

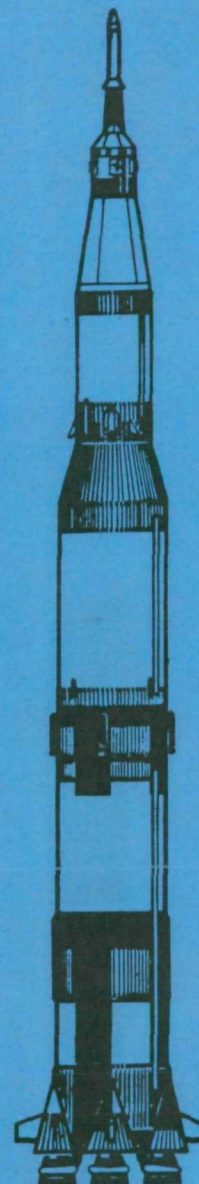
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THE **BOEING** COMPANY

G & C BOOST AND ABORT STUDY SUMMARY

EXHIBIT B OF CONTRACT NAS9-12183

JUNE 30, 1972



REPORT

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HOUSTON, TEXAS

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Contract No.: Exhibit B of NAS9-12183

This final report summarizes the work accomplished under Exhibit B of NASA/MSC Contract NAS8-12183. A six degree of freedom simulation of rigid vehicles was developed to study Space Shuttle Vehicle boost-abort guidance and control techniques. The simulation was described in detail as an all digital program and as a hybrid program. Only the digital simulation was implemented. The equations verified in the digital simulation were adapted for use in the hybrid simulation. Study results were obtained from four abort cases using the digital program. The six reports, previously released, which provide detail study results are given in the Reference list to this report.

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ABSTRACT

Subject: G&C Boost and Abort Study Summary

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Report No.: 5-2581-HOU-093

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A summary of work accomplished in conjunction with Exhibit B of Contract NAS9-12183 is provided. The simulation, Launch and Abort Simulation for Spacecraft (LASS), was developed. LASS is a 6DOF rigid body simulation and was developed as an all digital computer program and a hybrid computer program. Only the digital version of LASS was implemented and abort studies conducted. The studies included aborts from the launch pad, aborts occurring at nominal launch region of maximum dynamic pressure, and aborts from nominal launch near staging where the orbiter returns to the launch site. In addition aborts were conducted from nominal launch region of maximum dynamic pressure where the orbiter heads for Bermuda as the landing site. Most of the equations proposed for use in the hybrid simulation were verified during digital simulation runs.

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1.0 SUMMARY

Simulations of the Shuttle launch configuration, Launch and Abort Simulation for Spacecraft (LASS), were developed to study abort guidance procedures which would steer the orbiter from a time where the abort occurred to the near vicinity of a preselected landing site. The simulation was developed for aborts occurring during launch, as a result of booster malfunctions, where orbiter systems function in their nominal sense. The simulations evolved in two parts. The first was a rigid body 6 DOF digital computer program designed to study adequacy of abort guidance procedures and determine, in a very preliminary sense, if control problems might exist. The second part was a rigid body 6 DOF simulation using hybrid techniques, designed to provide an orbiter pilot the capability of monitoring and manually controlling the abort process.

The digital simulation was developed and tested with aborts occurring at the launch pad, from the region of nominal launch maximum dynamic pressure and from a region near nominal staging during launch. For each of these abort cases the orbiter was steered back to the vicinity of the launch site for landing. An additional study was performed where the abort took place from nominal launch region of maximum dynamic pressure and the orbiter was steered to Bermuda for landing.

The hybrid simulation was developed using the basic equations tested by the digital simulation. However, the hybrid features were not implemented or tested.

2.0 INTRODUCTION

Associated with each nominal launch is the possibility that the launch trajectory must be aborted. In the aborted case, the spacecraft must be given the capability of leaving the nominal launch trajectory and returning to earth. This requires that abort guidance and control procedures must be studied to assure safe return of the spacecraft and its crew. The Launch and Abort Simulation for Spacecraft (LASS) was developed as a tool to be used in the accomplishment of the required abort guidance and control studies.

