Risk Analysis of Earth Return Options for the Mars Rover/Sample Return Mission

A Report to the National Aeronautics and Space Administration
Johnson Space Center

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Eagle Engineering, Inc.
711 Bay Area Boulevard, Suite 315
Webster, Texas 77598
(713) 338-2682

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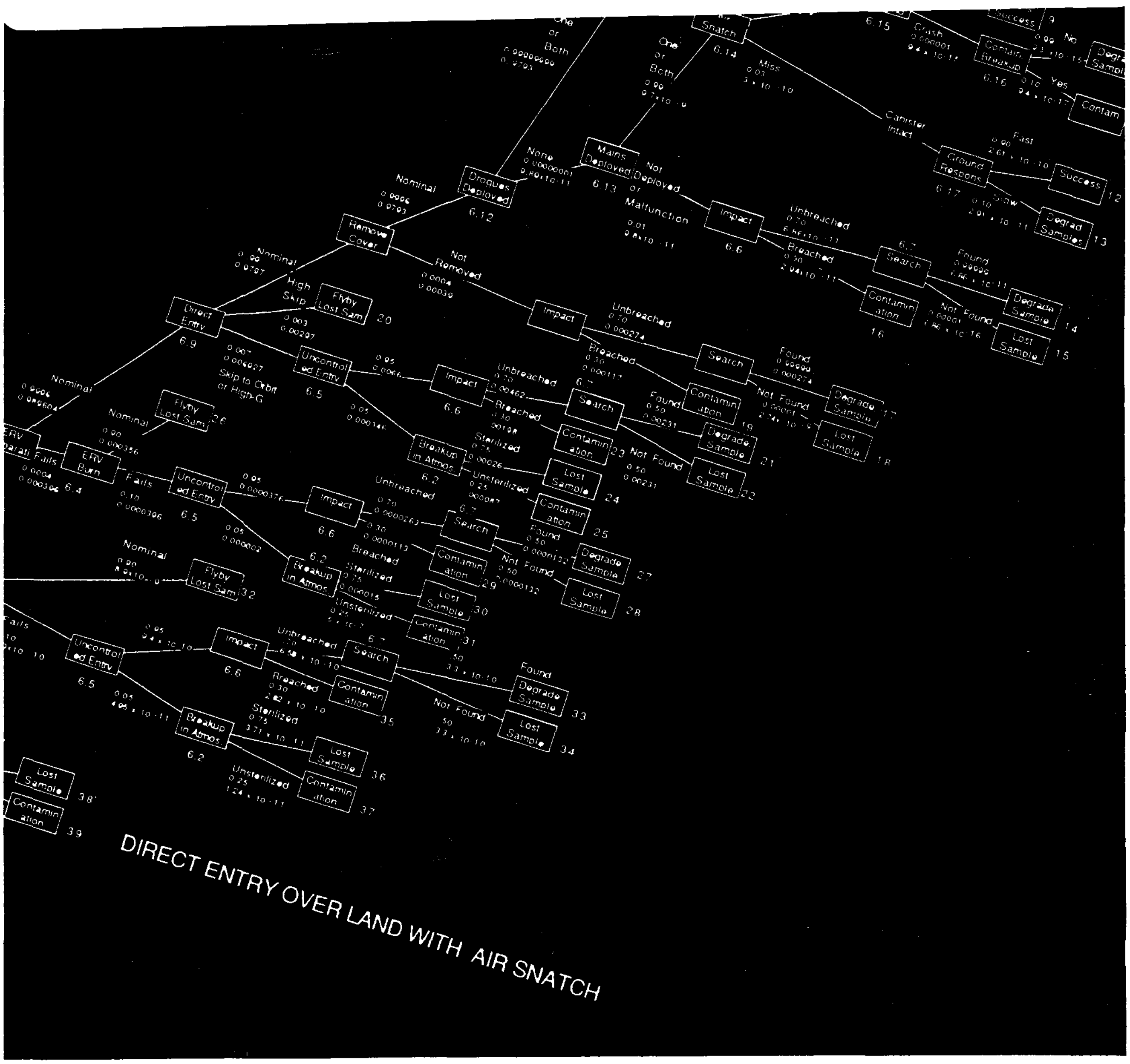

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July 13, 1988

EAGLE

Foreword

This study quantifies the relative risk of several different options for the return of Mars surface samples to Earth. Risk of mission failure (loss of sample), breach of sample canister that might result in back-contamination of Earth with Mars organisms, should they exist, and risk of the sample getting too warm are all estimated. This data will help Mars Rover/Sample Return Mission Planners select the best method for Earth return.

The following individuals participated in this study:

Dr. John Alred was the NASA technical monitor for the Advanced Space Transportation Support (ASTS) contract of which this study was a part.

Dr. David Thompson was the NASA task manager for this particular study.

Dr. Douglas Blanchard, Mr. Joe Gamble, Dr. James Gooding, Mr. Harry Norton, Ms. Shelby Lawson and others, all with NASA, provided valuable advice, data, and technical review.

Mr. Bill Stump was the Eagle ASTS Contract Project Manager

Dr. Charles Simonds was the Eagle Task manager for this study.

Other Eagle participants in the study included Mr. Jeff Kline, Mr. Bill Stump, and Mr. R.G. Ruiz.

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1.0 Executive Summary

Four options for return of a Mars surface sample to Earth were studied to estimate the risk of mission failure and the risk of a sample container breach that might result in the release of Martian life forms, should such exist, in the Earth's biosphere. The probabilities calculated refer only to the time period from the last mid-course correction burn to possession of the sample on Earth.

Two extreme views characterize this subject. In one view, there is no life on Mars, therefore there is no significant risk and no serious effort is required to deal with back-contamination. In the other extreme view, public safety overrides any desire to return Martian samples, and any risk of damaging contamination greater than zero is unacceptable. Zero risk requires great expense to achieve and may prevent the mission as currently envisioned from taking place. The major conclusion of this report is that risk of sample container breach can be reduced to a very low number within the framework of the mission as now envisioned, but significant expense and effort, above that currently planned will be needed. There are benefits to the public that warrant some risk. Martian life, if it exists, will be a major discovery. If it does not exist, there is no risk.

The four options for Earth return studied included:

Direct Entry - the Sample Return Capsule (SRC) enters the Earth's atmosphere directly from the interplanetary trajectory and descends to the surface with redundant parachutes. An airsnatch of the capsule is then assumed to aid in thermal control of the sample. In the event of a missed airsnatch, the capsule will land on land.

Aero and Propulsive Capture to the Freedom Space Station - The SRC is braked aerodynamically (aerocapture) or propulsively such that it ends up in an orbit coplanar with Freedom Space Station. The altitude of the orbit is assumed to be in the range of 200 to 270 nm (370 to 500 km) with decay times on the order of a few months to several years depending on the solar flux. An Orbital Maneuvering Vehicle (OMV) retrieves the SRC to the Freedom Space Station where the sample canister is removed and repackaged in a rugged container designed to maintain the required temperature (-40° C). The sample is then returned to Earth in the Orbiter.

Aerocapture to a Shuttle Compatible Orbit and Shuttle Return - The SRC is braked aerodynamically into a 370 km (200 nm) orbit. The Shuttle then retrieves the SRC directly and returns it to Earth.

Table 1.0-1 contains probabilities calculated using a fault tree analysis of the sequence of mission events. The probabilities are calculated using estimated probabilities for each of up to twenty events in a sequence all multiplied together. Roughly 30 different events are used in the calculations. Most of these events occur in several options and therefore the results have a high level of relative accuracy although all the estimates may be systematically biased high or low.

The individual event probability estimates have large uncertainties and the results must be viewed with some skepticism. However, these numbers provide a more quantitative assessment of the relative risk of contamination of the various return options than has been provided to date.

To translate breach of canister probabilities to real back-contamination probabilities, the probability that Martian life that can do damage on Earth exists and is capable of surviving the interplanetary transfer must be factored in. The probability that Martian life exists, etc., might be 0.01 or less, thus divide the canister breach numbers by 100 or 1,000 to get an approximate risk of contamination.

Prior to departure from Mars, a sample transfer from the Mars ascent vehicle to the Earth Return Vehicle/Sample Return Capsule is assumed to occur such that the exterior of the returning vehicle is sterile.

The mission success probability estimates are not representative of the entire mission because the Earth return is only the end of a much longer sequence. On the other hand, the breach of canister estimates are representative of the mission as a whole because almost all the failures resulting in sample canister breach occur in the vicinity of Earth.

The first column below shows the probability of success, where success is defined as simply returning the contained sample, even though it may be warm (degraded sample). The 100% success column is the probability of returning the contained, temperature controlled sample.

The degraded sample column in the table refers to the probability that the sample will become too warm, significantly warmer than -40° C. The scientific community needs to seriously examine what the temperature requirements should be.

Table **1.0-1**, Summary of Fault Tree Calculations

Option	Sample Returned, Bio. Isolated (100 Succ. + Sample Degraded)	100 % Success	Sample Degraded	Sample Can. Breached *	Sample Lost
Direct Entry	98.15	97.64	0.55	0.45	1.36
Prop. Capture to Freedom Space Station	96.69	90.38	6.31	0.74	2.57
Aerocapture to Freedom Space Station	96.68	89.61	7.07	1.66	1.66
Aerocapture to Shuttle	96.71	91.72	4.99	1.62	1.66

* The canister is breached in such a manner that contamination of Earth could occur if pathogens are on board. This includes several types of breaches: just cracking the seals, losing the unsterilized sealed canister on Earth, destruction of the canister and spreading of the sample in a crash on Earth, and spreading of the sample in the upper atmosphere after a capsule break-up.

