the equivalent angular position of the signal at its input. When measuring the SXT SDA position, the 16X resolver output is fed to the DRB and the output from the DRB is fed to the PAV. The DRB is adjusted until a null is obtained on the PAV. The angle indicated on the ADU then becomes the functional angle of the resolver. Since this measurement is made with a 16X resolver, the actual shaft angle error is one-sixteenth of the angle read on the ADU.

These resolver measuring units used in the functional tester, have a resolution of 3.6 seconds and an accuracy of two seconds. The accuracy is independent of functional error, transformation ratio and phase shift of the resolver under test. The satisfactory operation of these units are checked as per KPS 11K 216251, JDQ 03459. This procedure certifies the equipment to the accuracy described above.

Therefore, the uncertainty in SXT SDA measurement contributed by the Functional Tester is assumed to be the 3.6 second resolution divided by the 16 speed step-up the resolver, or 0.22 seconds.

OPERATOR REPEATABILITY - Operator error contributions to the test data taken in performance of JDQ 03357, SXT SDA accuracy, were determined by examining eight data sheets concerned with the ability of each pair of operators to repeat the same reading. Four different pairs of operators were represented and three test stands were examined in the eight data sheets. The data is taken from OUA SN 11, SN 12 and SN 13.

The test procedure requires that the repeatability between readings be held to .013° maximum or 46.8 seconds, divided by 16, which is 2.92 seconds.

The spreads on the data sheets vary from 0.89 second to 1.8 seconds, which is somewhat less than the 2.92 seconds allowed. The standard deviations on these sets of readings varies from 0.33 to 0.78 seconds (see Table 4-14 for data summary). This indicates that a repeat run of any data could differ from the initial run by 0.78 x 2 = 1.56 second in 63 percent of all tests, and if a 2σ or 95 percent confidence is desired, the variation could be as much as 3.12 seconds.

Table 4-14

SXT SDA TEST DATA SUMMARY

| Run | OUA SN | Spread (sec) | Std. Dev. (sec) | 2σ Spread (sec) |
|---|---|---|---|---|
| 1 | 13 | 1.12 | 0.50 | 2.0 |
| 2 | 11 | 1.80 | 0.78 | 3.1 |
| 3 | 11 | 0.89 | 0.37 | 1.5 |
| 4 | 11 | 1.80 | 0.63 | 2.5 |
| 5 | 11 | 1.12 | 0.37 | 1.5 |
| 6 | 12 | 1.12 | 0.39 | 1.6 |
| 7 | 12 | 1.34 | 0.48 | 1.9 |
| 8 | 12 | 0.89 | 0.33 | 1.3 |
| Average | | 1.27 | 0.48 | 1.9 |

It is difficult to assign an uncertainty figure to the operator based upon this limited data. Realizing that the variations examined here include the one second uncertainty in setting the rotary table must be taken into account. A conservative estimate uses the maximum 2σ spread, and subtracts the rotary table uncertainty with a resulting 2.1 second uncertainty assigned to the operator.

From the data summary, it is evident that the error spread is not a perfect indication of the uncertainty in the readings, however, it is a usable criteria. If the allowable error spread were reduced from 2.92 seconds to about 1.5 seconds, and the test method were improved to allow the tighter value, confidence in the results could be increased.

CONCLUSION - Table 4-15 summarizes all nonrepeatability contributing factors. The figures shown in the table represent the worst case conditions. The test equipment does not appear to be the cause of the large shifts observed, for there is no error source even approaching the 20-second shift that was observed in testing AGE 202.

The optical unit itself is subject to suspicion, for, when vibrated, the assemblies, held by screws and locknuts, are capable of shifting the few ten thousandths necessary to cause the observed shifts.

One method of determining if and where a shift in the OUA occurs would be to instrument all suspected interfaces (as well as some continuous members) with strain gages, capacitor sensors, birefringent coatings and/or scribe lines where suitable, to measure any shifts during and after vibration.

To eliminate the effect of the PTF variations, the Auxiliary PTF can be used by adding a fixed plate and azimuth mirror assembly. Once set up, this test fixture would not be adjusted or even handled until completion of the OUA test program.

Table 4-15

SXT SDA NONREPEATABILITY SUMMARY

Test Equipment

| Test Item | | Max. Nonrepeatability |
|---|---|---|
| Precision Balls | | 0.21 sec. |
| PTF Turntable | | 1 sec. |
| Azimuth Mirror | | 1 sec. |
| Functional Tester | | 0.22 sec. |
| Operator | | 2.1 sec. |
| | Total | 4.53 sec. |
| | RMS | 2.53 sec. |

Table 4-15 (Cont.)

OUA

| Test Item | Max. Nonrepeatability |
|---|---|
| SXT Head Mounting | 0* |
| Resolver | < 1 sec. |
| Resolver Rotor Mounting | 0* |
| Resolver Stator Mounting | 0* |
| Resolver Housing Mounting | 0* |
| Trim Module | 0.45 sec. |
| Other Structural Shifts | 0* |

*Areas for further investigation

SUMMARY OF OUA TEST DATA - The test procedure was modified to include taking data on the 1X resolver output in addition to the 16X resolver output as a second check. The SXT SDA zero results, as measured on the Optical Units completed this quarter, are summarized as follows:

| AGE | 124 | 201 | 202 |
|---|---|---|---|
| Final Test | -5 | +1.7 | +23* |
| Confidence Test | +2.9 | +7.2 | + 5 |
| 2012736 Assembly | +1.9 | +3.9 | + 3 |
| Apparent Shift | 7.0 sec. | 5.5 sec. | 20 sec. |

*Unit was reworked.

SXT SHIFT INVESTIGATION - The Optical Unit Assembly (OUA) is a precision opto-mechanical assembly. The accuracies and tolerances specified approach the state of the art in assemblies of this type of instrument and are specified in seconds of arc. While the numbers being reviewed are as high as 10 arc-seconds, it should be remembered that 1 arc second is equivalent to a slope of $5 \times 10^{-6}$ inches/inch.

With the review of shifts that took place on AGE 202 (SN 13), it became apparent that areas not previously considered vulnerable were indeed contributing to the SXT SDA and TDA errors.

DISCUSSION. OUA, SN 13, was subjected to ten vibration cycles and accuracy tests over a period of nearly two months. All of the data taken during this period and the significant events were assembled into two major groupings, data relating to trunnion angle measurements and data relating to shaft angle measurements.

In spite of the large volume of data presented, the first important finding that must and has been stressed, is that each suspected failure history must be supported by all of the data which can have bearing on the point in question. Unknowingly, the analysis of SN 13 was hampered by the incompleteness of the data and most of what was accomplished could have been done in less time with more complete data at each stage. The rule which has now been promulgated is that all related accuracy measurements shall be completed irrespective of failures as a prerequisite to any failure action.

A second generalized finding of the investigation was an assignment of degrees of confidence and degrees of precision to the various measurements made. Confidence ratings based on the degree of reliance on test equipment calibration procedures and on dependence on equipment handling techniques such as torquing of mounting screws, cleaning of mounting surfaces, adjustment of illumination and control of warmup. Precision ratings are based on the scale reading divisions involved such as the ADU or the filar micrometer settings for high precision versus visual estimates from reticle dimensions for low precision. The approximate ratings follow:

| | Confidence | Precision |
|---|---|---|
| Reticle Eccentricity | 2 Second | 1/2 Second |
| Shaft Perpendicularity | 5 Second | 1/2 Second |
| Plane of SLOS to LLOS or to SDA | 2 Second | 5 Second |
| R line Sep. at Self Check | 2 Second | 2 Second |
| TDA Angle at Self Check | 2 Second | 1 Second |
| TDA Zero | 3 Second | 1/2 Second |
| SDA Zero | 5 Second | 1 Second |
| Trim Pot Output TDA | 1 Second (4.5 mv) | 1 Second |
| Trim Pot Output SDA | 2 Second (4.5 mv) | 2 Second |

The above listing does not cover all cases k  is a fair estimate based on various efforts to analyze procedures used in calibration and comparing data taken under conditions that preclude significant change in the quantities being measured. For example, 11 determinations of SDA perpendicularity on SN 13 covered a spread of 13 seconds, all within specification. Seven of these were in a region of half this spread and five were within a spread of about three seconds.

The third item for discussion before going into the particulars of the three unit histories is the technique of data analysis that can be used to localize failures. This technique can be summed up in three statements:

a. Examine related data for compatibility. The incompatibility gives the clue to the cause.

b. Establish that incompatibility is outside the range of normal uncertainty of measurement.

c. When a tenable diagnosis has been determined, the parts themselves can be examined giving due consideration to mechanical probability where a number of choices exist. Mechanical probability is a combination of design and verification of workmanship procedures.

The data history of SN 13 provides sufficient examples to illustrate most, if not all, of the ways that data analysis can be employed.

The first step is to establish the stability of the reticle and objective lens relationship to the shaft axis. On SN 13, 11 measurements of reticle eccentricity are recorded, all under 3 seconds of arc and all falling into approximately the same direction of the eccentricity relative to the trunnion measurement plane. Therefore, diagnosis can start on the assumption that this quantity which is measured with high confidence and precision is stable. If it were not stable, it would be a factor in judging shaft shifts and in relating TDA measures relative to the LLOS by comparison to self-collimation measurements of TDA since only the latter depend on the reticle, objective and shaft relationship.

The second step is to examine SDA perpendicularity data for changes in the lateral direction. Significant changes in this direction are very uncommon but should be eliminated in the process of seeking cause of SDA failures. Perpendicularity variations of SDA are very common in the up-down direction because of the shorter base of the mounting in this direction, but these shifts have no effect on the evaluation of other data. In SN 13, the lateral spread of this data was about 4 seconds in 11 measurements and therefore insignificant. Note the earlier reference which included the up-down variation.

The data on reticle eccentricity and shaft perpendicularity is in the acceptance data package and is not repeated in this report.

TDA DATA ON SN 13. The TDA data on SN 13 is a different matter, with events of interest following vibrations No. 1, No. 4, No. 5, No. 6, No. 7, No. 8 and possibly No. 9.

The event following vibration No. 1 was recorded as a trunnion shift and was retrimmed. The shift was not due to trim pot change which remained constant. It was not due either to a mechanical shift between the trunnion mirror and the trunnion 64X resolver rotor but to a shift of the fixed mirror which is adjusted by lapping of pads according to the evidence of the measurements. The clue is that the shift measured at the self check (90° TDA) position is twice that indicated in the TDA 0° position. This relationship between the changes does not recur subsequently in the data and may be ascribed to the dislodgement of some foreign material on one of the mirror pads. More recent studies of SN 17 have uncovered the probable cause and cure of this condition. (This was corrected by implementing a shop change to alleviate the problem.)

Vibrations No. 2 and No. 3 had no effect on TDA but No. 4 showed a change which, though small, was greater than the uncertainty of measurement and led to an investigation series of tests in which additional data taking procedures and controls were instigated. The new series added measurements of TDA at 0° with the trim pot disconnected. The changes which were observed relative to trunnion showed equally at 0° and 90° and untrimmed at 0° indicating that the fault lay between the index mirror and the 64X resolver rotor. Trim voltage was not monitored but it can be safely presumed to remain constant since it had not been handled for potting and because the untrimmed data followed the trimmed data. The investigation at the end of the series found the resolver rotor tight on the trunnion and a sizable amount of foreign matter under a pad of the index mirror. At this point, it is important to note that the fact that SDA errors were also present was important in determining that the fault would lie at the mirror pad interface with the trunnion rather than at the 64X resolver rotor interface.

The last of the events associated with a vibration was shown to be erroneously charged to the vibration, at least as the major cause. At this point, the monitoring of the Trim Pot output was belatedly taken up after being neglected from the trim following vibration No. 2. When the shifts appearing during vibration No. 8

were rezeroed by the trim pot and its voltage measured, it was found to check with the value it had during the period of TDA stability at zero. All other data on TDA was brought back to agreement by this operation. Furthermore, the difficulty was traced to the potting as even partial removal of the potting affected the trim output.

As a result of this series, the following permanent corrective measures were put into effect:

a. Cleaning of all parts involved in the mounting of the mirrors and beamsplitter.

b. Monitoring of the flatness and quality of the critical surfaces. This control led to further corrective measures as it has been determined that the mirror bushing may damage the pad due to insufficiently smooth surface finish.

c. Monitoring trim pot output after potting.

d. Running all tests necessary for full investigation of failures.

e. Use of two vibration runs as a means of indicating stability of the overall system.

SDA SHIFTS ON SN 13. To all of the factors which may be involved in a TDA shift, uncertainties of an involved PTF certification procedure must be added a more complex interrelation between index mirror shifts, and effects of reticle eccentricity and SDA perpendicularity in analyzing SDA shifts. Only the last two were completely removed from the suspect list on SN 13. PTR certification, though the most chronic offender, see SN 14, did not play an important part in the SN 13 investigation.

