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955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D.C. 20024

B70 03009

SUBJECT: The Effect on Vehicle Performance of Thrust and Isp Variations Due to Delta Guidance Thrust Modulations - Case 310

DATE: March 5, 1970

FROM: J. A. Sorensen

ABSTRACT

Delta guidance equations provide logic which causes several throttle pulses to a nominal thrusting engine during the braking phase of the LM descent trajectory. The modulated thrust profile saves about 90 ft/sec ΔV cost, which provides the capability of adding 300 lb more payload if the engine maintains a nominal Isp. This study shows that if Isp is lost because of the throttle transient, a small decrease in gained performance can result. A decrease of 1 sec in overall Isp reduces the gained payload capability about 80 lb. If the Isp loss only occurs during the throttle pulses, the payload loss is only about 6 lb per sec of Isp.

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MEMORANDUM FOR FILE

ANALYSIS

During the braking phase (P63) of the LM descent trajectory, the delta guidance equations provide logic which can cause several engine throttle pulses (down from FTP, the fixed throttle position). These pulse-downs cause the descent trajectory to resemble that of a vehicle having a low-thrust engine. Such a trajectory has about 90 ft/sec less ΔV cost to reach the landing point.

The values of mass-flow rate ($\dot{m}$) and specific impulse (Isp) utilized to obtain this theoretical performance increase are assumed to be functions of the thrust (T) only. With the thrust given, a value of Isp is obtained from a table which represents the steady-state value corresponding to that thrust. Then, the resulting mass-flow rate is computed from these values of thrust and Isp using $\dot{m} = T/(g_o \text{ Isp})$.

The number of pulses which occur during the braking phase is partly dependent upon the transient character of throttling. There are 1.4 seconds elapsed between when the accelerometers are read and a command to change the throttle setting is issued. The change command is a ramp function of 3200 bits/sec where one bit equals 2.7 lb thrust. The actual engine thrust responds as a lag network with a 0.3 sec time constant. That is, the engine transient response must be modeled as a delayed ramp signal fed into a $1/(\tau s+1)$ transfer function. The length of a pulse is also dependent upon the magnitude of the guidance parameters used to issue the throttle command and the throttle setting during the pulse. The period between issuing a throttle-down command and a throttle-up command typically varies from four to twelve seconds.

It is questionable whether the steady-state value of the Isp associated with thrust during the transient pulse-down adequately represents actual engine performance. Isp and thrust may be lost due to the pulsed profile. Therefore, a computer study was made to determine what effect lower Isp values (caused by throttle pulsing) had on the overall performance. The thrust model used during FTP was $T = 9850 + 0.3t$ lb. The Isp model was slightly high. The initial value of vehicle weight (w_o) was 33,292 lb.

For the first set of computer runs, it was assumed that during each pulse, $\dot{m}$ corresponded to the nominal value associated with the lower throttle setting of the pulse, but Isp and thrust decreased. These results are presented in Table 1. Here, it is seen that the overall change in Isp (defined as $Isp = \Delta V/(g_o \ln(w_o/w_f)))$ is linear with the Isp change during the pulse. The increased propellant required per 1 sec change in Isp during the pulse is less than about 3 lb. This sensitivity is based on the worst of several noisy data points.

For the second set of runs, it was assumed that during the throttle pulses, the Isp was again less than nominal. But here, the mass-flow rate was correspondingly increased so that the desired thrust was achieved. This is based on the assumption that a certain thrust level is required during the pulse, and that *a priori* knowledge of loss of Isp is compensated for by a higher throttle setting and $\dot{m}$ during the pulse. The LGC guidance parameters were adjusted so that five, six, and seven pulses occurred during the braking phase. The results of these runs are presented in Table 2. Again, a linear change in overall Isp resulted. The increased propellant required per 1 sec change in Isp during the pulse is again less than 3 lb.

The third set of runs considered the case where the overall Isp (not just during the pulse) would be lowered because of the engine throttling. This assumes that a certain number of engine pulses do occur, i.e., the overall acceleration level at FTP is not lowered. Thus, $\dot{m}$ is correspondingly increased to produce the nominal FTP thrust. An engine was considered having parameters which would normally cause seven pulses. The results are presented in Table 3. It can be seen that an engine with a 1 sec decrease in overall Isp requires about 40 lb more propellant to land. This simulation sensitivity can be considered to be a conservative case. In reality, if throttling causes a drop in Isp which tends to remain after returning to FTP, the thrust level would drop. This would cause throttling down to decrease in frequency or stop. The decreased pulse frequency would either cause the Isp to be partially restored to its nominal value, or the vehicle would continue to perform as with a low thrust engine.