LASS was developed as a six degree-of-freedom model of a nonsymmetrical rigid vehicle. The present LASS simulations were developed with certain limitations and assumptions. These limitations and assumptions are:

1. The earth is assumed to be a rotating sphere.
2. LASS does not include means for determining wind effects on the simulated vehicle.
3. LASS does not include provisions for fuel slosh and vehicle bending.
4. The vehicle is simulated with mass symmetry in the body $X_B - Z_B$ plane.
5. The engines are simulated with ideal engine actuators, engine gimbaling without inertial effects, and instantaneous thrust build up and tail off.
6. LASS assumes attitude control augmentation using auxiliary control surfaces will not be required.
7. LASS assumes thrust forces along body X and Z axis are mainly dependent on engine pitch gimbal actuation. Hence, coupling can be ignored when computing forces in the X and Z directions for determining moments about the Y axis due to thrust.
8. No RCS jet dynamics or jet select logic are simulated. During periods of time when the vehicle engines are burning, attitude control is accomplished by engine gimbaling. When engines are off and the vehicle is coasting, the ideal autopilot provides the required RCS control torques to the appropriate moment equation. Thus, the pseudo RCS system provides sufficient torques to keep attitude errors nearly zero.

2.0 INTRODUCTION (Continued)

9. The aerodynamic force and moment equations are written in the body axis system. Aerodynamic data must be transformed from stability axis to body axis where necessary.

LASS was developed along two basic concepts. The first was the development of a digital 6 DOF simulation of rigid vehicles. The objectives were to develop and test abort guidance techniques that will:

- a. Steer the orbiter to an abort target coincident with fuel depletion.
- b. Place orbiter at a terminal energy state from which a landing could be made.
- c. Result in an abort trajectory which can be controlled and does not violate selected guidelines.

The digital program was also used to evaluate the various displays that an orbiter pilot might find useful in monitoring and controlling the orbiter along an abort trajectory.

The second concept was the modification of LASS into a hybrid computer program. The hybrid process is also a 6 DOF simulation of rigid vehicles. The objectives were to:

- a. Evaluate the adequacy of the various display parameters to convey information of abort status to the orbiter crew.
- b. Define manual control mode requirements.
- c. Gain confidence in abort guidance procedures which could be used compatibly for both automatic and manual control during the abort phase.

The arrangement of necessary equations were provided, but the hybrid simulation was not implemented. However, most of the processes proposed for use by the hybrid were tested using the digital version of LASS.

3.0 DEVELOPMENT OF LASS AS A DIGITAL SIMULATION

3.1 Background

At the time LASS was developed two separate launch pads were considered. Launch azimuth, desired orbit, and orbit inclination angle were also considered variables to the shuttle mission. Consequently, LASS was developed to include the shuttle launches in their nominal sense where the above parameters could be initialized to designate the launch trajectory. The abort feature would then be included as a perturbation of the launch trajectory into an abort trajectory.

The math models were developed for a 6DOF nonsymmetrical rigid vehicle. The vehicles simulated are in two configurations. The first is the launch configuration and the second is the orbiter only configuration.

This development of LASS was implemented using assumptions and limitations that are in addition to those found in Section 2.0. These are:

1. Vehicle center of gravity is limited to displacements along the body X direction. Displacements along body Y and Z axis are constrained to zero.
2. Aborts result from a booster malfunction. Hence, orbiter systems are assumed to function in their nominal sense.
3. Simple inertial attitude hold during vehicle separation is assumed adequate to assure booster-spacecraft separation. The simulation is not oriented for detail studies of separation dynamics.
4. A canned roll maneuver during launch is not required (vehicle oriented in boost plane at liftoff).
5. Launch guidance method starting with a fixed pitch profile and followed by the MIT version of E guidance as modified for thrust limiting is assumed adequate to provide nominal launch trajectories. The simulation was developed such that an abort can only take place at a preselected launch time during simulation of a nominal launch.

