NASA Technical Memorandum 104772

+Vbar Breakout During Approach to Space Station Freedom

Scott D. Dunham
Lyndon B. Johnson Space Center
Houston, Texas

National Aeronautics and Space Administration
Lyndon B. Johnson Space Center
Houston, Texas

June 1993

CONTENTS

TABLES

FIGURES

Introduction

The plume environment in which Space Station Freedom (SSF) will operate is very important for structural analysis because loads induced by the Orbiter jet firings on SSF can cause severe damage to the SSF structure. All jet firings that could be encountered during an approach to SSF need to be analyzed to test the dynamic structural integrity of the SSF, particularly the solar arrays (SAs). As a result, the jet firings from a +vbar breakout sequence need to be modeled to calculate the various forces and torques on the SSF structure. The current Orbiter breakout burn is damaging to the SAs so there exists the desire to decrease the breakout burn magnitude while maintaining necessary safety clearances. Also, in an attempt to decrease SA loading, breakout modes are divided into two classes during an approach to SSF. The transition point between these two classes has been determined as a function of the SA placement. For this analysis, the transition point is defined as 75 ft from Interface to Interface (ITI) between the Orbiter and SSF. For berthing approaches, ITI means the distance between the Remote Manipulator System (RMS) end effector and the SSF grapple fixture. For docking approaches, ITI is defined as the distance between the Orbiter docking plane and the SSF docking plane. If the ITI range is outside of or at the transition point, the first burn of the breakout sequence is a radial down (-X Rectilinear Shuttle Body Coordinate System (RSBY), or +Z Local Vertical/Local Horizontal Coordinate System (LVLH)) firing. Inside the transition point, the first burn of the breakout is a Norm-Z, or +Z RSBY, firing.

In addition to the "position along the approach" distinction of the breakout, this study addresses the two philosophies of breakout, which are Non-Time-Critical (NTC) breakout to return on a future day and Time-Critical (TC) breakout which requires the Orbiter to deorbit within 30 minutes of the emergency declaration. The bulk of this study deals with the NTC breakout and its firing histories while the TC breakout is not analyzed in detail since it is extremely unlikely to occur and since, most likely, it could not be protected for anyway, due to a large Orbital Maneuvering System firing essentially at the back of SSF. As a result, the TC breakout is only covered in a cursory manner. This study protects for immediate collision with SSF as well as long-term safe trajectory issues. Some criteria chosen for this study are from the "Acceptable Clearance Criteria for Payloads Ejected from the Orbiter Cargo Bay" memo by DA2/T. Holloway, dated October 9, 1990.[1] Although this memo deals with acceptable clearance for payloads ejected from the bay, the criteria are applied here because the breakout scenario includes structure approaching the Orbiter cabin. The acceptable "worst case" clearance is therefore chosen to be five feet, as stated in the memo. The worst case scenario covers many errors and is detailed later. An earlier study was performed to determine the initial firings for Preliminary Design Review for use in loads analysis.[4] This study will update to the Conceptual Design Review (CDR) data base and complete the breakout sequences. The purpose of this study, therefore, is to determine the bounding breakout firings required to place the Orbiter on a safe trajectory when performed between +vbar intercept and mating under worst case conditions. Once the firing histories are developed, they will be provided to the loads community to analyze the loading on the SSF SAs and associated structure for CDR.

Assumptions and Constraints

The following assumptions and constraints were used for this study.

1. SSF and the Orbiter can hold ±1 deg deadbands throughout the entire breakout.

   All analyses on approaches to SSF have been constrained by this rule. Failure to perform to this capability holds the potential of structural damage due to plume loading on SAs that are not in an optimal position.

2. A redundant laser sensor is available to the pilot.

   This eliminates the need to protect for range rate error inside of 100 ft that would need to be protected for if the closed-circuit television overlays were being used.

3. No plume-induced vehicle dynamics are modeled in the simulation.

4. Vernier attitude control is used in this study.

   The Vernier jets induce a -Z RSBY rate, or closing rate, during a +vbar approach. While this is not bad for the plume loads on the SAs, the attitude firings can cause a decrease in the opening rate and, therefore, the Vernier jets are worst case for clearance analysis.

5. The Orbiter maintains maximum area "into the wind" throughout breakout sequence and propagation.

   This increases drag and therefore is consistent with worst case for the long-term clearance analysis, since higher drag on the Orbiter will tend to bring it back towards SSF from behind.

6. Impulse input is at a rate of approximately one pulse per second.

   This allows for verification of the correct input and placement of a delay in the breakout maneuver.

7. The RMS can be moved out of the way quickly enough that the RMS is not a clearance issue during a breakout from a berthing approach.

   This reduces the envelope of clearance protection that needs to be maintained throughout the trajectory.

8. The SAs for gravity gradient structure attitudes (Stage Configuration 5 (SC5)) are aligned with the Y LVLH axis. For horizontal attitudes (Permanently Manned Capability (PMC)), the arrays are assumed to have certain constraints for the feathering positions. Alpha is to be between zero deg and -90 deg, and Beta has no restrictions and is placed in the worst case for clearance position for each run.

9. The altitude chosen for this study is 220 nautical miles (nmi). The study analyzes the tail-down +vbar approach currently baselined for MB3 through PMC. Digital Autopilot (DAP) A will be used throughout analysis.

10. The assumption is made that the Orbiter Reaction Control System (RCS) jet firings do not damage the SSF solar arrays when the Orbiter is outside of a 1000-ft radius sphere centered at SSF.

    This assumption is based on the structural loading community's belief that there should be no impact to firing RCS jets outside of a 1000-ft radius sphere centered at the SSF mating interface.

Operational Concerns and Goals

The following concerns and goals were used when defining this study.

1. Develop a generic breakout procedure for all flights to SSF.

2. Maintain flexibility for attitude control during the breakout procedure.

   Since the crew will want to maintain visual contact if possible, it is desirable not to place restrictions on the attitude of the Orbiter during the breakout. For the analysis, the Orbiter will be kept in a "tail to the Earth" attitude throughout the entire trajectory. Also, the attitude firings that are likely during a breakout will help with initial clearance and thus were not included to maintain worst case.

3. Refrain from imposing restrictions on the mode in which the translational firings are input.

   This requires that the pilot be able to perform the breakout burn in either Pulse (Discrete) mode or Accel (Norm) mode. Pulse mode allows for a more precise burn input but it requires longer to complete all of the necessary inputs. Accel mode inputs the burn quicker but is less accurate in obtaining a desired burn magnitude. Flight data and simulation data show that the pilots can hit their targets in Accel mode to within ± 0.2 fps. Therefore, this study will determine the minimum burn required with analysis done in Pulse mode and then incorporate the needed pad to account for burning in Accel mode.

4. In addition to the 5-ft safety margin for the initial clearance, the guideline was set to have at least a 2-nmi buffer (fig. 1) between the Orbiter and SSF when the Orbiter is behind SSF on its separation trajectory.

   This allows for time and distance for cleaning up the trajectory during real-time operations.

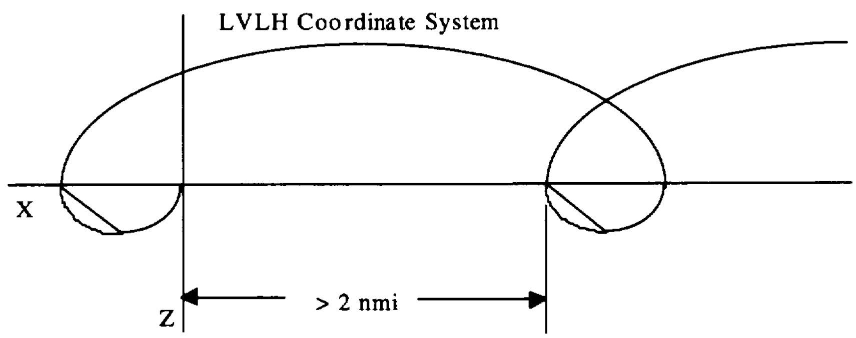
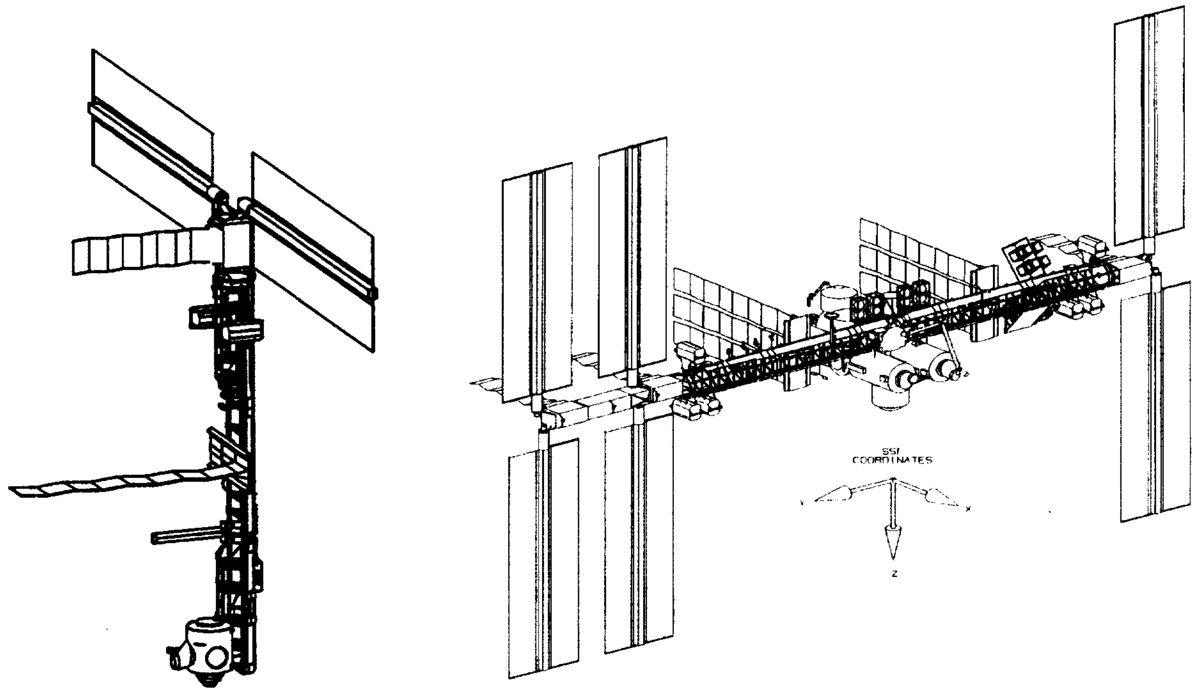


Figure 1. Example of Long-Term Safety Buffer.

Models

Two SSF structure configurations were chosen as the models for this study: SC5 (fig. 2) and PMC (fig. 3). SC5 was chosen because its structure extends farthest along the LVLH -Z axis, and therefore represents the worst case structural clearance for the Norm-Z velocity burns which result in the Orbiter going over the SSF structure. PMC was chosen because it has the full structure on orbit and has the SAs on the port side. SC5 is assumed to have the SAs aligned with the LVLH Y axis and therefore presents no Y constraints on the breakout if there is sufficient clearance in the X-Z LVLH plane. PMC is a different matter. The SA position can influence clearance greatly if the Orbiter has an initial state dispersed in the -Y direction. As a result of this influence, protection during the breakout is provided for Alpha angles between zero deg and -90 deg. Beta angles are constrained and are positioned for the worst case structural clearance condition. The geometric characteristics for these structures were provided by B. Benkowski with McDonnell Douglas Space Systems Company at Huntington Beach. The models have been updated through 7/23/91.



Figures 2-3. SC5 and PMC.

