Massachusetts Institute of Technology
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COLOSSUS Memo #316, LUMINARY Memo #215, SKYLARK Memo #27

TO: Distribution
FROM: William M. Robertson
DATE: April 20, 1971
SUBJECT: Limitations in the Astrodynamic Orientation and Ephemeris Routines.

The attached vue-graphs were presented and discussed at the Joint NASA/MIT Development Plan Meeting #65 on 14 April 1971.

The essential points of the presentation were that:

1.) The only limitations in the Orientation and Ephemeris Routines caused by AGC Coding/Scaling are that the Apollo 15, 16 & 17 launches must occur before 17 February 1964. This provides more than a year of "pad" in case the launch of Apollo 17 slips from its current date of December 1972. There are no limitations on the Skylab launches since the necessary constants are in erasable memory in the Skylark program, and can be reset.

2.) There are essentially no mathematical limitations in the Orientation and Ephemeris Routines. In other words, the current formulations continue to be valid over three or four years when current operating procedures continue to be used. The LUMINARY moon position ephemeris does degrade somewhat after $2\frac{1}{2}$ years, but the degradation is gradual, and does not affect the IMU alignment over three to four years.

For details of the accuracy of these routines over several years time span, the reader is referred to:

- SGA Memo 10-71 for Orientations.
- 23S Memo 70-68 for Ephemerides.

