APOLLO SPACECRAFT SOFTWARE CONFIGURATION CONTROL BOARD
PROGRAM CHANGE REQUEST

NUMBER *(Completed by FSB)*

1.0 COMPLETED BY ORIGINATOR

1.1 ORIGINATOR	DATE	1.2 ORGANIZATION	APPROVAL	DATE
R. F. Stengel	12-3-69	MIT/IL		

1.3 EFFECTIVITY	1.4 TITLE OF CHANGE
LUMINARY 1D	Attitude Command During Manually-Controlled Lunar Landing

1.5 REASON(S) FOR CHANGE

(a) To improve LM handling qualities during Lunar Landing.

(b) To aid in achieving pinpoint landings.

1.6 DESCRIPTION OF CHANGE

(a) ACA commands angular attitude about pitch & roll axes, angular rate about yaw axis. (It currently commands angular rate about all axes).

(b) Implement in ATT HOLD only during P64, P66, and P67.

2.0 SOFTWARE CONTROL BOARD OR FLIGHT SOFTWARE BRANCH DECISION FOR VISIBILITY IMPACT ESTIMATE BY MIT

2.1 ☐ APPROVED ☐ DISAPPROVED

2.2 REMARKS:

2.3 SOFTWARE CONTROL BOARD OR FLIGHT SOFTWARE BRANCH SIGN OFF

DATE

3.0 MIT VISIBILITY IMPACT EVALUATION:

3.1 SCHEDULE IMPACT

3.2 IMPACT OF PROVIDING DETAILED EVALUATION

3.3 STORAGE IMPACT

3.4 REMARKS:

3.5 MIT COORDINATOR

DATE

4.0 SOFTWARE CONTROL BOARD ACTION

4.1 ☐ IMPLEMENT AND PROVIDE DETAILED CHANGE EVAL. ☐ PROVIDE DETAILED CHANGE EVALUATION ☐ DIS-APPROVED

4.2 REMARKS

4.3 SOFTWARE CONTROL BOARD SIGN OFF

DATE

5.0 MIT DETAILED PROGRAM CHANGE EVALUATION

5.1 MIT COORDINATOR

DATE

5.2 MIT EVALUATION

6.0 SOFTWARE CONTROL BOARD DECISION ON MIT DETAILED PROGRAM CHANGE EVALUATION

6.1 ☐ START OR CONTINUE IMPLEMENTATION ☐ DISAPPROVED OR STOP IMPLEMENTATION

6.2 REMARKS:

6.3 SOFTWARE CONTROL BOARD SIGN OFF

DATE

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	R. F. Stengel	12/3/69	MIT/IL

CONTINUATION SECTION: *(Refer to Block Number and Title on Program Change Request form.)*

1.5 Reasons for Change:

c) Piloting difficulties during the Apollo 12 lunar landing

1.6 Description of Change:

As discussed extensively in Ref. 1, attitude command should be much easier to fly than rate command, as the pilot is required to monitor fewer variables. ACA deflections provide translational acceleration and deceleration directly, requiring less control anticipation than that required by the present manual mode. When the ACA is released, the spacecraft rotates to the local vertical and holds horizontal velocity.

It is suggested that a dual mode attitude control, similar to the existing rate command mode[(2)], is the best solution to this problem. For attitude command changes over one DAP-cycle greater than a breakout level, the Direct Attitude Mode would be entered. In this mode, the optimum switching parabola with zero attitude dead band would be used to initiate the attitude change. No rate limit would be applied. When a target dead band sufficient to assure the continuation of firing by TJETLAW was reached, or when a time limit had been exceeded, control would revert to the present Pseudo-Auto Mode, with commands interpreted as attitudes rather than rates.

Controller sensitivity and linearity should be optimized through numerous handling qualities simulations. It is estimated that the maximum commanded attitude would lie between 20 and 40 deg, corresponding to

REMARKS:

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controller sensitivity (outside the 2 deg deflection deadband) of 2.5 to 5 deg/deg. The linear-quadratic scaling of the rate command mode[(2)] would probably be undersirable, as holding a given attitude would require more ACA deflection, and more torque, than the corresponding linear controller.

A review of the literature reveals that attitude command for the lunar landing has been tested at NASA FRC,[(3-5)] although the testing was not as extensive as rate command testing. The limited numerical results and the comments of Mallick, Kluever, and Matranga are generally favorable to attitude command.[(4)] Their negative observations are that pilots of the LLRV found the control less "natural," and that positive controller pressure is required to maintain non-zero attitude. The pilots did say, however, that attitude command is "easier to fly, especially near touchdown." The authors reach the same conclusion from analog-simulator and VTOL results, and add:

> The greatest benefits from attitude control would seem to result from reduced initial training time to fly a craft so controlled, from the reduced continued pilot attention to control which results in reduced pilot fatigue over flights of long duration, and from more precise control under instrument flight conditions.[4]

The mode can be accepted or rejected using extended verbs.