Both SC5 and PMC approaches are docking scenarios. The structural differences between SC4 and SC5 are very small with the exception of the berthing adapter and the docking mechanism, so the only concern with interchanging the two configurations is the clearance issue. When an ITI range is established, the cabin of the Orbiter is closer to the SSF structure on a docking run than it is on a berthing run, even though the ITI range is identical (fig. 4 and fig. 5). Also, the RMS can be moved, which allows even more clearance than in the docking case; therefore the docking to SC5 is a more extreme case than a berthing to SC4. The analysis will develop breakout maneuvers to provide a safe trajectory for a docking approach to SC5 and these maneuvers will, by default, protect for the extreme berthing case.

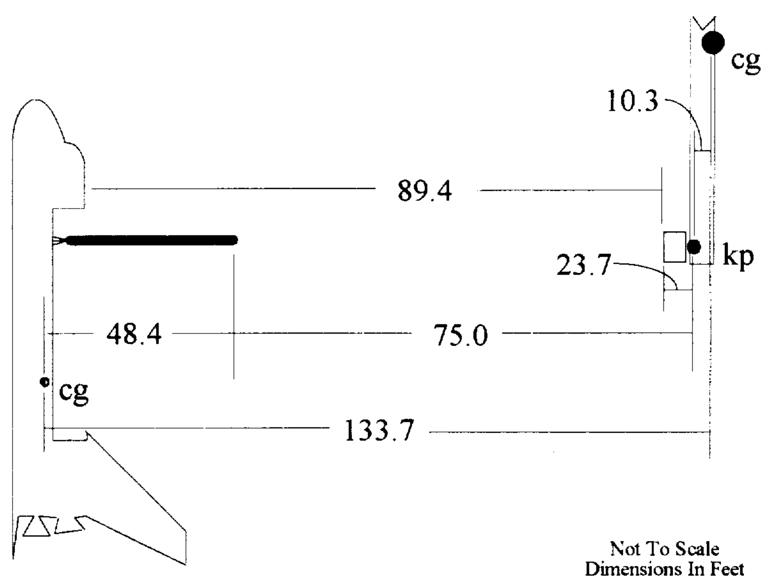


Figure 4. Berthing to SC4.

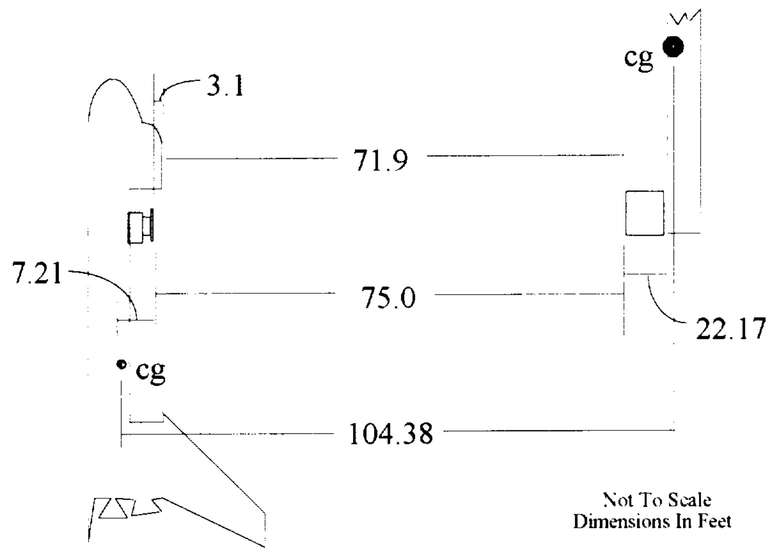


Figure 5. Docking to SC5.

The major points of concern on these models are the outmost structural pieces. the docking interface (DI): the target locations and the center of gravity (cg) locations. The mass properties for the SC5 structure are from the Integrated Operations Scenarios dated February 1992. and the mass properties for PMC are from Lockheed data dated 4/30/91.

TABLE I. SC5 AND PMC MASS PROPERTIES.

SC5 Structure	PMC Structure
Weight = 161724 lbs Inertias in slugs*ft*ft Ixx = 1.40E7 Ixy = -9.38E7 Iyy = 1.42E6 Iyz = 9.66E5 Izz = 1.34E7 Ixz = 2.37E5 Drag Area = 10451.2 FT^2 for Cd = 2.0	Weight = 470907 lbs Inertias in slugs*ft*ft Ixx = 6.92E7 Ixy = -2.38E6 Iyy = 9.12E6 Iyz = 1.45E6 Izz = 7.31E7 Ixz = 1.31E6 Drag Area = 20119.25 FT^2 for Cd = 2.0

The docking interface locations relative to the cgs of each configuration are determined from the geometric diagrams of the two structures.

TABLE II. SC5 AND PMC RELATIVE DOCKING INTERFACE LOCATIONS.

SC5 Structure LVLH (cg to DI)	**PMC Structure LVLH (cg to DI)**
X = 22.17 ft	X = 42.49 ft
Y = -12.33 ft	Y = -23.23 ft
Z = 59.18 ft	Z = 7.70 ft

The Orbiter modeled for this study has the following mass properties:

TABLE III. ORBITER MASS PROPERTIES.

Orbiter Modeled (Shuttle Structural Coordinate System)					
	Weight (lbs)			cg (inches)	
	247165.98			X = 1095.30 Y = 0000.03 Z = 0377.45	
Ixx =	887302 sl*ft*ft		Iyz =	971	sl*ft*ft
Iyy =	6386877 sl*ft*ft		Izx =	247376	sl*ft*ft
Izz =	6694367 sl*ft*ft		Ixy =	-5632	sl*ft*ft

The DAP settings for the Orbiter are set to the following values:

TABLE IV. ORBITER DAP CONFIGURATION.

DAPLOAD Settings		
ITEM	DAP A	DAP B
TRANS Pulse MAG	0.05 ft/s	0.01 ft/s
PRI ROT Pulse MAG	0.20 deg/s	1.00 deg/s
VER ROT Pulse MAG	0.02 deg/s	0.1 deg/s
PRI AUTO MNVR Rate	0.20 deg/s	1.0 deg/s
VER AUTO MNVR Rate	0.02 deg/s	0.1 deg/s
PRI ATT Deadband	1.00 deg	1.00 deg
VER ATT Deadband	1.00 deg	1.00 deg
PRI Rate Deadband	0.07 deg/s	0.07 deg/s
VER Rate Deadband	0.02 deg/s	0.02 deg/s

Breakout Regions

Because of the sensitive nature of the SAs on SSF, regions of different DAP modes have been established to reduce plume loading on the arrays. Regions I, II, and III (fig. 6) are defined by the Orbiter's jet capabilities during its approach to SSF. The type breakout is defined by the first burn in the sequence. In Region I, which is the area when the Orbiter DI is between 0 ft to 75 ft from the SSF DI, the Orbiter is in Norm-Z, or No Low-Z, mode. A Norm-Z firing, which fires jets directly at SSF, is the most desirable burn for a breakout because it accelerates the Orbiter directly away from SSF. Norm-Z mode is allowed in Region I for the approach and required for a breakout so it is the first burn in a Region I breakout. Therefore, a Region I breakout is identified as a Norm-Z breakout. The Norm-Z firings are too damaging to SSF to be used outside of 75 ft ITI, so the Orbiter is in Low-Z mode in Regions II and III. Because of the Orbiter's inability to fire the Norm-Z jets, an alternate breakout is required. The breakout for Regions II and III starts with a radial down (-X RSBY, +Z LVLH) burn. This results in the Region II and Region III breakouts being referred to as radial breakouts. Regions II and III have the same burn profiles but the magnitudes of the burns are different. The radial breakout area was split into two regions to eliminate the need to protect for the large +vbar intercept dispersions in Region II.

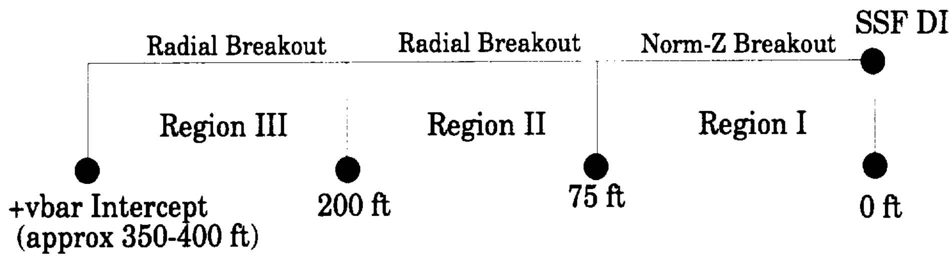


Figure 6. Breakout Regions Defined by Distance Between Orbiter DI and SSF DI.

Database

The initial conditions (ICs) for this study are taken from a set of approaches flown in the Systems Engineering Simulator.[3] The database consists of 97 docking-to-Assembly Complete, or PMC, runs and 58 berthing-to-SC4 runs. As stated above, the two configurations to be studied are PMC and SC5. The docking-to-PMC trajectories are used for the breakouts from PMC and the berthing-to-SC4 trajectories are used for the breakouts from SC5. The 58 berthing approaches to SC4 are used for docking approaches to SC5 because both SC4 and SC5 are in a gravity gradient attitude hold mode. Therefore, the approach procedures and trajectories are very similar between the two configurations. The only bias is for the difference in distance ITI between a docking approach and a berthing approach.

Specific points along the trajectory are cut out for use as ICs in the analysis. The points chosen for this study are 0 ft ITI, 75 ft ITI, 200 ft ITI and vbar arrival. Since vbar arrival is difficult to obtain from a large trajectory data set, a method was developed to estimate its location. When the Orbiter reaches the vbar, ± 1 deg, the pilot modes the Orbiter from inertial attitude hold to AUTO mode. The database is scanned for the next data entry after the Orbiter is moded to AUTO mode. Therefore, vbar arrival is defined as the entry just after the Orbiter is moded to AUTO, or Post-AUTO.

The parameters needed for ICs are the closing rate (fig. 7), the crosstrack relative position (fig. 8), and the crosstrack relative velocity (fig. 9). The crosstrack relative position and velocity are based on the alignment of the Orbiter relative to SSF. The origin of the system displayed in the figures is defined as the position of the Orbiter DI when the Orbiter Crew Optical Alignment Sight (COAS) is perfectly aligned with the SSF COAS target and has no relative rates. The ICs are generated by starting the Orbiter at this aligned position and then adding in dispersions in both position and rate.

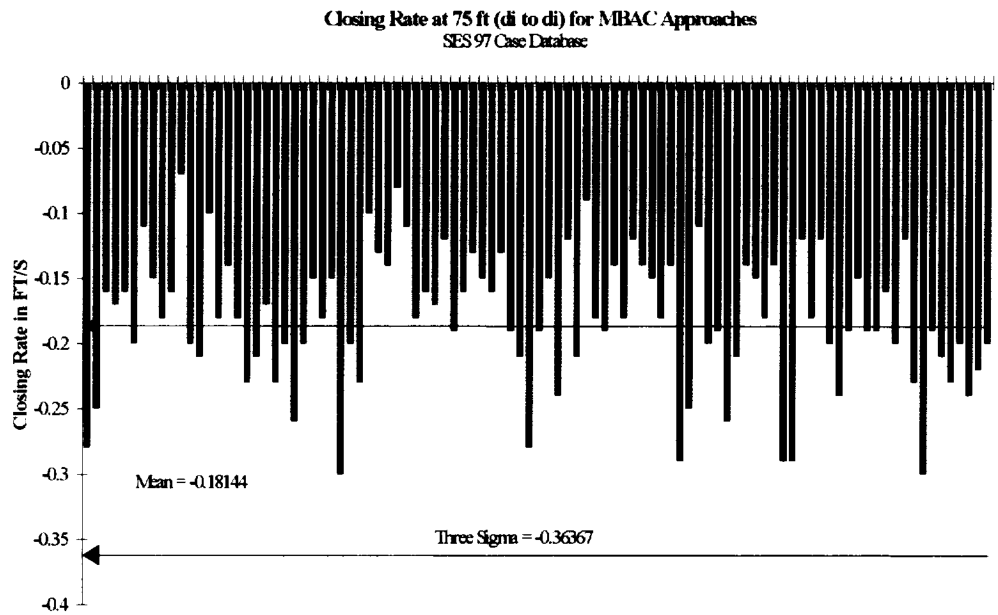


Figure 7. Data Example from Docking Approach to PMC.