The SDA history of SN 13 shows that the unit did not shift during the No. 0 and No. 1 vibrations but showed a large change after vibration No. 2 which was insignificantly reflected in the data shown for the R line separation at the self check point or SLOS to SDA at zero. The trim output was also stable. The difficulty was presumed, correct, according to this data, to be a shift of the SXT head relative to the 16X resolver rotor. The three screws which secure this relationship were tightened per MIT/IL recommendation and the No. 3 vibration which followed again caused a change of smaller magnitude with somewhat less conclusive isolation of cause and effect. The No. 4 vibration indicated a settling down which is slim evidence of the value of the revised torquing procedure since the unit had behaved at least as well for the first two vibration cycles before the retorquing.

In the series of three vibrations, No. 5, No. 6 and No. 7, run for engineering study, an entirely new set of conditions was manifested in which the previously stable SLOS to SDA and LLOS condition was radically altered and the R line separation at self check also increased beyond the range which could be an error of measurement.

These shifts were all in the same direction and subsequently their relative magnitude was used to show that they were all consistent with a change in the angle between the normal to the trunnion mirror and a plane normal to the trunnion axis. By tracing out the spherical trigonometry on a model it was shown that a unit change in this angle will produce 1.4 units of change in the SLOS to SDA measurement at zero and 2.2 units of change in the SDA zero measurement. If due allowance is made for a tendency to underestimate measurements of the R line separation at self check based on line thickness judgment, the changes occurring after vibration No. 5, No. 6 and No. 7 are noted to follow this ratio closely. In addition to this evidence, reasoning from the mirror pad configuration, an SDA shift from this cause is quite certain to be accompanied by a TDA shift. This held true in this case as one of the pads interfacing the trunnion mirror and its mount was dirty and thorough cleaning eliminated further large shifts from this source.

Subsequent work in this area has shown the need to further refine procedures and examination of surfaces so that future units should be absolutely stable at the interface of all mirrors and their mounts.

Optical Unit Assembly, SN 14, was built and tested concurrently with SN 13 so that the experience gained from one would be carried over to the other. However, not all the lessons learned from SN 13 were available in time to apply throughout the test cycle of SN 14.

The differences are as expected under the circumstances - fewer cases of inadequate data, earlier correction of the failures through earlier recognition and a final result closely paralleling the performance of SN 13.

The significant results on this unit are those concerned with the first vibration. Here a large difference is observed in the TDA at zero which contrasts with a change in the opposite direction for TDA at self check. When uncertainties of measurement are deducted from this difference, it is still obvious that a fixed mirror must be involved in the shift since the two-to-one relationship between the effect of fixed mirror shift versus index mirror shift is the only mechanism discovered for causing the changes in these measurements to be in the opposite direction. Furthermore, since fixed mirror changes at only one pad will result in SDA changes, the fault on the fixed mirror had to be on more than one pad. This rationalization was supported by the actual findings and cleaning up the index mirror pads and the mounting of the fixed mirror on which lapping adjustments are made, the serious shifts were eliminated. Again, as noted in the discussion of SN 13, newer findings showing how this damage comes about and better controls of these surfaces are expected to eliminate the smaller residuals of instability which can be discerned by comparing the changes throughout the remainder of this study.

Data taken on this unit showed the value of measuring trim output voltage and measuring the untrimmed SDA and TDA zeroes. Only having these data on file saved this unit from more fruitless reinvestigation. Also, at the last stage of testing an error was measured in the PTF SDA Zero certification. This susceptibility to change, added to the uncertainty of exact recalibration, is a problem which has only partially solved by additional cross checks in the certification procedure.

The data on SN 15 indicated that none of the changes show trends and only two are slightly over the usual uncertainties of measurement. The changes to SDA, TDA at 0° and 90° at the date of 17 May are the result of trim and not to be confused with vibration changes. The two questionable changes are the TDA at 90° change from 34 to 29 after vibration No. 2 and the SDA 0° untrimmed from +4.5 to -1.2 after vibration No. 3. No positive explanation can be offered for these changes other than to point out that they are isolated incidences and unconfirmed by comparison to other changes.

An examination of the vibration integrity curves for the complete test cycle indicated no out-of-tolerance conditions in either TDA or SDA "0" of SN 16 existed, with less than a two arc-second total shift in TDA "0". No retrim adjustment was required during the testing of this unit.

SUMMARY AND CONCLUSIONS. The vibration integrity test results, have shown the trend of vibration shifts for SXT TDA and SDA "0"s for the units. A comparison of results for SN 13, SN 14, SN 15 and SN 16 showed a significant reduction in the shaft and trunnion shifts from unit to unit due to steadily improved assembly techniques and additional controls.

It should be noted that the careful analysis and interpretation of test data has proven an invaluable aid in focusing attention on suspected problem areas.

Although the magnitude of SXT SDA and TDA shifts have been greatly reduced by increased mounting torque value for the SXT head and careful monitoring of mirror mounting surfaces, further reductions can only be achieved by implementing design changes in the OUA and improvements in certification and monitoring procedures on the test equipment. These design changes and procedure changes will entail a cost impact on the program. KI recommends that the OUA production be continued with the following actions that are already incorporated into the design and procedures:

a. Increased torque values on screws.

b. Two vibration cycles during final assembly and sell-off.

c. Inspection of mirror and mirror mounting surfaces for cleanliness, flatness, and quality of finish.

d. Review in depth of all shifts occurring during testing to isolate and correct the shift cause.

SXT HEAD SHIFT PREVENTION. In order to prevent possible shifts between the SXT Index Head Assembly and the SXT Telescope Tube Assembly, an investigation of methods of strengthening the interface was performed.

The easiest change was to increase the torque on the three No. 10-32 screws that hold the SXT head to the telescope tube. Tests were performed, and it was found that the screws fail at 95 inch-pounds, and the beryllium holes were not damaged. Based upon these results, the production torque requirements were increased from 24 to 40 inch-pounds.

1. Double Diamond Pin Method. Attention was then focused on the dimensional tolerances of the Diamond Pin (1011769) and Dowel Pin (MS 16555-640) which are mounted on the Telescope Tube Assembly (2011893) and their respective clearance holes on the Sextant Head Housing (2011252).

The above tolerances add up to a total of 0.002 which, over a span of 2.7717 ± 0.0004 (distance between two pins), will permit an angular displacement of 2.5 minutes.

Since the tolerance on the distance between the two pins (dimension 2.7717 ± 0.0004, see detail 3 of Figure 4-33) in the Telescope Tube Assembly (2011893) and the distance between the clearance holes in the SXT Head Housing (2011252) can not be changed (decreased), it was recommended that the following steps be taken to decrease the total tolerance and thus restrict the amount of possible angular shift due to vibration:

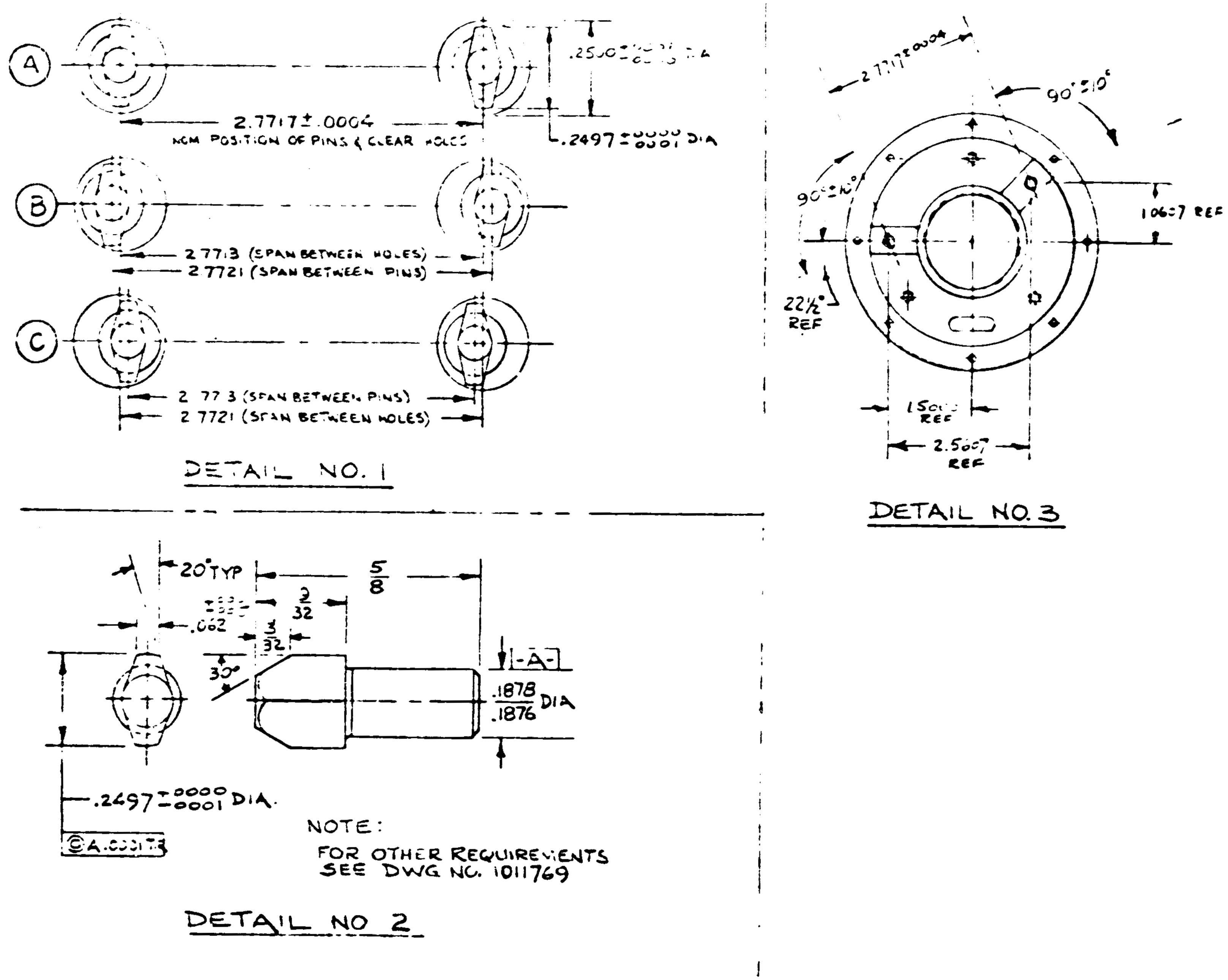



Figure 4-33. SXT SDA Zero Ref. Shift

a. Remove existing diamond pin (2011789) and Dowel Pin (MS 16555-640) from the Telescope Tube Assembly (2011893).

b. Replace with two new Diamond Pins (detail 2 of Figure 4-33). Install the diamond pins parallel to each other and perpendicular to the line running between the two holes (see detail 3 of Figure 4-33).

c. Rework existing "H" and "L" holes in the Sextant Head Housing (2011252) to read as follows:

"H" hole = $0.2500^{+0.0001}_{-0.0000}$ dia. x 438 deep

C'bore 0.312 dia. x 031 deep

"L" hole = $0.2500^{+0.0001}_{-0.0000}$ dia. through

C'bore 0.312 dia. x 0.031 deep

An analysis of this new method of assembly reveals that in the most extreme condition the new tolerances will permit 0.0010 displacement. This displacement may allow an angular shift of 74.25 seconds compared with the existing condition which may allow an angular shift of up to two minutes and 30 seconds.

Furthermore, the worst condition will exist only when the distance between the two diamond pins equals exactly the distance between the clearance holes (see detail number 1 condition A). Then and only then will there occur a clearance of 0.0010 which would permit the full angular shift of 74.25 seconds.

However, the two diamond pins and their respective clearance holes will most likely tend to approach each other (see detail 1 of Figure 4-33, conditions B and C) thus approaching the desired zero shift between the Sextant Head to the Telescope Tube.

2. Cementing of Wedges. Another method was then examined whereby existing OUA's could be improved without requiring major disassembly. The method chosen involves the cementing of two beryllium wedges (see Figure 4-34 of SK HB 5018) to the interface location between SXT Index Head Assembly (2011701) and Telescope Tube Assembly (2011893) as shown on the sketch (SK HB 5018) representing in part the Optical Unit Subassembly Stage II (2011890).