A simple explanation for the difference between probabilities for direct entry and the other three options is the dependence of the three Earth orbit options on one or more Shuttle launches. The Shuttle mission success rate is currently 96 % based on 25 launches. Success rates for major booster programs such as Araine (81 %), Atlas (80 %), Delta (93 %), Long March (88 %), Titan (96 %), Proton (92 %), (Simanis and Gubby, 1988) are all in the range of 85 to 95 %. An average over 447 missions for all these vehicles results in a success rate of 91.4 %. No other launch vehicle has ever done better than 96 %. Even if the Shuttle success rate goes up to 99 % (the actual number used in the calculations), the ability to get a Shuttle into the right orbit on time is in question.

At present, low parking orbits (370 km or 200 nm) are proposed for the return vehicles. These orbits can decay within a few months at solar maximum for the aerocapture vehicles under discussion. The baseline sample return in 2001 occurs when solar activity is approaching its peak. The risks for the options using a low Earth parking orbit can be significantly improved by raising the altitude of the parking orbit to allow long life.

Based on the results in Table 1.0-1, direct entry is the preferred return method. Other evaluation criteria, such as the Earth launch mass for the various options, was not considered. The only extra-terrestrial sample returns to date (6 Apollos and 3 Lunas) were direct entry. The unmanned missions, the Russian Lunas, were parachute landings on land.

An alternative way to view the different options is in terms of relative complexity. The simpler the option, the better the chance of success. To see the simplicity of direct entry relative to the other options, consider the approximate number of roughly equivalent operations needed to nominally execute the different return options from the last mid-course on.

Direct Entry	Aerocapture to Shuttle	Aerocapture to Space Sta.	Propulsive Capt. to Space Sta.
14	27	68	69

A sensitivity analysis of the Table 1.0-1 results was run to see their sensitivity to changes in the individual event probability estimates. The probability of each nominal event was raised to 1.0 to remove it from the calculation and then the failure probability was increased by a factor of 10 to make it prominent in the calculation. Figure 1.0-1 shows a scatter plot of all the runs. Significantly, the direct entry runs cluster with the least risk for both canister breach and mission failure. **Direct entry is the preferred option even if any of the component risk element numbers is in error by a factor of 10.**

Measures can be taken to significantly reduce the risk of canister breach below the 0.45% calculated for direct entry. These include:

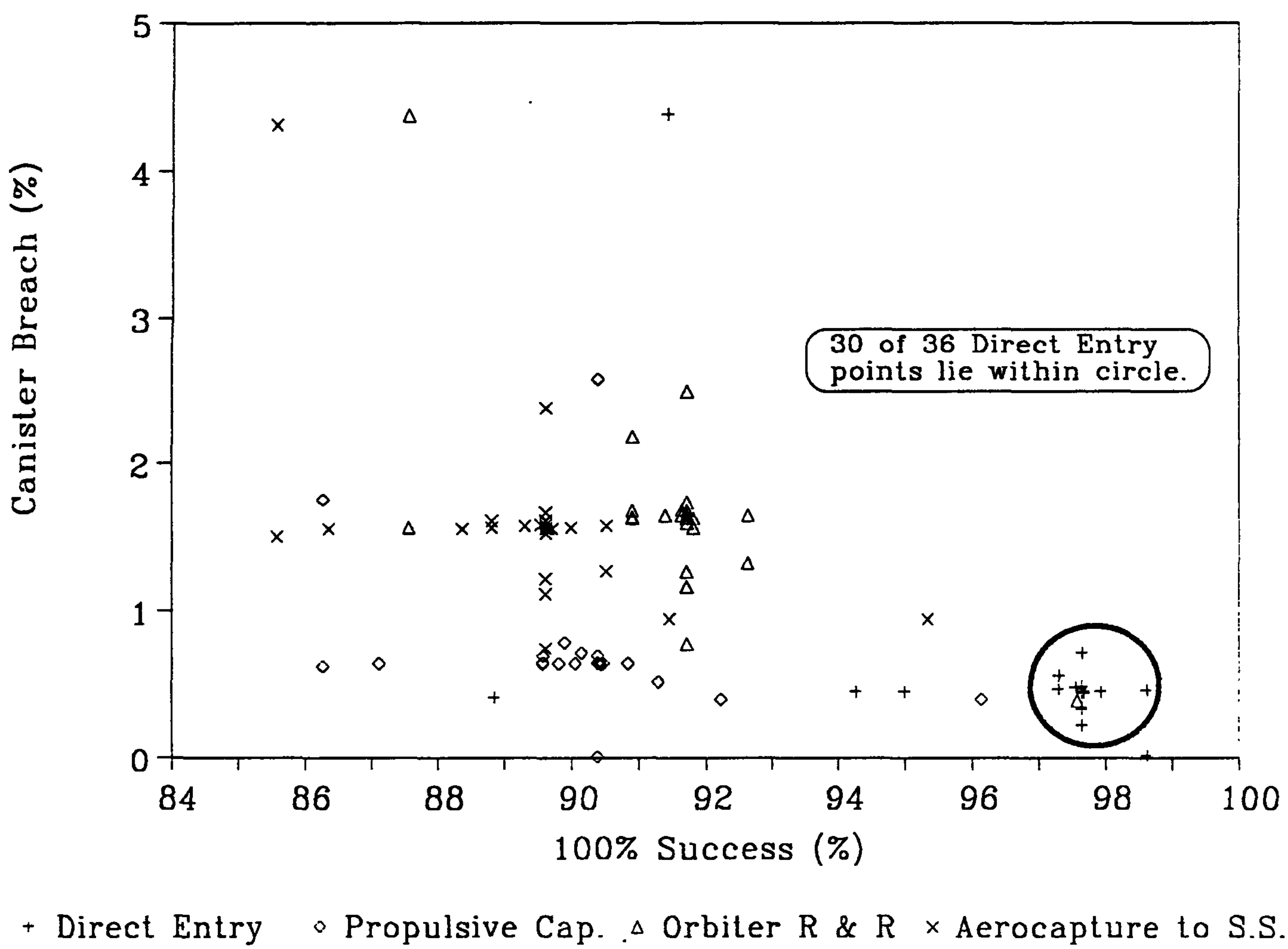
a) Fully redundant subsystems in the ERV and SRC.
b) Dual main and drogue chutes (already assumed in the calc.)
c) SCA capable of maintaining seals in a no chute impact.
d) Ability to flyby Earth until ERV separation.
e) Flight test for entry vehicle.

f) Redundant airsnatch aircraft.

Other risk reduction measures applicable to all the options include:

a) Cancellation of the sample return portion of the mission if signs of life are seen on Mars by the rover.
b) Monitoring the sterile transfer operation in Mars orbit with TV cameras. Any anomaly would be cause to leave the sample in Mars orbit.

Figure 1.0-1, Scatter Plot of Sensitivity Analysis Runs



2.0 Introduction/Mission Description

This analysis is a top level Failure Mode Effects and Criticality Analysis of the Earth return part of the proposed Mars Rover/Sample Return mission. The analysis focuses exclusively on category I (Catastrophic Failures which will cause system loss) and category II (Critical failures which will result in major system damage which will result in mission loss). (MIL-STD-1629A)

The Mars Rover/Sample Return mission will return samples of the Martian surface to Earth. Current studies anticipate phase A studies in 1989 with the first launch in 1998/99 and return in 2001. Various methods of flying the overall mission are still under study.

Figure 2.0-1 (Cunningham and Kahl, 1988) shows one proposed method. Two separate Titan 4 with Centaur launches place a rover and an ascent vehicle on the surface of Mars at Mangala (6° S, 147° W). The payloads carried to Mars are aerobraked into Mars orbit. The rover has a range of 20-40 km. It collects samples and places them in the ascent vehicle for return to Earth. When the ascent vehicle is loaded with samples, it launches to orbit and docks with an Orbiter in Mars orbit. The Orbiter carries a stage to return the sample to Earth. The sample is placed within this stage via a sterile transfer and launched toward Earth. The sample rides in a Sample Canister (SC) inside a Sample Canister Assembly (SCA). The SCA is nominally sterile on the exterior.

When the vehicle reaches the vicinity of Earth, it is composed of two parts, the Earth Return Vehicle (ERV) which is a carrier for the Sample Return Capsule (SRC) which enters the atmosphere or parks in Earth orbit. On the order of 4 hours prior to Earth entry or Earth orbit insertion (EOI), the SRC separates from the ERV. For the aerocapture and direct entry options, the ERV will go on to enter the Earth's atmosphere.

A significant requirement of the program is to keep the sample at -40°C or below during transit (Gooding, 1988). This is to be achieved by an insulated thermal protection cover that opens when that end of the vehicle can be pointed at deep space.

Seven basic options exist for the SRC after separation from the ERV: direct entry to the Earth's surface, aerocapture or propulsive capture to low Earth orbit and Orbital Maneuvering Vehicle (OMV) recovery to the Freedom Space Station, aerocapture or propulsive capture to low Earth orbit and recovery by the Shuttle, and aero or propulsive capture to elliptical Earth orbit and recovery by an upper stage to low Earth orbit. In this study, propulsive capture to the Shuttle, which is nearly identical to aerocapture to the Shuttle for the purposes of this study, is not considered. Aero or propulsive capture to high elliptical orbits are also not considered. The high elliptical orbits are beyond the range of the OMV, and a larger upper stage is required to retrieve the sample.