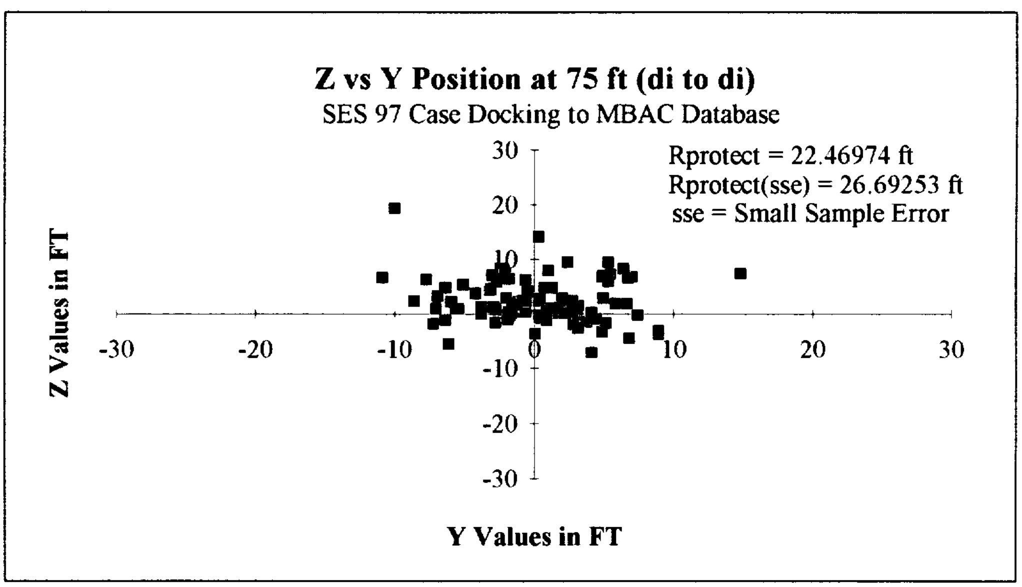


Figure 8. Example Data from Docking Approach to PMC.

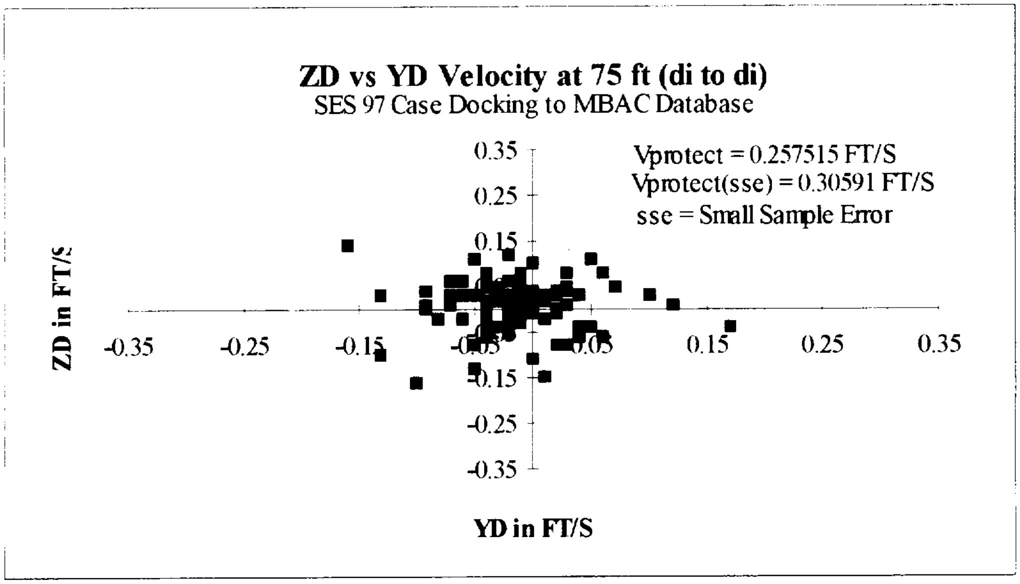


Figure 9. Example Data from Docking Approach to PMC.

Method for Analysis

The method for obtaining the results in this study follows the listed steps.

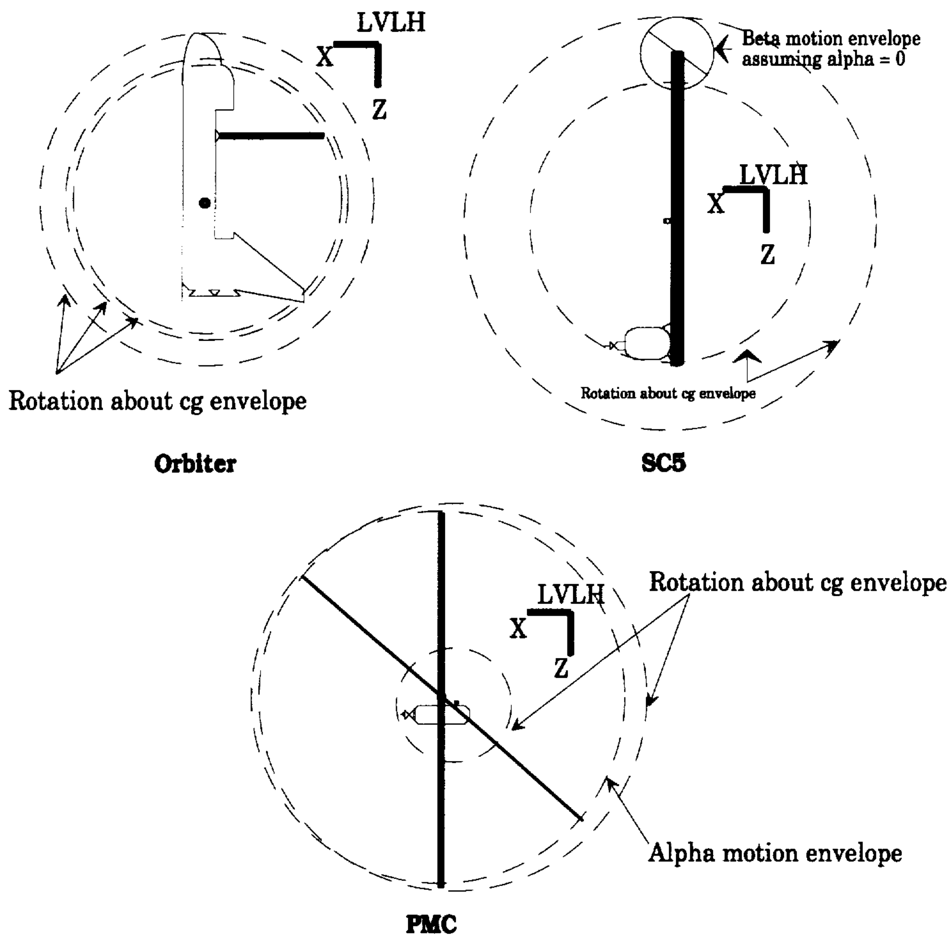
A. Breakout matrix development to cover all possible dispersion combinations for the boundaries of each region for each configuration.

B. Generate the necessary statistical worst case ICs for each of the cases in the study. This requires the relative Y and Z positions (X is set due to the specific ITI distance constraint for the boundaries of each region) and the Y and Z relative velocities (the X relative velocity is the 3 sigma number determined from the database).

C. These initial states are input into the Desktop Automated Real-Time Simulator (DARTS) processor, and the man-in-the-loop simulation is run using the operational margin guidelines (to be defined later) and the candidate burn profiles set up for this study. The burns are done in Pulse mode to get clearly defined velocity inputs. The process involves inputting the necessary jet firings and then allowing the processor to propagate the Orbiter through time. The propagation was continued for three hours and forty five minutes to try to obtain about two and a half revolutions of orbit travel. This time is needed to obtain the desired results such as long-term clearance and separation phasing.

D. Relative motion plots are produced for both the X-Z and Y-Z planes for the breakout simulation for each run.

E. Clearance analysis involves using a set of overlays depicting the Orbiter, SC5, and PMC structures (figs. 10-12). These overlays are created to the scale of the trajectory plots created by DARTS. These overlays also contain the deadbanding or motion range circles to protect for attitude or position errors. Even though entire circles for complete rotation about the cg are shown, only realistic angular rotations were used for clearance analysis.



Figures 10-12. Overlay Figures (not to scale).

F. These overlays are then placed along the trajectory plot to determine the clearance available at specific points along the plot. This is where the determination is made whether or not the 5-ft margin of safety is preserved. If the final value is positive, then the firing input was sufficient to obtain the necessary clearance under worst case conditions. This process is continued until a value of velocity input is found that satisfies all the cases.

G. The analysis detailed above defines the minimum burn input needed to achieve a safe trajectory. The minimum burn is developed from simulation using Pulse mode so that the input burn is very accurate. If the minimum burn were performed in Accel mode, the burn would not be as accurate and the potential exists for not achieving the needed input. Accel burns have been performed to be within ± 0.2 fps of the target burn in flight and simulation. To protect for the Accel burn, the minimum burns derived in Pulse mode, which are the Pulse mode target burns, must be increased to cover the possible error in an Accel burn. To protect for possible "undershoot," the Pulse target is raised by the amount of error seen, or 0.2 fps, to become the new Accel target burn. However, since this document is intended to be used by the loads community for design cases, the maximum burn needs to be modeled. Since the Accel target burn could be missed on the high side, a situation termed "overshoot," the burns used by the loads community need to be the Accel target plus the possible overshoot error, or 0.2 fps. As a result, the minimum Pulse burn, defined the Pulse target burn, will be increased by 0.4 fps for use by the loads community to protect for either Accel or Pulse modes during a breakout.

Worst Case Definition

With the distance between mating interfaces set to various specific distances ITI, worst case conditions can be determined. The error, or margins, that are protected are broken into two categories: Initial State Error and Operational Margins.

Initial State Error

Statistical error has to be modeled into the initial Y-Z plane position and velocity data to provide protection in both the relative position and velocity conditions. These errors are computed and incorporated into the initial data put into the DARTS processor.

A. Due to the small sample size (97 and 58 samples), an error factor has to be included in the dispersions for the initial state. This percentage of error is determined by both the sample size and the confidence level desired for the value (fig. 13). This method is taken from Elementary Statistics by Mario F. Triola. For the 97-case data set the error incurred will be 18.79% for a 99% level of confidence while the 58-case data set has an error value of 24.35% for a 99% confidence level.

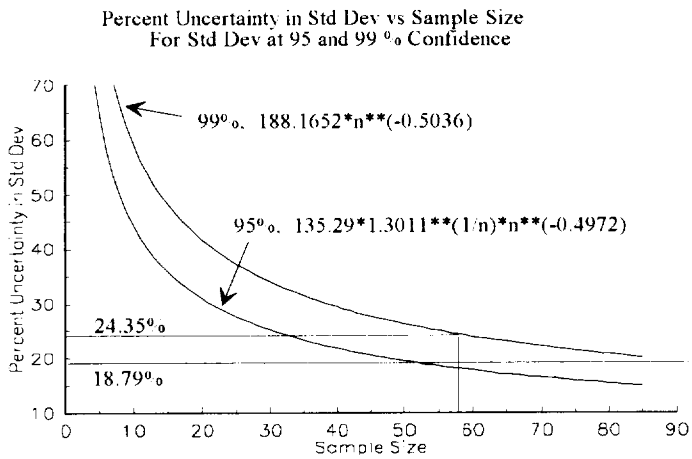


Figure 13. % Error vs. Sample Size.