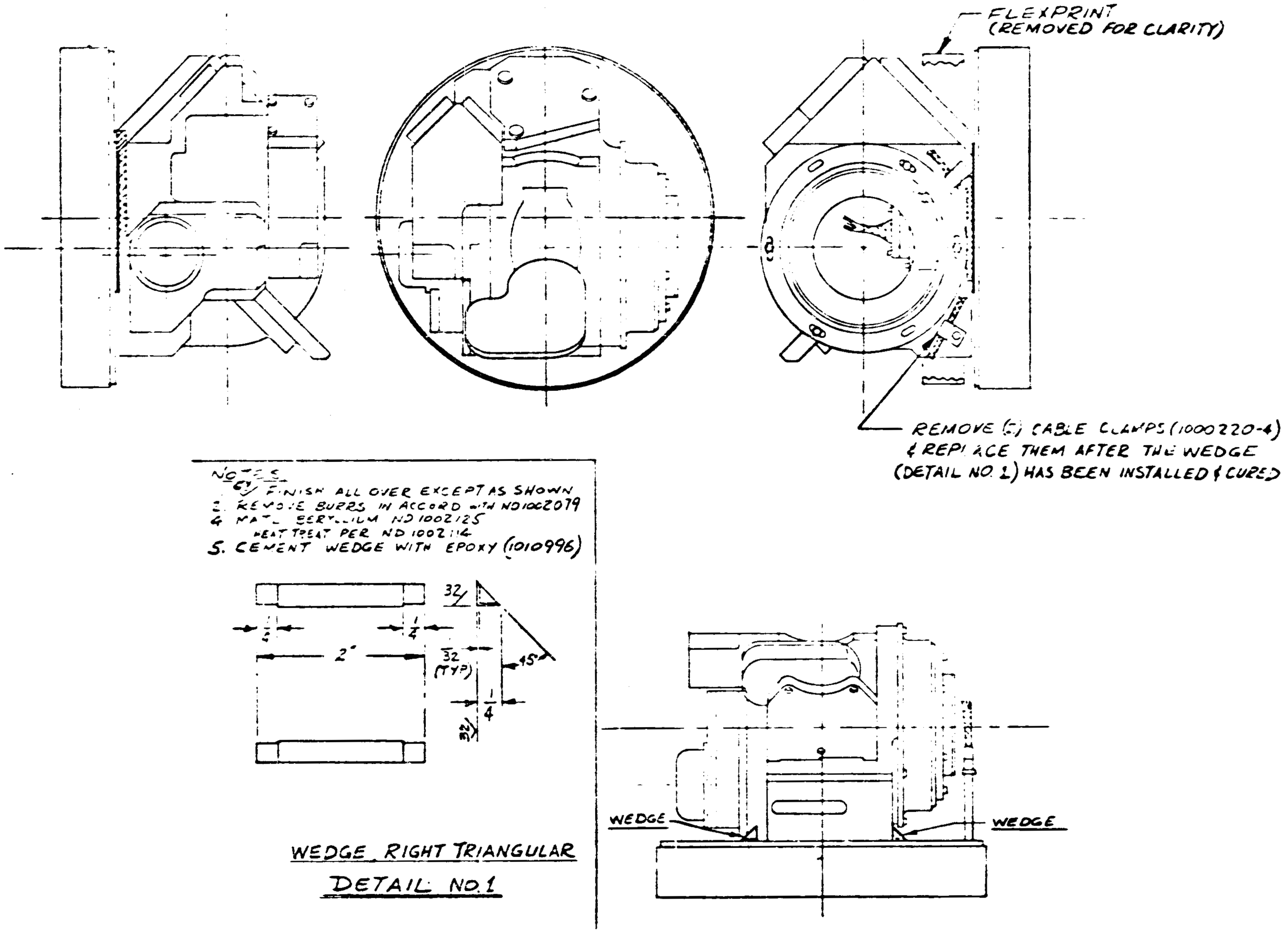



Figure 4-34. SXT Index Head & Wedges Assy.

The two wedges would be cemented, one on each side of the SXT Head, using Epoxy Resin Adhesive (1010996) which should be spread on both congruent sides of the right triangular wedges. An alternate Epoxy could be "Bondmaster M688" per ND 1002004 Type I.

The wedges are designed with undercuts at each end of the wedges. This is for the purpose of permitting the wedges to be pried loose, should the necessity arise to remove them in order to disassemble the unit.

In order to gain access to install the wedges, it will be necessary to temporarily remove the Flexprint and Connector Assemblies (1012519 & 1012520) and the two cable clamps (1000220-4) located under the 64X Resolver which hold down the harness assembly.

The proper procedure for cleaning the surfaces and preparation before cementing shall be observed.

After cementing the wedges in place, reinstall the previously removed Flexprints and harness assembly with the two cable clamps.

Upon further investigation this method of securing the SXT Head against SDA shift did prove sufficient and thus avoided the necessity of securing the SXT Index Head Assembly with two diamond pins as described above.

4.5.2.17 OUA Internal Corrosion

PROBLEM. Evidence of corrosion has been found inside two OUA's, AGE 121 and AGE 201A. The corrosion appeared in the form of small white flakes, which, in the case of those found in AGE 121, have been identified as principally Beryllium Hydroxide.

HISTORY OF UNITS. AGE 121 has been shipped several times between AC Electronics and NAA, and has been installed in Spacecraft No. 14.

AGE 201A showed no evidence of corrosion, following the completion of the qualification tests. The unit was then exposed to uncontrolled environments including various high humidity conditions. Corrosion in the unit at this time is therefore not considered significant.

RECOMMENDATIONS. Initiation of a practice of periodic Nitrogen purging for all field OUA's is recommended. Kollsman is reviewing the overall corrective actions.

### 4.5.2.18 Anodizing of SXT and SCT Panels

BACKGROUND. The decision having been made to black anodize the SXT Panel, PN 2012727, and the SCT Panel, PN 2012728, as an anti-corrosion measure, a vendor was selected and a Purchase Order placed. The vendor, Summit Finishing of Thomaston, Connecticut, chosen after consideration of th[illegible] sources, is a company with broad experience and capability in metal finishing operations, but with limited background in working with beryllium. Because of the tight schedule, and in view of the value of the panels being anodized, considerable concern exists as to the eventual capability of the vendor.

A close liaison was maintained with the Chief Chemist of Summit. Some significant exchanges during this liaison are as follows:

1. Summit was informed, in advance of TDRR action, of the new thickness requirement and of the salt-spray requirement that would be imposed when Anodizing Specification ND 1002127 was replaced by ND 1002296. The vendor's initial reaction indicated the possibility that he could not fully comply with these requirements.

2. KI Engineering and Reliability representatives visited the Summit facility on 11 May 1966 to clarify anodizing specification requirements and evaluate the vendor's tooling. The requirements of the new specification ND 1002296, were discussed, and it was agreed that some changes were needed.

   a. The dimensional loss per surface would have to be changed from 0.0001 to 0.00015 for Type I (dull) or Type II finishes. The Reliability representative was working with MIT/IL to effect such a change.

   b. Due to the dimensional loss, black anodize should be removed from the $0.3125 \pm {}^{0.0005}_{0.0000}$ hole, since the tolerance could easily be violated by anodizing. A change request was submitted 12 May 1966.

   c. Kollsman QC noted that a 30 to 60 second etch allowed by the specification would result in an excessive loss of material and recommended great caution in use of this process. Some consideration is being given to removal of this portion of the specification.

3. The vendor agreed to run salt-spray tests a[illegible] measure anodize thickness on samples provided by KI, [illegible] so directed.

It is intended that all P.O.'s on which ND 1002296 is called out will call for such vendor measurements.

4. Three samples of known Outer Diameter (OD) were left with the vendor to measure performance of three surface preparation methods as follows: Vapor blast; 5 to 10-second etch, 30-second etch. Dullness of finish and degree of dimensional loss were to be checked for each. The samples have since been completed with the following results:

   Vapor blast - semi-gloss finish - no dimensional loss
   5-second etch - semi-gloss finish - 0.0001 inch diameter change.
   30-second etch - dullest of three finishes - 0.0003 inch diameter change.

   The use of a dry grit blast was discussed with the vendor as the potentially optimum surface preparation.

   Two SCT Panels were black anodized, and passing through Incoming Inspection. MRB approval was necessary, since the anodize finish is not dull in all areas especially around the counter window. The panels are entirely suitable for use in prime equipment, and should pass MRB.

   Due to ambiguity in the anodize field callouts on the panel drawings, the two tapped holes for mounting the eyepiece flanges were not anodized. The vendor had stopped work on later panels due to uncertainty in this matter. Therefore, KI Purchasing had instructed the vendor (through Engineering memo AET-6-329, 5-26-66) that these 5/16 inch tapped holes should not be anodized, and that work proceeded without further delay.

ACTIONS

1. Panel drawings 2012727 and 2012728 were changed by TDRR's 29147 and 29145 respectively. By virtue of these Class I changes:

   a. The new ND 1002296 specification was imposed.

   b. Type III finish had replaced Type I except in limited areas around the counter windows of panel 2012728.

   c. Requirement for anodize was omitted in the 0.3125 inch holes, which are dimensionally critical.

2. A specimen, one of the three noted above, was checked for anodize thickness, and found to be 0.0005 inch. This is the nominal value of the required 0.0003 to 0.0007 inch range.

   The second of the three specimens was processed for salt-spray testing.

   An RTM was processed to establish a standard test specimen procedure per the requirements of ND 1002296. This procedure was applied to all future orders, with KI supplying the beryllium sample pieces.

CONCLUSIONS AND RECOMMENDATIONS - Summit Finishing appeared to have the capability to meet all requirements of the black anodize on panels 2012728 and 2012727. This was especially true in view of the clarifications affected by the recent drawing changes. Reasonable schedule demands were satisfied as KI maintained a close liaison with the vendor.

4.5.3 Lunar Module Engineering

4.5.3.1 Accomplishments

SUMMARY - The L M Project Office continued coordination efforts in the areas summarized as follows and expanded in the ensuing paragraphs.

1. Procurement - Continued emphasis was placed on alleviating vendor difficulties involving procurement of the remaining critical long-lead item (e.g. reticles).

2. Manufacturing Support - Continued support to manufacturing was provided for purposes of developing improved manufacturing assembly alignment, and test procedures to facilitate delivery of the AOT production models. As a result of these efforts, one production model was delivered and one production model assembled and tested.

3. Design Review and Evaluation - The design of the vacuum testing equipment, incorporating the vacuum test adapter, was finalized. Test techniques related to final AOT acceptance tests under vacuum environment were evaluated and the application of oxidation prevention coating, the new pressure seal, and cam lock additions to the AOT were reviewed.

4. Ground Support Equipment (GSE) - The FAT plan was developed and implemented for the AOT Tester (large base).

Procurement of the AOTT (small base), Valve Covers, Lens Covers, and adapter plate modification to the delivered AOT Shipping Containerwwas completed.

The details pertaining to each of the foregoing accomplishments are discussed in the following paragraphs.

SHIPMENT OF PRODUCTION - Project Engineering extended support to Space Division Manufacturing during the reporting period. The objective was to continuously develop and refine AOT assembly, alignment and test techniques prior to shipment of production AOT's. As a result of these efforts, the first production AOT PN 6011000-000, SN 7 (LM SN 601) representing the "baseline configuration" was shipped. The buildup and testing history for this unit is documented in Acceptance Data Package (ADP) No. LM-6.

EVALUATION OF RELAY LENS ASSEMBLY PROBLEM - The suspected bias error shift component contributed by the displacement of the relay lens assembly during reexposure to acceptance level vibration was evaluated and resolved by KI and MIT/IL. The relay lens assembly was secured to the inner tube with epoxy, effective AOT SN 8 (LEM SN 602)

VACUUM TESTING OF AOT - TDRR Proposal K-506^ to MIT/IL modified the LEM Procurement Specification 6011000 to include functional testing under vacuum environment was approved per TDRR 25457. During this period, ERP-K76R2, added vacuum capability to the present AOT final test fixture (FTE) and AOT Tester (GSE), was approved for FTE only with cut-in effectivity on AOT SN 11, (LEM SN 605). All designs (e.g. vacuum test adapter, vacuum test unit assembly) modifying the AOT test equipment (FTE) were finalized and drawings subsequently released for manufacture or procurement. In addition, new alignment and test procedures were developed for this added vacuum capability.

Evaluation of the effects of focal plane shift on the objective lens and relay lens assemblies of the AOT due to vacuum environment were completed via computer ray trace in preparation for subsequent delivery of a vacuum-focused AOT.

OTHER ACCOMPLISHMENTS - Other accomplishments during the period included a detailed design review of the proposed application of oxidation prevention coating (gray paint or black anodize) to affected beryllium parts of the AOT. ERP K109 was generated to implement this requirement as follows:

1. On assembled AOT's, a coating of gray paint was applied to accessible beryllium parts in specific locations per ND

1002291 and ND 1002294 with cut-in effectivity on AOT SN 8 (LEM SN 602) and cut-out effectivity on AOT SN 9 (LEM SN 603).

2. On unassembled AOT's, a coating of gray paint and/or black anodize was applied on beryllium detail parts per ND 1002291 and ND 1002127 with cut-in effectivity on AOT SN 10 (LEM SN 604) and up.

INFORMAL DESIGN REVIEWS - In addition, LM Project Engineering effort was expended in informal design reviews of the new AOT pressure seal and eyepiece assembly and processing of design changes through Kollsman. The following paragraphs present the results of these efforts.

1. Addition of new material Strain Isolation Pressure Seal PN 6011143 - Acceptance and qualification requirements for the proposed new pressure seal design by MIT/IL were reviewed for compatibility with the requirements of the present seal, PN 6011096, which was accepted and qualified by Kollsman during the previous reporting period. Modifications to the present Kollsman test equipment and procedures were necessary to accept and qualify the proposed new pressure seals due to the change of material and additional requirements imposed. For detailed information, see ERP-K138.