3.1 Background (Continued)

6. Tables for aerodynamic data for the spacecraft are compatible for angles of attack up to 60° . If angles of attack (α) between 60° and 90° are desired, the aerodynamic coefficient for an α of 60° is used. If α is greater than 90° , aerodynamic coefficients are set to zero. If α is less than zero the Tables are interrogated with the magnitude of α . Maneuvers requiring large angles of attack (α greater than 60°) will be restricted to times when the dynamic pressure (q) is small. Thus, errors of the above process are assumed small with respect to thrusting effects.
7. Interrogation of aerodynamic tables for large angle-of-sideslip (β) is assumed to be a linear extrapolation of the data tables.
8. Aerodynamic force and moment coefficients are assumed to be a linear function of α about the trim value for the longitudinal derivatives and a linear function of β about the trim value for the lateral derivatives. For the simulation mechanization, all of the linear coefficients will be programmed and looked-up as a function of Mach number and α or β .

LASS was developed as a series of subroutines to provide ease in program modifications. LASS contains 23 subroutines and 9 function routines not including the output plot package. These routines are described in detail in reference 1. A brief discussion of the subroutines are provided in the following sections.

3.2 LASS Program Input/Output

LASS program input is provided by four data cards read by the master FUN subroutine and data statements found in INITIA and other subroutines. However, basic run control is provided by the input data cards.

LASS program output is accomplished from INITIA and READO subroutines. The INITIA subroutine outputs specific control parameters and constants used to identify the simulation run. The READO subroutine is used to output tabulations of selected variables and plots of selected parameters. The plots are in the form of time histories where time starts at vehicle launch.

3.3 The FUN Routine

The FUN routine controls LASS. It is used to sequence LASS throughout a launch to insertion or launch to terminal energy conditions associated with the abort. The routine causes launch guidance or abort guidance and output provisions to be called for each second. Whereas, equations of motion, aerodynamics, and autopilot are called five times per second.

FUN recognizes certain flags which are inputted or generated within LASS to select GUIDAN (launch guidance), ABGUID (powered abort guidance), or PBC (unpowered abort guidance) when required. Depending on an input flag the AUTOPI (ideal autopilot) or AUTOP2 (conventional autopilot) is selected during powered flight. When engines are off, FUN selects AUTOPI which provides attitude control.

3.4 The INITIA Subroutine

The INITIA subroutine is called up once during each simulation run. This subroutine performs launch targeting functions, initializes various simulation parameters, and outputs parameters that are printed to identify the simulation run. Launch targeting is divided into two parts. The first constitutes development of orbit insertion targeted state vectors. The second part constitutes the definition of a unit vector normal to the desired orbit plane. INITIA contains many of the data tables that provide information for the atmospheric model, mass characteristics model, and launch guidance pitch profile commands.

3.5 The GUIDAN Subroutine

The GUIDAN subroutine provides vehicle launch guidance commands from the time of launch until either abort time is reached or orbit insertion is reached. The actual guidance equations are adapted from E-Guidance as modified for thrust limiting. Immediately after launch the launch vehicle is caused to follow a prescribed pitch angle for a designated time. Presently, this designated time is 212 seconds ground elapsed time (GET), which may be changed if necessary. The desired vehicle acceleration vector command is not allowed to differ from the actual vehicle acceleration vector by more than six degrees. This is required when conventional forms of autopilots are used. When the abort time is reached GUIDAN relinquishes control of the vehicle to abort guidance.

3.6 The EOM Subroutine

The EOM subroutine is used to simulate the vehicle propulsion system and vehicle relationships in space. The subroutine computes vehicle attitudes, attitude rates, position, velocity, and accelerations in the desired coordinate reference frame and is executed five times per second.

Presently, LASS is thrust limited to 2.5 gees during launch and 3 gees during abort. The fractional throttle setting is computed as the ratio of limited thrust to unlimited thrust. Vehicle positions and velocities are integrated using a trapezoidal integration technique. Relationships between body and inertial coordinates are maintained and updated in the form of a direction cosine matrix.

3.7 The AERO Subroutine

The AERO subroutine is used to compute translational and rotational forces resulting from aerodynamic influences on the vehicle. AERO uses three additional subroutines and a function routine to accomplish this purpose. The COEF subroutine contains aerodynamic coefficients of the B9U/161C launch configuration and selects the desired coefficient based on angle of attack, angle of sideslip, and mach number. The COEFO subroutine contains aerodynamic coefficients of 161C orbiter and uses the Z1 function subroutine to select the desired coefficient from the tables. The atmospheric model, ATM053, assumes the earth is a rotating sphere and uses the 1962 standard atmospheric tables.