The following paragraphs describe the return options in more detail:

1. **Direct entry of the sample to the Earth's surface.** The sample return vehicle enters the Earth's atmosphere directly from the interplanetary trajectory, then is slowed by aerodynamic braking, and parachutes to a land surface, such as the mid-continent U.S. An air recovery (air snatch) with an aircraft retrieving the sample before it reaches the surface was baselined to aid in thermal and biological

control. A land recovery improves the outcome of various failures, such as a missed air snatch, main chute malfunction, or highly off-nominal trajectory. The only other unmanned extra-terrestrial sample returns, Lunas 16, 20, and 24 used land recovery with no airsnatch.

Redundant drogue and main chutes are assumed to reduce the probability of parachute failure to a small number. The entry vehicle is assumed to be a Discoverer-type capsule, not requiring attitude control. Attitude control may prove to be needed to achieve an acceptable error ellipse on the ground however.

2. **Aerocapture or propulsive capture to low Earth orbit, and recovery by the Space Shuttle,** perhaps using the Orbital Maneuvering Vehicle (OMV) to retrieve the vehicle in orbit. In this study, the Shuttle is assumed capable of rendezvousing directly with the SRC and grappling it with the Orbiter's Remote Manipulator System (RMS). Use of the OMV significantly complicates the mission, but would allow use of a long-life parking orbit for the SRC, at altitudes as high as 1,000 nautical miles (nm) or 1,850 km.

   The aerocapture SRC is assumed to be a small Apollo shape capsule that flies a profile in the upper atmosphere and then exits when the appropriate amount of energy has been dissipated. Following exit from the atmosphere a small burn raises the perigee out of the atmosphere and circularizes at a low altitude, currently 370 km. The vehicle must maintain attitude control to control the temperature of the sample. The current plan calls for the vehicle to remain active for 90 days.

3. **Propulsive or aerocapture to the Freedom Space Station.** The sample is circularized in LEO and then brought to the Freedom Space Station by the OMV. The OMV does not normally reside at the Freedom Space Station and must be brought to orbit for this purpose. Several options exist for handling the sample at the Freedom Space Station. The simplest is taken as the baseline here. The OMV is docked on the truss and the RMS places the SRC in a secure container. The sample canister assembly is removed from the SRC and placed in another secure container, capable of providing active thermal control if required. The two containers are returned to Earth in the Orbiter.

Each option is progressively more complex and interrelated with other programs. Four simple criteria are of interest in evaluating the options listed above:

1. The probability of 100% mission success.

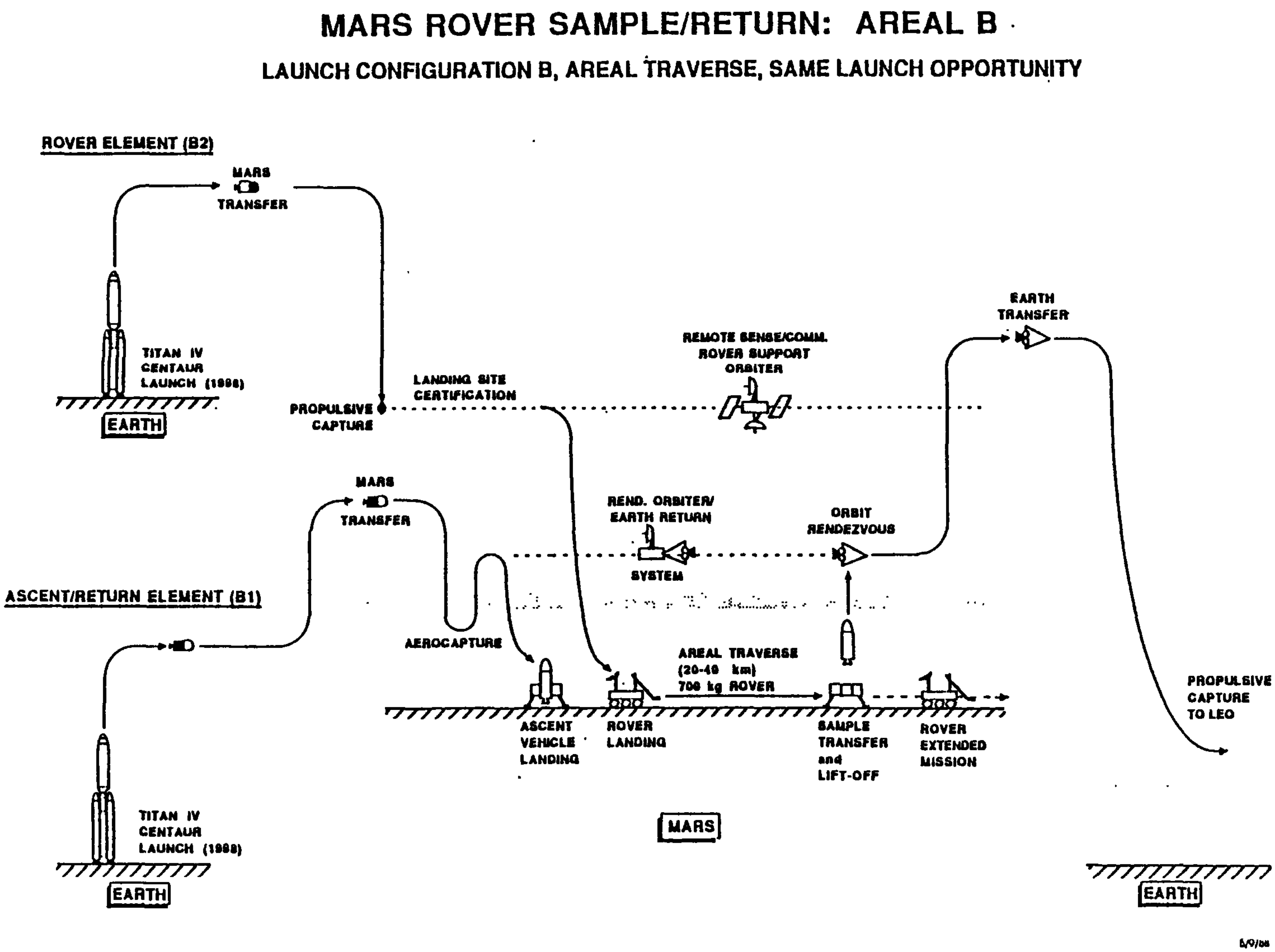
2. The risk of breach of container in the biosphere which is related to the risk of contaminating Earth with microorganisms from Mars.

3. The risk of loss of the sample.

4. The risk of degradation of the sample. Failure to maintain the required temperature (-40°C at present) is an example of this type of failure. This would result in a significant loss of information in the sample.

A significant fraction of the information about Mars stored in the samples may be lost if the sample is heated to temperatures above about -15°. The objective of keeping the sample cold is to preserve the clay minerals, salts, and water ice (if present) in its Martian condition. These materials preserve a record of how the Martian atmosphere and lithosphere have interacted for 10's of millions, and possibly billions of years. As such, these easily destroyed constituents may preserve critical information about whether the Martian climate was ever conducive to life.

Figure 2.0-1, Mars Rover/Sample Return Mission Sequence
(Cunningham and Kahl, 1988)



3.0 Description of the Hardware Elements

The hardware elements are defined at a pre-phase A level of detail at this point in time. The most detailed description available is included here for the sample return hardware in order to try to understand a baseline conceptual design that can be evaluated and evolved.

The following general definitions aid the discussion:

Sample Canister (SC) -	This is the can that carries the sample, sealed on the Martian surface.
Sample Canister Assembly (SCA) -	The SC is placed inside this can in Mars orbit. The outside of this can is sterile.
Sample Return Capsule (SRC) -	The SRC holds the SCA through aero or propulsive braking and while it is in Earth orbit.
Earth Return Vehicle (ERV) -	The ERV carries the SRC through the interplanetary voyage from Mars back to Earth. The ERV and SRC separate before Earth capture and the ERV flies on by Earth or enters, depending on the case.
SRC Canister -	When the SRC is brought to the Shuttle or Freedom Space Station it is placed in the SRC canister, a sealable can. Before the lid is shut, the SCA is removed from the SRC and placed in the SCA canister.
SCA Canister -	Before the SRC is sealed in its canister, the SCA is removed and placed in a smaller canister. This small can is arranged to provide thermal control and a redundant biological seal. It is also sturdy enough to survive some types of Shuttle crashes.
Canister Pallet -	Both the SRC and SCA Canisters are located on a pallet which carries appropriate power hook-ups, thermal control, instrumentation, data processing equipment, and mechanical connectors for riding in the payload bay down to the Earth's surface and for hook-up to the Freedom Space Station truss.
Orbital Maneuvering Vehicle (OMV)-	The OMV is a small spacecraft which will go out and get the SRC and bring it back to the Freedom Space Station or Shuttle. The OMV does not currently have a home on the Phase 1 Freedom Space Station. It must be delivered and docked to an enhanced Station some time well before the arrival of the SRC at Earth.

3.1 Earth Return Vehicle

The Earth Return Vehicle (ERV) is a spacecraft bus that carries the SRC. It reduces the mass that must be inserted into Earth orbit or aerobraked to the surface to a minimum by carrying the power, propulsion, and other features needed for the interplanetary flight.

Figure 3.1-1 (Norton, 1988) shows a sketch of the vehicle with the SRC inside configured for propulsive capture. Table 3.1-1 (Norton, 1988) shows a mass, power and subsystem breakdown of the ERV. This version of the ERV is spin stabilized (6 rpm during cruise).

Figures 3.1-2 (Lawson, 1988) and 3.1-3 (Lawson, 1988) show an ERV configured to carry an aerocapture Sample Return Capsule. Table 3.1-2 (Gamble, 1988) shows a preliminary weight statement and subsystem breakdown for this vehicle. Table 3.1-3 (Gamble, 1988) describes the ERV propulsion system.