2. Addition of new cam lock device to AOT Telescope Eyepiece Assembly, PN 6011846 - A preliminary design review was conducted at KI with MIT/IL during this period to evaluate all drawings affected by MK 289. All comments and suggestions were submitted to MIT/IL for evaluation and implementation of change to the drawings.

COORDINATE SYSTEM REIDENTIFICATION - The present Alignment Optical Telescope (AOT) Coordinate System, as defined in Procurement Specification 6011000, was found to be incorrect. An analytical study of the problem was made in an attempt to obtain a mathematical translation to the new coordinate system. This effort was successful and resulted in the following correction factors:

1. Elevation readings in the present coordinate system were corrected by a factor of .5.

2. Azimuth readings in the present coordinate system were corrected by a factor of .866.

The Kollsman analysis was forwarded to AC Electronics. An analysis performed by AC resulted in correction factors of .525 and

.866 for elevation and azimuth readings, respectively. Consequently, there was satisfactory agreement between the KI and AC analyses.

4.5.3.2 LEM Ground Support Equipment (GSE)

ASSIGNMENT

Connector Covers
Valve Covers
Lens Covers
Shipping Container
AOT Tester
Vacuum Test Adapter

ACCOMPLISHMENTS

Connector Cover, PN 6014012 - This cover now used on the deliverable AOT's.

Valve Cover - This cover, is an integral part of the Gas Injection Valve Adapter, PN 1022893, and was authorized by approval of ERP-K60. One adapter with cover was delivered for each AOT production unit.

Lens Cover - This cover actually consists of three special covers: Objective Protective Cover, PN 6014306; Eyepiece Protective Cover, PN 6014307; and Transparent Prism and Head Protector, PN 6014035. A composite reference drawing No. 6014056 had been created.

Shipping Container - PN 6014000, required additional hardware and an adapter plate to permit mounting the shock recorder called for in ERP-K21. Although mounting facilities were originally designed into the shipping container, a change in the model shock recorder necessitated additional effort. The retrofit should be completed during the next reporting period. An additional reference drawing had been created to illustrate the proper shipping configuration of an AOT within the shipping container.

Vacuum Test Adapter - The Vacuum Test Adapter and associated auxiliary equipment required to test a vacuum-focused AOT was scheduled to go into preliminary operation 8 June 1966. This equipment would be used to test the first of the Vacuum Focus Instruments, AOT 603.

AOT Tester (AOTT) PN 6014003 - On 20 May 1966 AOT, SN 1, at GAEC, was delivered to AC. First Article Test (FAT) Plan indicated compatibility between KI FTE and GSE. The unit was accepted with one waiver (KIC-C-202) on SLOS, repeatability requirements.

In the right detent position, the reading was nine arc-seconds out of tolerance in Azimuth. As part of the corrective action listed on the waiver, KI will provide an addendum to the ADP, showing need for more averaging of data. A TDRR would then be processed to the Procurement Specification to incorporate additional averaging.

DESIGN CHANGES - The principal efforts of the LEM Project Engineering group were directed toward resolving the instability (shifts) exhibited by the AOT under vibration. An extensive evaluation program was conducted on the AOT Learner Model, SN 1. Results of this evaluation led to a number of design changes which were incorporated on AOT 604, SN 10. This unit was built and tested. Final Acceptance test results were excellent and the unit, which was designated the Qualification System, was delivered at AC Electronics in time for the start of Qualification testing.

A design change was incorporated into the objective lens assembly improving the AOT alignment, obtaining a more symmetrical field of view and consequently improved alignment. Evaluation of this change was scheduled for the AOT L/M, SN 1. In addition, field plot measurements on AOT's 606, 607 and 608 were obtained and plotted for assessing present alignment procedures. Monitoring of production units, fabrication liaison and participation in the AOT Qualification test program rounded out the remaining efforts of the group.

## 4.6 ENGINEERING - PERIOD ENDING 31 DECEMBER 1967

### 4.6.1 Engineering Activities

Engineering activity during this year, was a continuation of vendor and in-house support that began in 1966. The following information covering the period of 1967 lists all these problems and shows the action taken and conclusions arrived at for each of them.

#### 4.6.1.1 Long-Lok Screws

PROBLEM - Contamination was found in thread holes after installation of Long-Lok screws. Preliminary investigation revealed that Long-Lok screws which were not preformed required greater torque than preformed screws, to provide the same clamping action.

ACTION - Test data of the Long-Lok investigation has been compiled, and conclusions presented in a final report, "The Effects of Pre-forming Long-Lok Screws", AE-67-032.

CONCLUSION - No further action was required in this area.

#### 4.6.1.2 Manual Adjust Knob

PROBLEM - Upon release the Manual Adjust Knob would bind intermittently and/or hesitate to pop out with positive action.

ACTION - All changes necessary to implement the Manual Adjust Knob change have been approved, and all TDRR and ECO action was taken. The last of the associated changes was TDRR 33029 on SCT Panel, PN 2012765, calling for anodize of the chamfer cut for the O-ring.

CONCLUSION - Effort against the Manual Adjust problem is therefore concluded.

#### 4.6.1.3 1012157 Resolver - Epoxy Reinforcement

PROBLEM - A single failure of nonrepeatable accuracy after alignment, occurred.

ACTION - Application of an epoxy reinforcing bead as a product improvement has been completed on all in-house 1012157 resolvers. Since only a single failure has taken place, and no pattern of design or fabrication inadequacy is indicated, no drawing change is required.

CONCLUSION - No further action is contemplated on this matter.

4.6.1.4 Beryllium Anodize of Panels

PROBLEM - Several painted SCT Panels PN 2012717 exhibited damage to the Be anodize surface. Local pitting to bare metal and lifting under "tape" test occurred only after the panel was returned for anodizing of another area.

BACKGROUND (Chronological Order of events)

a. Two panels (one painted and one unpainted) were successfully processed.

b. Three painted panels failed by exhibiting pitting, and one unpainted panel was successfully processed.

c. Vendor's methods were changed to eliminate acid cleaning.

d. Two panels (one painted and one unpainted) worked successfully.

e. Four more painted panels were processed, with three showing evidence of pitting.

ACTION

a. Tests and analysis were performed after initial loss of three pieces indicated possible trouble from use of an acid compound (Nitric Acid-Ammonium Acid-Fluoride Compound) in cleaning. This compound will destroy Be anodize. Vendor's methods were revised to exclude this compound.

b. All panels requiring reanodize first were stripped of paint.

c. A change order was processed, per proposal K889, to remove anodize from only area in which lifting occurred. Anodize was required here for corrosion protection.

CONCLUSION - The problem of anodizing panels was resolved by ·ising the vendor's methods as follows:

a. All paint was stripped from panels before reanodizing.

b. Approval of K889 was received, which removed the requirements of anodizing the underside of the panel.

4.6.1.5 64X Resolver Peak-to-Peak Error

PROBLEM

a. Multiple in-house rejects resulted from resolver peak-to-peak error at 2012736 and 2011000 assembly levels.

| | |
|---|---|
| Resolver | Spec 20 arc seconds p-p |
| OUA | Spec 24 arc seconds p-p |

b. Assembly tolerance buildup of two (2) to six (6) arc seconds caused Resolvers close to the limit of specification to fail at final OUA test. This necessitated rework and retest.

c. Clifton and Reeves were the two resolver sources of supply. Reeves' units generally had lower component error and perform better in the OUA.

ACTION - Change Proposal K-887 was processed to change the Procurement Specification peak-to-peak specification from 24 seconds to 30 seconds. This would allow all available resolvers to meet specification.

Engineering ran peak-to-peak accuracy tests on five resolvers assemblies (PN 1012065), three Clifton units, SN's 1523, 1524 and 1527, and two Reeves units, SN 1011 and SN 1055. The tests were conducted, using OUA's and the Resolver Testing Fixture, each with three different test circuits; the three-wire grounded hookup specified in the resolver procurement specification, the three-wire ungrounded hookup specified by AC Electronics (currently used for TDA "O" only) and the four-wire hookup specified in the OUA procurement specification for peak-to-peak accuracy. In addition to Kollsman's tests, the Resolvers were returned to their respective manufacturers for accuracy tests.

CONCLUSION - The results showed that, with the current Apollo OUA test equipment specified in the OUA procurement specification, inspecification peak-to-peak accuracy can only be achieved with the four-wire hookup, even though the Resolver assemblies are tested in the grounded three-wire configuration by their manufacturers. Neither Kollsman nor the Resolver manufacturers had a definite explanation for this phenomenon, based on the limited test results from this investigation. The three Clifton Resolvers that were out of tolerance in all the Kollsman tests were all in tolerance at Clifton on their equipment.

Kollsman reran the three Clifton units, SN's 1523, 1524 and 1527, using in-line Index Heads from AGE's 219, 220 and 221 and the Learner Model OUA Resolver/Index Head combinations that gave in-specification accuracy for the three remaining optical units.

A report on the information obtained by Kollsman engineering is contained in Engineering Memo AET-7-478.

4.6.1.6 Eyepieces

PROBLEM

a. SXT Adjustable Eyepiece, PN 2012700

(1) Eyeguard, PN 2012609-Eliminate binding at fine aluminum thread.

(2) Focus Adjustment - Eliminate binding due to galling thread, improper piloting and tendency to override end of adjustment.

(3) Lens, PN 2011782 - Eliminate susceptibility to damage (Lens protrudes beyond housing).

b. SCT LER Eyepiece - PN 2012691

SCT Mirror Housing - PN 2012699

SCT Adj. Eyepiece - PN 2012719

(1) Strain Relief - Provide adequate strain relief (with retrofit capability).

(2) Connector potting - change to more rugged potting material such as RTV60 to avoid self propagating cracks.

(3) Heater Lead Splice - Eliminate vulnerable splice by incorporating heater lead into cable.

(4) Insulation Blankets - Change to material with better molding and foaming characteristics such as isocyanate (L-13) or NOPCO (302).

c. SXT Mirror Housing - PN 2012699

Change material of plug, PN 2012124, (Assembly, PN 2012699) to eliminate galling of thread (aluminum on aluminum).

ACTION - All changes against strain relief and connector potting were approved and all TDRR and ECO action was taken. Figure 4-35 shows nature of change.

CONCLUSION - A design plan for eyepiece improvement was submitted to AC Electronics. See Figure 4-36.

4.6.1.7 SXT Head Mirror Mounting

PROBLEM - Mirror shifts of SXT head.

ACTION - The following proposals were submitted to render the SXT Head Mirrors more stable during vibration, and eliminate mirror shifts:

a. Proposal K-769-2011712-new mirror bushing configuration

b. Proposal K-770-2012735 - new mirror bushing configuration

c. Proposal K-873-2011712 - shorter screw length to permit proper mounting.

CONCLUSION - Proposals a and b were rejected, and c was pending. Meanwhile, with changes of wave washer loading having been approved, Kollsman continued to control the screw length problem of c, by selection at assembly. A change was also granted to the Procurement Specification increasing the allowable SXT Trunnion zero shift.

Since implementation of these changes and procedures, SXT Trunnion shifts during vibration have been within specification.

4.6.1.8 SXT TDA Vibration Shifts

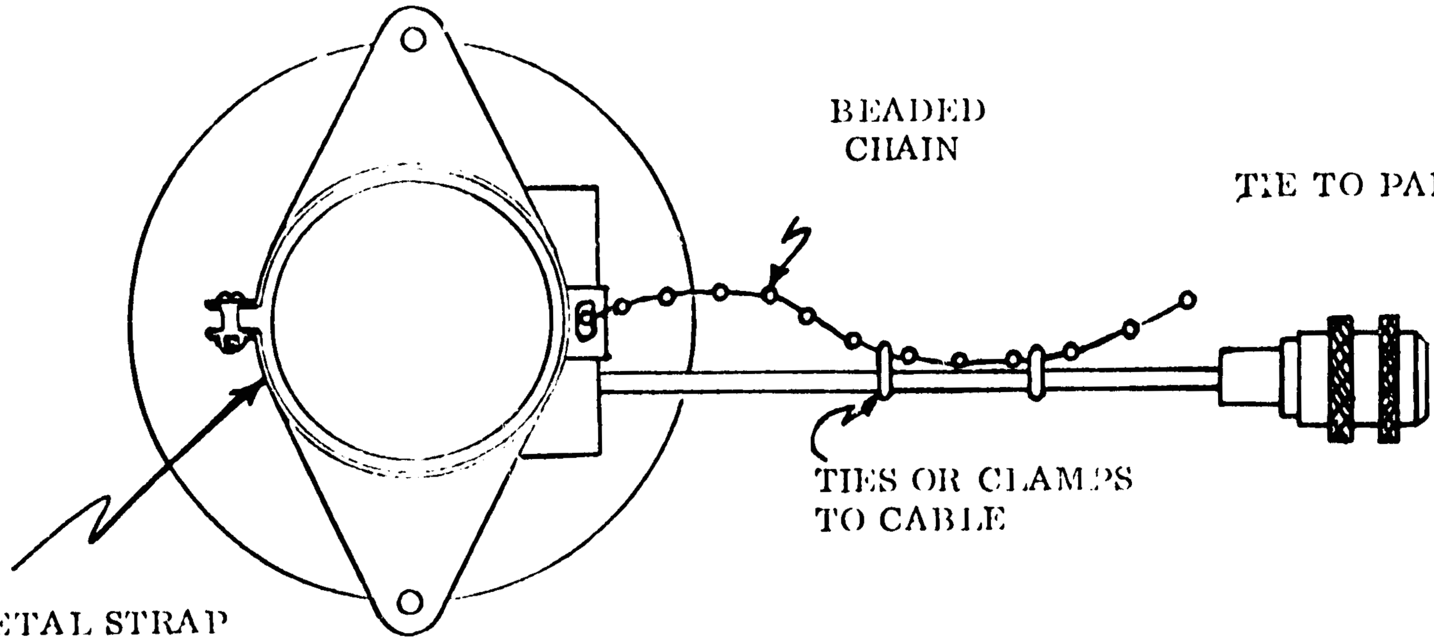
PROBLEM - SXT TDA zero shifted as a result of vibration.