B. The ideal situation during an approach is for the Orbiter's COAS reticle centerline to be perfectly aligned with the COAS target on SSF and to have zero relative crosstrack rates. However, due to piloting constraints, Orbiter performance, and control limitations, the Orbiter does not stay on the centerline. As a result of these real world limitations, the approach trajectories vary around the alignment point as the crosstrack relative velocities are altered due to DAP firing cross-coupling, crew thruster inputs, and orbital mechanics. To generate initial conditions for this study, the variability of the approach has to be considered and protected for since a generic breakout is desired. The method shown below (fig. 14) defines one way to encompass the position error about the centerline by calculating a circle about the centerline, the perfectly aligned trajectory, which statistically bounds all of the variations in position derived from the database. This method is conservative but it allows one to select positions anywhere along the circle and still have at least 99.7% probability of protection for position errors.

$$Y_{rms} = \sqrt{\sigma_y^2 + \mu_y^2} \qquad Z_{rms} = \sqrt{\sigma_z^2 + \mu_z^2} \qquad R_{rms} = \sqrt{Y_{rms}^2 + Z_{rms}^2}$$

$$Rdisp = 3.44 * R_{rms} * \Gamma$$

σ = standard deviation — μ = mean

Γ = % increase due to small sample size — σ^2 = variance

Figure 14. Equations for Initial Condition Development Method.

This same method was applied to the crosstrack relative velocities to obtain a circle of protection, which has a radius of Vdisp, about a null rate point. Once again, this method is conservative but it allows the easy selection of initial conditions for analysis.

Operational Margins

These protections are implemented during the DARTS runs to deal with computer problems or human error.

A. A 10-second waiting period for decision time is input at the first of the outer breakouts; i.e., at 75 ft ITI. This wait time was chosen in a discussion with the Guidance and Procedures Officers.

B. To verify that the correct number of pulses are being recognized by the DARTS processor, the pulses are input at approximately 1 pulse per second, which is much slower than will probably occur real time.

C. The breakout is performed with a series of Pulse (Discrete) pulse inputs, not in Accel (Norm) mode, due to the sensitive nature of the velocities needed and to make the input longer; this delays the correction. Protection for Accel burns is added afterwards as described in the Method for Analysis section.

Definitions for Analysis

The Rdisp and Vdisp values for dispersion computed earlier can be combined in various ways depending upon which case is being protected for. A matrix of approximately 50 runs captured the various combinations of ICs for both configurations at all three regions' boundaries. The distance along the vbar is set for each case depending upon which boundary of which region is being analyzed. The X closing rate is also set according to which boundary of which region is to be studied. The cross-track positions and velocities are varied, depending upon which area clearance is being checked for.

$$Rdisp = Ydisp = Zdisp$$

$$Vdisp = YDdisp = ZDdisp$$

The dispersed initial conditions are created by setting the Orbiter so that it is the proper X distance ITI and the center of the Orbiter COAS is centered on the SSF COAS target. The crosstrack position is then moved a distance in either the ± Z direction, the ± Y direction, or a combination of both. The relative velocities are varied in the same manner.

For this analysis. several areas along the protection circle are investigated. These areas divide into two classes. The extreme regions represent the areas on the protection circle in which the dispersion is either all ± Z or all ± Y. The second region is the combination area. This area is halfway along the circumference of the RMS circle between two extremes. The combination area allows the possibility of dispersion in two directions at once.

Extreme Cases

Y Align:
Y aligned means that the Y relative position is set so that the Orbiter COAS is at the same Y LVLH coordinate as the SSF COAS target.

Z Align:
Z aligned means that the Z relative position is set so that the Orbiter COAS is at the same Z LVLH coordinate as the SSF COAS target.

Z up:
Indicates the Orbiter moved up a distance Rdisp in Z (or in the direction of the -Z axis) from the (0.0) point.

Z dn:
Indicates the Orbiter moved down a distance Rdisp in Z (or in the direction of the +Z axis) from the (0.0) point.

Y rt:
Indicates the Orbiter moved a distance Rdisp in the direction of the -Y axis from the (0.0) point.

Y lft:
Indicates the Orbiter moved a distance Rdisp in the direction of the +Y axis from the (0.0) point.

Combination Cases

YP:
Indicates the Y value needed to be on the position protection circle halfway between the Z extreme case and the Y extreme case.

ZP:
Indicates the Z value needed to be on the position protection circle halfway between the Z extreme case and the Y extreme case.

YDP:
Indicates the YD value needed to be on the velocity protection circle halfway between the ZD extreme case and the YD extreme case.

ZDP:
Indicates the ZD value needed to be on the velocity protection circle halfway between the ZD extreme case and the YD extreme case.

*** Same Direction Convention As Above ***

Both Regions

(0,0) Point:
Defined as the relative DI position of the Orbiter in the Y-Z LVLH plane where the SSF COAS target is centered in the Orbiter COAS.

*** Same Direction Convention Used For Relative Velocities ***

TABLE V. INITIAL CONDITIONS FOR SC5 AND PMC AT 0 FT ITI.

SSFcg to SScg SC5 Structure		
At 0 ft DI to DI		
X =	29.38	ft
XD =	-0.1618	ft/s
Yalign =	-12.33	ft
Zalign =	93.79	ft
Rdisp =	6.7924	ft
Vdisp =	0.1254	ft/s
YP =	4.8029	ft
YDP =	0.0887	ft/s
ZP =	4.8029	ft
ZDP =	0.0887	ft/s

SSFcg to SScg PMC Structure		
At 0 ft DI to DI		
X =	48.54	ft
XD =	-0.1015	ft/s
Yalign =	-23.23	ft
Zalign =	44.99	ft
Rdisp =	0.9360	ft
Vdisp =	0.0642	ft/s
YP =	0.6619	ft
YDP =	0.0454	ft/s
ZP =	0.6619	ft
ZDP =	0.0454	ft/s

TABLE VI. INITIAL CONDITIONS FOR SC5 AND PMC AT 75 FT ITI.

SSFcg to SScg SC5 Structure		
At 75 ft DI to DI		
X =	104.38	ft
XD =	-0.3894	ft/s
Yalign =	-12.33	ft
Zalign =	93.79	ft
Rdisp =	46.4957	ft
Vdisp =	0.3902	ft/s
YP =	32.8774	ft
YDP =	0.2759	ft/s
ZP =	32.8774	ft
ZDP =	0.2759	ft/s

SSFcg to SScg PMC Structure		
At 75 ft DI to DI		
X =	123.54	ft
XD =	-0.3637	ft/s
Yalign =	-23.23	ft
Zalign =	44.99	ft
Rdisp =	26.6925	ft
Vdisp =	0.3059	ft/s
YP =	18.8744	ft
YDP =	0.2163	ft/s
ZP =	18.8744	ft
ZDP =	0.2163	ft/s

TABLE VII. INITIAL CONDITIONS FOR SC5 AND PMC AT 200 FT ITI.

SSFcg to SScg SC5 Structure		
At 200 ft DI to DI		
X =	229.38	ft
XD =	-0.6063	ft/s
Yalign =	-12.33	ft
Zalign =	93.79	ft
Rdisp =	87.8870	ft
Vdisp =	0.7548	ft/s
YP =	62.1450	ft
YDP =	0.5338	ft/s
ZP =	62.1450	ft
ZDP =	0.5338	ft/s

SSFcg to SScg PMC Structure		
At 200 ft DI to DI		
X =	248.54	ft
XD =	-0.5752	ft/s
Yalign =	-23.23	ft
Zalign =	44.99	ft
Rdisp =	67.6491	ft
Vdisp =	0.6479	ft/s
YP =	47.8350	ft
YDP =	0.4581	ft/s
ZP =	47.8350	ft
ZDP =	0.4581	ft/s

TABLE VIII. INITIAL CONDITIONS FOR SC5 AND PMC AT POST-AUTO.

SSFcg to SScg SC5 Structure		
At Post-AUTO		
X =	366.08	ft
XD =	-1.0500	ft/s
Yalign =	-12.33	ft
Zalign =	93.79	ft
Rdisp =	170.14	ft
Vdisp =	1.3077	ft/s
YP =	120.3070	ft
YDP =	0.9247	ft/s
ZP =	120.3070	ft
ZDP =	0.9247	ft/s

SSFcg to SScg PMC Structure		
At Post-AUTO		
X =	386.49	ft
XD =	-1.1688	ft/s
Yalign =	-23.23	ft
Zalign =	44.99	ft
Rdisp =	103.66	ft
Vdisp =	1.4144	ft/s
YP =	73.2997	ft
YDP =	1.0001	ft/s
ZP =	73.2997	ft
ZDP =	1.0001	ft/s

Results

The general plan for this study is to initially iterate on the first burn in the sequence to achieve two main goals. The first goal is to provide adequate initial clearance between the Orbiter and SSF. The second goal is either to have the first burn place the Orbiter on a long-term safe trajectory or to place the Orbiter in a position so that subsequent burns can be performed without inducing plume loads on the SSF SAs. As stated earlier, RCS burns outside of 1000 ft are assumed to be acceptable, so the initial burn should either place the Orbiter on a long-term safe trajectory or position the Orbiter outside of 1000 ft so that additional burns can be performed.

Region I

The Norm-Z burn in the Region I breakout was hoped to be enough to place the Orbiter on a safe long-term trajectory. A single burn magnitude has been identified to provide acceptable initial clearance between the Orbiter and the SSF structure for all of the various initial conditions that were analyzed. The magnitude of this burn is 0.7 fps (+X LVLH) in Pulse mode. The clearance met the criteria placed upon it by this analysis for each of the ICs generated for the distances of 0 ft ITI and 75 ft ITI, the boundaries of Region I. The closest approach, which is produced by one of many initial conditions, is shown below (fig. 15) for three candidate burn magnitudes.

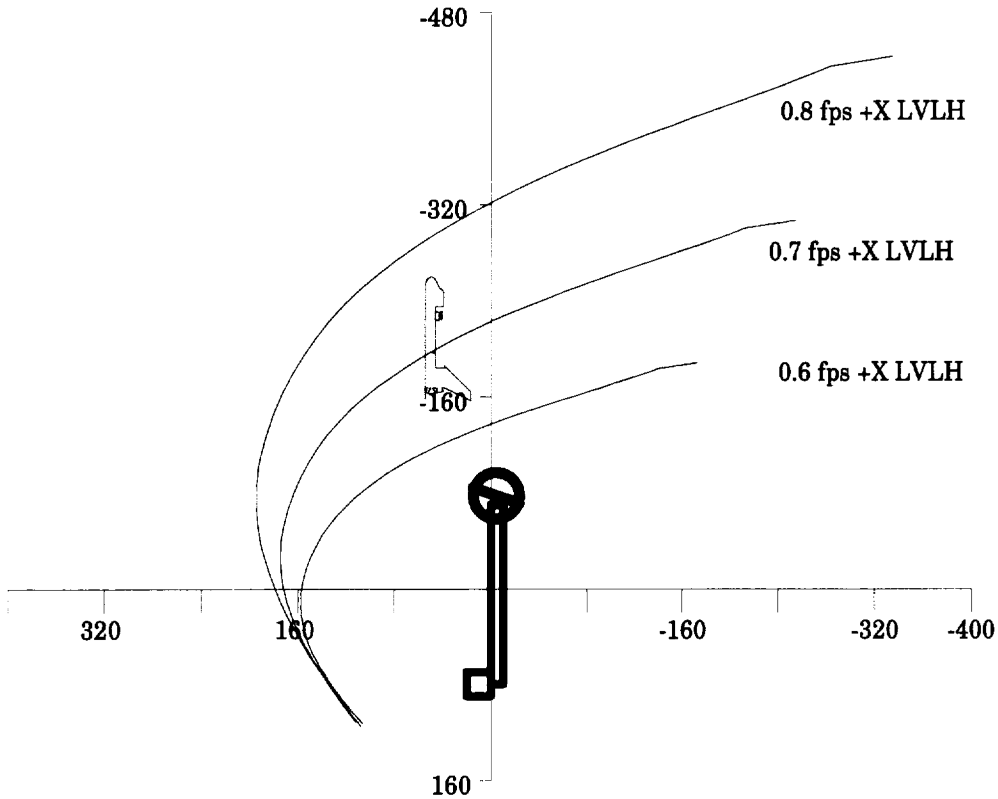


Figure 15. Initial Burn Results for Region I Breakout.

