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LUMINARY Memo #186

To: Distribution
From: David Moore
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Subject: APS Impulse Burn for APOLLO 14

Summary

The following memo is concerned with the test plan and results of the performance tests on the APS Impulsive Burn to be used on APOLLO 14 for the short rendezvous portion of the mission. The parameters are listed, nominal values enumerated, and off-nominal values discussed. The results of the tests are also tabulated and an analysis of these results is given. It is seen that the variations of results can be predicted.

Data Presentation

The data in this memo is presented in a plan statement-discussion-table format. The order of data presentation is:

- A) Test plan
  - 1) Parameters
  - 2) Nominal values
  - 3) Off-nominal values
- B) Discussion
- C) Tabulation of data

Test Plan for APS Impulse Burns

Purpose:

Ascertain performance of impulsive burn to be used on "short rendezvous", Apollo 14.

Parameters:

1) CG Location and Mass
2) Burn-Time
    a) engine-on delay
    b) engine-off delay
3) Steady-State Maximum Thrust
4) Guidance Tolerances
    a) Autopilot deadband
    b) Mass error (LGC-ENV)

Nominal Values:

In the accompanying chart, the test parameters marked nominal have values that are as follows:

1) CG Location and Mass
    a) Mass = 5843 lbm
    b) CG Location = (257.4, -.1, 5.5) inches
    where the NAV. Base center is at (307, 0, 49.87) inches.
2) Burn-time
    a) Engine-on delay = 0.243 sec.
    b) Engine-off delay = 0.1897 sec.
3) Steady-State Thrust = 3470 lbf.

Off-Nominal Values:

The sets of data used in this test include values generated by NASA and by MIT. These values are:

A) NASA generated 3σ data where $\pm 3\sigma = \pm$parameter
    1) CG Loc and Mass
        a) $\pm\Delta CG = \pm(.8,\ .1,\ .1)$ in.
        b) $\mp\Delta$ Mass = ± 27 lbm.

2) Burn-time

$\pm\Delta$ Time = $\pm .183$ sec.

where + Δ Time = long burn time

and - Δ time = short burn time

3) Thrust:

Δ Thrust = $\pm$ 100 lbf.

where +100 lbf = High Thrust

and -100 lbf = Low Thrust

B) MIT-Generated, Off-nominal data:

1) CG Loc and Mass:

   - a) CGZ off-nom, $\Delta CGZ = 1$ in
   - b) MIT $\pm 3\sigma = \pm\Delta CG = \mp(1, .01, .18)$
   - c) $\pm 3\sigma = \pm\Delta$ Mass = ± 200 lbm.

2) Burn-time: same data as NASA

3) Thrust: Same data as NASA

4) Guidance Tolerances:

   - a) Deadband for DAP either $.3^{\circ}$ or 1° (tests run with both compared)
   - b) Mass error: Run tests with large (200 lbm) and small (50 lbm) mass errors (LGC-ENV)

Data:

The data results are tabulated in the tables following the APS IMPULSE TEST MATRIX.

Discussion: The analysis concerning the performance of the APS Impulse burn, with the parameters defined in the test matrix, consists of two parts. One, the contribution of the parametric changes involving CG location and mass, burn time, and maximum thrust. The other facet of analysis involves the guidance tolerances with emphasis on the maximum attitude error contribution to burn performance.

A) Parametric changes:

The major contribution to burn performance due to parametric changes is the amount of VGX residual after the burn. The following will discuss each of the test cases with this in mind.

1) This case is the base nominal for the rest of the test cases in that all the parameters involved are the nominal values, decided upon by NASA/MSC - MIT powered flight personnel. The VGX residual is small (-.2 fps) and this residual is the reference for the rest of the cases. The burn time for the nominal case is 3.519 seconds.

2) This case involves a change in CG location and mass in a 3σ manner, as suggested by NASA/MSC; Guidance and Performance division of MPAD. The heavier than nominal vehicle tends to make the LGC perform the TGO calculation with a slight increase in burn time (in direct proportion to the slight increase in LM mass). So, the VGX reflects this slight increase in burn time by a slight overburn from the nominal VGX.

3) This case also involves a NASA/MSC-suggested CG location as mass change, but in a -3σ manner. This means that the LM is slightly lighter which results in a slightly shorter burn time. This inturn is reflected in the slightly lower VGX from the nominal.