References

1. Stengel, R. F., "Improved Manual Control of the Lunar Landing," MIT/IL Spacecraft Autopilot Development Memo #24-69, Cambridge, July 29, 1969

2. Stengel, R. F., "Manual Attitude Control of the Lunar Module," MIT/IL Report E-2394, Cambridge, June, 1969.

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3. Matranga, G. J., Washington, H. P., Chenoweth, P. L., Young, W. R., "Handling Qualities and Trajectory Requirements for Terminal Lunar Landing," NASA TN D - 1821, Washington, August, 1963

4. Mallick, D. L., Kluever, E. E., Matranga, G. J., "Flight Results Obtained with a non-Aerodynamic Variable Stability, Flying Platform, "Soc. of Eng. Test Pilots, 10th Symposium and Banquet, Los Angeles, Sept., 1967

5. Matranga, G. J., Mallick, D. L., Kluever, E. E., "An assessment of Ground and Flight Simulators for the Examination of Manned Lunar Landing, "AIAA Flight Test Simulation and Support Conference, Cocoa Beach, Feb., 1967.

REMARKS:

Massachusetts Institute of Technology
Instrumentation Laboratory
Cambridge, Massachusetts

R. Larson

TO: David Hoag

FROM: Robert F. Stengel, Group 23C

DATE: December 2, 1969

SUBJECT: Piloting Difficulties during the Apollo 12 Lunar Landing

Pete Conrad has indicated that it took all his test piloting skills to achieve a successful landing of the Lunar Module during the Apollo 12 mission. The task was made more difficult by dust kicked up by the main engine exhaust while in close proximity to the surface; however, lunar landing under ideal conditions demands that the pilot operate at the limit of his ability - and even that may not be quite sufficient, expecially for future landing sites in harsher terrain.

Reference 1 indicates that longitudinal position and lateral velocity were actively controlled during the Apollo 11 landing. This result is obtained by comparing probability distributions of Armstrong's commanded rates against experimental results reported in Reference 2. In other words, the difficulty of the landing precluded active control of lateral position, which was less important than the downrange maneuver required to over-fly a boulder field.

The lunar landing task is discussed in detail in MIT IL Spacecraft Autopilot Development Memorandum #24-69, "Improved Manual Control of the Lunar Landing."[3] This memo describes linear and nonlinear models of position control in the landing trajectory. In this memo, it is observed that the simplest linear model of position control, which neglects human pilot dynamics, is unstable unless

a) Second-order compensation is applied by the pilot

b) Inner feedback loops (angular position, horizontal velocity) are closed by the pilot.

Alternatively, a non-linear model is examined. Here it is assumed that the pilot attempts to be an optimal ("bang-bang") controller. The information processing requirements of several manual control schemes are examined, with particular attention paid to the "modes of flying" used be astronaut-subjects in landing simulations with the NASA LMS. It is shown that 2 changes to the DAP manual control mode logic reduce pilot workload by 33%. The changes are:

a) Addition of a coordinated turn capability

b) Use of attitude command rather than angular rate command.

PCR 884 and 885 were submitted to the Software Configuration Control Board during August, 1969. The coordinated turn option (PCR 884) was approved for off-line evaluation; the attitude command option (PCR 885) was disapproved. An off-line implementation of PCR 884 has been completed by J. E. Jones of Group 23C; digital and hybrid simulation of this assembly will begin within the next few days. In lieu of control board approval, work on the attitude command mode has been suspended.

The contention that attitude command is easier to fly is verified by flight test in the LLRV. 4-6. The following quotation from Mallick, Kluever, and Matranga takes on added significance in light of Conrad's comment that he had to rely on instruments for the actual touchdown:

> The greatest benefits from attitude control would seem to result from reduced initial training time to fly a craft so controlled, from the reduced continued pilot attention to control which results in reduced pilot fatigue over flights of long duration, and from more precise control under instrument flight conditions.[5]

LLRV pilots are also quoted as saying that attitude command is "easier to fly, especially near touchdown."[5]

The experience of 2 lunar landings combined with the results of manual control theory and extensive earthbound simulation suggests that the coordinated turn and attitude command options should be evaluated for future lunar landing missions. Accordingly, work on PCR 884 will continue, and a PCR covering the attitude command mode will be submitted in the near future.

Robert F. Stengel

Robert F. Stengel

References

1. Stengel, R. F., "The Manually-Controlled Landing of Eagle," MIT IL Spacecraft Autopilot Development Memo #28-69, Aug. 6, 1969.

2. McRuer, D. T., Hofmann, L. G., Jex, J. R., Moore, G. P., Phatak, A. V., Weir, D. H., Wolkovitch, J., "New Approaches to Human Pilot-Vehicle Dynamic Analysis," AFFDL-TR-67-150, Wright-Patterson AFB, Feb., 1968.

3. Stengel, R. F., "Improved Manual Control of the Lunar Landing," MIT IL Spacecraft Autopilot Development Memo #24-69, July 29, 1969.

4. Matranga, G. J., Washington, H. P., Chenoweth, P. L., Young, W. R., "Handling Qualities and Trajectory Requirements for Terminal Lunar Landing," NASA TN D-1821, Washington, Aug., 1963.

5. Mallick, D. L., Kluever, E. E., Matranga, G. J., "Flight Results Obtained with a Non-Aerodynamic Variable Stability, Flying Platform," Soc. of Eng. Tests Pilots, 10th Symposium and Banquet, Los Angeles, Sept., 1966.

6. Matranga, G. J., Mallick, D. L., Kluever, E. E., "An Assessment of Ground and Flight Simulators for the Examination of Manned Lunar Landing," AIAA Flight Test Simulation and Support Conference, Cocoa Beach, Feb., 1967.

Distrubution

Internal

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