The next part of the study determines whether the 0.7-fps (+X LVLH) burn would place the Orbiter on a long-term safe trajectory that meets the constraints imposed earlier in this document. Figure 16 below shows that 0.8 fps (+X LVLH) does not meet the criteria and 0.7 fps (+X LVLH) is entirely unacceptable.

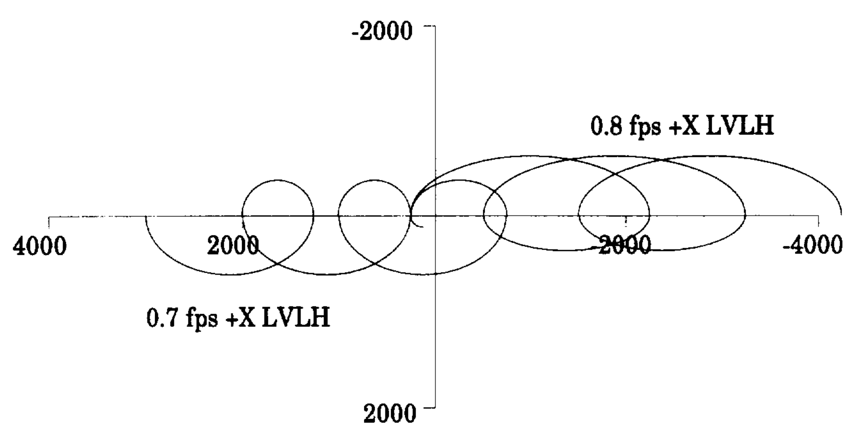


Figure 16. Two Unsuccessful Single Burn Breakouts from Region I.

To obtain the necessary long-term clearance, two possible solutions are present. The first solution is to increase the magnitude of the initial burn in Region I so the single burn will place the Orbiter into a safe trajectory. The second alternative is to add two burns to the sequence. The first additional burn will move the Orbiter outside of the 1000-ft radius envelope without pluming the SAs; the second additional burn will place the Orbiter on a safe trajectory. Due to the critical nature of the loading of the SAs, the second method is chosen. Another concern that was dealt with is the ICs' effect on the trajectory. Since a second burn is needed to obtain long-term clearance, the temptation exists to plan a second (+X LVLH) burn when the Orbiter is just above SSF (fig. 15). The problem with this is that the trajectories shown (fig. 15) are for one initial condition, and a different initial condition could place the Orbiter directly in front of the station if the second burn is set to occur on a timed response. This makes the breakout an initial condition dependent sequence which is not the desired generic breakout. Once again, this leads to the second method listed above where a radial burn (-Z LVLH) eliminates the dependence on the initial condition and allows the breakout to become a generic timed event.

To implement the second method, additional constraints have to be considered. The initial burn will now at least stop the Orbiter from closing and impart some opening rate. Also, initial clearance must be obtained if for some reason the second burn is not executed or not performed correctly. This leads back to the solution obtained earlier that the best initial burn is 0.7 fps (+X LVLH). Since radial down (+Z LVLH) burns and out-of-plane (OOP) (±Y LVLH) burns are damaging to the SAs on most flights inside of 75 ft ITI, a radial up (-Z LVLH) burn is selected for the second burn in the sequence. This burn will raise the Orbiter at least 1000 ft above SSF; the Orbiter can then perform another (+X LVLH) burn to safely phase away behind SSF. The radial up-firing results in the Orbiter's jets firing down where there is no SSF structure. This burn is the least harmful of all the possible firings; therefore its magnitude should be of no consequence to the loading on the SAs.

The final burn should also cause no harm to the SSF SAs owing to its distance from SSF and the fact that the jets are generally firing away from SSF at ignition. The only final concern with this new method is the possible clearance concerns with the Orbiter's tail when the Orbiter is very close to SSF. When the Orbiter is near to dock, the tail of the Orbiter is underneath the SSF structure; therefore the Orbiter must open a distance before the second burn, radial up (-Z LVLH), is performed. Since the initial burn is set to 0.7 fps (+X LVLH), the time to wait between burn one and two needed to be determined. Several times were tried and the time of two minutes was chosen. The third burn should be performed at approximately the -rbar crossing, so a wait time of 15 minutes was chosen between burns two and three. Runs were performed to define the second and third burns. The second burn is 1.8 fps (-Z LVLH) and is performed two minutes after the completion of the 0.7 fps (+X LVLH) initial burn. Figure 17 below shows the difference between the closest single burn 0.7-fps breakout and various breakouts using the new three-burn sequence.

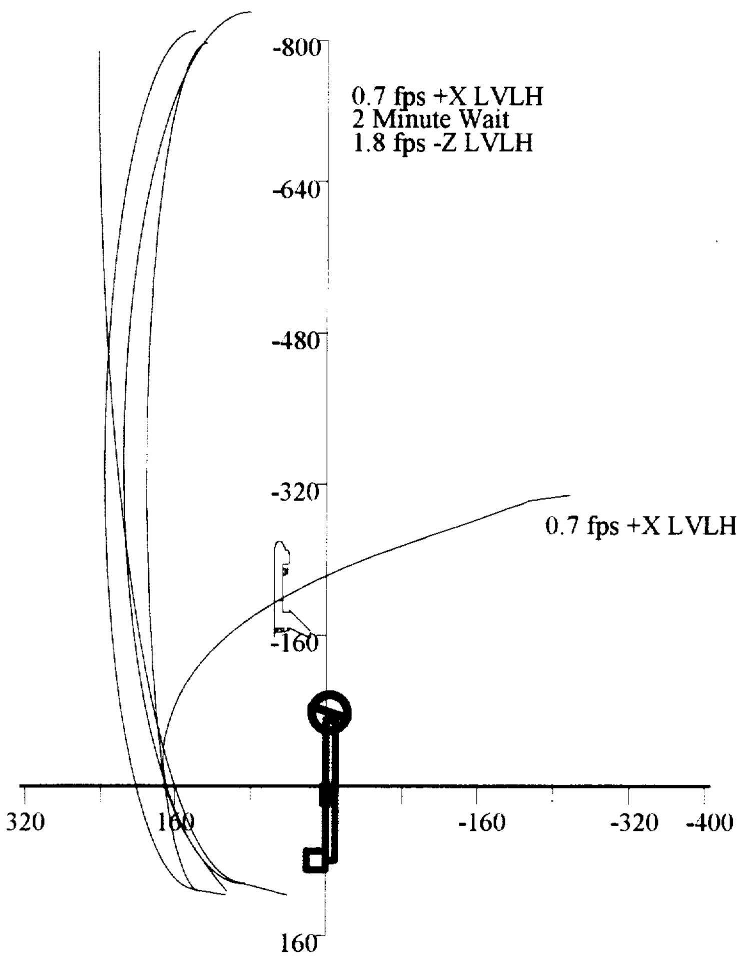


Figure 17. Region I Breakout Initial Clearance with Complete Breakout Sequence.

The burn magnitude of burn three was chosen to be 1.8 fps (+X LVLH). Figure 18 below demonstrates the closest approach breakouts using the three-burn breakout. The closest return for a Region I breakout from SC5 is a -vbar intercept at about 36 000 ft while the closest -vbar intercept for breakouts from PMC is about 39 000 ft. These two scenarios phase away from SSF at rates of 34 000 ft/rev and 40 000 ft/rev for breakouts from SC5 and PMC, respectively.

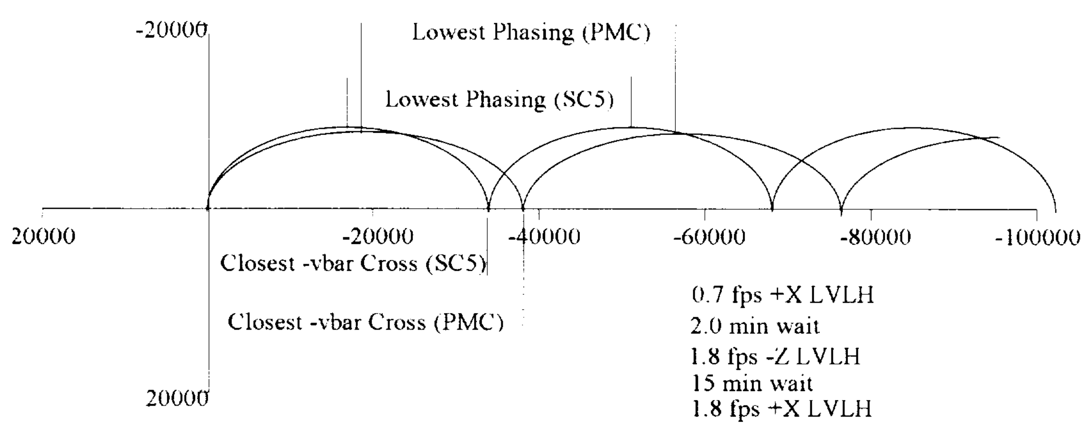


Figure 18. Minimum Successful Breakouts from Region I for Each Configuration.

The defined sequence of 0.7 fps (+X LVLH), 2-minute wait, 1.8 fps (-Z LVLH), 15-minute wait, and then 1.8 fps (+X LVLH) was then tested for all combinations of ICs at both boundaries of Region I. The results of these runs are summarized in Tables IX and X.

TABLE IX. REGION I (0-75 FT DI TO TO) SC5 BREAKOUT MATRIX.

Stage	Range (DI-DI) (ft)	Burns (ft/s)	IC	Closest Approach (ft)	-rbar crossing (ft)	Range at Burn 3 (ft)	Phasing (ft/rev) (nmi/rev)	-vbar crossing (ft,n mi)	Prop Used (lbs)
SC5	0	0.7, 1.8, 1.8	Z up ZD up	40	800	1580	41000 6.70	40000 6.58	143
SC5	0	0.7, 1.8, 1.8	Z dn ZD dn	37	800	1250	40625 6.686	41875 6.89	143
SC5	75	0.7, 1.8, 1.8	Z dn ZD dn	65	760	1250	34375 5.65	35938 5.91	142
SC5	75	0.7, 1.8, 1.8	Z up ZD up	55	800	1250	38125 6.27	39375 6.48	143
SC5	75	0.7, 1.8, 1.8	Z dn ZD up	65	700	1090	34375 5.65	35938 5.91	143
SC5	75	0.7, 1.8, 1.8	Z up ZD dn	51	800	1300	37812 6.22	39062 6.42	143

TABLE X. REGION I (0-75 FT DI TO DI) PMC BREAKOUT MATRIX.

Stage	Range (DI-DI) (ft)	Burns (ft/s)	IC	Closest Approach (ft)	-rbar crossing (ft)	Range at Burn 3 (ft)	Phasing (ft/rev) (nmi/rev)	-vbar crossing (ft,n mi)	Prop Used (lbs)
PMC	75	0.7, 1.8, 1.8	Z up ZD up	35	875	1300	39063 6.43	40938 6.74	143
PMC	75	0.7, 1.8, 1.8	Z dn ZD dn	60	875	1000	36875 6.07	38750 6.38	143
PMC	75	0.7, 1.8, 1.8	Z dn ZD up	58	830	1250	36875 6.07	38438 6.33	143
PMC	75	0.7, 1.8, 1.8	Z up ZD dn	58	900	1100	38750 6.38	40000 6.58	143
PMC	75	0.7, 1.8, 1.8	Y lft YD lft	50	830	1200	38125 6.27	40000 6.58	143
PMC	75	0.7, 1.8, 1.8	ZP dn ZDP dn YP rt YDP rt	60	875	1100	37500 6.17	38750 6.38	143
PMC	75	0.7, 1.8, 1.8	ZP up ZDP up YP rt YDP rt	33	850	1300	38750 6.38	40313 6.63	143

The results show that this candidate burn sequence satisfies all constraints and criteria for the NTC breakout from Region I. The Pulse mode NTC Region I breakout is 0.7 fps (+X LVLH), 2-minute wait, 1.8 fps (-Z LVLH), 15-minute wait, and then 1.8 fps (+X LVLH). Now the protection for Accel mode must be added on. The above-defined burn magnitude must be met in order for the breakout to work, so your Accel mode targets must be increased to at least the minimum acceptable burn plus the error of undershoot, 0.2 fps. The new targets for Accel mode become 0.9 fps (+X LVLH), 2-minute wait, 2.0 fps (-Z LVLH), 15-minute wait, and then 2.0 fps (+X LVLH). Since this is the new target, there still exists the possibility of overshoot in Accel mode, another 0.2 fps, so the loads team performing analysis on the SSF SAs should design to the maximum possible breakout that might occur. Therefore, the structural design breakout for Region I is 1.1 fps (+X LVLH), 2-minute wait, 2.2 fps (-Z LVLH), 15-minute wait, and then 2.2 fps (+X LVLH).