4) This test involves a substantial change in burn time, accomplised with changes in the engine-on delay and engine-off delay. This burn time is considerably shorter, then than for the nominal case. One would expect a considerable underburn in VGX of about 3.3fps. Indeed, VGX = + 3.1 fps; i.e. on underburn of 3.1 fps, as expected. Thus, the underburn is accounted for by the decrease in burn time.

5) This test also involves a considerably shorter burn time (by approximately changing the engine-on and engine-off delay times), but the case is further complicated by setting the steady-state maximum thrust lower than the nominal (by 100 lbf.). This case would then be expected to show an underburn even more than in case #4, by about 1.9 f.p.s. Indeed, we see that VGX = +5 so that the VGX underburn is accounted for by the short burn time and the lower than nominal steady-state thrust.

6) This test also involves the short burn time as did case 4) and 5). The change in the thrust is to make it higher than nominal (by 100 lbf). This would make the VGX residual overburn case 4) by about 1.9 fps (as case 5 was 1.8 fps underburn from case 4). This is what is seen in that VGX = + 1.2 fps. Thus, the VGX residual is accounted for by the short burn time and high thrust.

7) This test involves changing the burn time so that it is considerably larger than the nominal. This would mean that on overburn of about 3.3 fps would be in order. This is seen in that VGX= - 3.7 fp. Thus, the VGX overburn is accounted for by the longerburn time.

8) This test also involves the long burn time and includes the thrust change to a lower level than the nominal. This would mean an underburn of about 1.9 fps from case 7). This is seen to be true in that VGX = 1.7 fps. Thus, the VGX overburn is accounted for by the long burn time and the low thrust.

9) This test involves the long burn time and a thrust change to a higher level than the nominal. This would lead to a prediction of an overburn of about 1.9 fps. This is seen to be the case in the VGX = -5.9 fps. Thus, the VGX overburn is accounted for by the long burn time and high thrust.

10) This test involves one of two NASA-suggested worst cases, with +3 σ CG location and mass, long burn time, and low thrust. This combination of parameters lengthens the burn time, but the off-nominal CG location is slightly closer to the thrust axis than the nominal which results in not so much an overburn as expected from the long burn time contribution. The low thrust also contributes an underburn component to the overall VGX result. The result is predicted to be about 1.5 fps overburn from the nominal. This is seen to be the case in that VGX = -1.9 fps. Thus, the VGX overburn is accounted for by the NASA-suggested parametric variations

11) This test involves the other NASA-suggested worst case, with -3 σ CG location and mass, long burn time, and high thrust. This combination increases the total burn time from the nominal but the lower than nominal vehicle mass decreases the burn time from case 7). The CG locagion and mass are slightly farther away from the thrust axis than the nominal. All of this is interpreted so as to expect an overburn, expecially from

the higher than nominal thrust, of a greater amount than case 10). This amount is about 4.2 fps overburn, mainly from the high thrust. We can see that VGX = -6 fps, just about as predicted. Thus the VGX overburn is accounted for by the NASA-suggested parameter variations.

12) This test involves a mass-error; i.e. The LGC and the environment estimate the mass differently. In this case the error is 200 lbm. The other parameters are nominal valued so that only the contribution due to the mass error may be ascertained. In the calculation for TGO, the LGC uses a heavier vehicle mass estimate than is the actual vehicle mass. This means that the burn time will be longer than the nominal, resulting in an overburn. It is predicted that the overburn will be about 2.6 fps from nominal. As can be seen, the VGX = 3.0 fps. Thus the VGX overburn is accounted for by the mass error.

13) This test involves an offset of the Z-component of the CG location by 1 inch, with all other parameters nominally-valued. This has a two-fold effect on the VG residuals. The VGX residual and the VGZ residual are both affected by the CGZ offset from nominal. The VGZ affect is due to the attitude error, which is discussed in the second part of this analysis. The VGX is affected by the Z-axis offset only slightly; i.e. about a .5 fps overburn prediction. As can be seen, VGX = -.6 fps. Thus the VGX overburn is accounted for.

14) This test combines the parameter change of test 12) and 13). This worst case of mass error and CGZ offset produces the predicted overburn in VGX and the VGZ overburn is also discussed in general in these and part of the analysis.