3.8 Mass Characteristics Model

The mass characteristics model contains data for B9U/161C launch configuration and is composed of seven function subroutines and one subroutine. The model uses vehicle mass remaining to select center of gravity location information and moment of inertia information from data tables. The FAT subroutine is used for data interpolation by all of the function subroutines. The using subroutines of LASS obtains data from the mass characteristics model using function statements. Whenever a center of gravity displacement value or a moment of inertia value is desired, the presence of a properly argumental symbol causes the execution of the function statement.

3.9 The AUTOPI Subroutine

The AUTOPI subroutine is termed the ideal autopilot and uses the ACC subroutine to provide angular accelerations in three rotational modes. The autopilot model controls the vehicle by computing the angular accelerations necessary to rotate the vehicle, compute the necessary thrust moments to create the required accelerations, and determines the engine gimbal angles necessary to cause the required thrust moments. The model functions as an adaptive gain system, is more stable than conventional autopilots, and is insensitive to large fluctuations in acceleration commands from guidance models. The model is also used to provide an RCS function during the coasting portion of the abort. In this function the correcting torque is provided and used in the EOM moment equations. The AUTOPI subroutine was used to gain confidence in the math models during the initial developmental stage and is used to control the vehicle while conventional autopilot gains are computed.

3.10 The AUTOP2 Subroutine

The AUTOP2 subroutine is used as a conventional form of autopilot. It is used to control the launch or abort when engines are burning. The autopilot uses a conventional engine control law. The form of the control law is

$$S = A_0 + A_1 \Theta_E + A_2 \dot{\Theta}_E$$

where: S - engine deflection

A_1, A_2 - weighting coefficients or gains

Θ_E - present vehicle attitude error

$\dot{\Theta}_E$ - present vehicle attitude rate error

A_0 - bias term

The engine pitch command contains the bias term and allows the thrust vector to be directed through the vehicle center of gravity. Vehicle pitch, yaw, and roll are reflected into engine gimbal pitch and yaw using identical forms of the equation with attitude and attitude rate feedback. Vehicle pitch and yaw commands are used to drive the pitch and yaw gimbals respectively. Vehicle roll command is added differentially to the pitch gimbal to provide vehicle roll control.

3.11 Abort Guidance

The purpose of abort guidance is to direct the orbiter to the near vicinity of a selected landing site after an abort. The abort maneuver itself is divided into two phases. The first phase, commencing when the abort is initiated, controls the orbiter burn to an intermediate target. The intermediate target is chosen such that the orbiter will reach the target coincident with fuel depletion. During this time the ABGUID subroutine controls orbiter attitudes using the TARGET subroutine for targeting information. The second phase is used to control orbiter attitudes when engines are off and the orbiter is coasting to its terminal energy state. The simulation ends when the orbiter reaches an energy state corresponding to 150,000 feet altitude and 7,800 feet per second velocity when a downrange landing site is selected and at 100,000 feet altitude and 1,860 feet per second velocity when the launch pad is the desired landing site.

3.11.1 The TARGET Subroutine

The targeting problem is to determine a desired engine burnout state vector when the vehicle's present state vector and the desired landing site is known. The burnout velocity is determined as a function of earth's central angle between radials to the orbiter and desired landing site and the desired reentry angle of attack. The problem is solved using an iterative process. The desired altitude at burnout is selected as 200,000 feet when the orbiter returns to the launch site and 250,000 feet when the orbiter aborts to a downrange landing site.

3.11.2 The ABGUID Subroutine

The function of ABGUID subroutine is to steer the orbiter to desired burnout state vectors. The powered abort guidance phase is divided into two parts. The first part, termed weighted open loop guidance, is used initially after abort. The orbiter is kept in the launch plane while thrust is used to gain altitude and direct the orbiter in the direction of launch (in the launch plane). The process utilizes abort target altitude and altitude rate as pseudo terminal conditions. This continues until the orbiter can reach burnout conditions coincident with propellant depletion. The second part of powered abort guidance is closed loop. The guidance is now explicit requiring present and terminal state information.