ACTION

a. The SXT shift was brought under control per use of wave washer with higher loading and a rolled edge. The drawing change was accepted by CCB. See Figures 4-37 and 4-38.

b. Production has experienced a problem in producing washers with higher loading-the parts required for OUA 214.

Kollsman reworked washers have more consistent, though lower, pressure.



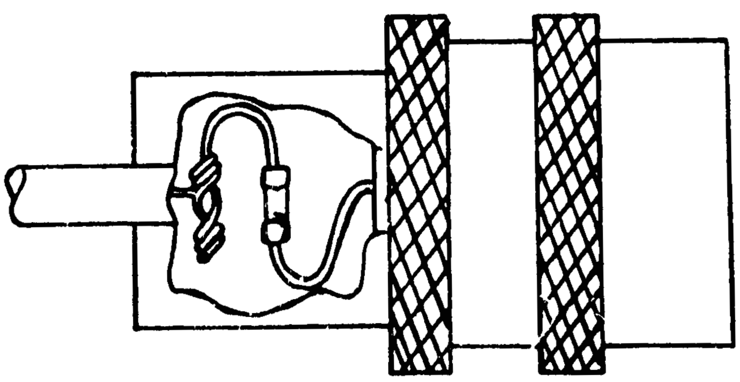
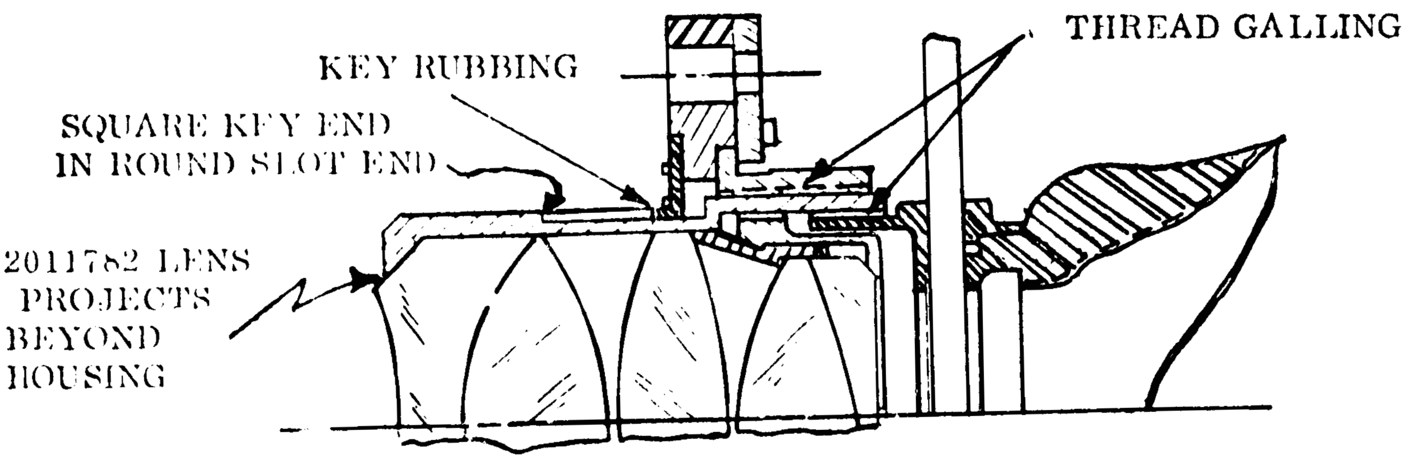



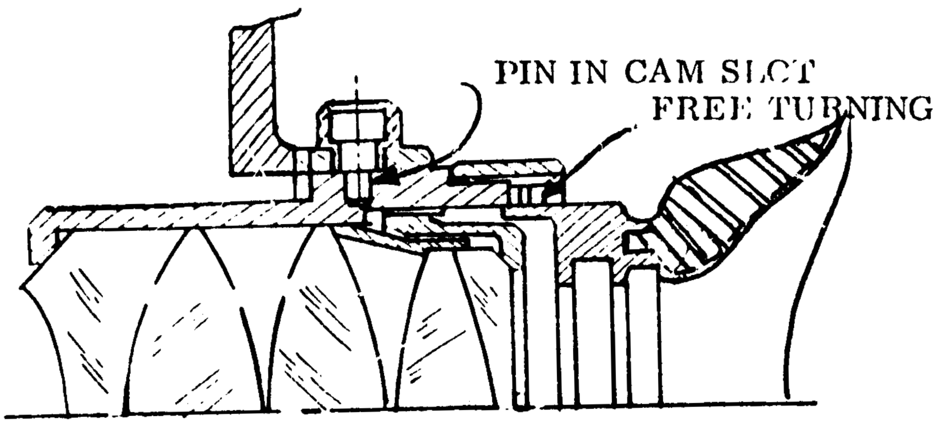

Figure 4-35. ERP 192, Fuse and Stress Relief

PRESENT DESIGN



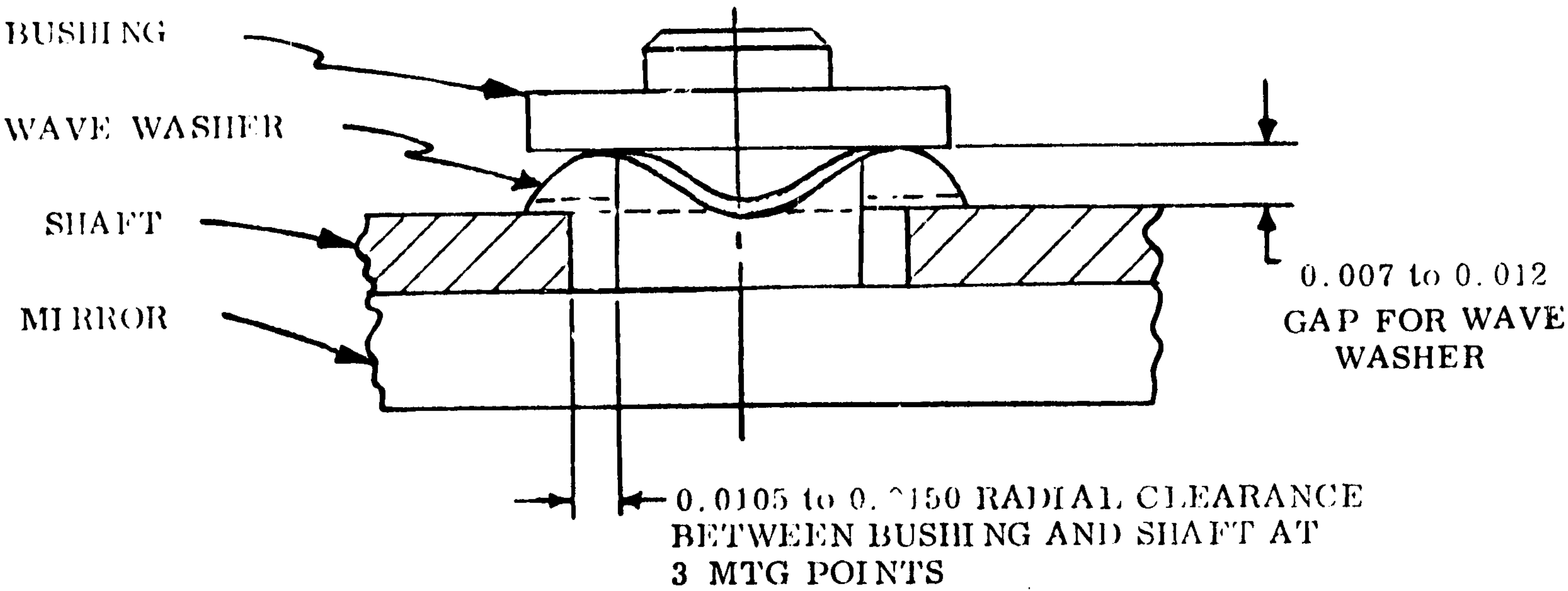

SCREW TYPE FOCUS

PROPOSED NEW DESIGN
(OLD MIT/IL RECOMMENDATION)
CAM TYPE FOCUS




SWIVEL EYEGUARD

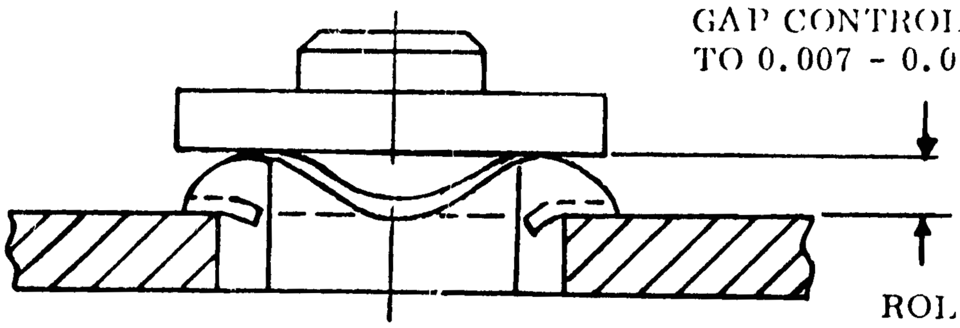
Figure 4-36. SXT Eyepiece Assembly, PN2012700




| WASHERS CHECKED 2011213 NO. REV. | MEASURED GAP (IN.) | LOAD (LBS.) |
|---|---|---|
| STOCK | 0.007 | 7 |
| STOCK | 0.012 | 4 |
| WASHERS REMOVED FROM AGE 207 AFTER SYSTEM FAILURE | 0.0083 min. | 5.5 |
| | 0.0010 Max. | 5.0 |

WASHER PRESSURES WERE CHECKED USING FIXTURE

**Figure 4-37. SXT Vibration Shifts, Original Design**




SN 025, 021, 024, 029
AGES 207, 209, 210, 211

MIN PRESSURE: 8 LBS.
MAX PRESSURE: 26 LBS.

EVALUATION LEARNER MODEL - 3 MIRRORS

3 WASHERS = 10#
3 WASHERS = 11#
3 WASHERS = 12#

Figure 4-38. SXT Vibration Shifts Latest Design, PN 2011213, Revision A

The Learner Model OUA, rebuilt with Kollsman reworked washers, was vibrated and analyzed for TDA shifts.

A quantity of washers sufficient for the remaining OUS's has been received from the vendor and placed in stock.

CONCLUSION - No further steps need be taken in this area.

4.6.1.9 SXT Shaft Spring Back (Figure 4-39)

PROBLEM

a. SXT shaft moves (jumps) when power is removed

b. Observed at NAA, AC and Kollsman

c. Observed only during manual direct mode operation during G&N Functional Tests

d. Variations in magnitude up to 0.4 degrees observed

e. Important in training and ground testing. Not critical during flight.

ACTION (Kollsman Investigation of Problem)

a. No servo loop during manual direct mocd

b. No electrical lock after hand controller is released

c. Only mechanical damping or friction can hold position

d. OUA is designed and assembled for minimum friction

e. OUA P.S. and Final Test Procedures do not monitor open loop characteristics.

(KOLLSMAN INVESTIGATION OF CAUSE)

a. Flexprints proved to be the components responsible

b. No changes to flexprints are practical

c. Spring back magnitudes are shown in Table 4-16

d. A summary of findings of the investigation is given in report AE-67-030, "SXT Shaft Axis Spring Back".

