



*Very Interesting! - Minutemen*

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION  
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REPLY TO  
ATTN OF: EG7-71-73

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MEMORANDUM

TO: FA/Chairman, Apollo Software Configuration Control Board

FROM: EG/Chief, Guidance and Control Division

SUBJECT: LGC Throttling Commands After Lunar Touchdown

As in the previous two Apollo lunar landings, the LGC issued oscillating throttle commands to the DPS subsequent to the Apollo 14 touchdown. Also, just as in those two landings, the engine stop command had been issued by the crew before the LGC commands could be transmitted to the descent engine. Changes implemented prior to Apollo 14 did result in an improvement by a factor of two compared to Apollo 12 in that after touchdown, the throttling commands peaked at 7.5% rather than 15%. Even so, that performance still does not represent a completely satisfactory system operation. For this reason we have analyzed the problem further and have an explanation of the cause of the throttling. The current procedures for engine shutdown do, however, appear to adequately assure that the LGC commands will not be seen by the DPS. Therefore, we are not recommending any changes to the system. The following discussion is intended to give further insight into the problem.

The most probable reason for the commands after touchdown arises because of the effect the stationary spacecraft has on the throttling equation. This equation may, to first order, be represented by the difference relationship.

$$A_n - A_{n-1} = \frac{V_D - V_n}{\tau} - \left(1 + \frac{L}{\tau}\right) (V_n - V_{n-1}) - K \left(1 + \frac{L}{\tau}\right) (A_{n-1} - A_{n-2}) \quad (1)$$

where:

A is acceleration  
L,  $\tau$  are erasable constants  
K is variable which is a function of a fixed constant, computation time, and the difference between the two preceding throttle commands  
 $V_D$  is the desired velocity input by the crew  
n is the nth computing cycle

The equations, with the correct gains, operate fine in normal flight but become neutrally stable at touchdown. The reason for this is that the PIPA feedback, represented by the term  $(V_n - V_{n-1})$ , goes to zero once the spacecraft is at rest. Since this represents the damping in the second order system, we now have a second order system with zero damping; in other words, a neutrally stable system.

To gain a somewhat better insight to the overall post-touchdown performance, we can transform (1) to the Z-plane and look at the characteristic with  $(V_n - V_{n-1}) = 0$ . Using the Apollo 14 loads, we arrive at:

$$Z^2 + (1.233 - K)Z - 1.233K = 0$$

Letting  $K = 0.5$ , which is about the value for the Apollo 14 touchdown conditions, we have roots at  $Z = +1.0$  and  $Z = -.616$ . The first root is on the unit circle and signifies neutral stability. The second root means the system oscillates at sample frequency, once per second in this case.

The theory fits the observed data and can be correlated with the Apollo 12 and 14 performance. Both spacecrafts landed with essentially the same altitude rate. The feedback gain changes between Apollo 12 and 14 account generally for the decrease in throttle commands noticed in Apollo 14.

An important fact is that throttling after touchdown is here to stay with the current throttle equations. About the only thing that can be done would be to open the throttle loop at the time the final PRO is made to disable the DAP. Even then the PRO would have to occur within one second after pad contact to assure no commands are transmitted to the descent engine.

It is doubtful that the additional safety afforded by disabling the throttling equations by the final PRO warrant changing the ropes for the remaining flights. The procedures for engine shutdown on the first three flights have proved adequate. For the remaining three flights, the single point engine-off failure of a failed-on stop switch has been eliminated by having the crew depress both stop switches at touchdown. This procedure should afford adequate assurance that the LGC commands will not be seen by the DPS.

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