Region II

As defined earlier, the first burn of the Region II breakout will be a radial down (+Z LVLH) firing. Due to orbital mechanics, if a second burn is not performed then the Orbiter would come right back at SSF after one revolution. This requires that a second burn be performed for a Region II breakout. The constraints on the first burn will be to obtain adequate initial clearance between the Orbiter and SSF, and to position the Orbiter to a point where the second burn can be performed without damaging the SAs on SSF. The second burn needs to be a posigrade, or (+X LVLH), burn to raise the Orbiter above SSF and phase away behind it. In this study, the second maneuver was performed one quarter revolution, or about 22.5 minutes, after the first burn. This second burn is outside of the 1000-ft radius envelope so the plume impact should be minimized. An earlier study determined the initial burn magnitude to be 1.5 fps (+Z LVLH).[4] This value was tested again and proved to be the minimum value to satisfy the clearance criteria. Figure 19 below shows the closest trajectory when performing a 1.5-fps (+Z LVLH) breakout in Region II.

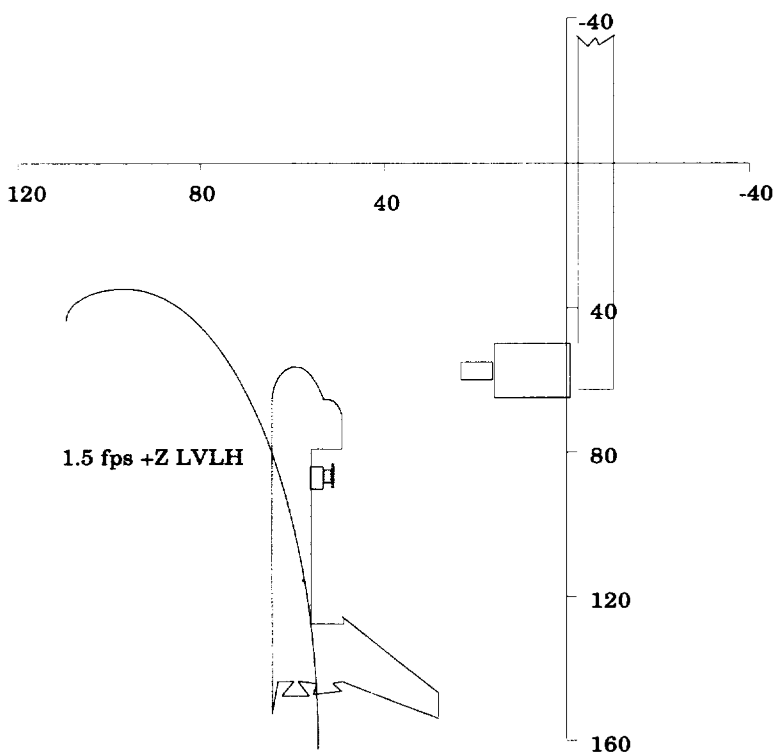


Figure 19. Minimum Successful Initial Clearance for Region II Breakout.

With the first burn set to 1.5 fps (+Z LVLH), the Orbiter will travel below the +vbar for the assigned time of 22.5 minutes. The second burn will be performed to place the Orbiter in a safe trajectory to phase behind SSF. An iteration was performed on the magnitude of the second burn to try to obtain the minimum burn to satisfy the long-term clearance criteria established earlier. Magnitudes of 2.0 fps and 2.8 fps were attempted unsuccessfully (fig. 20).

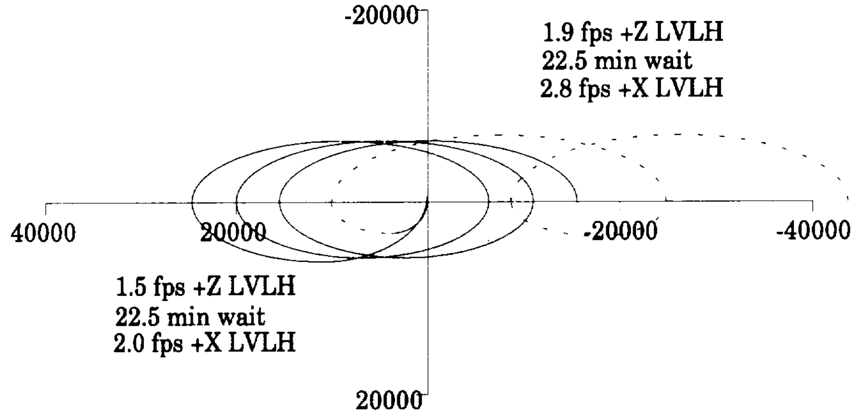


Figure 20. Examples of Unsuccessful Region II Breakouts.

The magnitude of the burn was increased until the conditions of the analysis were met with a magnitude of 3.8 fps. Figure 21 below presents the worst case closest approach trajectories. The closest -vbar intercept occurs on a breakout from SC5 at about 14 000 ft behind the SSF. The phasing from this breakout is from about 18 000 ft/rev to about 40 000 ft/rev.

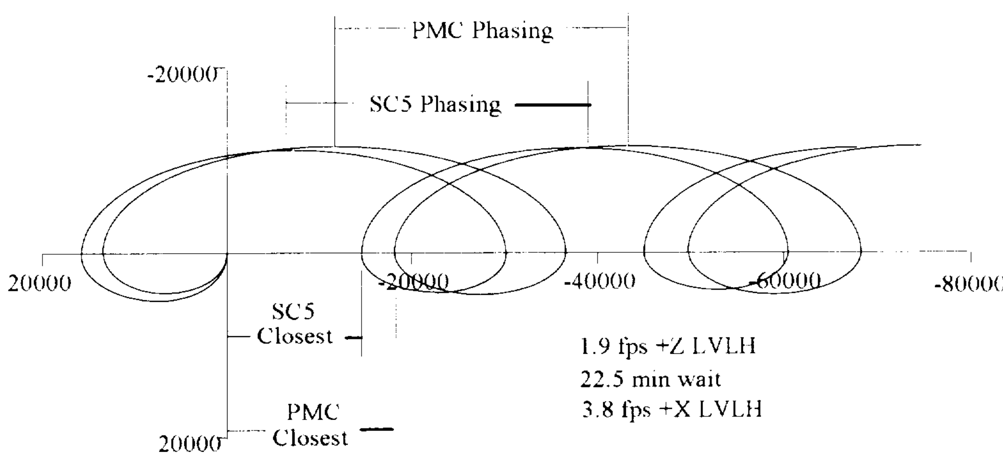


Figure 21. Minimum Successful Breakouts from Region II for Each Configuration.

Tables XI and XII present the summary of the cases performed on DARTS for the Region II breakout. Closest approach, phasing and -vbar intercept data are presented for each case. Some were unsuccessful for burns below the final breakout design of 1.5 fps (+Z LVLH), 22.5-minute wait, and then a 3.8 fps (+X LVLH) burn. The column titled "2nd Burn Range" presents the position of the Orbiter relative to SSF when the second burn is performed. The "b" stands for "below" and the "f" stands for "in front of." This also shows that the second burn is well outside the 1000-ft envelope when it is performed.

TABLE XI. REGION II (75-200 FT DI TO DI) SC5 BREAKOUT MATRIX.

Stage	Range (DI-DI) (ft)	Burns (ft/s)	IC	Closest Approach (ft)	-rbar crossing (ft)	2nd Burn Range (ft)	Phasing (ft/rev) (nmi/rev)	-vbar crossing (ft, nmi)	Prop Used (lbs)
SC5	75	1.5, 2.8	Z dn ZD dn	70	8000	3000 b 6000 f	23000 3.78	11000 1.8	129
SC5	75	1.5, 2.8	Z dn ZD up	68	6500	2800 b 4800 f	22500 3.7	13000 2.13	129
SC5	75	1.9, 2.8	Z dn ZD dn	68	9000	3500 b 7000 f	23000 3.78	9000 1.48	145
SC5	75	1.9, 3.8	Z dn ZD dn	70	9750	3500 b 7000 f	35000 5.76	22000 3.62	172
SC5	75	1.5, 3.8	Z dn ZD dn	70	9500	3200 b 6000 f	36000 5.92	23000 3.785	156
SC5	75	1.5, 3.8	Z dn ZD up	70	8000	2500 b 4500 f	36000 5.92	26500 4.36	155
SC5	75	1.5, 3.8	Z up ZD up	30	8000	2000 b 4000 f	39000 6.42	32000 5.27	155
SC5	75	1.5, 3.8	Z up ZD dn	54	9000	2700 b 5000 f	39000 6.42	29000 4.77	156
SC5	200	1.9, 2.8	Z dn ZD dn	180	8000	5000 b 7000 f	18000 2.96	300 .049	145
SC5	200	1.9, 3.8	Z dn ZD dn	180	10500	4500 b 8400 f	30000 4.94	14000 2.30	172
SC5	200	1.9, 3.8	Z dn ZD dn XD=0	180	10000	3200 b 7000 f	41000 6.75	28000 4.61	172
SC5	200	1.5, 3.8	Z dn ZD dn	180	10000	4000 b 8000 f	32000 5.27	15000 2.47	156
SC5	200	1.5, 3.8	Z dn ZD up	180	8000	3000 b 4200 f	31000 5.10	19000 3.13	155
SC5	200	1.5, 3.8	Z up ZD up	100	7500	2000 b 3500 f	37000 6.09	30000 4.84	155
SC5	200	1.5, 3.8	Z up ZD dn	160	10000	3500 b 6000 f	36000 5.92	24000 3.95	156

TABLE XII. REGION II (75-200 FT DI TO DI) PMC BREAKOUT MATRIX.

Stage	**Range (DI-DI) (ft)**	**Burns (ft/s)**	**IC**	**Closest Approach (ft)**	**-rbar crossing (ft)**	**2nd Burn Range (ft)**	**Phasing (ft/rev) (nmi/rev)**	**-vbar crossing (ft, nmi)**	**Prop Used (lbs)**
PMC	200	1.9, 3.8	Z dn ZD dn	180	10000	3500 b 7000 f	34000 5.59	19000 3.13	156
PMC	200	1.5, 3.8	Z dn ZD dn	190	9500	3500 b 6000 f	34000 5.59	21000 3.46	143
PMC	200	1.5, 3.8	Z dn ZD up	160	8000	2500 b 4000 f	34000 5.59	25000 4.11	143
PMC	200	1.5, 3.8	Z up ZD up	90	7000	1800 b 2500 f	39000 6.42	32000 5.27	143
PMC	200	1.5, 3.8	Z up ZD dn	140	9500	3000 b 5000 f	39000 6.42	28000 4.61	143

The Pulse mode results for the Region II breakout are 1.5 fps (+Z LVLH) followed by a 22.5-minute pause and then a 3.8 fps (+X LVLH) burn. To protect for Accel mode, once again the magnitude will have to be increased by 0.2 fps for the new target values and then by another 0.2 fps for the structural loading design cases. This leaves 1.7 fps (+Z LVLH) followed by a 22.5-minute pause and then a 4.0-fps (+X LVLH) burn for the target burns, and 1.9 fps (+Z LVLH) followed by a 22.5-minute pause and then a 4.2-fps (+X LVLH) burn for the structural design breakout from Region II.