3.2 Sample Return Capsule

Figure 3.2-1 (Norton, 1988) shows a Sample Return Capsule configured for propulsive capture into LEO. Table 3.2-1 (Norton, 1988) shows a weight and subsystem breakdown for this vehicle. The SRC has two stages of propulsion for Earth orbit insertion. The four motors marked "1" in the figure do the first burn. The two motors marked "2" do the second burn. The vehicle is spun up by the ERV prior to the burn to a high rate. After the burn a "yo-yo" is deployed to reduce the spin rate to about 5 to 6 rev./min. This is the only attitude control this version of the SRC has.

Liquid propulsion systems for propulsive capture SRCs are also being considered in addition to solids.

This version of the SRC has a small circumferential solar array and batteries. These operate a small S-band beacon. Thermal control is provided by a thin insulated door over the SCA. The hinge motor for this door is driven by a small aft-looking thermal sensor. Heat flux above a certain limit, detected by this sensor causes the door to close until the flux drops.

Figures 3.2-2 and 3.2-3 (Norton, 1988) show block diagrams of the power and communications and data handling subsystems of the ERV/SRC vehicle. The Mars Orbit Vehicle (MOV) or Mars Rendezvous Orbiter (MRO) is also included but is not relevant to this study.

Figure 3.2-4 (Lawson, 1988) and 3.2-5 (Gamble, 1988) show a representation of the Sample Return Capsule (SRC) designed to aerocapture into low Earth orbit (LEO). Table 3.2-2 (Lawson, 1988) shows a weight statement and breakdown by subsystem. Table 3.2-3 (Gamble, 1988) includes more information on the propulsion system.

3.3 Direct Entry Capsule (DEC)

Figure 3.3-1 (Kerridge and Atzei, 1987) shows a DEC designed for a comet sample retrieval. The DEC for MRSR should be similar although the vehicle may have a different aerodynamic profile. The DEC does not circularize in Earth orbit, but rather enters directly to the surface, deploys parachutes, and is recovered in the air by a large aircraft before it hits the ground. The subsystems for the DEC are predicted to be similar to those in the SRC.

Figure 3.3-2 shows a discoverer capsule shape, which may prove to be a more desirable profile since it is aerodynamically stable in one position without active control.

3.4 Sample Canister (SC) and Sample Canister Assembly (SCA)

The Sample Canister is the original can into which the samples are placed on the Martian surface. Prior to launch from the surface, it is closed and sealed. Figure 3.4-1 shows a concept for this can. The SC is taken to orbit and placed inside the Sample Canister Assembly (SCA). A sterile transfer is accomplished, such that when the SCA shuts its lid, the exterior of the SCA is sterile. The SCA is contained within the SRC and is thermally controlled by opening and shutting a lid that covers it and perhaps by rolling it out on tracks facing deep space.

3.5 Orbital Maneuvering Vehicle (OMV)

Figure 3.5-1 shows the OMV and its propulsion module that may have to be changed out between SRC retrievals if two vehicles are to be retrieved. A rendezvous sequence performed by the OMV may require as many as 10 burns if a Shuttle type maneuver sequence is used. The OMV will be commanded from the ground once it is beyond a certain distance from the Freedom Space Station. When the OMV is within the Freedom Space Station control zone, it will be controlled by the crew in the Station.

3.6 Canister Pallet

Figure 3.6-1 (Simonds, 1988) shows a concept for the canister pallet which may hold the canisters into which the SRC and SCA will be placed. The canister pallet will be brought up in the Shuttle payload bay, placed on the Freedom Space Station truss, loaded and sealed with the SRC and SCA and then taken to Earth in the Shuttle payload bay. In a pure Shuttle recovery, the canister pallet would remain in the payload bay throughout the flight.

Figure 3.1-1, Earth Return Vehicle (ERV) with Propulsive Injected SRC (Norton, 1988)

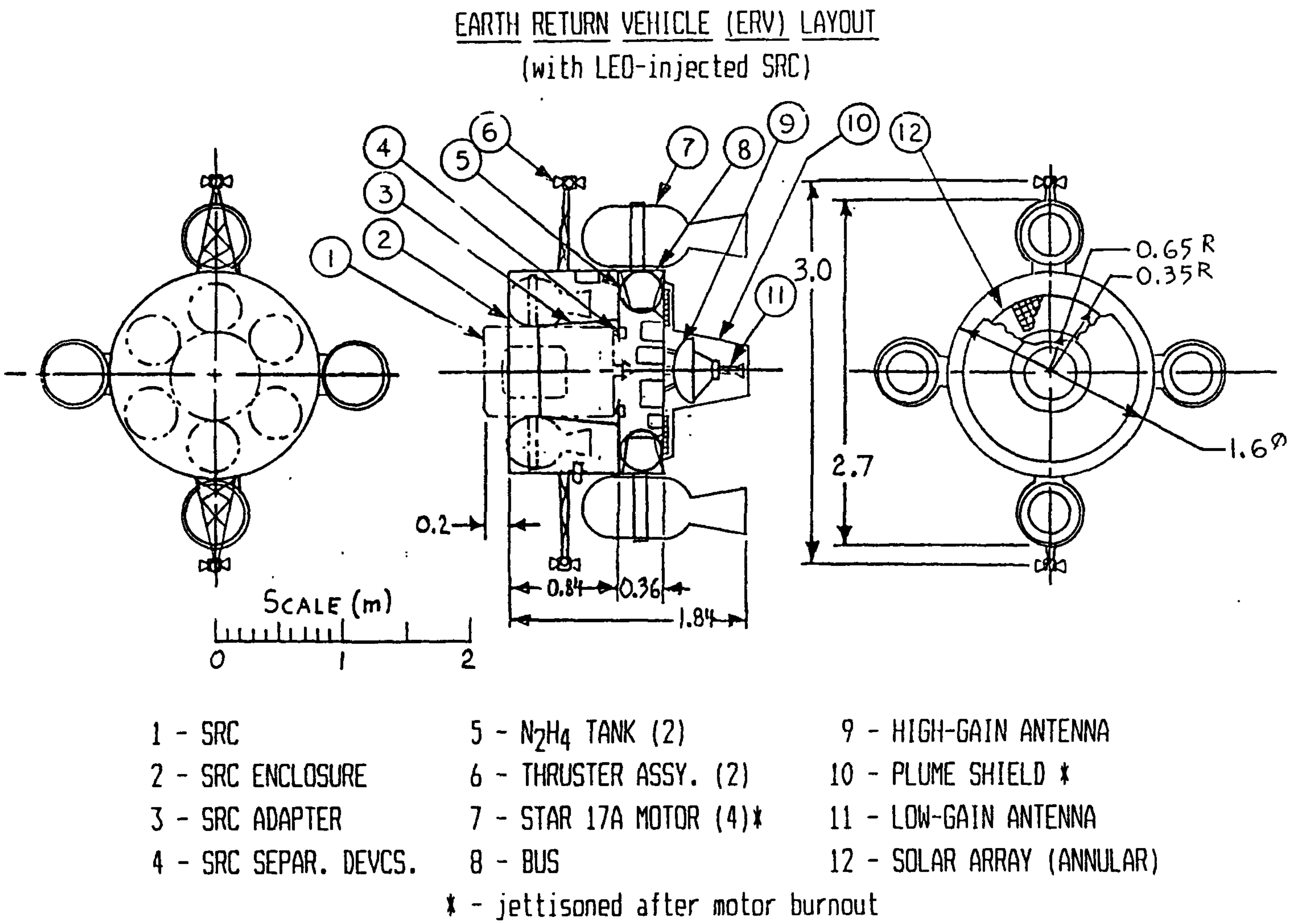


Table 3.1-1, Earth Return Vehicle System Breakdown, Propulsive Capture SRC (Norton, 1988)

Subsystem/Element	Mass (kg)	Pwr (W)	Remarks
Telecommunications:	(18.4)	(24.2)	
X-bd. transponder & CDU (2)*	5.0	14.0	(MO) JPL Techn.
X-bd. SSPA (1.2 W RF) (2)	2.0	6.0	1/4 CRAF (80% CRAF inherit.)
TMU (2)	1.1	3.0	CRAF (100%)
Receiver RF Switch	0.5	-	CRAF (50%; less power)
Transmitter RF switch	0.5	-	CRAF (50%; less power)
Interface/Control (2)	2.8	1.2	GLL, CRAF
Cables, hybrids	1.0	-	60% CRAF
Wave guides	1.6	-	50% CRAF
Diplexers (2)	0.8	-	CRAF
Low gain antenna	0.4	-	CRAF
High gain antenna (1.5m), feed	1.5	-	new
ERV/MRO RF switches (4)	1.2	-	new
Power & Pyro:	(17.1)	(5.0)	
Solar array (annular body-mtd.)	2.2	-	GaAs, 0.9 m^2, 57 W @ 1.6 AU
Batteries	2.3	-	$LiTiS_2$, 150 W.h
Bi-dir. conv., Ctl., Distrib.	5.6	4.0	1/3 of CRAF
Shunt regulator	1.6	1.0	1/2 of CRAF
Shunt radiator	1.8	-	1/2 of CRAF
Pyro switching unit (2)	3.6	-	GLL, CRAF
Command and Data:	(11.0)	(8.8)	
Main unit, TLM & CMD (2)	10.0	8.0	(SME-50%), updated, Gulton
Data storage	1.0	0.8	(new) 1 Mbyte, solid-state
Attitude Control:	(10.8)	(8.6)	(spin-stabilized)
Acquis. sun sensor (3)	0.3	0.1	Pioneer V.(M.-P.)(80%)
Cruise sun sensor, +/-64° FOV (2)	1.0	0.6	ADCOL (off-the-shelf)
Star sensor	2.9	1.0	Pioneer V.(M.-P.)(80%), Ball
Attitude data processor	5.7	6.9	Pioneer V.(M.-P.)(60%)
Nutation damper (passive)	0.9	-	Pioneer V.(M.-P.)(80%)
Cabling:	(17.0)		
Sys./subsys. cabling	16.0		
SRC umbil. cable	1.0		
Temp. Control:	(6.0)		
Insulation	2.8		
Louvers	2.4		
Heaters	0.8	(20.0)**	

