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# MANUAL BOOSTER CONTROL

# DISPERSION ANALYSIS



MANNED SPACECRAFT CENTER

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## 1.0 SUMMARY AND INTRODUCTION

The purpose of this document is to define the rationale required to develop and document manual Saturn control contingency procedures and to summarize the data which demonstrates that crew control is feasible within acceptable limits.

The manual control procedures were verified utilizing the Dynamic Crew Procedures Simulator (DCPS). Validations were conducted in two phases, launch (liftoff to earth parking orbit) and TLI. The launch vehicle math model simulation has been verified by numerous data point comparisons with current MSFC simulation for both nominal and off-nominal conditions. Six test subjects were used to establish a cross section of pilot performance and to aid in the accumulation of data. Two of the subjects have current mission assignments.

## 2.0 LAUNCH PHASE

The simulation employed the current Mission F launch vehicle timeline and sequence of events, based on the AS-505 Launch Vehicle Operational Trajectory, published April 17, 1969. Spacecraft displays and modes of operation were to the CSM 106 configuration. Manual takeover during first stage flight and second stage flight to tower jettison was accomplished by placing the CMC-IU switch to CMC and allowing the stored polynominal to steer the launch vehicle. Manual crew control was accomplished during second stage and third stage by the Commander activating the spacecraft rotational hand controller and commanding attitude corrections based upon the difference between actual and onboard cue card values of attitude, inertial velocity, altitude rate and altitude. The onboard cue card (Figure 1) was based on the May 18 Operational Trajectory. The end conditions were read from onboard DSKY displays and are summarized in Table I.

## 3.0 TLI PHASE

The TLI procedures are divided into two phases, the pre-TLI ignition platform failures which occur up to six minutes prior to ignition and post-TLI ignition platform failures which occur at or after TLI ignition. Platform failures that occur between these periods do not allow sufficient time to reorient the spacecraft configuration. For these failure cases, the first opportunity should be aborted and TLI accomplished at the second opportunity.

### 3.1 Platform Failure Prior to TLI

A technique using the ORDEAL drive was selected over a time attitude profile method because of the precise alignment target provided by one degree markings on the FDAI ball at the zero-zero position and because it was consistently easier to fly the profile. The rationale for the basic procedure is contained in Reference 1. Briefly, the procedure employs ORDEAL's ability to drive the FDAI at a rate closely approximating the time history of the nominal inertial pitch profile. Selecting the appropriate ORDEAL start time and torquing rate permits the flight crew to average the steering errors over the TLI burn, effectively eliminating them. Manual yaw steering is less demanding because the required launch vehicle yaw profile lends itself to one attitude setting for the entire TLI burn. Roll is always 180 degrees. The manual maneuver in preparation for TLI ignition is begun at approximately 30 minutes prior to ignition. The procedure, Figure 2, is to first align the space vehicle to the inertial burn attitude, select the ORDEAL configuration, then slew the FDAI ball to zero-zero and repeat the process until a precise space vehicle/ORDEAL alignment is obtained. At 2 minutes 20 seconds prior to ignition ORDEAL torquing is started and the space vehicle is maneuvered to the desired yaw setting. The crewman commands attitude changes to the launch vehicle with the spacecraft rotational hand controller to maintain the FDAI pitch, yaw and roll attitudes and commands launch vehicle cutoff at the desired velocity as read from the DSKY. The THC rotated counter clockwise and reset after one second is used for engine cutoff.

### 3.2 Platform Failure After TLI Ignition

The technique for failures after TLI ignition is identical to that described in Section 3.1 except for the initialization of ORDEAL, accomplished prior to ignition. In this case the launch vehicle is still under IU control and is maneuvering at a precise orbital rate, until guidance release. Therefore, the Commander initializes the

ORDEAL with a constantly moving vehicle. The procedure, Figure 3, developed for this case is accurate and simple. The ORDEAL is slewed to 25 degrees at 5 minutes prior to ignition and is checked at 3 minutes and 1 minute, and should read 17 and 9 degrees respectively. The crewman "fine tunes" as required to correct the alignment. The ORDEAL torquing is started at ignition with a 5 degree bias which the launch vehicle will steer until the FDAI reads zero, approximately 20 seconds after ignition.