*Comment: The above 14 tests were performed with a .3 degree autopilot deadband. The predicted VGX variations have been seen to agree with the actual, and the VGZ variations will be discussed in the second part of the analysis. The remaining four tests were performed with 1 degree autopilot deadband. The reason for this was to see if the prediction of VGZ overburn would be seen in the actual test, and the VGX analysis is based on the parameters already mentioned.

1) This test involves the same analysis as the test-case 1) for the .3 degree deadband. The results and conclusions are the same for the VGX overburn.

14) This test involves the same analysis as the test case 14) for the .3 degree deadband. The results and conclusions are the same for the VGX overburn.

15) This test involves the MIT-suggested $+3\sigma$ CG location and mass variation from the nominal, with a slight mass error. The combination of the CG location and heavier than nominal vehicle mass results in an underburn of about 1 fps from the nominal case 1). This is seen in that the VGX = +.7. Thus, the VGX underburn is accounted for.

16) This test involves the MIT-suggested -3σ CG location and mass variation from the nominal. This combination also produces a predicted underburn. The light vehicle mass results in a shorter burn time from nominal and the CG location is farther away from the thrust axis than the nominal so that the resulting predicted VG is about a .6 fps underburn. This is seen to agree with the actual test in that VGX = +.5 fps. Thus, the VGX underburn is accounted for.

17) This case involves a worst-NASA worst case; combining test 11), with 1° deadband and a 200 lbm error between LGC and ENV. The contribution to the VGX overburn is broken down into the following components:

   a) 200 lbm error; VGX = -3 fps
   b) Long burn time + high thrust; VGX = -6 fps

Thus we may predict a 9 fps overburn for VGX. Indeed, this is the case, so that the VGX is accounted for.

Discussion: B) Autopilot operation contribution:

The Autopilot specialists have examined all of the tests and find that the performance is accounted for due to the attitude errors incurred in DAP operation. Craig Work has prepared the following statement concerning the nominal test case, which he feels is a general discussion of the VGZ overburn situation.

The nominal test case is a 3.5 second APS impulse burn executed under program 42. Special DAP interest is given this burn because the guidance is inactive during it, and any performance peculiarities are traceable to the DAP operation. As reported above, the VGX performance variations have been attributed to the parametric variations in the test matrix. Ullage during the burn was produced with the TTCA, and the ullage thrust vector did not pass through the C.G., which is forward in the +Z direction. Responding to the resulting pitch the DAP pulsed off the rear ullage jets, reducing their duty cycle to maintain burn attitude. The offset acceleration estimator is intended to aid the DAP in this sort of situation, but the estimator is inoperative during ullage (being started at IGNITION). The vehicle maintained a 2.6 degree negative pitch error during the ullage, generating a noticeable contribution to the +Z delta-V error. One-half second after IGNITION, ullages terminates, but the engine thrust is present. The engine thrust vector is canted 1.5 degrees from the nominal x-axis toward the C.G., reducing the pitch torque lever arm from the value during ullage, but the thrust level is higher. Attitude error increases slightly in pitch, but the offset acceleration estimator informs the DAP of the offset torque, and the RCS jet firings increase after two seconds, bringing the attitude error back into the coast zone before thrust termination. The maximum pitch attitude error was 2.8 degrees and the Z-axis delta-V error was 5.5 fps (overburn), which would have been steered out by the guidance in a non-impulsive burn.

The CGZ offset seen in test 13) and 14) merely increase the delta-V error during ullage and therefore the pitch error. The error incurred would have been steered out in a non-impulsive burn in these cases also.

The matrix of tests showed vriations on nominal case re-entry, but slight ones. Thus we conclude that the overall DAP control was correct and satisfactory. Also, we conclude then, that the VGZ overburn is accounted for and attributed to the attitude error as discussed above.

*Comment: There **are** plots enclosed which show the vehicle pitch rate error and the vehicle pitch error for the nominal test case. These illustrate the discussion above.

<ins>Conclusion</ins>: The test results indicate that all parametric changes cause predictable variations in VGX. Also the DAP operation produces predictable variations in VGZ. We therefore conclude that the test matrix and the resulting data make it possible to ascertain the performance of the Apollo 14 APS impulse burn. Our purpose is therefore achieved.