Region III

The breakout from Region III will be the same as for Region II except that the burns will be of larger magnitude, owing to the larger dispersions in the ICs near vbar intercept. The initial radial down firing was increased until the closest case met the clearance criteria for the analysis. Figure 22 below displays this 2.0-fps (+Z LVLH) magnitude, in the closest approach trajectory.

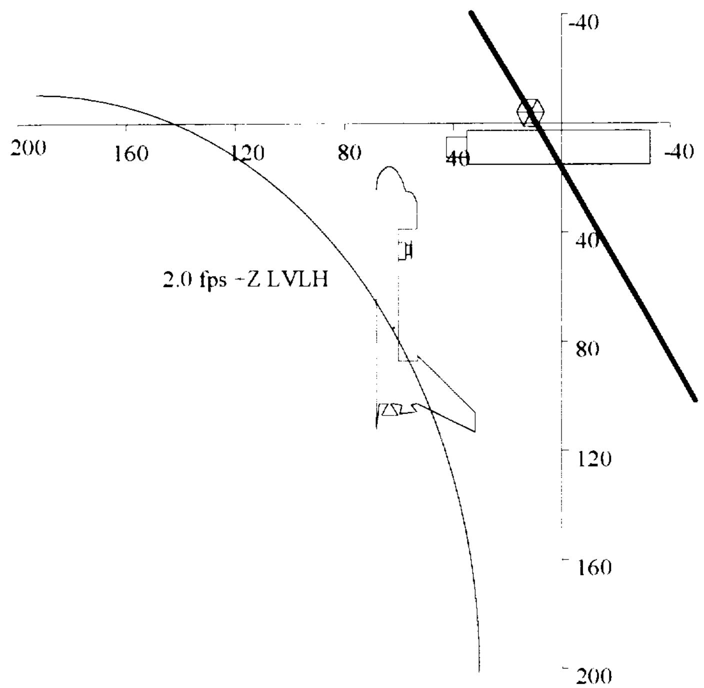


Figure 22. Minimum Successful Initial Clearance for Breakout in Region III.

Since the radial component of the breakout increases and the ICs are larger, the second burn will have to increase in order to still maintain a safe trajectory. The value was increased by 1 fps to 4.8 fps and the limiting case showed an unsuccessful result by not providing at least a 2-nmi buffer behind SSF (fig. 23).

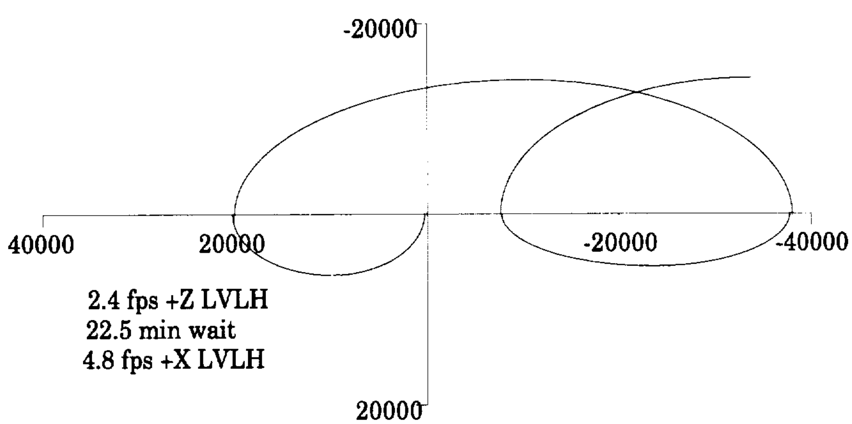


Figure 23. Example of Unsuccessful Breakout from Region III.

The magnitude of the second burn was increased again to a value of 5.3 fps. This value satisfied the clearance constraints on the problem. The worst case closest trajectories (fig. 24) show that the nearest -vbar intercept is at about 13 000 ft. The phasing setup by the breakout is about 50 000 ft/rev.

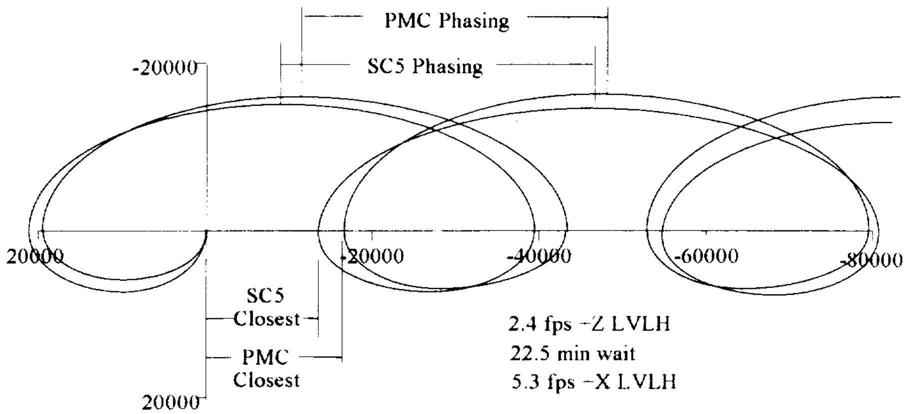


Figure 24. Minimum Successful Region III Breakout for Each Configuration.

A summary of the cases tested for Region III is presented in Tables XIII and XIV. The SC5 cases were performed mostly with a second burn of 4.8 fps until the limiting case was identified. However, since a larger second burn only helps the clearance, all cases that clear for a 4.8-fps burn will easily clear with a 5.3-fps burn. Once again, the second burn in each case is performed well outside of the 1000-ft envelope.

TABLE XIII. REGION III (200 POST-AUTO FT DI TO DI) SC5 BREAKOUT MATRIX.

Stage	Range (DI-DI) (ft)	Burns (ft/s)	IC	Closest Approach (ft)	-rbar crossing (ft)	2nd Burn Range (ft)	Phasing (ft/rev) (nmi/rev)	-vbar crossing (ft, nmi)	Prop Used (lbs)
SC5	200	2.0, 4.8	Z dn ZD dn	190	12000	4500 b 9000 f	44000 7.24	25000 4.11	199
SC5	200	2.4, 5.3	Z dn ZD dn	190	14000	5000 b 9000 f	52000 8.56	31000 5.1	226
SC5	200	2.0, 4.8	Z dn ZD up	180	11000	3250 b 6000 f	43000 7.08	31000 5.1	198
SC5	200	2.0, 4.8	Z up ZD up	100	9500	2500 b 4250 f	52000 8.56	40000 6.58	199
SC5	200	2.0, 4.8	Z up ZD dn	130	13000	3750 b 7000 f	50000 8.23	34000 5.59	199
SC5	Post Auto	2.0, 3.8	Z dn ZD up	400	9000	5000 b 6000 f	20000 3.29	4000 0.66	172
SC5	Post Auto	2.4, 4.8	Z dn ZD dn	400	14000	7000 b 10000 f	34000 5.59	7000 1.15	214
SC5	Post Auto	2.4, 5.3	Z dn ZD dn	400	14000	7000 b 10000 f	40000 6.58	13000 2.14	225
SC5	Post Auto	2.0, 4.8	Z dn ZD dn XD=0	400	13000	4000 b 9000 f	50000 8.23	33000 5.43	198
SC5	Post Auto	2.0, 4.8	Z dn ZD dn	400	13000	6000 b 10000 f	33000 5.43	8000 1.32	199
SC5	Post Auto	2.0, 4.8	Z dn ZD up	300	10000	4500 b 7000 f	33000 5.43	17000 2.79	199
SC5	Post Auto	2.0, 4.8	Z up ZD up	90	9000	3000 b 4500 f	45000 7.40	36000 5.92	199
SC5	Post Auto	2.0, 4.8	Z up ZD up XD=0	280	7500	500 b 1200 f	64000 10.53	60000 9.87	199
SC5	Post Auto	2.0, 4.8	Z up ZD dn	220	12000	5000 b 9000 f	46000 7.57	27000 4.44	198

TABLE XIV. REGION III (200 POST-AUTO FT DI TO DI) PMC BREAKOUT MATRIX.

Stage	Range (DI-DI) (ft)	Burns (ft/s)	IC	Closest Approach (ft)	-rbar crossing (ft)	2nd Burn Range (ft)	Phasing (ft/rev) (nmi/rev)	-vbar crossing (ft, nmi)	Prop Used (lbs)
PMC	200	2.4, 5.3	Z dn ZD dn	180	12000	4000 b 8000 f	54000 8.88	37000 6.09	207
PMC	200	2.0, 5.3	Z dn ZD dn	180	12000	4000 b 7000 f	54000 8.88	37000 6.09	197
PMC	200	2.0, 5.3	Z dn ZD up	110	10000	3000 b 5000 f	53000 8.72	42000 6.91	197
PMC	200	2.0, 5.3	Z up ZD up	100	9500	2000 b 3750 f	59000 9.71	50000 8.23	197
PMC	200	2.0, 5.3	Z up ZD dn	100	11000	3500 b 6000 f	58000 9.54	45000 7.40	197
PMC	Post Auto	2.4, 5.3	Z dn ZD dn	260	15000	6000 b 10000 f	43000 7.08	17000 2.79	207
PMC	Post Auto	2.0, 5.3	Z dn ZD dn	260	14000	6000 b 10000 f	43000 7.08	17000 2.79	197
PMC	Post Auto	2.0, 5.3	Z dn ZD up	140	10000	3500 b 5000 f	43000 7.08	27000 4.44	197
PMC	Post Auto	2.0, 5.3	Z up ZD up	18	9000	3000 b 4000 f	50000 8.23	40000 6.58	197
PMC	Post Auto	2.0, 5.3	Z up ZD dn	200	13000	5000 b 9000 f	50000 8.23	30000 4.94	197

The final design burn for Region III is 2.0 fps (+Z LVLH), a 22.5-minute pause, then a 5.3-fps (+X LVLH) burn in Pulse mode. To protect for Accel mode, again the magnitude will have to be increased by 0.2 fps for the new target values and then by another 0.2 fps for the structural loading design cases. This leaves 2.2 fps (+Z LVLH) followed by a 22.5-minute pause, and then a 5.5-fps (+X LVLH) burn for the target burns and 2.4 fps (+Z LVLH) followed by a 22.5-minute pause, and then a 5.7-fps (+X LVLH) burn for the structural design breakout from Region III.

Conclusions

NTC Breakout

Complete generic breakout sequences have been defined for all approaches to SSF. This analysis specifically outlines the magnitudes and procedures for a breakout in any of the described regions during a tail-down +vbar approach to SSF (fig. 25). The values presented in figure 25 are the target burns for an Accel breakout during an approach. The ± 0.2 fps accounts for error in the execution of the burns where the lower limit is the minimum burn required to achieve a safe trajectory. The minimum burn could be achieved to more accuracy using Pulse mode to input the burns but this requires a longer amount of time. The upper limit on the burns represents the maximum burn expected during a breakout. This magnitude is the value that should be protected during loads analysis on the SSF SAs.