At platform failure the crewman flys the space vehicle to FDAI pitch zero and resumes yaw steering manually based on a time attitude cue card. The procedure did not compromise the nominal crew monitoring task.

## 4.0 RESULTS

The timeline and sequence of events used in the simulation was based on the nominal operational trajectory as were the initial conditions of orbital parameters, time base 6 start time, inertial attitude velocity, etc. No failures were programmed for the launch and TLI phase other than IU platform failure. Various thrust misalignments up to 1.2 degrees (3 sigma) in pitch and yaw plus J-2 swirl torque values of varying amounts were included. Slosh and bending mode characteristics were not included in this simulation; however, three of the test subjects compared the flight and handling characteristics of DCPS with the MSFC validation simulation. They found no significant difference.

### 4.1 Launch Phase

The most sensitive portion of the launch phase manual guidance occurs in the last two to three minutes before insertion cutoff. For best results, the test subjects recommended that major errors from launch vehicle steering should be trimmed out before the time of SII-SIVB staging. Then small attitude adjustments are all that is required to reduce altitude rate to near zero and to hold altitude constant. The data, Table I, indicates that this technique will produce maximum orbital eccentricities of approximately 10 nautical miles.

### 4.2 TLI

Initial procedures development runs confirmed that the ORDEAL procedure, described above, was superior to the time pitch procedure. Use of the FDAI error needles and platform angle readouts to hundredths of a degree from the DSKY registers further improved the accuracy of the procedures. The test subjects exercised the basic and refined procedure and their results are contained in Table II. The improved procedure was implemented April 4, 1969; therefore, data prior to that time while included for history should be considered preliminary and not representative.

The column in Table II labeled "Velocity Error" contains the velocity vector between the nominal run (first row of Table II) and each simulation run. This is illustrated by the sketch shown in Figure 4. The IU guidance was not operative during the simulation, therefore, insertion errors based on launch vehicle targeting are not available. It is believed the values listed approximate the total insertion error because insertion altitudes were close to nominal and TLI ignition time was correct for all runs. Thus the errors shown are representative of the SPS maneuver that would be required immediately after insertion.

The TLI procedure accuracy is particularly sensitive to vehicle attitude alignment. The pre-TLI and post-TLI failure crew control accuracies compared so closely that no separation of them has been made. A one degree bias maintained over the full burn yields approximately 170 feet per second error. This is demonstrated by the data from the early development runs. For example the average error prior to the incorporation of the CDU-error display procedure was 191.6 feet per second compared to 96.2 feet per second afterwards. The TLI procedure is insensitive to the ORDEAL torquing start time. A 6 second start delay yields only 10 feet per second inaccuracy.

## 5.0 CONCLUSION

Manual control of the launch vehicle can be accomplished for all phases. Using the techniques and final procedures contained here, launch phase insertions can be accomplished to near nominal orbital conditions and translunar insertion can be accomplished with an average dispersion of 96 feet per second at cutoff.