## ASTRODYNAMIC ORIENTATION AND EPHEMERIS ROUTINES

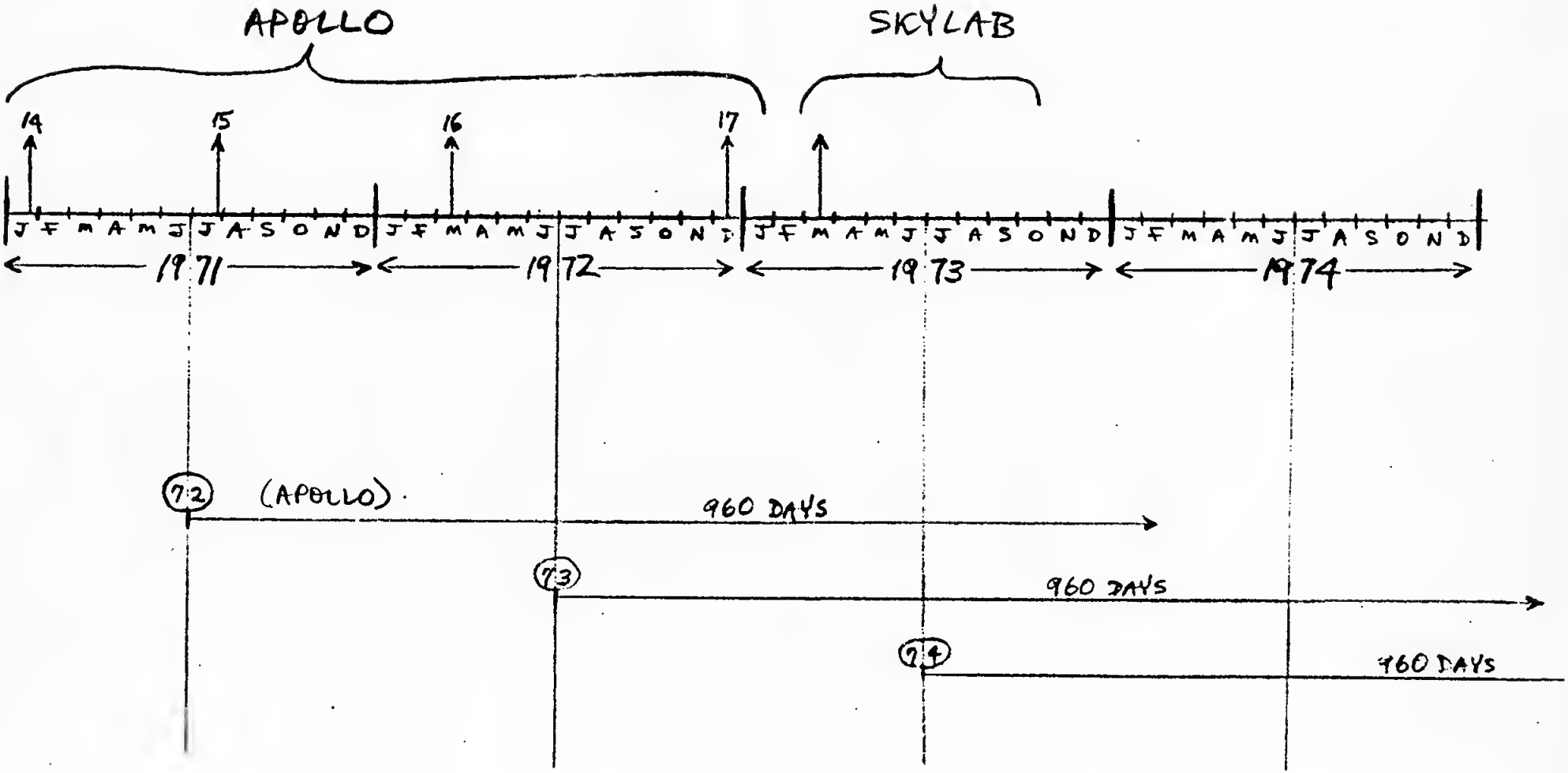
### AGC Coding/Scaling Limitations

| | Planetary Inertial Orientation Routine (PIOS) | Lunar-Solar Ephemerides Routine |
|---|---|---|
| COLOSSUS (Apollo 15, 16, 17) | Tephem < 963.2 days<br>Launch before 17 February 1974 | None, as erasable constants are reloaded for every 14 day interval (i.e. every mission) |
| LUMINARY (Apollo 15, 16, 17) | Tephem < 963.2 days<br>Launch before 17 February 1974 | Tephem < 993 days<br>Launch before 19 March 1974 |
| SKYLARK (Skylab) | Tephem < 963.2 days<br>No launch limitation (erasable constants can be reset) | Tephem < 993 days<br>No launch limitation (erasable constants can be reset) |

Definitions:

APOLLO $T_{ephem}$: Time interval between July 1, 1971, 0000 hours Greenwich, and the instant at which the computer clock is zeroed (liftoff).

SKYLAB $T_{ephem}$: Time interval between an arbitrary epoch (nominally taken to be the preceeding July 1, 0000 hours Greenwich), and the instant at which the computer clock is zeroed (liftoff).


APOLLO
SKYLAB
14
15
16
17
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D
1971
1972
1973
1974
72 (APOLLO)
960 DAYS
73
960 DAYS
74
960 DAYS

# ASTRODYNAMIC ORIENTATION AND EPHEMERIS ROUTINES

## Mathematical Model Limitations

| | Planetary Inertial Orientation Routine (PIOS) | Lunar-Solar Ephemerides Routine |
|---|---|---|
| COLOSSUS (Apollo 15, 16, 17) | Earth: Accurate to about $\pm 3.5$ micro-radians over more than four years (subtends 70 feet on surface).<br>Moon: Accurate to about $\pm 180$ micro-radians over more than four years (subtends 1000 feet on surface)<br>Assumptions: See Note 1 | SUN: Accurate to about 150,000 km over 14 days (relative error $10^{-3}$)(sun distance = $1.5.10^{8}$ km)<br>MOON: Accurate to about 1km over 14 days (relative error $3.10^{-6}$).<br>ASSUMPTIONS: See Note 2 |
| LUMINARY (Apollo 15, 16, 17) | | SUN: Accurate to about $\pm 0.025^{o}$ over three or four years.<br>MOON: Accurate to about $\pm 1.1^{o}$ over $1\frac{1}{2}$ years, to about $\pm 2^{o}$ over three years.<br>ASSUMPTIONS: See Note 3 |

NOTES:

1. Precession/Nutation/Libration erasables reset every 14 days (each mission) in accordance with current standard operating procedure.
2. Sun/Moon erasables reset every 14 days (each mission) in accordance with current standard operating procedure.
3. No resetting of constants at all.