* Some numbers in paren. indicate system redundancy
** Short term, bat. powered

Table 3.1-1, Earth Return Vehicle System Breakdown, Propulsive Capture SRC, Continued (Norton, 1988)

Subsystem/Element	Mass (kg)	Pwr (W)	Remarks
Mechan. Devices:	(4.7)		
SRC release/separ. devices (3)	2.1		
SRM rel./separ. devices (4)	1.6		
SRC umbil. cable cutter	0.1		GLL
Plume shield rel./separ. dev. (3)	0.9		
Structures:	(46.4)		
Bus. w. equip. supts.	21.2		w.GR/Ep reinforced load path
SRC enclosure	6.6		0.9 mm fil.-wound Kevlar/Ep
SRC adapter	10.4		Gr/Ep
Thruster outriggers (2)	3.2		
Antenna supports (tripod)	0.6		
Plume shield	4.4		thin Ti, TiO_2 coated
Subtotal:	131.4	46.6	
Contingency:	17.7	7.0	(18% of 72.5 INTG.,+ 8% of 58.9 ELEC.; 15% Power)
Total (dry):	149.1	53.6	
RCS (spinner-type):	(67.8)		for 200 m/s (TCM and ACS)
Inerts and supports	15.8		
Propellant	52.0		N_2H_4
Subtotal (ERV + RCS):	216.9		
TEI PROP.:	(851.7)		for delta-V = 2023 m/s
Inerts and supports	106.3		4 STAR 17A, stretched 11.7 in solid
Propellant	745.4		
Total (ERV wet + TEI PROP.):	1,068.6		
Cumulative Total (ERV+SRC):	1,463.7		(for SRC inj. into 370 km circular Earth orbit)

Figure 3.1-2, Earth Return Vehicle (ERV) with Aerocapture SRC (Gamble, 1988)

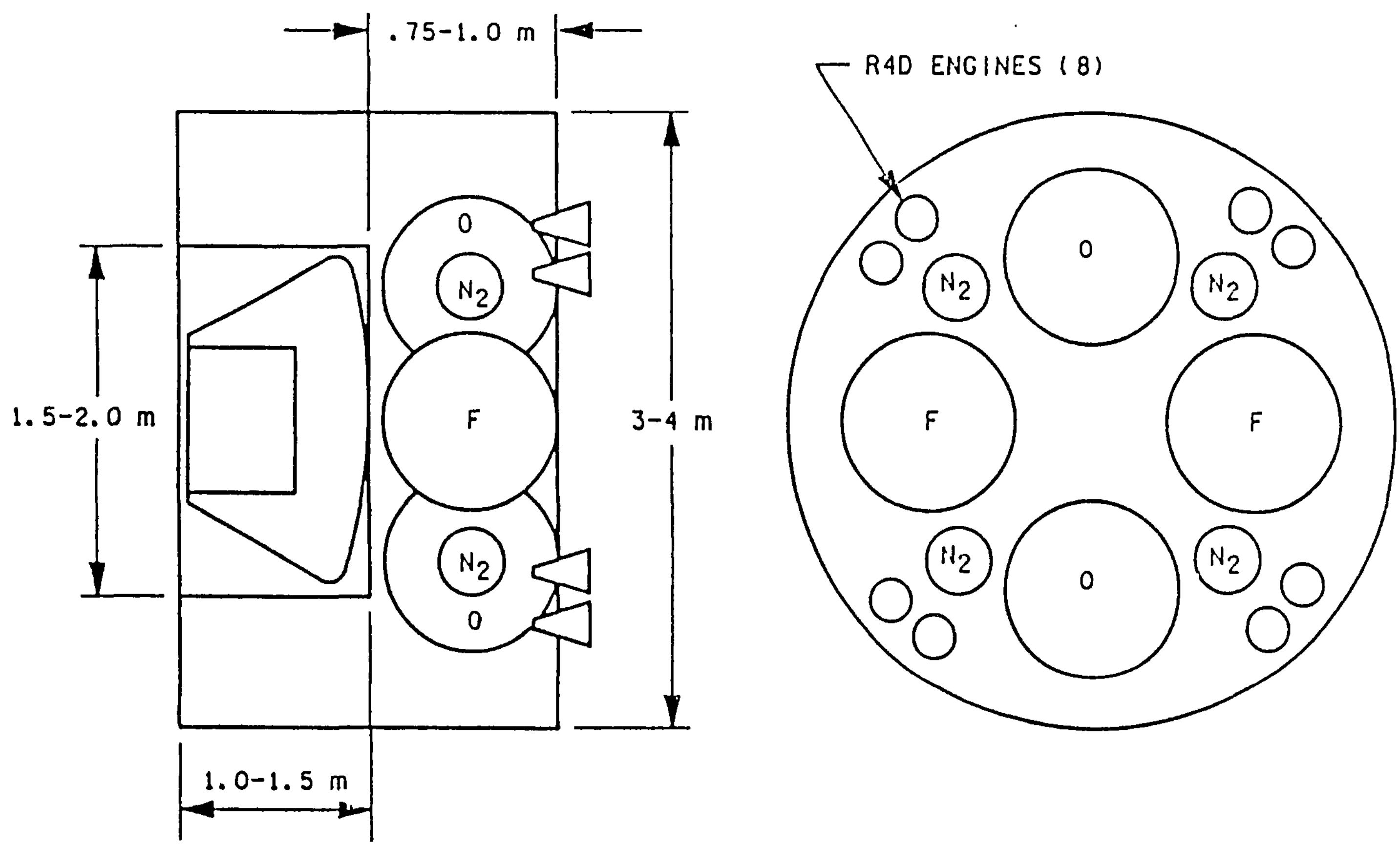


Figure 3.1-3, Earth Return Vehicle (ERV) with Aerocapture SRC (Lawson, 1988)

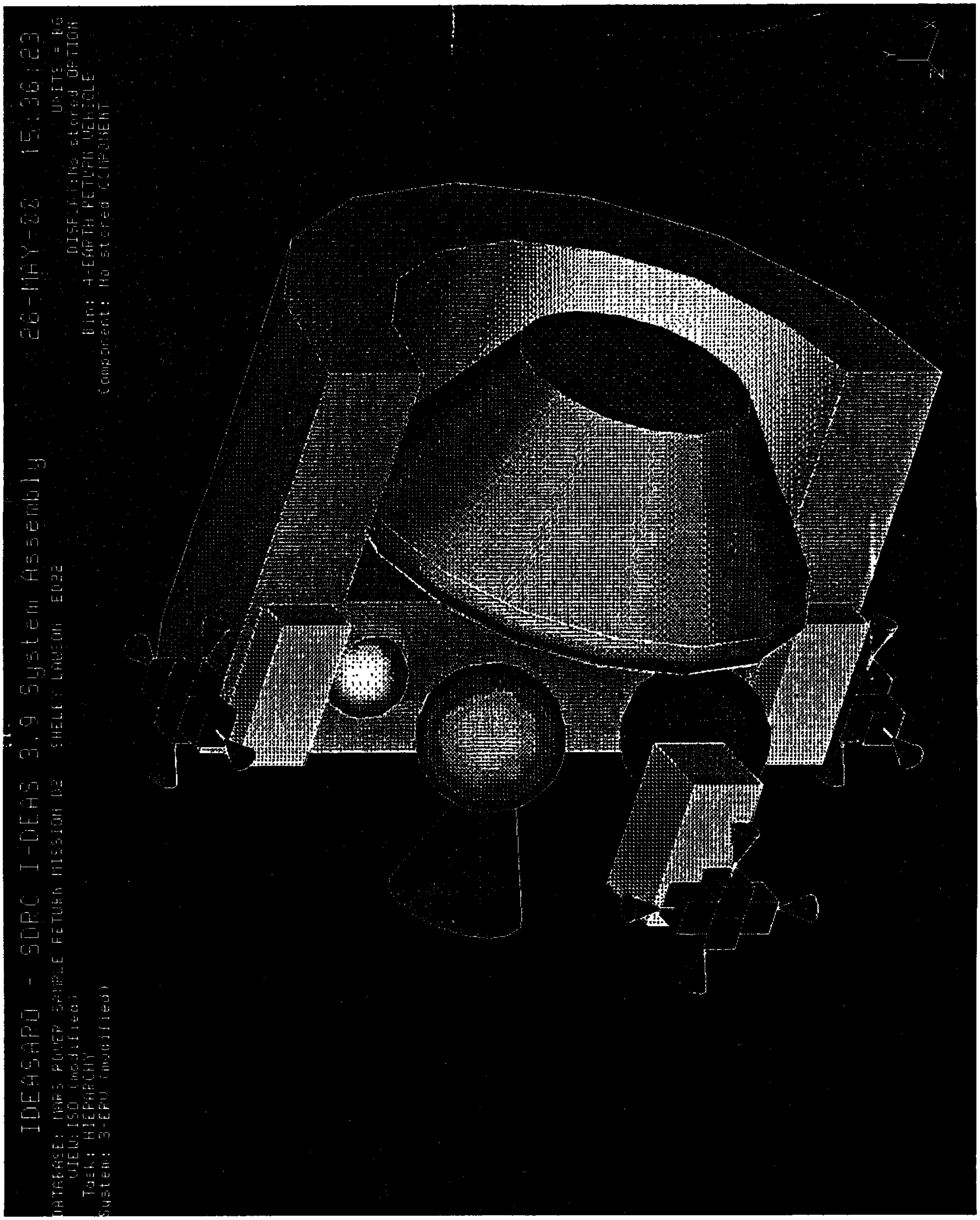


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Table 3.1-2, Earth Return Vehicle Weight Statement, Aerocapture SRC (Lawson, 1988)