Figure 1
Launch Phase Cue Card
AS 505 LAUNCH

| Time | $\theta$ | $V_i$ | $\dot{H}$ | H |
|---|---|---|---|---|
| 00:00 | 90 | 1,341 | 0 | 0 |
| 00:30 | 86 | 1,391 | 295 | 0.7 |
| 01:00 | 69 | 1,847 | 825 | 3.3 |
| 01:30 | 47 | 3,050 | 1,485 | 9.0 |
| 02:00 | 32 | 5,125 | 2,198 | 18.1 |
| 02:15 CECO | 27 | 6,559 | 2,511 | 24.0 |
| 02:30 | 23 | 7,915 | 2,814 | 30.7 |
| 02:40 OCO | 22 | 9,032 | 3,009 | 35.7 |
| 03:00 | 22 | 9,266 | 2,632 | 44.8 |
| 03:30 | 28 | 9,840 | 2,161 | 56.6 |
| 04:00 | 25 | 10,492 | 1,809 | 66.4 |
| 04:30 | 22 | 11,248 | 1,482 | 74.6 |
| 05:00 | 19 | 12,105 | 1,185 | 81.2 |
| 05:30 | 16 | 13,071 | 921 | 86.4 |
| 06:00 | 12 | 14,157 | 693 | 90.4 |
| 06:30 | 9 | 15,379 | 506 | 93.4 |
| 07:00 | 5 | 16,759 | 366 | 95.6 |
| 07:30 | 2 | 18,327 | 283 | 97.2 |
| 07:40 CECO | 12 | 18,900 | 280 | 97.4 |
| 08:00 | 3 | 19,567 | 267 | 98.4 |
| 08:30 | 1 | 20,800 | 248 | 99.7 |
| 09:00 | 356 | 22,054 | 256 | 100.9 |
| 09:13 ECO | 354 | 22,677 | 280 | 101.5 |
| 09:30 | 350 | 22,871 | 206 | 102.2 |
| 10:00 | 346 | 23,425 | 102 | 103.0 |
| 10:30 | 344 | 24,009 | 28 | 103.4 |
| 11:00 | 341 | 24,626 | -013 | 103.4 |
| 11:10 | 340 | 24,836 | -018 | 103.4 |
| 11:20 | 339 | 25,049 | -023 | 103.4 |
| 11:30 | 338 | 25,269 | -018 | 103.3 |
| 11:43 | 339 | 25,561 | 0 | 103.3 |

Figure 2

# TLI BACKUP GUIDANCE PROCEDURES

| EVENT | |
|---|---|
| TB5 | KEY V46E |
| | GUIDANCE - CMC |
| | ORDEAL ALT = 200 NM |
| | EARTH/LUNAR = LUNAR |
| | V25 N22E |
| | LOAD R = 180°, P = 116°, Y = 0° (1st OPP) |
| | LOAD R = 180°, P = 115°, Y = 0° (2nd OPP) |
| | V62E |
| | MANEUVER LV TO NULL ATT ERROR NEEDLES |
| | KEY V16 N20E (DSKY R2 = 116.00°) |
| | NULL LV RATES |
| | ORDEAL FDAI #1 - ORB RATE |
| | ORDEAL MODE - FAST/HOLD |
| | SLEW FDAI #1 TO P = 0° |
| | INSURE R2 = 116.00° |
| TB6 | S-II SEP LT - ON |
| 51:00 | S-II SEP LT - OFF |
| | START DET COUNTING UP FROM 51:00 |
| 57:00 | INSURE FDAI #1 P = 0° & R2 = 116.00° |
| 57:40 | ORDEAL MODE - OPERATE/SLOW |
| | (STARTS ORDEAL TORQUING) |
| | MANEUVER LV TO |
| | P = 0°, Y = +3.5° AND MAINTAIN UNTIL BURN COMPLETE |
| 58:00 | KEY V37E 47E |
| | N20E |
| 58:36 | S-II SEP LT - ON |
| 58:38 | LV ULLAGE START |
| 59:42 | S-II SEP LT - OFF (IGN - 18 SEC) |
| 59:50 | N62E |
| 59:59 | ENG #1 LT - ON |
| 00:00 | IGNITION (__:__:__) GETI |
| 00:02 | ENG #1 LT - OFF |
| | FLY P = 0° |
| | Y = 3.5° |
| 05:44 | CUTOFF ON V1 = 35,600 THC - CCW FOR 1 SEC & RESET |