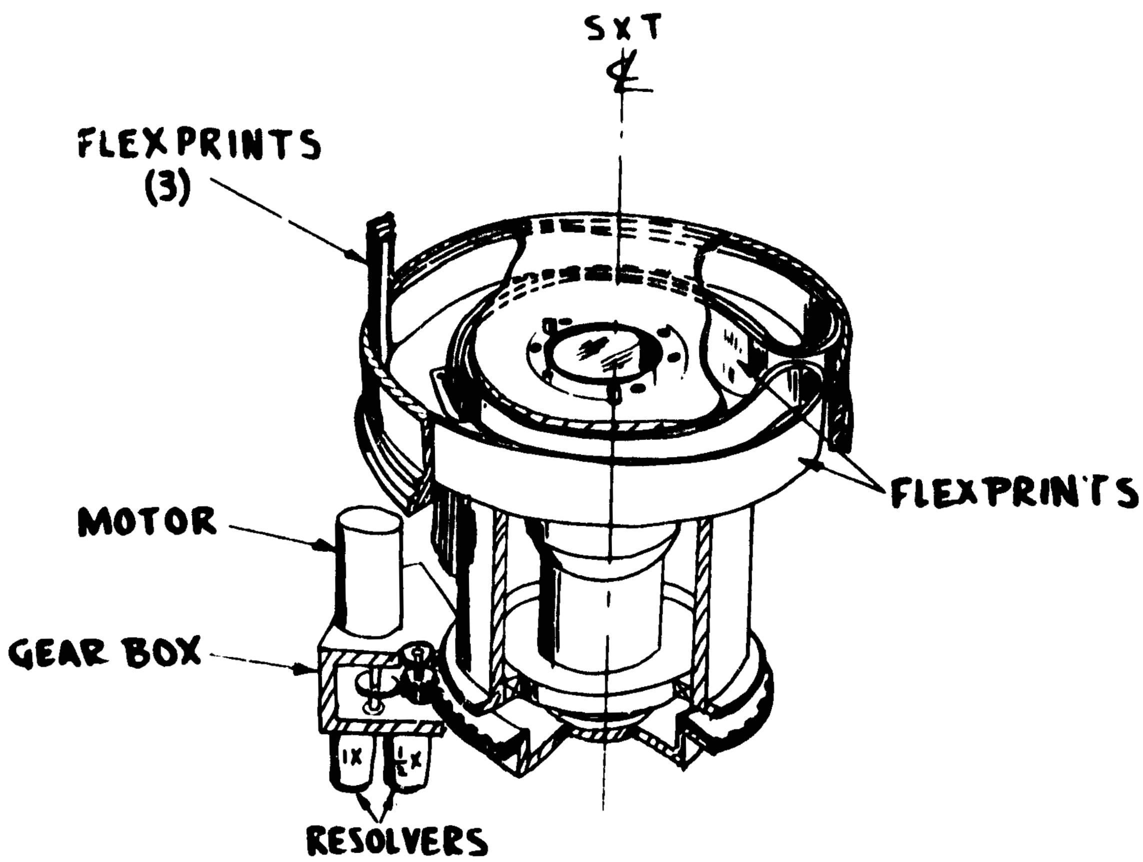



Figure 4-39. Flexprints in Sextant Shaft

ACTION

a. NASA is considering living with the condition

b. AC is considering the addition of a switch to keep motors energized. Tecnnically, this is the optimum solution.

c. Kollsman was requested to add a friczion producing, finger-to-shaft gear face which requires configuration change and a requalification program. This solution is technically inferior to Item b.

CONCLUSION - The problem is currently referred to AC for further action. Kollsman does not contemplate any further action to be necessary.

TABLE 4-16

SPRING BACK MAGNITUDES

| Location | Unit | Max. Spring Back |
|---|---|---|
| At Kollsman | Block 1-100 S/N 4 | 0.2° (12 minutes) |
| | S/N 023 | 0.08° (4.7 minutes) |
| | Learner Model | 0.1° ( 6 minutes) |
| At AC Electronics | S/N 018 | 0.3° (18 minutes) |
| | S/N 020 | 0.1° ( 6 minutes) |
| At N.A.A. | S/N 015 | 0.04° (2.4 minutes) |

4.6.1.10 Thermal Blankets

PROBLEM

a. The vendor yield was unsatisfactory. Internal voids and loose skin were major causes of rejection. All production and spares requirements have been delivered.

b. Long lead time between placement of the anticipated spares order and delivery of parts was normal.

c. The basic problem of engaging a vendor to manufacture thermal blankets without internal voids and loose skin still existed.

d. A new vendor was researched and a trip was made to Urethane Molders, Tonawanda, New York, for the purpose of formulating new fabricating techniques. The same problem areas were encountered by Urethane as those experienced by the present vendor.

ACTION

a. Cause (Uralane 577-1).

(1) Material - Foaming action difficult to control
(2) Pot Life - Very short (10-15 seconds
(3) Poor Rework Characteristic
(4) Vendcr lacks adequate capability

b. Investigation

(1) Various materials were evaluated, using wood molds and silastic molds. See Table 4-17.

TABLE 4-17

MATERIAL PERFORMANCE

| Material | Pot Life | Voids | Skin | Insul. Prop. | Spec. Reqt | Flammability Air | Flammability Oxy |
|---|---|---|---|---|---|---|---|
| Isofoam | 60 sec. | Slight | Good | Good | Accept | X | X |
| NOPCO | 30 sec. | Slight | Poor | Good | N/A | - | X |
| Chempol | 60 sec. | Severe | Poor | Good | N/A | X | X |
| PRC 1538 | 24 hrs. | None | Good | Poor | N/A | - | - |

(2) Production evaluation was conducted at Urethane, Inc. (new vendor) on 22 March 1967. The mold became available at Mutron 30 March 1967.

(3) Urethane capability includes:

Automatic dispensing
Rigid molds.

CONCLUSION - Prior to the conclusion of an engineering investigation a nonflammable Thermal blanket was requested.

4.6.1.11 Connectors

PROBLEM - Excessive wear has taken place on the coupling surfaces of the OUA bulkhead connectors, particularly in the detent grooves.

ACTION - A lubricant was recommended by AC Electronics, and a specification control drawing was generated for this lubricant. Instruction for application of this lubricant had also been provided by AC.

a. Cable clamps were provided to support the harness on the PTF and take the load off the connector.

b. A platform was used to support the alternate short cable.

CONCLUSION - All steps considered necessary for the protection of the connector were taken.

4.6.1.12 Purge Valve

PROBLEM - During the second quarter of 1967, Engineering investigated screw tip damage which occurred when 15 in-lbs torque was applied while closing the Purge Valve.

ACTION (Test Evaluation of Design Changes)

a. Length of the screw nose was reduced which caused the valve to seal at 5 in-lbs of torque. The operation was checked 18 times and the valve was sealed at 5 in-lbs without leaks.

b. The O ring was eliminated in standard assembly and torqued to 15 in-lbs with no evidence of leaks.

c. Test plates were ordered to repeat the preceding tests on four basic assemblies. Conclusions and results were reported in the third quarter of 1967.

CONCLUSION - Design change recommendations were based on test plate data.

4.6.1.13 Shelf Life Spares

PROBLEM - Shelf Life Spares. The government Block II spares record was reviewed and recommendations were made to reinspect parts and assemblies stored in the Bond Room for long periods of time. Lubrication is an area of basic concern.

ACTION & CONCLUSION - An unsolicited ERP. No. 203 was prepared and submitted to AC for further study and action.

4.6.1.14 Size 8 Resolver Errors

PROBLEM - Two size 8 resolvers were rejected as being out of specification.

ACTION - Engineering investigated the peak-to-peak errors of size 8 resolvers. The method of clamping was suspected. The effects of the Functional Tester were evaluated. A test fixture was designed to evaluate effects of clamps on shafts.

The two size 8 resolvers which were rejected for being out of specification were tested. Both size 8 resolvers were found to be well within specification after retest. No appreciable change was noted on peak-to-peak readings under varying clamp loads, from fingertight to 6 in-lbs.

CONCLUSION - The present method of operation was considered adequate.

4.6.1.15 Be Corrosion

PROBLEM - Evidence of Be corrosion was noted inside OUA base cavities.

ACTION - As a result of many tests performed by Reliability, a procedure was applied to OUA as a pilot run. Satisfactory results were obtained and manufacturing revised several Route and Tool books to implement this procedure.

CONCLUSIONS

a. Kollsman treated all future in-line bases with this procedure.

b. All OUA's returned for retrofit or repair were checked for corrosion and recommendations were made on an individual basis.

4.6.1.16 Exudate and Haze

PROBLEM - AC reported that a hazing condition had developed in SN 029.

ACTION

a. A review of past history was reopened. (Ref. Reliability, ARR 31).

b. Route and Tool operations were reviewed and procedures were tightened.

c. Further investigation disclosed that the "haze" seen in varying degrees on SXT windows was indeed a variation in the appearance of optical coating. Such variations are normal.

d. A Field Bulletin was sent to alert field engineers on the proper method of inspection of coated glass.

CONCLUSIONS

a. Variations in coatings (appearance) on SXT windows are normal.

b. No further investigation was required.

4.6.1.17 SXT Trunnion Hesitation

PROBLEM - Hesitation was observed by AC in the SLOS image as it translated the field of view during G&N system testing.

ACTION & CONCLUSION - AC directed Kollsman via KD 2374 to implement a study program to duplicate this phenomenon at the Kollsman facility. Subsequent amendments to the basic KD were received resulting in the plan of action in two phases as follows:

Phase I is described in detail in Report AE67-033, "Sextant Trunnion Hesitation Study".

Phase II is the Implementation Phase.

Alleviation of the SXT Trunnion Hesitation necessitates the redesign of Spring, PN 2011239, which is used in the 2011940 Spring and Collet Assembly.

The proposed spring exhibited an increase in torque and was also designed so that the loops will not touch when rotated from 0 through 255 degrees.

The following list of TDRR proposals were submitted to MIT/IL for DRB & CCB approval for in-line and retrofit action.

IN-LINE TDRR PROPOSALS

| | |
|---|---|
| K 892-2012766 | Spring (New Dwg.) |
| K 893-2012767 | Spring & Collect Assy. (New Dwg.) |
| K 894-2012735 | SXT Index Head Assy. |
| K 895-2012736 | OUA Subass'y Stage II |
| K 896-2011000 | OUA |
| K 897-2016207 | Procurement Spec. |

RETROFIT TDRR PROPOSALS

| | |
|---|---|
| K 910-8106063 | Kit Dwg. (New Dwg.) |
| K 911-2011000 | OUA |
| K 912-2012736 | OUA Subassy' Stage II |
| K 913-2012735 | SXT Index Head Ass'y |
| K 914-8106025 | Master retrofit kit list |
| K 915-2016206 | Procurement Spec. |
| K 916-2016207 | Procurement Spec. |

4.6.1.18 Non-Metallic Investigation - KD 2377

PROBLEM - Search out and substitute materials for:

AOT Seal, PN 6011143

AOT and OUA Eyepiece insulating blankets

Background (Chronological order of events)

10 May - Received KD 2377 - C.O. 205

10-16 May - Preliminary Investigation
a. Define total requirements for substitutes
b. Thermal analysis on OUA eyepieces
c. Material search initiated

22 June - Status meeting

a. Target for completion set for 15 November 1967

b. Program outlined and manpower assigned

| | | |
|---|---|---|
| 28 June | - | Thermal Evaluation test plan proposal submitted to AC |
| 19 June - 7 July | - | Consultation with material suppliers and fabrication |
| 28 June | - | ERP 206 submitted to AC |

Firms Consulted

| | | |
|---|---|---|
| 19 June | - | Dupont and Doge Fibers |
| 23, 27 June | - | 3M Co. |
| 27, 29 June | - | AGC Corp. |
| 27 June | - | Allied Chemical |
| 29 June | - | Borden Chemical |
| 29 June | - | Boonton Industries |
| 3 July | - | American Felt Co. |
| 3 July | - | Diaphragm Industries |
| 3 July | - | Conn Hard Rubber |

Programming

a. Table 4-18 outlines the program. Completion date for the final report.

b. Figures 4-40 and 4-41 summarize the manning and itinerary established for the program.

4.6.1.19 SXT Reticle Investigation

PROBLEM - A demarcation line was observed on the SXT reticle during the buildup of the 2012736 assembly level. It was determined after the Reticle assembly was removed from the unit and examined that the line was a fracture in the Cover glass of the reticle.

ACTION - The test objective was to build facsimile samples of Reticle assemblies and test them to determine optimum types of cement, cementing technique, tightening torques and thermal shock influence.