3.11.3 The PBC Subroutine

The PBC subroutine is used to control orbiter attitudes from main engine shutdown until terminal energy state is reached. During this time, angle of attack is modulated while maintaining a near zero bank angle. During nominal reentry, attitude commands are issued that keep body X-axis attitude near 25 degrees. When normal acceleration of the orbiter exceeds 1.8 gees, commands are issued that reduce angle of attack and thus reduce load factor. The coasting descent requires that angle of attack be greater than 22 degrees but less than 50 degrees. Specific details are found in both references 1 and 2.

3.12 The READO Subroutine

The READO subroutine performs three functions. The first function provides for the computation of parameters that may be of interest to an orbiter pilot. These display parameters are intended to provide the pilot a capability to assess abort status and/or provide information necessary to control the orbiter during abort. The second function is to collect values of selected parameters, periodically store these values, and periodically output the values in the form of tabulated listings. The third function is to provide for the periodic collection of selected parameters and, at termination of a LASS run, make plots in the form of a time history of these parameters.

4.0 DEVELOPMENT OF LASS AS A HYBRID SIMULATION

4.1 Background

The hybrid simulation was designed to study aborts initiated during launch. The basic simulation variables are the man-machine interface and the abort guidance procedure. The man-machine interface is divided into two parts. The first part involves display of parameters that are informative to the pilot. Both number of displays provided and information received was considered. The intent was to provide a small number of displays that are highly informative and allow adequate assessment of vehicle state. The second part involves definition of the manual control mode requirements.

This version of LASS is started when the abort is initiated. Thus, simulation of launch is not required. The development of the hybrid version of LASS was made with certain limitations and assumptions in addition to those found in section 2.0.

These are:

1. Data will be available either from use of the digital version of LASS or other sources to initialize the hybrid simulation at the time selected for abort. Thus, the hybrid version will start at abort and run until proper orbiter energy state is reached.
2. The simulation assumes the altitude at time of abort is high enough so that the orbiter main engines are adequate to maintain flight. At time of abort, it is assumed that the main SRMs and abort SRMs have been jettisoned.
3. Aerodynamic data is usually provided for angles of attack up to 60° . Consequently, logic is provided to handle this problem when large orbiter rotations are required during abort. If angles of attack (α) between 60° and 90° are desired, the aerodynamic coefficient for an α of 60° is used. If α is greater than 90° , aerodynamic coefficients

are set to zero. If α is less than zero the Tables are interrogated with the magnitude of α . Maneuvers requiring large angles of attack (α greater than 60°) will be restricted to times when the dynamic pressure (q) is small. Thus, errors of the above process are assumed small with respect to thrusting effects.

4. At the instant of abort, the vehicle is a delta winged three engined orbiter similar to O40C-2, with an external fuel cell attached. All SRM's are assumed to be jettisoned prior to abort which starts the simulation.

The launch and abort hybrid simulation is implemented by coupling a set of equations-of-motion, set of thrust limiting equations, and sets of launch abort equations with simulation of the spacecraft cockpit. The simulation is initiated at a preselected abort time. The simulation does not consider the aborts from the PAD or low altitude. When an abort is initiated, the abort guidance issues commands controlling the simulation with provisions for manual attitude and throttle control if necessary. At engine shutdown the orbiter separates from external fuel tank. The abort part of the simulation is terminated in a reentry footprint associated with a desired landing site. A brief description of the hybrid program is given in the following paragraphs and a detailed description is given in reference 2.

4.2 Equations of Motion (EOM)

The equations of motion are written in six degrees of freedom which provides summation of forces and moments along and about the orbiter/tank and orbiter body axes. The forces and moments result from external forces on the vehicle and are converted to vehicle translational and angular accelerations using vehicle mass remaining and mass characteristics. The

accelerations are integrated to provide vehicle position, velocity, attitude, and attitude rate. The relationship between body coordinate system and inertial coordinate system is provided and updated. The EOM is used to perform engine throttling and provide for pilot displays. The present form of the hybrid simulation does not contain vehicle aerodynamic data nor mass characteristics data. These tables have been left blank. However, logic has been provided for a three engine configuration.

4.3 Master Control-Digital Program

The master control program is used to sequence the autopilots and abort guidance programs, provide or accept mission time, and establish discretely that control the simulation. The vehicle engines are turned off or on when necessary and a discrete is set which indicates when orbiter/tank separation takes place. A discrete is also set which indicates whether the spacecraft is operating in an abort downrange or an abort for return to launch site mode.