## Figure 3

## Nominal Procedures

| | | |
|---|---|---|
| 28 | CDR | EMS MODE - NORMAL |
| | | SCS TVC SERVO PWR 1 AC1/MNA |
| | | SCS TVC SERVO PWR 2 - OFF |
| | LMP | START DSE |
| | CMP | FLT RECDR - RECORD |
| 57:00 | | START 3 MIN COUNT |
| | | ORDEAL FDAI #1 - ORDEAL |
| | | SLEW FDAI #1 TO PITCH 17° |
| 58:36 | | S-II SEP LT - ON |
| 58:38 | | S-IVB ULLAGE BEGINS |
| | | xxxxxxxxxxxxxxxxxxxxx |
| | | x TLI INHIBIT, ETC. x |
| | | xxxxxxxxxxxxxxxxxxxxx |
| 59:00 | | SLEW FDAI #1 TO PITCH = 9.0° |
| 59:42 | | S-II SEP LT - OFF (TIG - 18 SEC) |
| 59:52 | | FUEL LEAD |
| 59:55 | | ULLAGE STOP |
| | | INSURE FDAI #1 PITCH = 5.0° |
| 59:59 | | START ORDEAL TORQUING |
| | | ENG #1 LT - ON |
| (02:31:24)<br>00:00 | | IGNITION (__:__:__) GETI |