APS IMPULSE TEST MATRIX

Run #	DB (deg)	CG Loc. and Mass	Burn Time	Thrust	Mass Erro (lbm)
1	.3	Nominal	Nominal	Nominal	0
2	.3	$+3\sigma$(NASA)	Nominal	Nominal	0
3	.3	-3σ(NASA)	Nominal	Nominal	0
4	.3	Nominal	Short	Nominal	0
5	.3	Nominal	Short	Low	0
6	.3	Nominal	Short	High	0
7	.3	Nominal	Long	Nominal	0
8	.3	Nominal	Long	Low	0
9	.3	Nominal	Long	High	0
10	.3	$+3\sigma$(NASA)	Long	Low	0
11	.3	-3σ(NASA)	Long	High	0
12	.3	Nominal	Nominal	Nominal	200
13	.3	CGZ off by 1 in	Nominal	Nominal	0
14	.3	CGZ off by 1 in	Nominal	Nominal	200
1	1	Nominal	Nominal	Nominal	0
14	1	CGZ off by 1 in	Nominal	Nominal	200
15	1	$+3\sigma$(MIT)	Nominal	Nominal	50
16	1	-3σ(MIT)	Nominal	Nominal	50
17	1	-3 (NASA)	Long	High	200

"TABULATED DATA FOR SPECAPS RUNS"
DB = $.3^{\circ}$

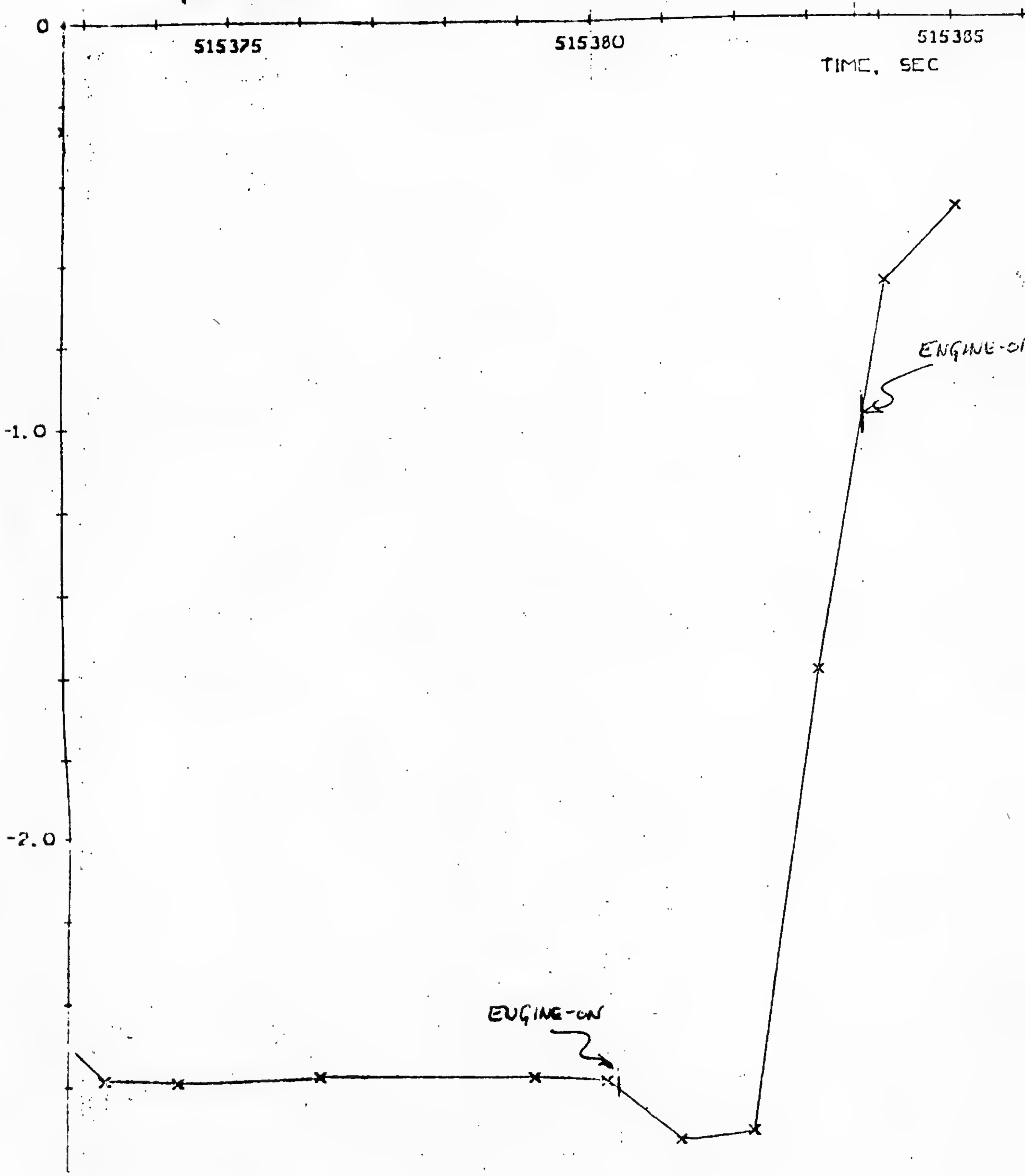
Run#	CGX(in)	CGY(in)	CGZ (in)	MASS(lbm	THRUST(lbf)	VGX(fps)	VGY(fps)	VGZ(fps)	B. T.(sec)	MASS ERROR (lbm)
1	257.4	-.18	5.55	5836	3470	-.2	+.6	-4.7	3.519	0
2	258.3	-.08	5.65	5863	3470	-.5	+.3	-4.8	3.549	0
3	256.6	-.288	5.45	5809	3470	-.2	+.9	-4.5	3.50	0
4	257.4	-.18	5.55	5836	3470	+3.1	+.6	-4.5	3.337	0
5	257.4	-.18	5.55	5836	3370	+5.0	+.5	-4.3	3.337	0
6	257.4	-.18	5.55	5836	3570	+1.2	+.7	-4.6	3.337	0
7	257.4	-.18	5.55	5836	3470	-3.7	+.9	-4.7	3.703	0
8	257.4	-.18	5.55	5836	3370	-1.7	+.3	-4.5	3.703	0
9	257.4	-.18	5.55	5836	3570	-5.9	+1.0	-4.8	3.703	0
10	258.3	-.08	5.65	5863	3370	-1.9	+.3	-4.8	3.733	0
11	256.6	-.288	5.45	5809	3570	-6.0	+.7	-4.7	3.683	0
12	257.4	-.18	5.55	6043	3470	-3.0	+.7	-4.9	3.661	200
13	257.4	-.18	6.55	5840	3470	-.6	+.7	-6.1	3.509	0
14	257.4	-.18	6.55	6040	3470	-3.3	+.8	-6.4	3.699	200