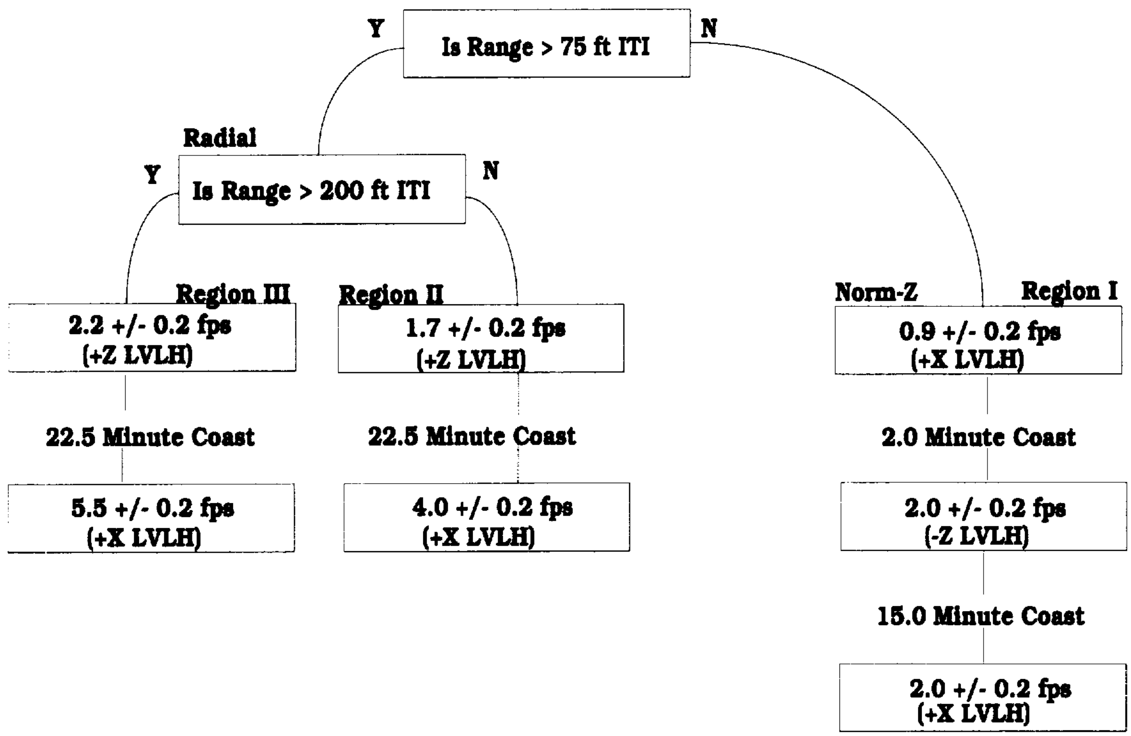


Figure 25. Procedural Flowchart for NTC Breakout.

TC Breakout

Although not explicitly covered in this analysis, the TC breakout is just an alteration of the data provided. The TC breakout is a breakout that ends in an emergency deorbit within 30 minutes of calling for the breakout.

Region I:
The TC breakout in Region I uses the same burns for burns one and two as the NTC breakout. The only difference between the two breakouts is the third burn. In the TC breakout, the third burn becomes the deorbit OMS burn. The Orbiter will be above and behind SSF so there is no risk of colliding with SSF. However, since the deorbit burn is an extremely large retrograde burn, the damage on the SSF SAs could be devastating. Due to time constraints on the breakout, there is no way to avoid being behind SSF and firing essentially right at the back of SSF once the deorbit burn begins.

Regions II and III:
The TC breakout in Regions II and III uses the same first burn as the NTC burn but then the procedure changes. Approximately 4-7 minutes after the first burn, a second burn, which is a 4-5-fps OOP (± Y LVLH) burn, needs to be executed. This OOP burn needs to go in the direction in which the Orbiter is heading OOP due to its IC. At 10-12 minutes after the second burn, the deorbit burn can begin. The Orbiter will be in front of SSF but it will be OOP enough so that the Orbiter will pass beside SSF as soon as the deorbit burn begins. There is a window on the deorbit burn that needs to be defined. If the window is violated, the Orbiter will begin to move back towards SSF and the deorbit burn potentially will lead to a collision. The second burn, the OOP burn, might cause damage to the SSF SAs due to its large magnitude and close proximity to SSF. This burn is required, however, to set up a safe passage for the deorbit. The deorbit burn, once again, holds considerable potential to damage the SSF structure.

An additional issue that came out of the TC breakout is that an OOP component often is entered into the deorbit burn to burn off fuel so that the Orbiter is within limits for entry. The unknown value of this OOP component makes it extremely difficult to define the OOP limits on burn two, so an agreement was reached with the Trajectory Operation Branch/DM4 that the OOP component of the deorbit burn would be placed such that the Orbiter will move away from SSF rather that towards it if an occasion arose.[2]

References

1. Holloway, T./DA2, "Acceptable Clearance Criteria for Payloads Ejected from the Orbiter Cargo Bay," DM2-90-135, October 9, 1990.

2. Pearson, D/DM42, "Emergency Deorbit During V-bar Approaches to SSF," DM4-92-70, May 22, 1992.

3. Rochon, B. V./LESC, "Preliminary SES Orbiter/SSF Approach Relative States," SMD-92-2562, JO 055-84-120, May 8, 1992.

4. Dunham, S. D./DM33, Initial Breakout Firings for Berthing, Tail Down, and +Vbar Approach to Space Station Freedom, JSC-36091, August 1992.

Appendix

National Aeronautics and
Space Administration

Lyndon B. Johnson Space Center
Houston, Texas
77058

NASA

OCT 0 9 1990

Reply to Attn of: DM2-90-135

TO: TA/Manager, Space Shuttle Integration and Operations Office

FROM: DA2/Assistant Director for Space Shuttle Program

SUBJECT: Acceptable Clearance Criteria for Payloads Ejected from the Orbiter Cargo Bay

Summary

Clearance criteria for payloads ejected from the orbiter cargo bay are a function of ejection direction and maturity of the ejection system. Previously flown systems will be less constrained than new systems and those with ejection delta-V components toward the orbiter cabin must guarantee adequate cabin clearance for worst case conditions. Clearance criteria for new ejection systems will be assessed on a system-unique basis.

Discussion

To effectively use analysis resources and ensure timely completion of flight planning activities, a comprehensive set of analysis criteria is mandatory. The following is a set of criteria recommended by MOD. Several distinctions will be made concerning ejection systems and the corresponding clearance criteria. These distinctions are maturity of the system (previously flown on the orbiter in its configuration) and direction of the ejection velocity components. Also, these clearance criteria must be met in a defined "worst case" scenario.

Operation of the orbiter and the payload ejection system can potentially encounter system failures on both sides which would decrease the expected clearance between the orbiter and ejected payload. Additionally, performance of component parts and dispersions in other factors can further reduce the planned clearance. Finally, the ejection system must perform such that an orbiter maneuver is not required to ensure satisfactory clearance for the close-in separation concerns. The method for combining these clearance reduction parameters is as follows:

a. Add the two worst case clearance reduction failures in the worst direction

b. Root sum square (RSS) the clearance reduction dispersions

c. Determine the worst case thermal bowing effects on available clearance

Failure + Failure + RSS + Thermal Bowing = clearance reduction

With the method of determining clearance reduction defined, application to the ejection systems is in order.

Mature systems with an ejection delta-V component toward the orbiter cabin must ensure that the payload and/or attached hardware clear the orbiter cabin/nose by at least 5 ft in nominal and contingency operations after applying the worst case clearance reduction previously discussed. Also, the system must ensure a positive clearance with all other orbiter structure, ASE, and other structure attached to the orbiter. The 5-ft cabin clearance is included as a confidence factor for the orbiter crew that the ejected vehicle does indeed have sufficient clearance with the orbiter; thereby precluding the crew from initiating an orbiter avoidance maneuver. Likewise, mature ejection systems without an ejection delta-V component toward the cabin must ensure positive clearance between the ejected vehicle and all other hardware or orbiter structure.

Ejection systems being flown for the first time must satisfy additional clearance constraints due to the lack of maturity in their system under flight conditions. In this case, the clearance criteria will be the same as a mature system plus an additional clearance margin assessed on a system unique basis. Ideally, the assessment could be made early in the system design to preclude flight design and system design impacts during later critical times.

Conclusions and Recommendation

Clearance criteria for payload ejection systems are a function of the system maturity, performance factors, and failure scenarios. The system must meet specified clearance reduction criteria and ensure the minimum required clearance. First time ejection systems may be assessed an additional clearance margin determined on a system unique basis.

MOD recommends the Shuttle Program Office adopt the Boeing clearance criteria currently in place for the configured IUS/payload ejection system.

T W Holloway

Tommy W. Holloway

cc:
RSOC
R16C/S. Anderson
R16C/M. C. Contella

NASA JSC
DM/J. C. Harpold
DM2/L. D. Davis
DM22/G. W. Ricks
DM23/C. C. Anderson
DM23/M. E. Donahoo
TA/H. F. Battaglia
TA/RSO/R. L. Blount
TA/C. H. Lambert
TC2/J. J. Conwell

National Aeronautics and
Space Administration

Lyndon B. Johnson Space Center
Houston, Texas
77058

NASA

Reply to Attn of: DM4-92-70

To: DM23/M.Donahoo

From: DM42/Head, Orbit Flight Dynamics Section

Subject: Emergency Deorbit during V-bar Approaches to SSF

The question has come up as to whether or not the flight dynamics officer (FDO) would compute an emergency deorbit maneuver solution with out-of-plane wasting if a major Orbiter anomaly occurred while completing a final approach to a target vehicle. Clearly the likelihood of such an event is extremely remote, but protecting for this case has driven the design of our current standard emergency deorbit breakout plan. The current plan has the crew performing a $<=$ 1.0 fps opening rate from the target, followed by a 4 fps out-of-plane (OOP) maneuver 4 minutes later, and then either a 3 fps posigrade maneuver (5 minutes later) or a perigee adjust/deorbit maneuver ASAP. The 4 fps OOP maneuver was designed to protect for a worst case scenario where the FDO would compute a fuel wasting deorbit burn that was 45 degrees out of plane. The timing of that burn (and the full 3 burn sequence) is tied strongly to the 45 degree angle protection. Things get worse for the SSF approach where a simple 1 fps opening rate is not plausible due to plume impingement on the solar panels. In this case, the first burn of the prox ops breakout is a downward 1-2 fps manuver. A new emergency deorbit sequence is under development to ensure that the SSF design is robust.

We have discussed this situation internally, and concluded that the FDO may not have time to compute the OOP fuel wasting deorbit maneuver during this emergency. She/he will compute the inplane optimum deorbit maneuver to an ELS. If time remains, a fuel wasting maneuver can be computed which we can assure will be in the same direction as the 4 fps OOP maneuver. The MOC deorbit maneuver processor (DMP) now chooses the OOP direction to minimize cross-range, but the FDO can quickly evaluate the PEG7 targets on the Deorbit Digitals display and evaluate the direction, and modify if necessary. The bottom line is: the SSF breakout maneuver can be designed without protecting for the 45 degree OOP wasting component. This will allow the design to be much simpler and less constrained to meet a specific timeline.

Don J. Pearson

DM42/DFPearson:mw:05/22/92:38052

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
June 1993

3. REPORT TYPE AND DATES COVERED
Technical Memorandum

4. TITLE AND SUBTITLE
+Vbar Breakout During Approach to SSF

5. FUNDING NUMBERS

6. AUTHOR(S)
Scott D. Dunham

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
NASA Lyndon B. Johnson Space Center
Flight Analysis Branch
Houston, Texas 77058

8. PERFORMING ORGANIZATION REPORT NUMBER
S-724

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Washington, D.C. 20546-001

10. SPONSORING / MONITORING AGENCY REPORT NUMBER
NASA TM-104772

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Unclassified/unlimited
Available from National Technical Information Service
5285 Port Royal Road, Springfield, VA 22161, 703-487-4600
Subject Category 13

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
A set of burn profiles has been developed to provide bounding jet firing histories for a +Vbar breakout during approaches to Space Station Freedom. The delta-v sequences have been designed to place the Orbiter on a safe trajectory under worst case conditions and to try to minimize plume impingement on Space Station Freedom structure.

14. SUBJECT TERMS
Rendezvous, Proximity Operations, Breakout, Plume, Space Station Freedom

15. NUMBER OF PAGES
37

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT
unclassified

18. SECURITY CLASSIFICATION OF THIS PAGE
unclassified

19. SECURITY CLASSIFICATION OF ABSTRACT
unclassified

20. LIMITATION OF ABSTRACT
UL

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18
298-102