The master control provides mission time in 0.2 second intervals. This should not be construed to indicate that the digital program should control time. Analog generated time could be used. However, if separate time generators are used, i.e. analog generated time and digital generated time, the two time generators should be synchronized. It should be noted that the digital autopilot require time in 0.2 second intervals and the guidance programs require time in one second intervals. The abort time must be inputted to initialize time and obtain ground elapsed time.

4.4 Abort Guidance-Digital Program.

The objective of an aborted shuttle mission is the safe return of the crew and vehicle. Abort guidance provides a technique for steering to a landing site after an abort during launch.

In the simulation an abort is commanded to take place at a preselected time from launch. If an abort simulation is desired K seconds after launch, K is assigned to the time variable in the Master control program. When an abort is commanded an abort guidance procedure controls the spacecraft to targets associated with the selected landing site. Near target, the engines are shut down when fuel is depleted and the vehicle is commanded to follow an attitude selecting process as it descends to earth.

The simulation ends when the orbiter reaches an energy state corresponding to 150,000 feet altitude and 7800 feet per second velocity when a downrange landing site is selected and at 100,000 feet altitude and 1860 feet per second velocity when the launch pad is the desired landing site. The abort guidance controls the vehicle attitude to avoid violating vehicle constraints and assures that the vehicle reaches the vicinity of the selected landing site.

The abort guidance process is divided into three basic parts. The first consists of a targeting function. The targeting function is used to determine a desired engine burnout state vector. The burnout velocity vector is the result of an iterative computational process. The second part consists of a steering function while the orbiter engines are burning. The basic problem is to cause the orbiter to achieve burnout state status coincident with propellant depletion. The third part consists of an attitude control for initial reentry in the earth's atmosphere. The process involves control of angle attack. Angle of attack is modulated while maintaining a near zero bank angle. By using this process violation of vehicle constraints is avoided.

4.5 Digital Autopilot

Two forms of digital autopilots are provided. The first autopilot is the ideal autopilot system described in section 3.9.

This autopilot is more stable than conventional forms of autopilots. It is included to provide a backup system, if the need should arise, to be used to control the vehicle while determining conventional autopilot gains, and to provide attitude control during the coasting portion of the abort. The second autopilot is a conventional form of an autopilot described in section 3.10, which is used during engine on portions of the abort. The autopilot may be selected by setting the proper flag in the master control program and is used to gain preliminary information concerning ability to control the orbiter during abort. The autopilots provide a manual take-over capability.

4.6 Simulator Crew Station

The crew station will be provided with certain vehicle controls and data displays. Manual controls are orbiter attitude control, engine throttle control, and auto-manual mode select switch. This switch in the manual position configures the simulation to recognize manual control commands. One of the objectives of this simulation will be to study useability of the various display parameters proposed. A tentative list of proposed displays are shown in reference 2.

4.7 Control System

During an abort, two operation modes are available, automatic and manual. In the automatic mode spacecraft attitudes are controlled by engine gimbaling when engines are thrusting. Either the conventional or ideal autopilots can be used to control engine gimbaling. When engines are not thrusting the ideal autopilot is used to compute rotating torques which are proportional to the body attitude errors. The torques are inserted in the proper EOM moment equations to reduce the attitude error to near zero. Thus, the torque is always large enough to maintain small attitude errors.

When the simulation is in manual mode, the manual attitude controller is used to provide desired attitudes to the autopilot. The pilot commands the attitude to reduce the error. The attitude error is the difference between the desired values provided by the abort guidance and actual attitudes provided by the EOM. The autopilot acts on the manually generated attitudes to gimbal engines or provide RCS torques.

The throttle controller provides throttle commands that are used by the EOM in computing thrust forces. At the same time the EOM is providing the desired throttle setting. If the commanded throttle and desired throttle is the same, additional throttle is not required. Only when a difference is noted should a change in throttle command be provided from the manual controller. Manual throttle control is applicable only during an abort.