Component	Total Dimensions	Total Mass
Structure	2.74m dia x 1.65m height with 1.9m dia x 1m height cutout for SRC	8.12 kg
Propulsion System		
Engines		
- R-40B engine (1)		7.26 kg
- R-1E engine (16)		25.4 kg
Propellant System		
- Fuel		147.9 kg
Fuel tank (2)	0.28m dia sphere	3.6 kg
- Oxidizer		244.0 kg
- Oxidizer tank (2)	0.28m dia sphere	3.6 kg
- Pressurant		21.8 kg
- Pressurant tanks (2)	0.16m dia sphere	20.2 kg
Misc Propulsion		4.1 kg
Total Propulsion System		477.86 kg
Thermal Control		1.36 kg
Avionics (No computer)		90.7 kg
High Gain Antennae		? kg
Solar Panels and Rechargeable secondary batteries (150% of required power)		? kg
ERV total (w/o SRC & Sample)		651.12

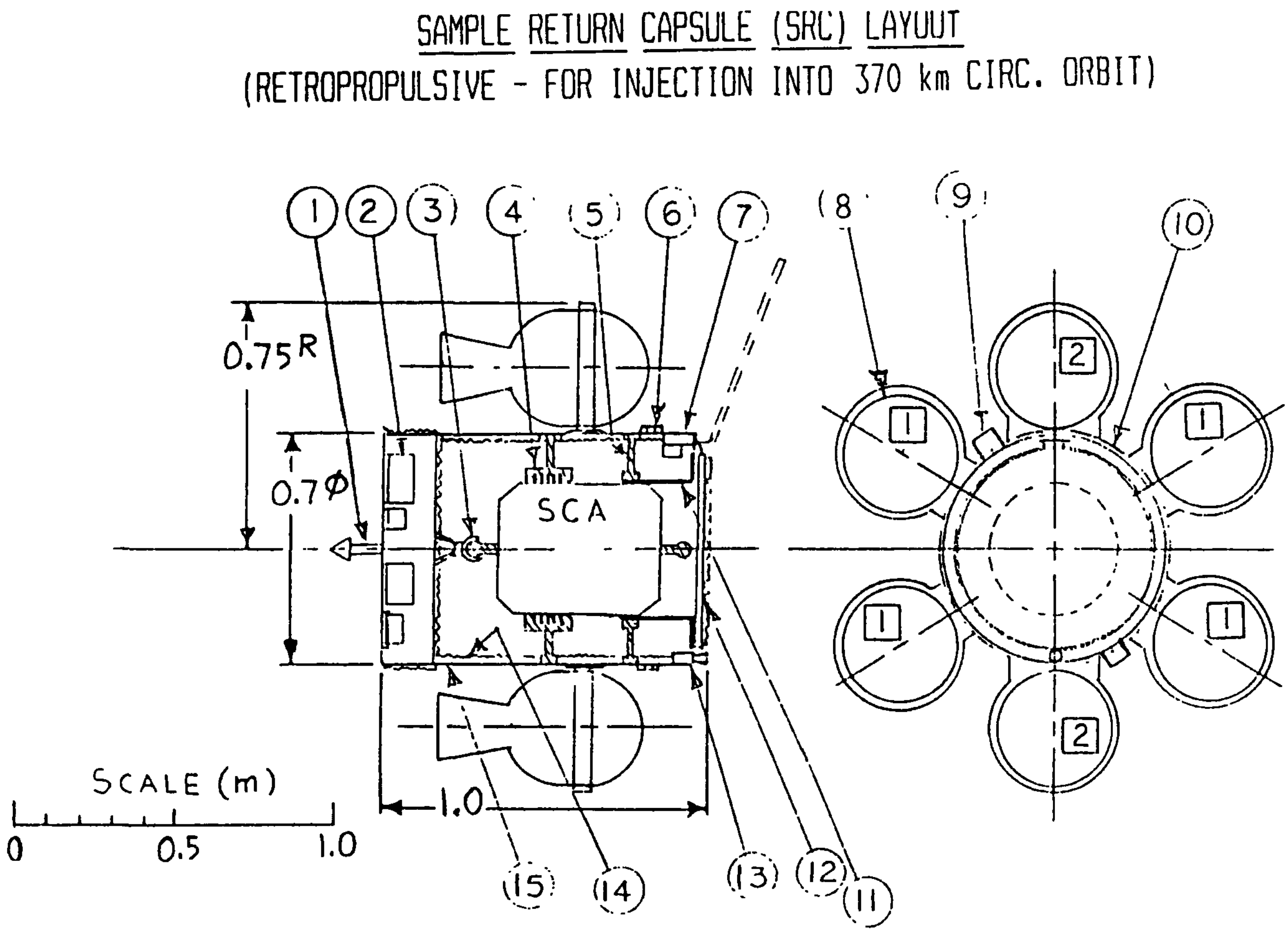
Table 3.1-3, Earth Return Vehicle Propulsion System, Aerocapture SRC (Gamble, 1988)

Assume Payload Mass of 360 kg (SRC + SCA)
Delta V Requirement = 2027 m/sec TEI (Primary)
= 200 m/sec TCM (RCS)

Option II - 1 Primary + 16 RCS

Item	
Primary engine (#)	R-40B (1)
Thrust, lbf (ea)	900
Isp, sec	309
Mass, lbm	16.0
RCS engine (#)	R-1E (16)
Thrust, lbf (ea)	25
Isp, sec	280
Mass, lbm	3.5 ea
Fuel system	MMH
Fuel mass, lbm	326
Number of tanks	2
Tank config.	Spherical
Tank radius, ft	0.92
Tank mass, lbm	3.95
Oxidizer system	NTO
Ox mass, lbm	538
Number of tanks	2
Tank config.	Spherical
Tank radius, ft	0.92
Tank mass, lbm	3.95
Pressurization system	N2
Press mass, lbm	4B
Number of tanks	2
Tank config.	Spherical
Tank radius, ft	0.54
Tank mass, lbm	22.25

Figure 3.2-1, Propulsive Capture Sample Return Capsule
(Norton, 1988)



1 - OMNI ANTENNA
2 - ELECTR. EQUIP.(TYP.)
3 - SCA RETENTION LATCH
4 - BRUSH BLOCK SUPT. RING
5 - RADIATOR SUPPORT RING
6 - SOLAR ARRAY
7 - COVER HINGE DRIVE
8 - STAR 13A MOTORS (6)
9 - DESPIN YOYO ASSY.(2)
10 - STRUCT. REINF. RING
11 - SCA RADIATOR
12 - RADIATOR COVER
13 - SOLAR INCID.SENSOR
14 - MLI (TYP.)
15 - BUS

Table 3.2-1, Sample Return Capsule (Propulsive) Weight Statement (Norton, 1988)

VEHICLE Subsystem/Element	Mass (kg)	Pwr (W)	Remarks
SAMPLE CANISTER ASSY. (SCA)			
Sample	5.0	-	
Sample vials (19)	1.4	-	
Teflon retainer block	0.8	-	
Inner container w. therm. insul.	1.8	-	
T & P sensors 0.3	1.5	(SRC power)	
Slip ring assy. 0.4	-		
Canister shell w. gasket	2.6	-	
Canister thermal insulation	0.6	-	
cover, seal mech., and lid assy.	1.6	-	
Lid hinge, drive, motor assy.	0.8	*	*(powered from RVR or MAV)
Seal drive motor	0.4	*	*(powered from RVR or MAV)
Lid latch mechanism	0.4	*	*(powered from RVR or MAV)
Retention shafts (2)	0.6	-	Kevlar/epoxy
Wiring, drives connector	0.4	-	
Subtotal without sample:	12.1	1.5	
Contingency:	2.2	0.2	(18% on mass)
Total without sample:	14.3	1.7	
Sample:	5.0		
Total with sample:	19.3	1.7	
SAMPLE RETURN CAPSULE (SRC)			
Electronics:	(8.9)		
Telecom. + Telem. Unit	1.6	3.4	8 b/s dwnlk.only, omni ant.
PWR: Solar array	0.4	-	Body mtd., GaAs, 0.15m^2, 8 W
Batteries	1.5	-	-$LiTiS_2$, 100 W.h
Condg./Ctl./Distrib.	1.0	-	
Event timer	0.2	*	Solid-state: * - milliwatts
Pyro unit (2), jettis. squibs	3.7	*	GLL/CRAF; * - 1 W to charge
Solar incidence sensor	0.2	0.1	
Hinge drive control unit	0.3	0.1*	* - standby power
Structures, Cabling, Mechanisms:	(31.9)		
Bus	9.4	-	1 mm AlAly, 4 2-mm stingers
Struct. reinforcmt. for SRM's	3.6	-	1 cm thk. x 10 cm Gr/Ep ring
SCA retention latch, support	0.6	-	Kevlar/epoxy support
SCA brush block support ring	3.0	-	Kevlar/epoxy
Radiator support ring	2.3	-	Kevlar/epoxy
SCA radiator (annular)	3.7	-	1 mm thick Cu, full hard
Hinged radiator cover	0.4	-	1 mm AlAly, covered with MLI
Rad. cover hinge drive	0.4	(4.0)	(intermittent power)
Despin yo-yo assy. (2)	1.0	-	incl. deploy., separ. mech.
Internal MLI blankets	1.3	-	1.9 m^2