ASTRODYNAMIC ORIENTATION AND EPHEMERIS ROUTINES (Continued)

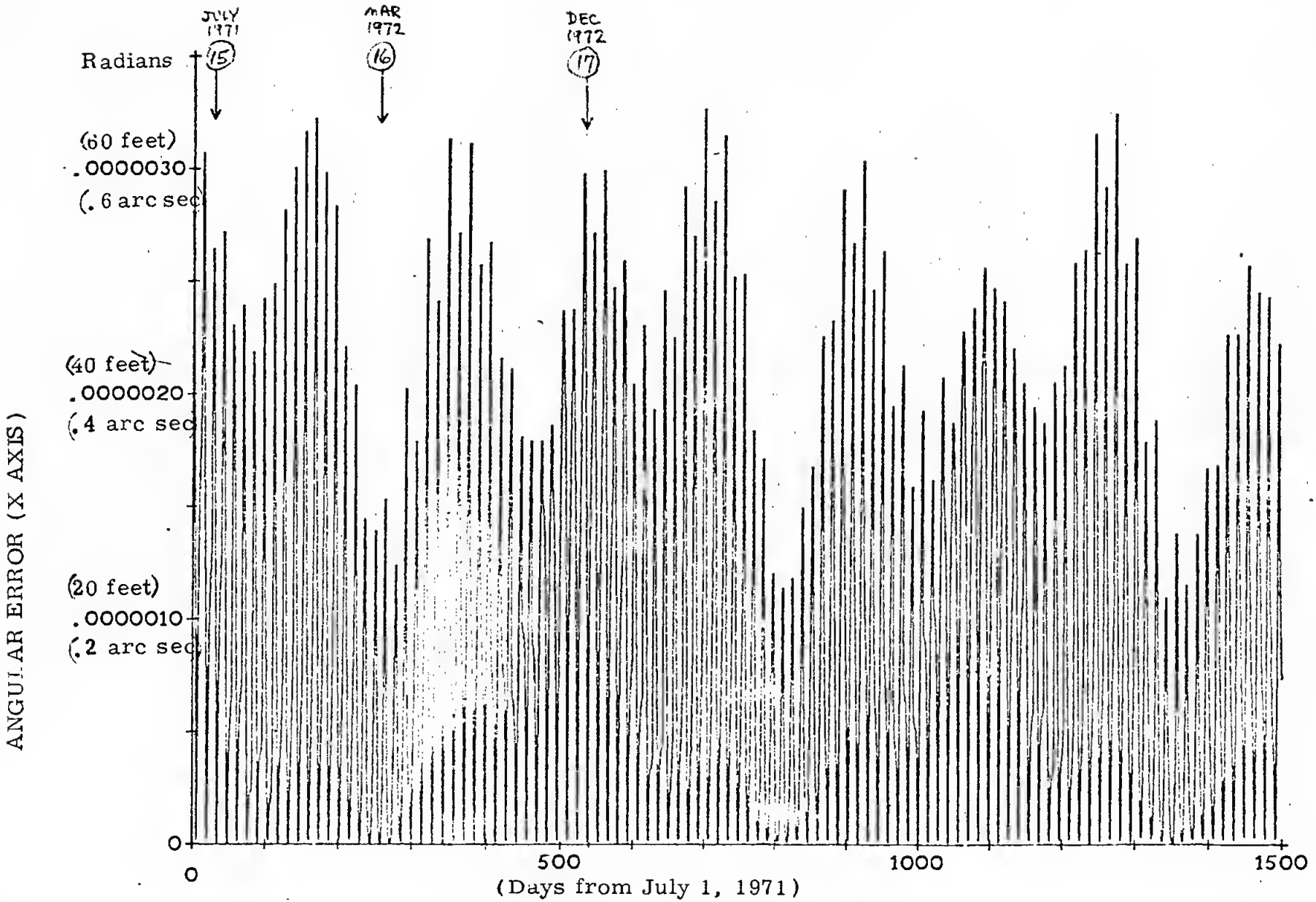
Mathematical Model Limitations (Continued)

| | Planetary Inertial Orientation Routine (PIOS) | Lunar-Solar Ephemerides Routine |
|---|---|---|
| SKYLARK (Skylab) | Earth (ONLY): Accurate to about ±15 micro-radians (6.5 arc sec) anytime.<br>ASSUMPTIONS: See Note 4 | SUN (ONLY): Accurate to about ±0.025° over three or four years.<br>ASSUMPTIONS: See Note 3 |