5.0 RESULTS OF SIMULATION RUNS

The design of the orbiter includes return of that vehicle to the earth for reuse. One concern is the definition of procedures necessary to return the orbiter in event of an abort during launch. The problem of aborting the Shuttle Orbiter from a nominal launch trajectory was investigated using the digital version of LASS (6 DOF rigid body simulation). The investigations were conducted for an abort of the orbiter (161C) from the baseline launch configuration (B9U/161C). Nominal launch takes place at 38.44° launch azimuth from Cape Kennedy. The nominal launch destination is a 55X100 nautical mile orbit inclined at 55 degrees. During launch the booster is thrust limited to 2.5 gees. After abort the orbiter engines are thrust limited to 3 gees.

The abort may occur at any point in the nominal launch trajectory. Each abort is assumed to result from a booster malfunction, thus, the orbiter systems are functioning in their nominal sense. The abort feature is incorporated as a perturbation of the nominal launch trajectory into an abort trajectory and includes both a powered phase and a unpowered phase. The powered phase ends when the orbiter fuel is depleted. The coast phase ends with the attainment of a suitable vehicle energy state.

The powered phase is divided into two parts. The first part, termed weighted open loop guidance, is used initially after abort. The orbiter is kept in the launch plane while thrust is used to gain altitude and direct the orbiter in the direction of launch (in the launch plane). The process utilizes abort target altitude and altitude rate as pseudo terminal conditions

and continues until the orbiter can reach the abort target coincident with propellant depletion. The second part of the powered abort guidance is closed loop. The guidance is explicit requiring present and terminal state information. The time from abort, which divides open and closed loop abort guidance, is termed the transition time.

LASS was designed as an all digital simulation and as a hybrid simulation of a 6 DOF rigid vehicle. Only the digital version of LASS was implemented. Several abort cases were studied using both ideal autopilot and conventional autopilot systems. Brief discussions of the studies are contained in the following sections.

5.1 Abort Studies Using an Ideal Autopilot System

The study objectives, using the ideal autopilot, were to: (1) develop and test abort guidance techniques which will guide the orbiter to abort targets coincident with fuel depletion; (2) assure nonviolation of abort constraints in a 6 DOF rigid body simulated environment; and (3) gain confidence in proper functioning of LASS. Abort cases considered were aborts occurring from the launch pad, aborts occurring at nominal launch maximum dynamic pressure, and aborts occurring near staging where the orbiter is steered to return to the launch site for a landing. During this testing the body rates were not allowed to exceed six degrees per second.

Testing, using this ideal procedure, demonstrated that the abort process is feasible using the vehicle simulated. Abort targets were nearly reached coincident with orbiter fuel depletion. Abort guidance placed the orbiter in an acceptable vicinity of the launch site. One of the weighting coefficients of the weighted open loop form of abort guidance was not correct for the abort from the launch pad. With the modification of this

coefficient, abort guidance produced results that were within accepted orbiter abort constraints shown in Table I. Specific study results for these cases are provided in references 3, 4, and 5.

5.2 Abort Studies Using a Conventional Form of Autopilot System

The study objectives, using the conventional autopilot system, were to develop and test abort guidance and control techniques that will: (1) Steer the orbiter to an abort target coincident with fuel depletion; (2) Place the orbiter at a terminal energy state from which a landing could be made; and (3) Result in an abort trajectory which can be controlled and does not violate selected abort constraints. Abort cases considered were aborts occurring from the launch pad, aborts occurring at nominal launch maximum dynamic pressure, and aborts occurring near staging where the orbiter is steered to return to the launch site after abort. Additional aborts were conducted where the abort occurs at nominal launch maximum dynamic pressure with the orbiter steered for Bermuda after abort. During this testing the difference between desired acceleration vector (provided by the guidance) and actual acceleration vector (provided by the equations of motion) was not allowed to exceed 6 degrees. Engine gimbaling was not allowed to exceed ten degrees.