TABULATED DATA FOR SPECAPS RUNS
DB = 1°

Run#	CGX (in)	CGY (in)	CGZ (in)	MASS (lbm)	THRUST (lbf)	VGX (fps)	VGY (fps)	VGZ (fps)	B. T. (sec)	MASS ERROR (lbm)
1	257.4	-.18	5.55	5836	3470	-.2	+.6	-5.5	3.519	0
14	257.4	-.18	6.55	6040	3470	-3.3	+.8	-6.4	3.699	200
15	256.3	-.19	5.3	6040	3470	+.7	+.5	-4.9	3.679	50
16	258.3	-.17	5.7	5640	3470	+.5	+.6	-5.7	3.369	50
17	256.6	-.288	5.45	6040	3570	-9.1	+.6	-6.0	3.843	200

Maximum Pitch Attitude Error - APS Impulse Burns

Run #	Deadband (Deg)	Maximum Pitch Attitude Error (Deg)
1	.3	-2.31
2	.3	-2.53
3	.3	-2.14
4	.3	-2.31
5	.3	-2.23
6	.3	-2.40
7	.3	-2.32
8	.3	-2.30
9	.3	-2.36
10	.3	-2.43
11	.3	-2.23
12	.3	-2.26
13	.3	-3.85
14	.3	-4.71
1	1	-2.77
14	1	-5.03
15	1	-2.81
16	1	-3.15
17	1	-2.95



(Q-AXIS) VEHICLE ATTITUDE ERRORS, DEGREES

Q-AXIS VEHICLE ESTIMATED RATES AND DESIRED RATES, DEG/SEC