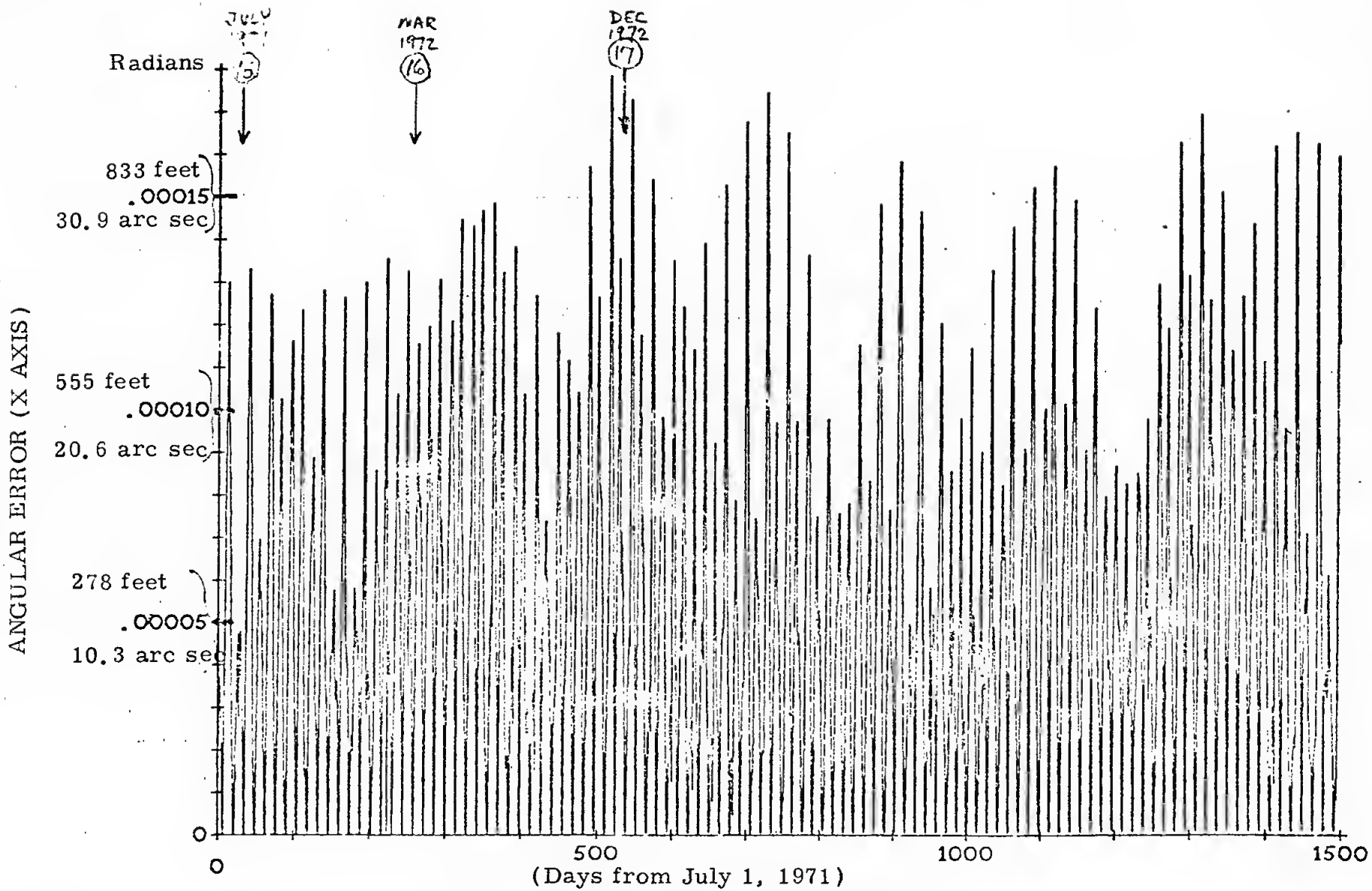
NOTES:

3. No resetting of constants at all.

4. Precession-Nutation erasable matrix reset every 56 days in accordance with proposed standard operating procedure.



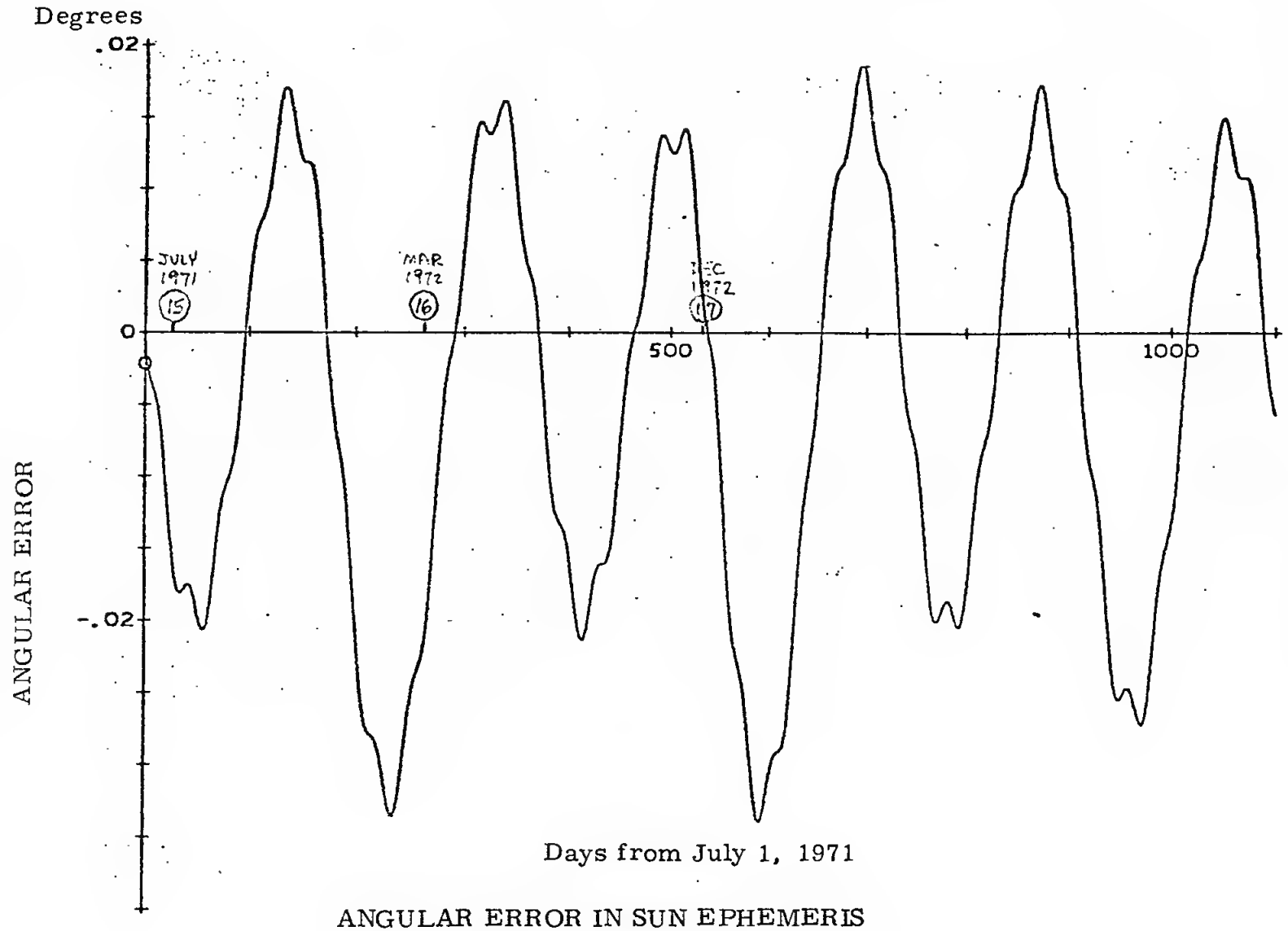

ANGULAR ERROR IN EARTH ORIENTATION
PLANETARY-INERTIAL ORIENTATION SUBROUTINE
(COLOSSUS-LUMINARY)