Figure 4

Velocities at TLI Insertion

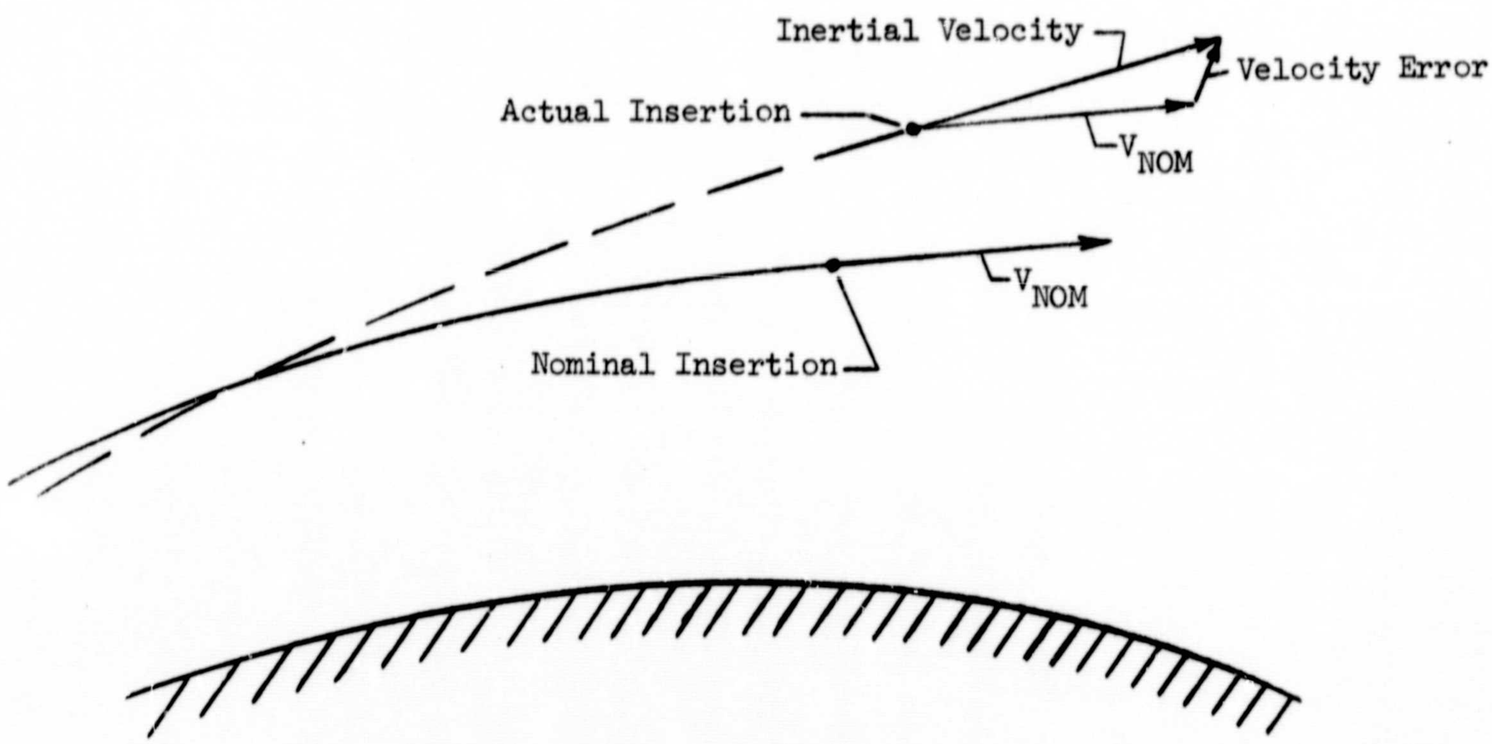

TABLE I

MANUAL GUIDANCE

LAUNCH PHASE END CONDITIONS

| Test Subject | Date | Time of Cutoff Min:Sec | Velocity FPS | Height of Perigee NM | Height of Apogee NM |
|---|---|---|---|---|---|
| Nominal | -- | 11:35 | 25,561 | 103.3 | 103.3 |
| A | 3-31-69 | 11:40 | 25,578 | 102.2 | 114.7 |
| A | 3-31-69 | 11:41 | 25,581 | 98.2 | 101.1 |
| A | 3-31-69 | 11:44 | 25,574 | 95.7 | 101.8 |
| A | 4-05-69 | 11:40 | 25,596 | 103.0 | 113.6 |
| A | 4-19-69 | 11:41 | 25,590 | 95.0 | 103.0 |
| A | 4-26-69 | 11:40 | 25,584 | 106.0 | 108.0 |
| A | 4-26-69 | 11:40 | 25,564 | 92.0 | 102.0 |

Note: All runs included thrust misalignments

TABLE II

MANUAL GUIDANCE

TLI PHASE END CONDITIONS FOR RUNS

| Subject | Date | Cutoff Conditions | | | | Remarks |
|---|---|---|---|---|---|---|
| | | Inertial Velocity FPS | Velocity Error FPS | Altitude Rate FPS | Altitude NM | |
| Nominal | March 31 | 35,598 | 0 | +4100 | 170.2 | |
| A | | 34,428 | | -7893 | 245.62 | Simulator Problem Invalid Run |
| A | | 35,681 | 125.1 | +4213 | 171.9 | Inertial Cue Card |
| A | | 35,638 | 165.7 | 4257 | 175.5 | Inertial Cue Card |
| A | | 35,722 | | 4377 | 180.2 | Ordeal Inoperative Invalid Run |
| A | | 35,648 | 253.8 | 4258 | 174.5 | Inertial |
| A | | 35,702 | | 4290 | 174.3 | 5° Yaw Attempt Invalid Run |
| A | | 35,570 | 180.5 | 4199 | 173.5 | Inertial |
| A | | 35,663 | 173.3 | 4339 | 176.6 | Inertial |
| A | | 35,701 | 165.7 | 4215 | 173.85 | Inertial |
| B | April 1 | 35,607 | 36.1 | 4089 | 169.1 | Reset Point At Ign -1 Minute |
| B | | 35,687 | 115.4 | 4189 | 171.2 | Reset Point At Ign -1 Minute |
| B | | 35,597 | 68.0 | 4079 | 167.9 | Reset Point At Ign -1 Minute |
| B | | 35,683 | 296.1 | 4473 | 175.9 | Full Alignment Procedure - Fam. |
| B | | 35,598 | 185.7 | 3955 | 166.4 | |
| B | | 35,658 | 91.5 | 4231 | 171.4 | |
| B | | 35,637 | 494.9 | 4681 | 182.3 | Poor Alignment |
| C | | 35,588 | 128.4 | 3940 | 166.3 | Reset Point At Ign -1 Minute |
| C | | 35,613 | 159.3 | 3945 | 165.8 | |
| C | | 35,640 | 106.4 | 4243 | 173.4 | |
| C | | 35,594 | 162.2 | 3929 | 166.2 | |
| C | | 35,638 | 387.0 | 3988 | 167.1 | Full Alignment Procedure |
| C | | 35,596 | 159.0 | 3978 | 168.3 | Full Alignment Procedure |
| E | | 35,574 | 163.5 | 3906 | 165.2 | Reset Point At Ign -1 Minute |