TABLE 4-18

PROGRAM OUTLINE

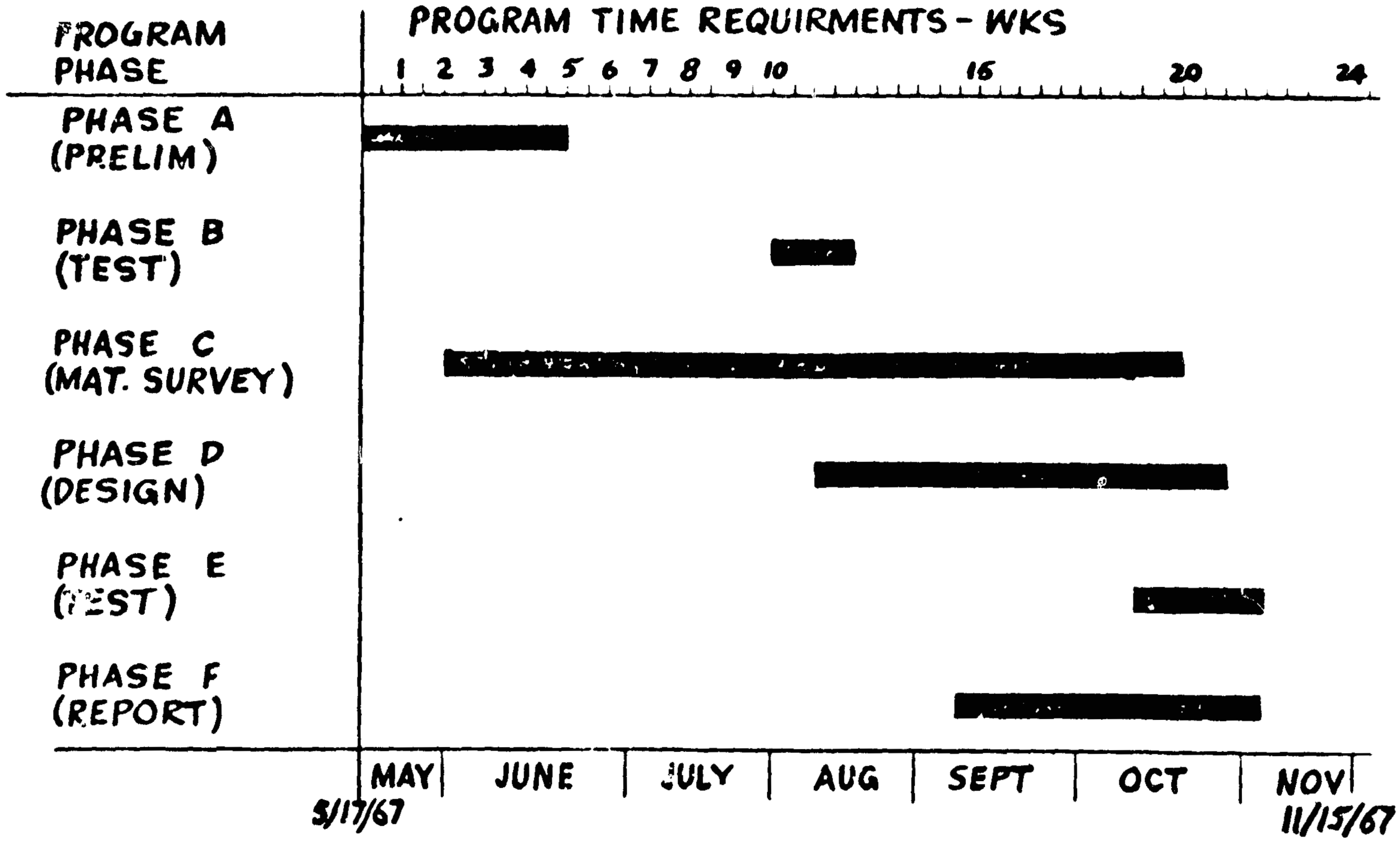
# PROGRAM OUTLINE

MAKEUP

SIX WORK PHASES (2 TEST PHASES [B & E]
PROPOSED - REQUIRE AUTHORIZATION)

1. PHASE "A" PRELIMINARY INVESTIGATION
   PLAN. THERMAL ANALYSIS. RESEARCH REQUIREMENTS. PRELIMINARY SEARCH
2. PHASE "B" (PROPOSED BUT NOT AUTHORIZED) THERMAL ENVIRONMENT TEST
   EMPIRICAL DATA. PRESENT CONFIGURATION
3. PHASE "C" MATERIAL SEARCH
   ELIMINATION PROCESS
4. PHASE "D" APPLICATION DESIGN
5. PHASE "E" (PROPOSED BUT NOT AUTHORIZED) THERMAL ENVIRONMENT TEST
   VALIDATION OF RECOMMENDED SUBSTITUTES
6. PHASE "F" FINAL REPORT

# SCHEDULING




MILESTONES

- JUNE 16 - PHASE A - COMPLETE
- JUNE 26 - ERP 206 SUBMITTED
- JUNE 28 - TEST PLAN SUBMITTED TO AC (PHASES B & E)
- JULY 24 - PHASE B START (DESIREABLE BY AUG 30)
- SEPT 30 - PRELIMINARY REPORT TO A.C.
- OCT 15 - PHASE E (NOT AUTHORIZED)
- NOV 15 - FINAL REPORT - INVESTIGATION COMPLETE

Figure 4-0. Scheduling

# PROGRAM FLOW

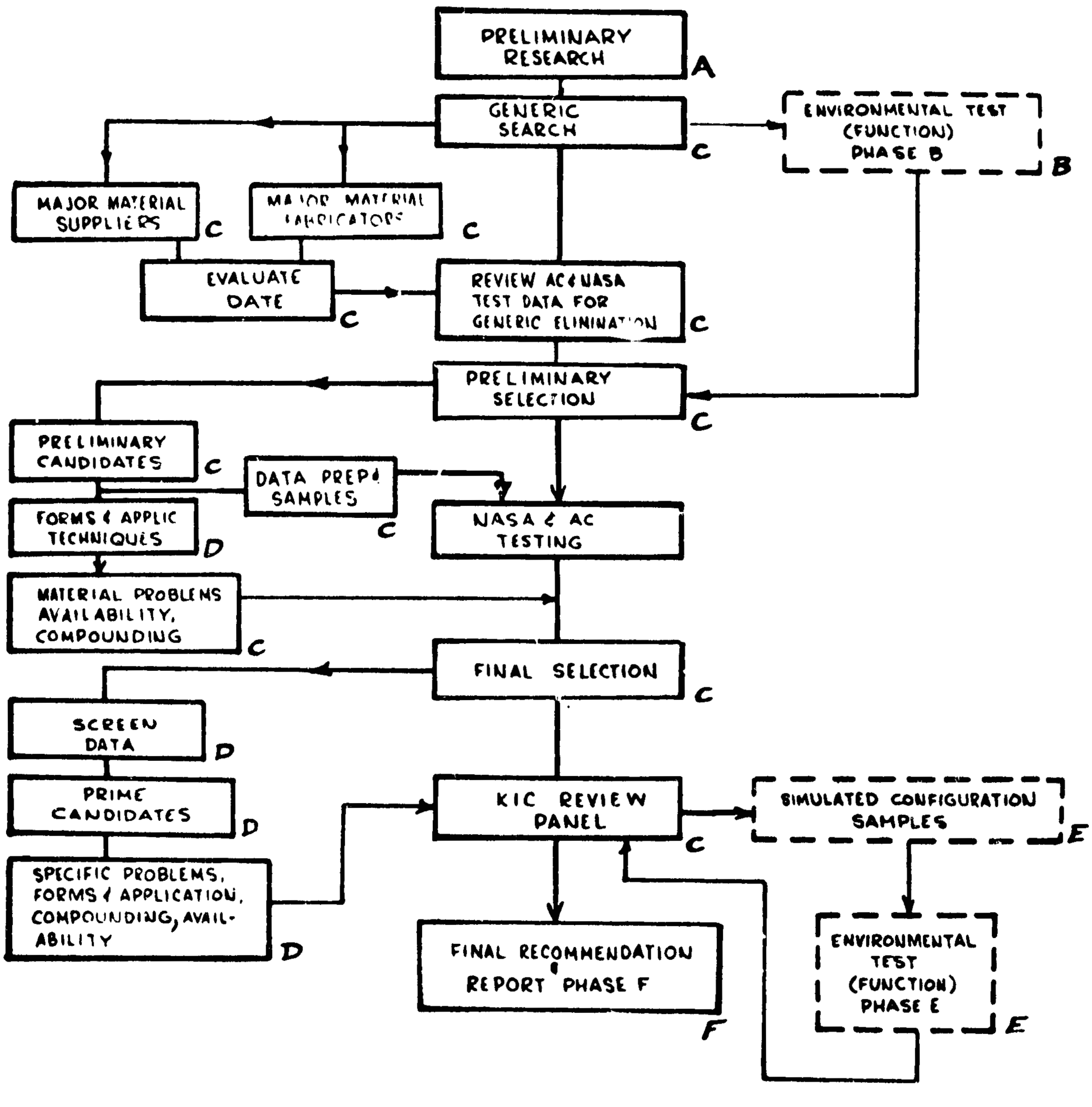



Figure 4-41. Program Flow

CONCLUSION - Revised Route and Tool procedures and stains measurements to minimize stain patterns in SXT reticle.

4.6.1.20 OUA 1-201 SN 014 Failure Analysis

PROBLEM - Engineering verified the two field failures on this unit and found the problems were due to an intermittent tachometer output on the SCT shaft motor, a high starting voltage on the motor itself and a tight mesh between the SCT shaft gearbox output gear and the shaft bull gear resulted in excessive wear on the output gear.

ACTION - A rework plan was presented to AC Electronics to refurbish the unit.

CONCLUSION - No further action is contemplated on this matter.

4.6.1.21 SCT Output Gear Drive Gear Wear Problem

PROBLEM - A failure on AGE 1-201 SN 014 OUA and a subsequent check of AGE 206 SN OUA disclosed an extreme wear problem at the mesh between the shaft drive gear (PN 2011655) and the shaft gearbox output gear (PN 2011278). Both units were used extensively in the field.

ACTION - Analysis of the gears in question disclosed the problem was due to an overly tight mesh. This mesh was adjustable at assembly. An examination of four other recycled field units showed no excess wear in this mesh.

Memo No. AET-7-441 was generated to visually observe this mesh under 40X magnification. The mesh was checked every 22-1/2 degrees on the shaft drive gear for some tooth clearance (backlash) and to insure that the teeth are not bottoming (interference).

CONCLUSION - Engineering developed a procedure which controlled the mesh by adjustment and altered the R/T books to reflect this information.

4.6.1.22 OUA Perpendicularity Problem

PROBLEM - It was found that a simulated shift in perpendicularity could be caused by the lamp used in the eyepiece to backlight the OUA during testing. Slight off centering of the lamp or collimating lenses in the lamp resulted in an off centered image of the OUA Reticle, thus duplicating the same effect as a perpendicularity error.

ACTION & CONCLUSION - The test procedure was changed to use a diffused light source without the eyepiece for backlighting the OUA. This fix was previously used successfully on the PTF for TDA "O" when a similar lamp problem gave erroneous results. Corrective action was covered in ECO 118856.

4.6.1.23 SXT Limit Stop Tests (Ref: Engineering Report AE-67-035 See Appendix B)

PROBLEM - A question was raised by NASA whether the OUA SXT limit stops were adequate to absorb repeated impacts from the shaft and trunnion axes at full slew speeds without fatigue and degradation.

ACTION - Kollsman measured the forces involved at the stops and visually observed the stops at impact. The full ablative cover assembly was mounted to the SXT trunnion for these tests. Both limit stops appeared adequate in operation and exhibited no fatigue, degradation or tendency to malfunction.

CONCLUSION - Therefore, there was no problem with the present design or components in either stop assembly.

Further engineering investigation was not required.

4.6.1.24 Pechan Prism Mount

PROBLEM - Dimensional analysis and tolerance buildup disclosed a potential loose Pechan prism mount on OUA AGE 215.

ACTION - An analysis of the other in-line units through AGE 221 disclosed a potential problem assembly. This assembly was mounted in the Learner Model OUA and vibration tested to determine if a problem resulted. Testing was schedule within the next two weeks due to backlog on the vibration equipment at this report period.

CONCLUSION - New assembly specifications were developed to select springs at assembly level.

4.6.1.25 Non-metallic Material Investigation

PROBLEM - To find non-metallic substitute materials as a substitute for the eyepiece blankets that will pass the NASA fireproof requirements.

ACTION - Apollo Program Materials Report, A-A-67-414, 31 August 1967, lists the activity up to that time.

From 31 August until the present, Kollsman was directed by AC Electronics to use "Viton" group material or equivalent for the OUA Eyepieces and "Beta Cloth" (teflon-coated fiberglass) for the LM.

OUA Eyepieces - "Vitron" sponge blankets were developed and drawings made. The drawings and ND documents are currently at MIT/IL for CCB approval. The vendor is processing initial limited quantity order.

LM - Metallic protective covers were developed for the LM heater pads and lamps. The drawings are currently at MIT/IL for CCB approval. Parts were made for evaluation on an in-house AOT.

CONCLUSION - "Vitron" sponge blankets were found not acceptable. Kollsman told t go ahead with metallic protective covers for eyepieces.

4.6.1.26 SCT Panel Counter Interference Problem

PROBLEM

a. A field failure on AGE-1-201 OUA disclosed an old problem in the OUA; the possible interference between the counters and the panel bezels.

b. A second problem developed during the investigation. It was found that some counter shades, when broughz back to their limit stops, interfered with the counter drum.

ACTION AND CONCLUSION

a. Engineering developed the dimensions for a gauge to measure the clearance on the panel bezels and altered the R/T books to allow the counter shades to protrude slightly above the optical base. Until now, Production had to adjust the counter shades to clear the top of the optical base. Now no adjustment would be allowed in changing the curvature of the shade. All adjustments were limited to the panel bezels and shade mounting.

b. Engineering analyzed the counter drawings and requested Quality Assurance to develop inspection procedures for the 1012512 counters before they are stocked.