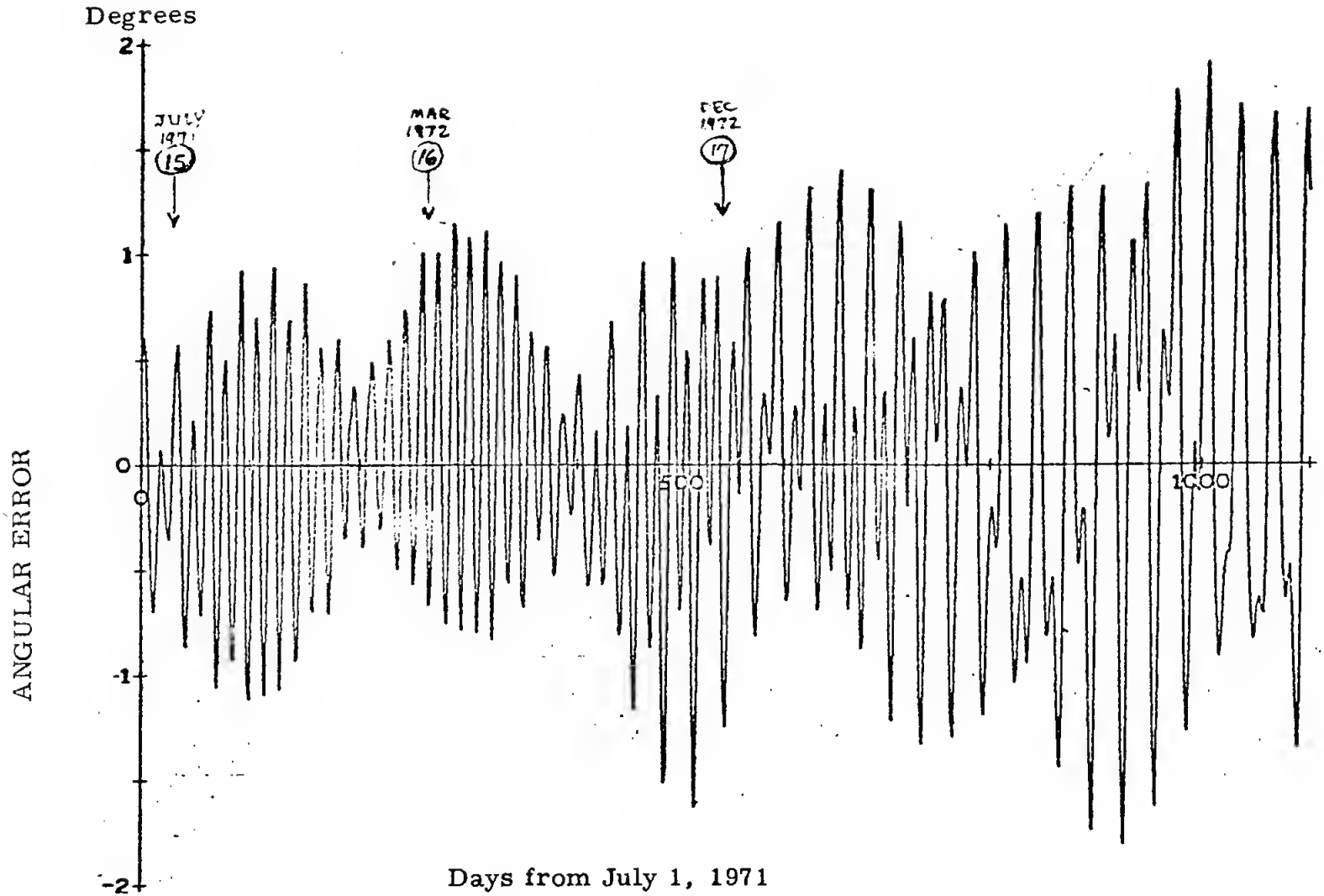

ANGULAR ERROR IN MOON ORIENTATION

PLANETARY-INERTIAL ORIENTATION SUBROUTINE

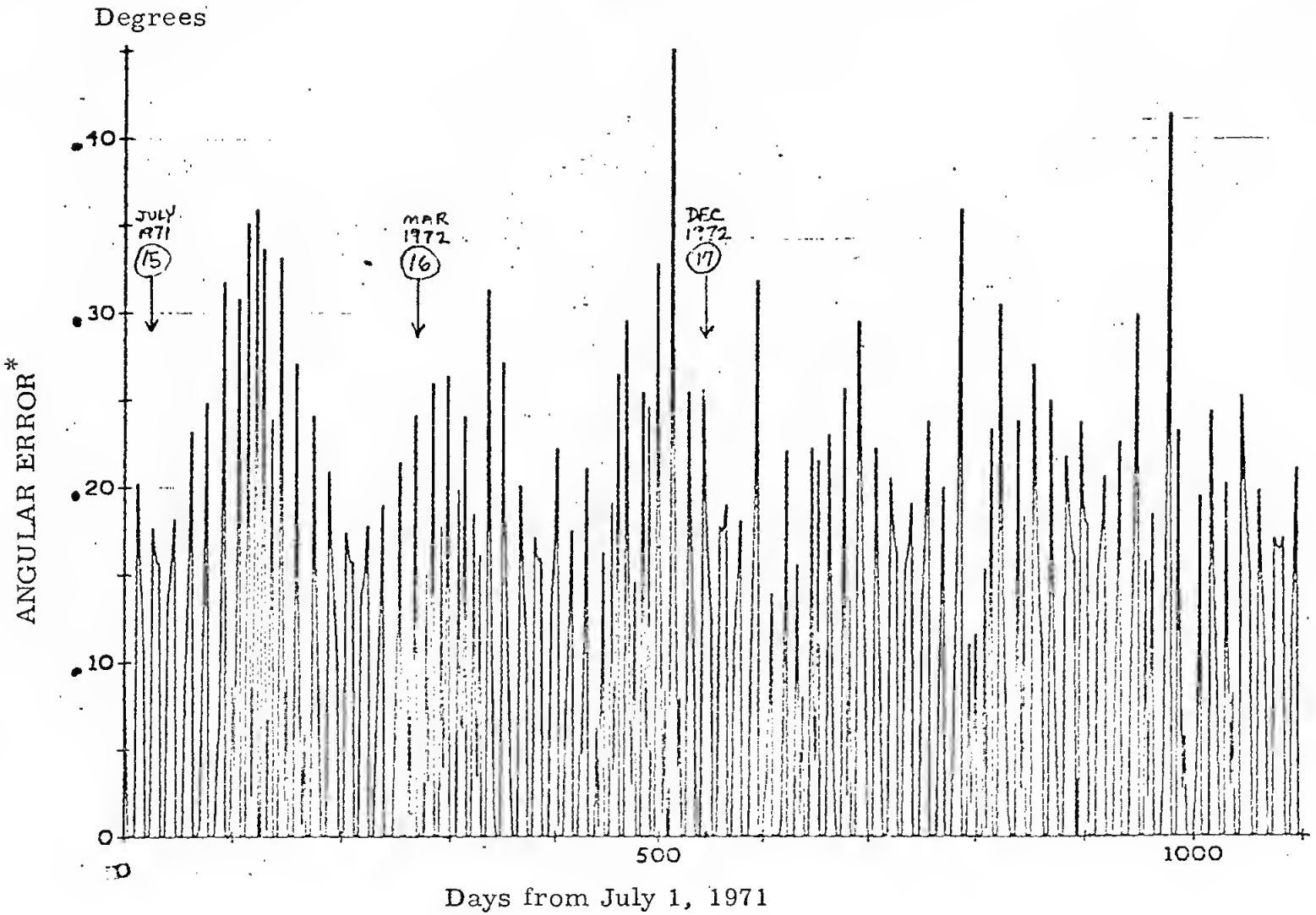
(COLOSSUS-LUMINARY)




ANGULAR ERROR IN SUN EPHEMERIS
LUNAR-SOLAR EPHEMERIDES ROUTINE
(LUMINARY-SKYLARK)




ANGULAR ERROR IN MOON EPHEMERIS
LUNAR-SOLAR EPHEMERIDES ROUTINE
(LUMINARY)




"LUNAR AZIMUTH ERROR"

(COMPONENT OF MOON EPHEMERIS ERROR WHICH AFFECTS IMU ALIGNMENT)

LUNAR-SOLAR EPHEMERIDES ROUTINE

(LUMINARY)

*Lunar Azimuth Error only shown when sun-moon angular separation between $40^{\circ}$ and $140^{\circ}$ corresponding to slightly outside the standard operating procedure range from $50^{\circ}$ to $130^{\circ}$.