Testing, using the conventional procedure, indicated that the abort process is feasible using the vehicle simulated. The results of these studies indicate that a common set of gains can be used to control a nominal launch and the abort cases studied. The use of a conventional autopilot required the implementation of modifications to abort guidance that prevented issuing large acceleration change commands to the autopilot. For the cases studied, the vehicle was not allowed to rotate faster than six degrees per second where rotation is about an axis selected to provide the smallest rotational movement

of the vehicle. This resulted from modifications to abort guidance required to produce stable conventional autopilot function. Engine gimbals angular deflection and gimbaling rates were noted during the aborts studied. Deflections of ± 10 degrees in pitch and ± 4 degrees in yaw would be adequate for the cases studied. The maximum requirements of engine gimbaling control authority occurs when large yaw changes are required during abort. In all abort cases studied the vehicle did not violate the abort constraints shown in Table I and placed the orbiter in a acceptable vicinity of the selected landing site. All of these abort cases were conducted without external winds, fuel slosh, and vehicle bending influencing the simulated vehicle. Specific study results can be found in reference 6.

6.0 RECOMMENDATIONS

The digital version of LASS contains a simulation of an obsolete version of the Shuttle concept. LASS should be updated and used to test engine gimbaling equations and both launch and abort guidance. If the SRMs are not jettisoned at abort, the abort guidance should be modified to a multistage configuration or some means of obtaining an average mass depletion rate should be provided. These items should be developed and tested prior to the implementation of the hybrid simulation.

The gain table used with the conventional autopilot was established using the B9U/161C configuration. A task to update LASS to the new vehicle configuration should include the determination of new gain tables. These were originally computed using the ideal autopilot to control a nominal launch.

In its present form LASS does not include the effects of external winds, fuel slosh, and vehicle bending as part of the simulated environment. These effects should be included to determine control problems with respect to vehicle stability for both automatic and manual control. Under these conditions several autopilot gain tables may be required to adequately control the orbiter during abort.

Presently, LASS contains features which allow throttling of the engines. New configurations involve using solid rocket motors which cannot be throttled. Basic methods of controlling axial accelerations involve changing burn rate (mass flow rate). Thus, throttling features may be either removed or modified.

This may also require addition of some form of thrust select logic to the propulsion model depending on when SRMs are jettisoned.

7.0

REFERENCES

1. Boeing Document D2-118387-1A and D2-118387-2A, "Users Guide for Guidance and Control Launch and Abort Simulation for Spacecraft (LASS)", June 30, 1972.
2. Boeing Report 5-2581-HOU-090, "Orbiter Aborts from Boost - Presimulation Report", June 30, 1972.
3. Boeing Report 5-2950-1-HOU-372, "Verification of LASS for Abort at 195 Seconds to the Launch Site", October 4, 1971.
4. Boeing Report 5-2581-HOU-007, "Study Results of a SSV Orbiter Abort at 74 Seconds Where the Orbiter Returns to the Launch Site", December 10, 1971.
5. Boeing Report 5-2581-HOU-022, "Study Results of a SSV Orbiter Abort at One Second Where The Orbiter Returns to the Launch Site", January 10, 1972.
6. Boeing Report 5-2581-HOU-068, "Boost and Abort G&C System Requirement", April 27, 1972.

TABLE I - ORBITER ABORT GUIDELINES*

POWERED PHASE

1. All rocket propellants except attitude control system propellants must be depleted prior to normal atmospheric flight.
2. Product of angle of attack (α) and dynamic pressure (\bar{q}) must be less than a maximum value $(\alpha\bar{q})_{\max}$. This maximum value was tentatively selected at 5000 deg-lb/ft².
3. Product of angle of sideslip (β) and dynamic pressure (\bar{q}) must be less than maximum value $(\beta\bar{q})_{\max}$. This maximum value was not selected.
4. The axial acceleration must not exceed 3 gees.
5. Orbiter main engine bell is to be extended when above 90,000 feet altitude.
6. The abort target is reached when:
 - a. time to go is less than 2 seconds
 - b. magnitude of altitude rate of change is less than 300 ft/sec
 - c. propellant remaining is less than 2,000 lbs.

UNPOWERED PHASE

1. Normal deceleration should not exceed 2.5 gees.
2. Maximum dynamic pressure (\bar{q}) should be less than 300 lb/ft².
3. After burnout the orbiter passes through the entry guidance take-over energy state at a range from the landing site so that the footprint associated with this energy state contains the landing site.

*NOTE: These guidelines were selected to gauge acceptability of the abort process and do not reflect that constraints have been established for the vehicle configuration studied.