SUMMARY

A decrease in Isp due to throttle pulses in the braking phase can cause an increased propellant requirement to land the LM. The Isp decrease was simulated as decreased thrust but nominal $\dot{m}$ during the pulse, nominal thrust but increased $\dot{m}$ during the pulse, and nominal thrust but increased $\dot{m}$ during the entire trajectory. The increases in propellant requirements for 1 sec decreases in Isp during the pulses and overall were roughly 3 lb and 40 lb, respectively. Delta guidance with nominal Isp can provide the capability of landing 300 additional lb of payload with the same amount of propellant. However, if the overall engine Isp decreases 1 sec because of engine throttling, this additional payload is reduced by 80 lb. This analysis does not mean to imply that the delta guidance thrust profile will cause a decrease in DPS Isp; it merely shows the relatively small sensitivity of payload to Isp increases or decreases when the delta guidance scheme is used.

J. A. Sorensen

2014-JAS-ksc J. A. Sorensen

Table 1. Variations in vehicle performance due to a decrease in Isp and thrust during the throttle pulses of delta guidance. Here the mass flow rate associated with the lower throttle setting is maintained. Overall Isp = $\Delta V/(g_o \ln(w_o/w_f))$.

Number of Pulses	Length of Pulses, sec.	ΔIsp per Pulse, $\frac{\text{lb force-sec}}{\text{lb mass}}$	ΔV, ft/sec	Final Weight w_f, lb mass	Δw_f, lb mass	Overall Isp $\frac{\text{lb force-sec}}{\text{lb mass}}$.
7	6	0	6516.1	17091.4	0	303.76
7	6	- 1	6515.9	17089.5	- 1.9	303.70
7	6	- 2	6507.8	17101.9	+10.5	303.64
7	6	- 3	6507.3	17100.5	+ 9.1	303.59
7	6	- 4	6506.8	17099.0	+ 7.6	303.53
* 7	6	- 6	6515.1	17079.5	-11.9	303.39
* 7	6	- 8	6514.6	17075.8	-15.6	303.27
8	6,6,6,6, 6,4,4,4	-10	6520.4	17060.5	-30.9	303.13
* 7	6	-12	6505.4	17083.0	- 8.4	303.03

*Throttled down 2 seconds after high gate.

Table 2. Variations in vehicle performance due to a decrease in Isp during the throttle pulses of delta guidance. Here the nominal thrust associated with the lower throttle setting is maintained by increased mass flow rate. Three pulse width-pulse frequency combinations are compared.

Number of Pulses	Length of Pulses, sec.	ΔIsp per Pulse, $\frac{\text{lb force-sec}}{\text{lb mass}}$	ΔV, ft/sec	Final Weight w_f, lb mass	Δw_f, lb mass	Overall Isp $\frac{\text{lb force-sec}}{\text{lb mass}}$
7	6	0	6516.1	17091.4	0	303.76
7	6	-3	6516.6	17083.9	- 7.5	303.58
7	6	-6	6517.0	17076.3	-15.1	303.39
7	6	-9	6517.1	17069.1	-22.3	303.21
*5 1/2	8	0	6530.7	17065.4	0	303.74
5 3/4	8	-3	6527.5	17064.0	- 1.4	303.56
5 3/4	8	-6	6527.6	17056.7	- 8.7	303.37
6	8	-9	6524.8	17053.4	-12.0	303.15
**5	10,8,8,8,8	0	6510.4	17101.8	0	303.77
**5	10,8,8,8,8	-3	6510.5	17095.2	- 6.6	303.60
**5	10,8,8,8,8	-6	6510.8	17088.1	-13.7	303.42
**5	10,8,8,8,8	-9	6511.0	17081.1	-20.7	303.25

*Pulse fraction means thrust level was in a pulse when switchover to the visibility phase occurred.

**Throttled down 2 sec after high gate.

Table 3. Variations in vehicle performance due to a decrease in Isp throughout the entire trajectory. The nominal thrust is maintained by increased mass flow rate.

Number of Pulses	Length of Pulses, sec	ΔIsp Overall, $\frac{\text{lb force-sec}}{\text{lb mass}}$	ΔV, ft/sec	Final Weight w_f, lb mass	Δw_f, lb mass	Overall Isp $\frac{\text{lb force-sec}}{\text{lb mass}}$
7	6	0	6516.1	17091.4	0	303.76
7	6	-1	6517.4	17051.4	- 40.0	302.75
8	6	-3	6521.4	16968.4	-123.0	300.74
8	6	-6	6522.7	16850.7	-240.7	297.73
8 1/3	6	-9	6536.0	16709.9	-381.5	294.71

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From: J. A. Sorensen

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