TABLE II (CONT)

| Subject | Date | Cutoff Conditions | | | | Remarks |
|---|---|---|---|---|---|---|
| | | Inertial Velocity FPS | Velocity Error FPS | Altitude Rate FPS | Altitude NM | |
| B | April 2 | 35,634 | 105.1 | 4198 | 171.9 | |
| B | | 35,630 | 247 | 3970 | 166.3 | |
| B | | 35,583 | 176.5 | 3919 | 164.7 | |
| B | | 35,603 | 207.2 | 4010 | 167.3 | |
| B | April 4 | 35,610 | 200.4 | 4038 | 167.9 | |
| B | | 35,603 | 303.2 | 3890 | 164.4 | |
| B | | 35,555 | 80.8 | 4035 | 168.0 | |
| B | | 35,694 | 117.3 | 4292 | 175.3 | |
| B | | 35,657 | 306.0 | 4576 | 181.1 | Begin Error Needle Procedures - Fam |
| B | | 35,628 | 79.3 | 4207 | 172.1 | |
| C | | 35,590 | 29.3 | 4188 | 171.7 | |
| C | | 35,631 | 112.7 | 4109 | 170.2 | |
| C | | 35,650 | 74.3 | 4247 | 173.5 | |
| E | | 35,620 | 125.6 | 4078 | 169.3 | |
| E | | 35,613 | 137.3 | 4333 | 175.6 | |
| A | April 5 | 35,591 | 162.8 | 4211 | 173.3 | Procedure Familiarization |
| A | & 7 | 35,625 | 163.0 | 4050 | 168.9 | Used 4° Yaw Should Be 3.5° |
| A | | 35,604 | 65.2 | 4120 | 170.5 | |
| A | | 35,594 | 35.7 | 4139 | 170.7 | |
| D | | 35,563 | 34.2 | 4153 | 171.9 | Familiarization |
| D | | 35,564 | 252.6 | 3858 | 164.6 | Poor Alignment |
| B | April 8 | 35,603 | 54.6 | 4230 | 173.1 | |
| B | | 35,551 | 255.2 | 4374 | 177.2 | Familiarization Nominal Procedures |
| B | | 35,635 | 64.3 | 4256 | 174.5 | Nominal Procedure |
| B | | 35,588 | 88.6 | 4249 | 174.7 | Nominal Procedure |
| B | | 35,614 | 43.7 | 4172 | 171.1 | Nominal Procedure |
| E | | 35,620 | 125.6 | 4078 | 169.3 | |
| E | | 35,613 | 137.3 | 4333 | 175.6 | |
| E | | 35,574 | 76.0 | 4205 | 173.0 | |
| E | | 35,582 | 51.3 | 4093 | 169.6 | |
| E | | 35,592 | 133.3 | 4298 | 174.9 | |

TABLE II (CONT)

| Subject | Date | Cutoff Conditions | | | | Remarks |
|---|---|---|---|---|---|---|
| | | Inertial Velocity FPS | Velocity Error FPS | Altitude Rate FPS | Altitude NM | |
| C | April 9 | 35,593 | 96.2 | 4232 | 172.8 | |
| C | | 35,649 | 83.7 | 4219 | 172.4 | |
| A | April 11, | 35,562 | 139.1 | 3976 | 167.6 | Fam. Nominal Procedure With Plat- |
| A | 12, 19 & | 35,614 | 174.4 | 4287 | 174.7 | form Failure at Ignition |
| A | 26 | 35,624 | 56.2 | 4149 | 171.4 | Contingency Procedure |
| A | | 35,636 | 113.9 | 4246 | 173.2 | |
| A | 4-19-69 | 35,574 | 74.2 | No Data | No Data | |
| A | | 35,600 | 221.8 | No Data | No Data | Poor Alignment |
| A | 4-26-69 | 35,665 | 111.0 | 4106 | 172.0 | |
| C | 4-11-69 | 35,583 | 83 | 4012 | 168.1 | |
| C | | 35,580 | 37 | 4103 | 170.2 | |
| C | | 35,592 | 56.8 | 4013 | 169.3 | |
| C | | 35,585 | 87.8 | 4062 | 172.9 | |
| C | | 35,632 | 107.2 | 4103 | 171.7 | |

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