Figure 3.2-2, Power Subsystem, MRO/ERV/SRC
(Norton, 1988)

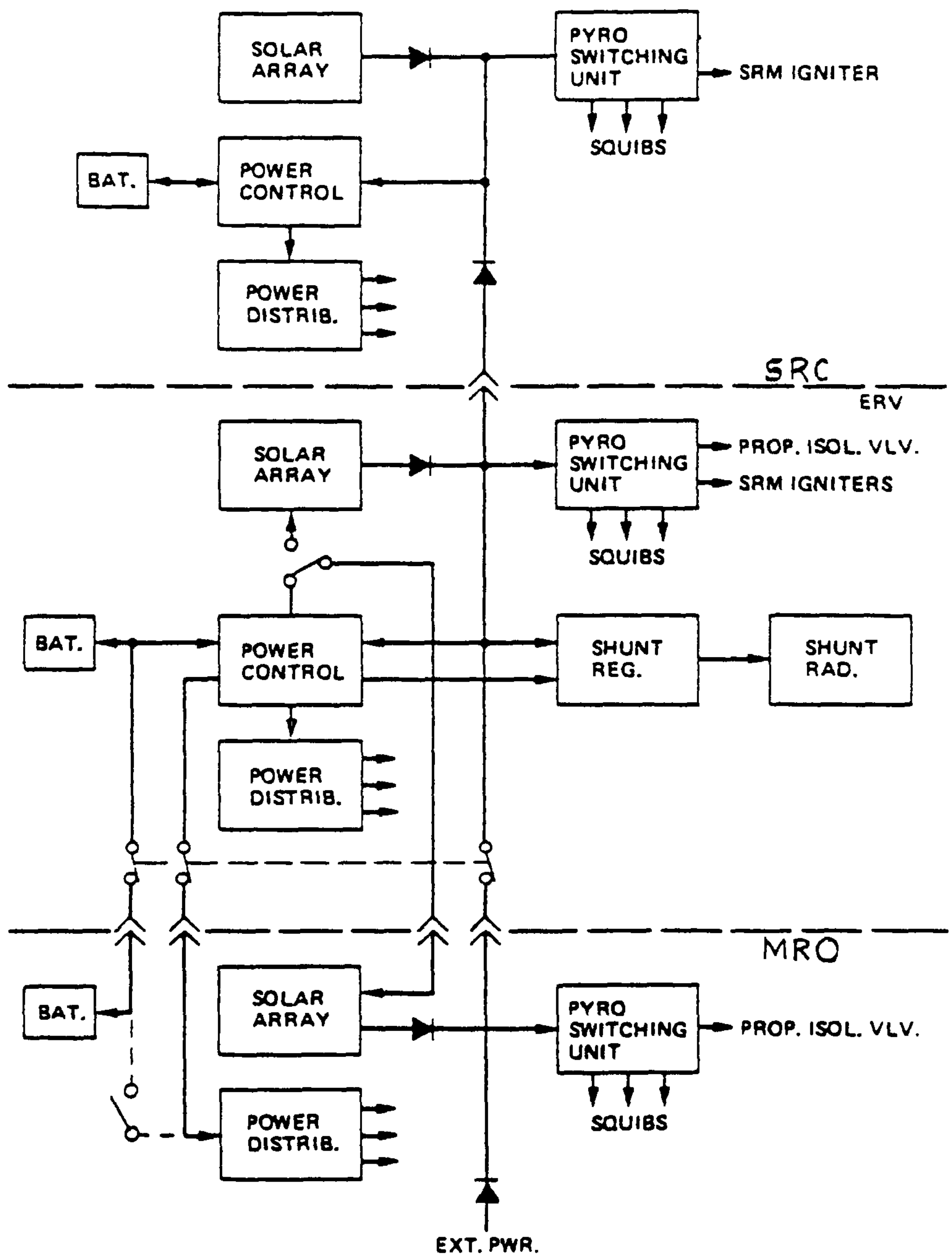


Figure 3.2-3, Communications and Data Subsystems, MRO/ERV/SRC (Norton, 1988)

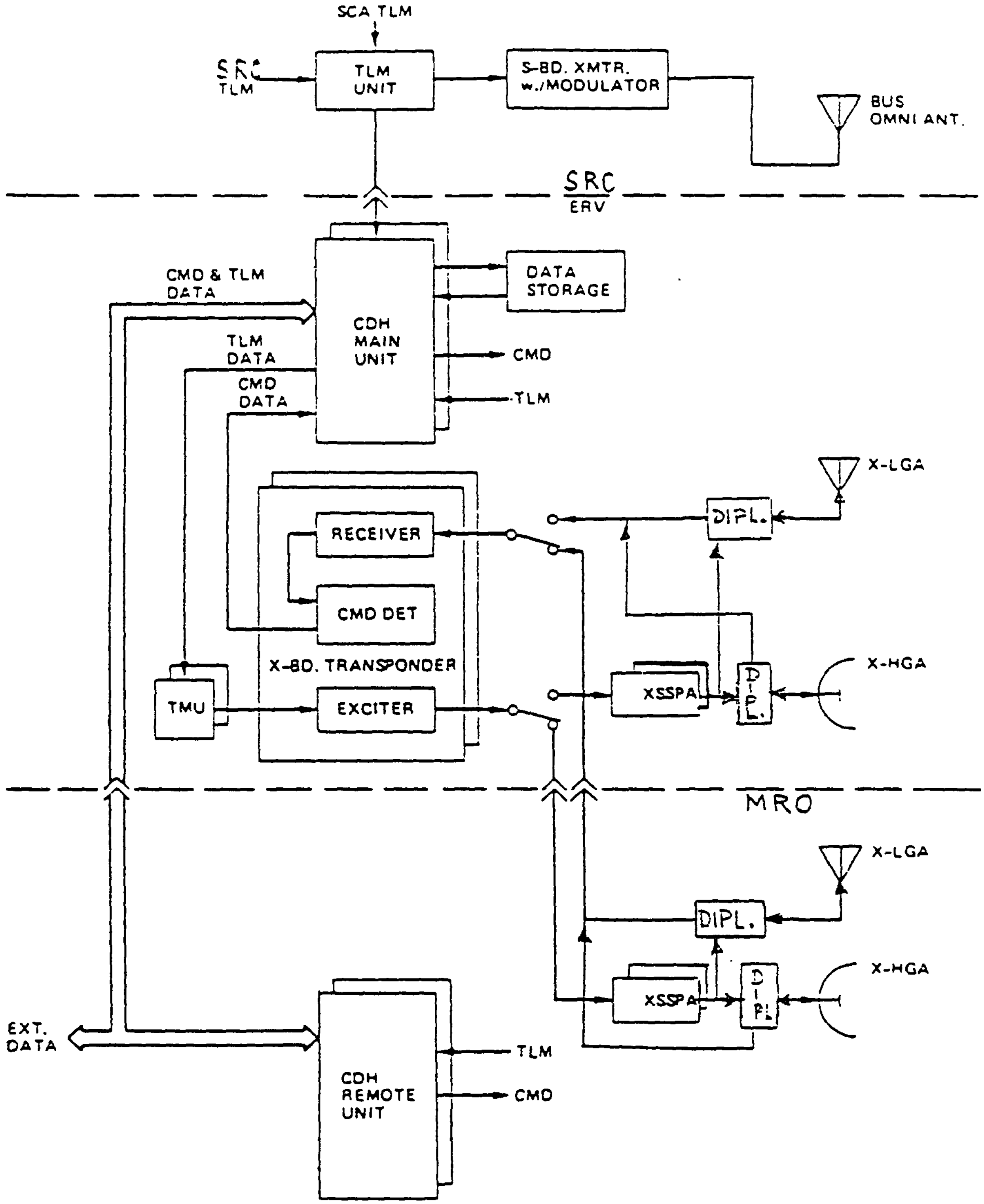


Figure 3.2-4, Sample Return Capsule configured for Aerocapture (Gamble, 1988)