## 4.6.2 GSE Engineering

### 4.6.2.1 OUA Protective Plastic Covers

AC requested an engineering budgetary from Kollsman on OUA Protective Plastic Covers. Engineering generated the following technical description:

Item 1 - Plastic Container

The bag will be of a pliable polyethylene or similar material with a preformed "zipper" edge capable of supporting a pressure of 2-3 psi. The OUA (less eyepiece), placed inside the bag, will be supported on the eyepiece panel, resting on simple blocks which are not included in the estimate. A plastic tube will extend from the bag with a standard tire valve attached, so that nitrogen can be easily inserted.

Item 2 - Plastic Cover

The hand-formed plastic cover will be adapted to the CM configuration with all of the ablative skin in place. The cover will be sealed to the CM skin via an adhesive tape, of a type currently in use by NAA and NASA.

Attached to the plastic cover will be a mechanical pocket holding a non-dusting type disposable dessicant.

## 4.6.3 Lunar Module Project Engineering

### 4.6.3.1 General Activities

During the first reporting period of 1967, the following units were fabricated and delivered:

a. AOT 609 (SN 15) delivered 31 January 1967

b. AOT 610 (SN 16) delivered 6 March 1967.

The aforementioned deliveries were made with no waivers issued against them.

During the second reporting period of 1967, Alignment Optical Telescope (AOT) 611 (SN 17) was fabricated and delivered without waivers, 29 May 1967.

During the third reporting period, Alignment Optical Telescopes (AOT's) 610 (SN 16), 611 (SN 17) and 612 (SN 18) were fabricated and delivered with the following design modifications.

a. Moistureproofing and illumination of the angle counter

b. Incorporation of dray in the Reticle Control Knob

c. Change in reticle illumination (clear to red bulbs)

d. Sealing of eyeguard plug.

Three AOT high density sunfilters (production units) were fabricated and delivered.

4.6.4 Engineering Activities

Extensive engineering design studies were initiated on an AOT sunshade and accompanying GSE. The purpose of the sunshade was to reduce stray light reflected from Space Capsule skin and rendevous radar thereby reducing the capability of star sightings.

This engineering effort was directed toward the incorporation of the following design changes into the Kollsman Learner Model.

a. Moistureproofing of the Angle Counter and provision for illumination.

b. Incorporation of drag in the Reticle Control Knob

c. Change in Reticle illumination (Clear to red bulbs)

d. Sealing of Eyeguard opening

e. Refined reticle.

The aforementioned design changes were demonstrated to NASA and the astronauts on the night of 8 June 1967 and were received very favorably. Design changes a. through d. inclusive were approved for both retrofit and in-line production.

The AOT High Density Filter design was completed and a prototype fabricated for evaluation.

Extensive engineering effort was directed in the following specific areas.

4.6.4.1 Moistureproofing of the Angle Counter and Provision for Variable Illumination

During AOT 604 qualification testing the Angle Counter window "fogged up" when the unit was exposed to humidity. Redesign of the counter housing was undertaken to provide moistureproofing . The moistureproofing was accomplished by both static and dynamic seal as well as coating the counter window witn an antifogging film. In addition, counter illumination was supplied via "wedge" lighting as is currently in use on the OUA.

4.6.4.2 Incorporation of Drag in the Reticle Control Knob

In order to make the Reticle Control Knob more stable, but sill maintain its "free-wheeling" or "slewing" characteristics, a drag feature was designed into the knob assembly in the form of an O-ring around the knob shaft. This modification is a field retrofit,

4.6.4.3 Change in Reticle Illumination

To obtain a sharper definition between target star, reticle cursor and spiral lines, and to facilitate the astronaut's physiological adaptation to darkened light environment (dark adaption), a change in reticle illumination from white to red was effected. Comparative tests were conducted on white and red bulbs to obtain voltage levels required to achieve the same illumination. Results will aid in fixing the voltage output of the Computer Control and Reticle Dimmer assembly by AC.

4.6.4.4 Sealing AOT Apertures

To prevent contamination of the unit, by infiltration of foreign particles through its various openings, a design effort was undertaken to seal off such ports. The effort resolved itself to one directed at the prime equipment and a GSE modification.

4.6.4.5 Reticle Contamination

Due to the astronauts' objections to so-called "false stars" in the reticle, requirements governing fabrication, acceptance and testing of this component were tightened. In addition, items discussed in paragraphs 4.6.4.3 and 4.6.4.4 have been expressly designed toward improving the condition of the reticle. To obtain a qualitative measure of what type of contaminants glow and could contribute to the "false star" problem, known particles were introduced on the Learner Model AOT with the following results in order of relative brightness.

Adhsesive, PN 1010838
Loctite Grade CV
Loctite Grade C
Ecco Bond

Flakes of thermal blankets, white paint and beryllium dust were invisible. The aforementioned order of brightness was under maximum reticle illumination (5 volts) however, under optimum reticle illumination (approximately 2 volts) the adhesive and Loctite were only slightly visible. Correlation between Kollsman results and field findings must be made before any firm conclusions can be made.

4.6.4.6 AOT High Density Filter

Design of a sun filter for the AOT is to permit sightings of the sun. The filter is designed for easy stowage in the spacecraft.

4.6.5 Qualification Program

AOT 604 (SN 10) was recycled through a qualification test program to determine whether design modifications on the AOT, i.e., counter moistureproofing and illumination, drag in Reticle Control Knob, etc., were adequate from a mechanical integrity standpoint. The unit passed the humidity test without fogging of the counter window or introduction of water into the counter.

## 4.7 ENGINEERING - PERIOD 1968 - 1969

### 4.7.1 Command Module Engineering

#### 4.7.1.1 General Activities

The major engineering effort during this period was a continuing analysis of the vendor and in-house problems that began during 1967.

### 4.7.2 Engineering Activities

#### 4.7.2.1 64X Resolver Testing (PN 1012065)

Both Reeves and Clifton units were acceptable in accordance with component testing procedures and tested further to assure good system performance.

Clifton units, S/N 1527 and S/N 1524, would not satisfy system requirements. Two Reeves units were ordered to satisy production shortage. Data indicated generally a lesser problem with Reeves units at system level tests.

#### 4.7.2.2 Eyepiece Protective Covers

Eyepiece fire drill tests conducted by NASA negated use of non-metallic insulating covers. Direction to develop metallic covers was received on 20 January 1968. Redesign was accomplished and a qualification set of eyepieces was shipped to AC on 20 February 1968.

The new covers satisfactorily passed qualification tests. Eleven sets of eyepieces with new covers were delivered during the report period.

#### 4.7.2.3 Eyepiece Vibrating Proofing

During ESU - Eyepiece qualification testing at AC, thumbscrews on PN 2012748 backed off during vibration. Flat and split washers were introduced by AC to vibration-proof screws.

Incorporation of this fix required modification of thumbscrews to accommodate the air focus shim used for ground testing. It was recommended to AC that wave washers be used to avoid changing screws. Sample wave washers were made which will provide the same loading achieved with the lockwasher.

#### 4.7.2.4 SXT Reticle Investigation

Simulated reticle assemblies, PN 2012425, were tested to evaluate strain characteristics on reticle glass. Samples bonded with rigid epoxy developed edge cracks similar to that reported in the last report period. Additional samples bonded with a flexible epoxy did not crack when subjected to the same test procedures.

Reinspection of all prime equipment uncovered no additional damaged reticles. A Class II change was processed, calling for the flexible epoxy to be used. Activity was closed out.

4.7.2.5 Pechan Prism Mount

Measuring techniques for determining shim requirements were revised to assure proper clamping of mount.

Assemblies suspected of having loose mounts were vibrated and found satisfactory. The activity was closed out.

4.7.2.6 AGE 209, S/N 021 SXT TDA Failure

After a prolonged period of testing at AC, the SXT TDA was found to be completely inoperative. Simulated tests were conducted at Kollsman in an effort to repeat failure with negative results. (Tests were filmed).

Dimensional studies were made indicating potential problem in areas of:

a. limit stops, and

b. interference with ablative covers.

Analysis and test were performed and results were reviewed jointly by Kollsman and AC for determination of cause of failure.

4.7.2.7 GSE Cover Conversion (KD2430)

PN's 2012796 and 2012797 (three of each) were shipped on an Engineering Waiver (No class A dwgs.) on 7 May 1968.

Torque required to engage covers with OUA was considered objectional by the astronaut. Torque requirements were established based on improved covers forwarded to NASA on 31 May 1968. Shipments were pending CCB approval of modified design and incorporates shimming to satisfy the torque requirements.

4.7.2.8 SCT Shaft Unbalance

A cyclic stiction phenomenon of the SCT Shaft was observed during testing at AC on AGE 206. Kollsman personnel were requested to assist in the investigation.

Erratic stiction was discovered caused by unbalance of the Ablative Cover assembled at AC. Testing at Kollsman was accomplished with a balanced metallic cover, PN 2012547.

4.7.2.9 Eyepiece Lubraction - KD 2436 - 7 May 1968
FR 13611 - 6 April 1968

Plungers of the quick disconnect feature would not move after qualification humidity test. Failure was attributed to corrosion products located between the plunger and eyepiece housing.

Per AC Directive, a change was processed to provide additional corrosion protection through application of grease to the plunger. A similar change was incorporated on cover assemblies.

4.7.2.10 Manual Adjustment Knobs (TDRR 36143)

a. Stainless steel bushings were added to the SCT Panel as an optional feature to improve wear characteristics at the interface of knob and panel.

b. Bushings were incorporated on AGE's 202, 203, 204, 205 and 209. In-line production commencing with AGE 219 also had bushings incorporated.

4.7.2.11 SXT Trunnion Limit Stops (KD 2441)

a. Limit stop failure after extensive testing of AGE 209, at AC, necessitated re-evaluation of the design.

b. The stop arrangement was redesigned to take higher impact loads and eliminated chance failure due to tolerance accumulation.

c. Limits of trunnion travel were minimized, thus reducing the potential of trunnion mirror interference with the ablative cover. Cover modification was required to eliminate all possibilities of interference.

d. Field modification was accomplished per AC Directive.

e. The final design was pending CCB approval.

4.7.3 Lunar Module Project Engineering

4.7.3.1 General Activities

During this reporting period, the following in-line Alignment Optical Telescopes (AOT's) were delivered:

| AOT | AOT |
|---|---|
| 614 | 617 |
| 615 | 618 |
| 616 | 619 |

During the same reporting period, the following AOT's were recycled through Kollsman for retrofit:

| AOT | |
|---|---|
| 606 | Simulator No. 1 |
| 607 | Simulator No. 2 |
| 608 | |

Both in-line and retrofit AOT's were delivered without waivers and with the latest design modifications (ref. Paragraph 4.1 of Technical Progress Report No. AA-67-415).

Six AOT high-density sunfilters were fabricated and delivered.

### 4.7.4 Engineering Activities

In this reporting period, design of the AOT sunshade was completed. Design was approved at a Critical Design Review held at NASA-MSC, Houston, Texas. Prototype sunshades were fabricated and delivered. One prototype underwent successful testing by NASA at Kitts Peak, Arizona.

During this period LM Project Engineering conducted an extensive engineering evaluation on an engineering model of the sunshade. This evaluation included both high level vibration and a three-day TV test. Excellent results were obtained testifying to the mechanical integrity of the sunshade.

Latest design modifications were incorporated, during this period, into the KSC AOT simulator S/N 4.

### 4.7.5 Field Site Activity

Past experience at the GAEC field site in the performance of OCP 37027, final checkout of the LM Guidance and Navigation system at the spacecraft level, always resulted in an "out-of-spec"condition. The Kollsman GAEC field site Lead Engineer contended that this condition was due to the inexperience of the GAEC Theodolite operators. During the checkout of the G and N system on board LM spacecraft No. 4, Kollsman Theodolite operators were used and the results were within specifications. GAEC then incorporated into OCP 37027 recommendations suggested by Kollsman to resolve past difficulties with this OCP.

Subsequently, at the time of the G and N system checkout on LM spacecraft No. 3 at NASA's KSC site, the test was conducted solely by Kollsman personnel, A team of technicians and engineers from the Syosset facility supported the Kollsman field site test engineers at KSC. Results of the test remained well within requirements. Simultaneously at GAEC, the G and N system on LM spacecraft No. 5 was being checked out by Grumman personnel. Results of this test were also well within specifications, thus confirming Kollsman's position on the aforementioned OCP. The test document, as it now exists, embodies all of Kollsman's recommendations. Resolution of this problem has provided a major step forward in finalizing an accurate, reliable G and N system checkout procedure.

4.7.6 Rangefinder

The design, manufacturing and delivery of the Rangefinder was the highlight during the early part of 1969. Late in November, 1968, after the Apollo 7 flight, NASA determined that a flight qualified Optical Rangefinder was required for the rendezvous of the Apollo 9 Command Module & LM. Apollo engineering, with management cognizance, immediately initiated work on the program, prior to the receipt of formal direction. The design and procurement of necessary materials was so expeditious that a prototype was delivered on 17 January 1969. A Qual. unit on 24 January, flight unit on 30 January and a back-up unit on 7 February.

The unit operated satisfactorily on the Apollo 9 mission in March 1969.

In view of the time constraints, engineering had performed a truly outstanding job in this endeavor.