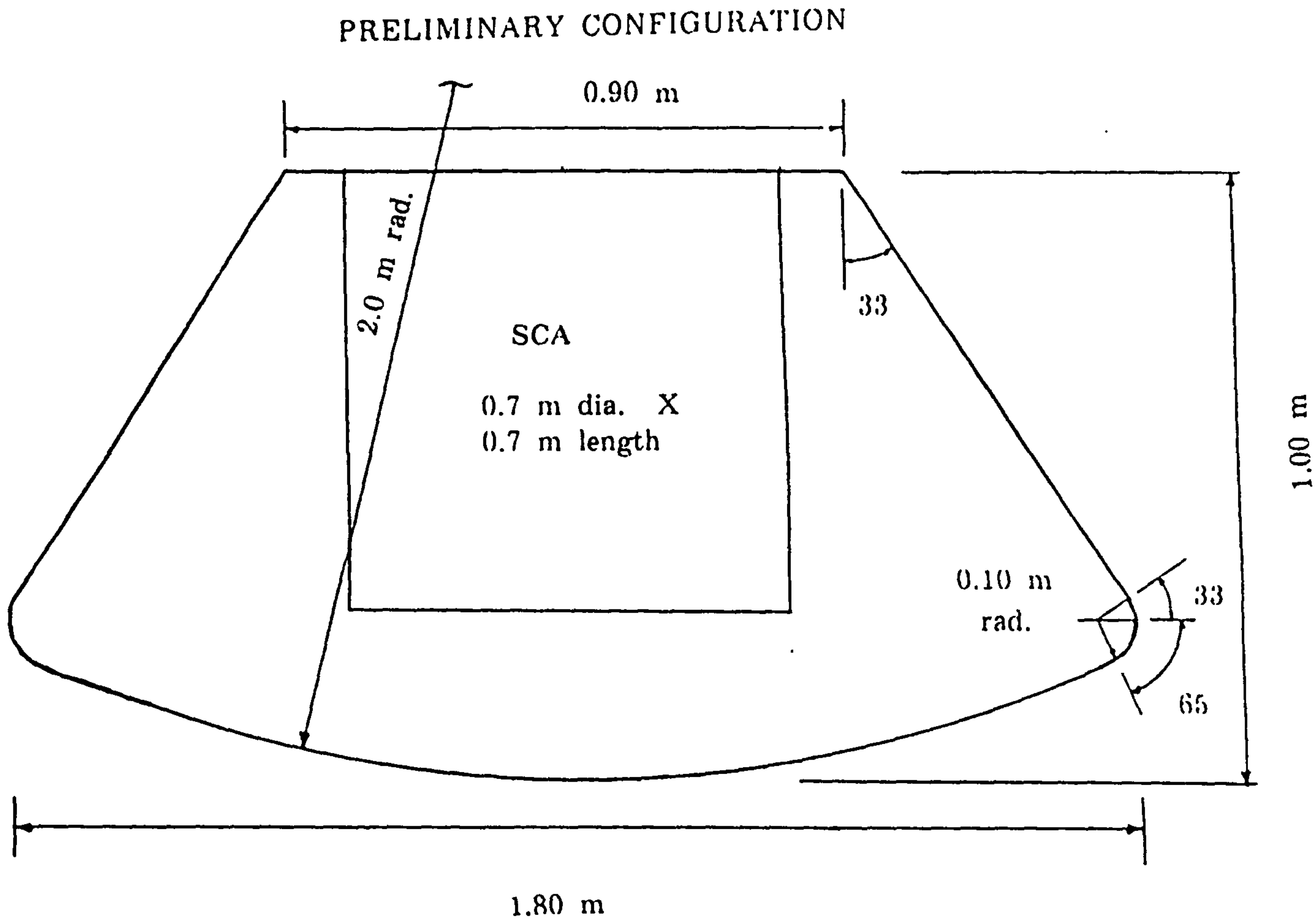


Table 3.2-2, Sample Return Capsule (Aerocapture) Weight Statement (Lawson, 1988)

Component		Total Dimensions (meters)	Total Mass (kg)
Sample Canister Assembly		.07m dia, 0.7m height cylinder	19 kg unloaded, 24 kg loaded
Propulsion System (will handle one failure per RCS pod)			
- Oxidizer		sphere	10.9 kg
- tank (2)		0.195 dia	0.18 kg
- Fuel		sphere	6.35 kg
- tank (2)		0.195 dia	0.18 kg
- Pressurant		sphere	0.91 kg
- tank (2)		0.1158 dia	0.91 kg
- R-1E engine (8)	nozzle .274m length, .1m dia, scarf 33° engine block .13m length, .14m width & height		25.4 kg
- R-6E engine (8)	nozzle .271m length, .055m dia, scarf 34° engine block .13m length, .065m width, .075m height		10.9 kg
- Misc Propulsion			1.36 kg
Total Propulsion			57 kg
Structure 1.8m scaled Apollo capsule with			
- Capsule 1.0m total height, 0.1m thickness			70 kg
- TPS			74 kg
			144 kg
Avionics (dual string)			
Computation & Data Handling (1)			
- Computer (2 fault tolerant) .29 , .22w, .19h			20 kg
IMU (3) .153 , .153w, .153h			6 kg

Table 3.2-2, Sample Return Capsule (Aerocapture) Weight Statement, Continued (Lawson, 1988)

Component	Total Dimensions (meters)	Total Mass (kg)	
Power (3 Battery Packs) 150% of req.	.254 , .254w, .20h	16 kg	
Power Distribution & Control/RCS Control Electronics (dual string), from AFE			
- Control Electronics	.20 , .38w, .23h	35 kg	
- Power Amplifier	.254 , .06w, .13h	2 kg	
- RF Switch (2)	.076 , .05w, .038h	1 kg	
- Diplexer	.15 , .05w, .044h	1 kg	
- RF Filter	.13 , .03w, .025h	1 kg	
Total (Power Dist)		40 kg	
Communications (taken from AFE) (2)			
- Electronics/transceivers (2)	.29 , .22w, .19h	10 kg	
- Antennas (2)	.203 dia half sphere	0 kg	
- Transponder (1)	.33 , .14w, .14h	5 kg	
Total (Communications)		15 kg	
Star Tracker (2) (from AFE)	.168 , .18w, .31h	10 kg	
Sample Return Capsule Accounted Mass (without SCA)		308 kg	(679 lbs)
Sample Return Capsule Accounted Mass with SCA		327 kg	(721 lbs)
Sample Return Capsule Accounted Mass with SCA & Sample		332 kg	(732 lbs)

* no thermal control mass growth included

Table 3.2-3, SRC Propulsion System (Gamble, 1988)

Item	
Primary engine (#)	R-1E (8)
Thrust, lbf (ea)	25
Isp, sec	280
Mass, lbm	7.0
Secondary engine (#)	R-6C (4)
Thrust, lbf (ea)	5
Isp, sec	290
Mass, lbm	3.0
Fuel system	MMH
Fuel mass, lbm	14.0
Number of tanks	2
Tank config.	Spherical
Tank radius, ft	0.32
Tank mass, lbm	0.2
Pressurization system	N2
Press mass, lbm	2.0
Number of tanks	2
Tank config.	Spherical
Tank radius, ft	0.19
Tank mass, lbm	1.0

Figure 3.3-1, Direct Entry Capsule
(Kerridge and Atzei, 1987)

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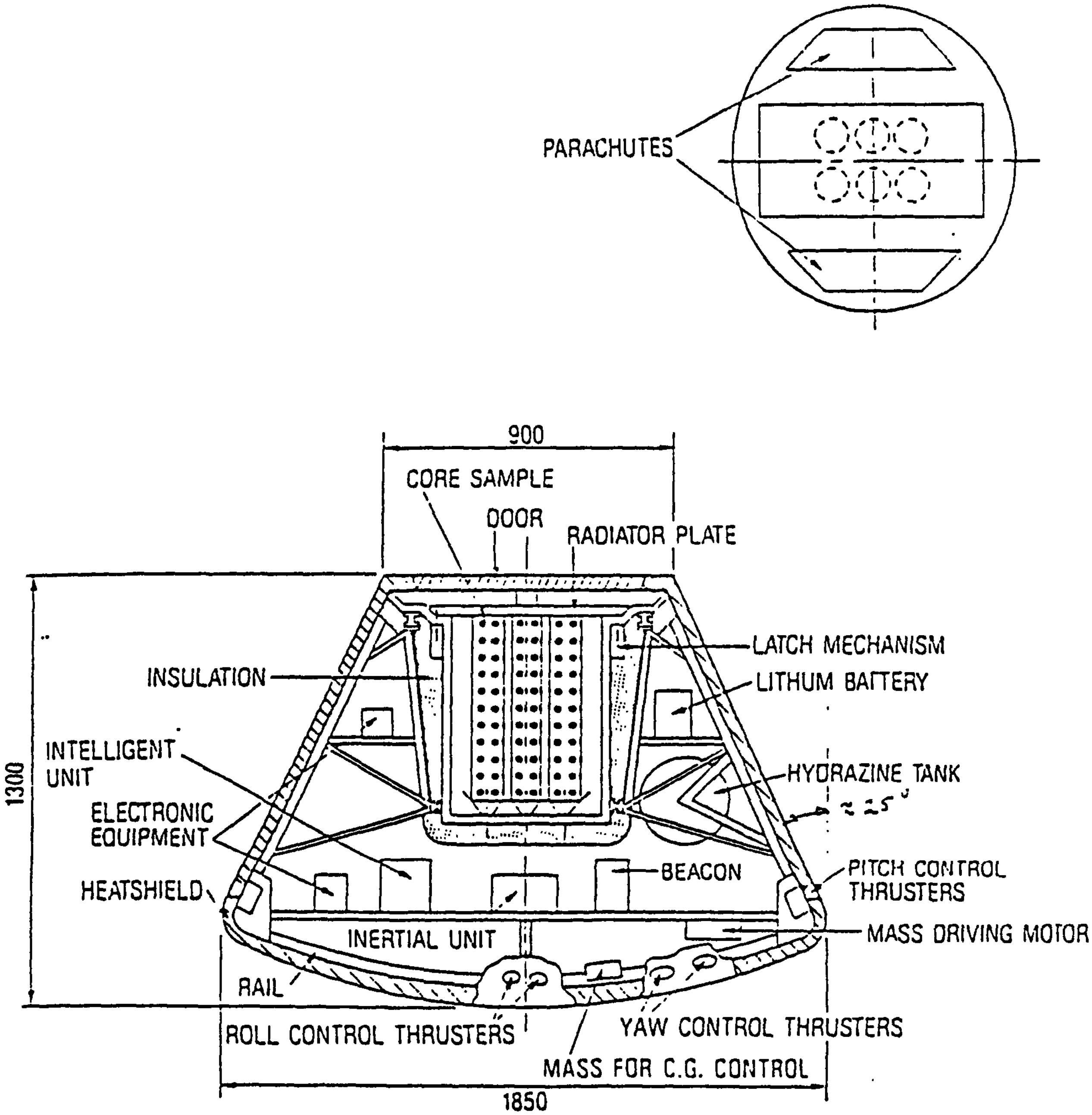

Figure 3.3-2, Discoverer Capsule Dimensions

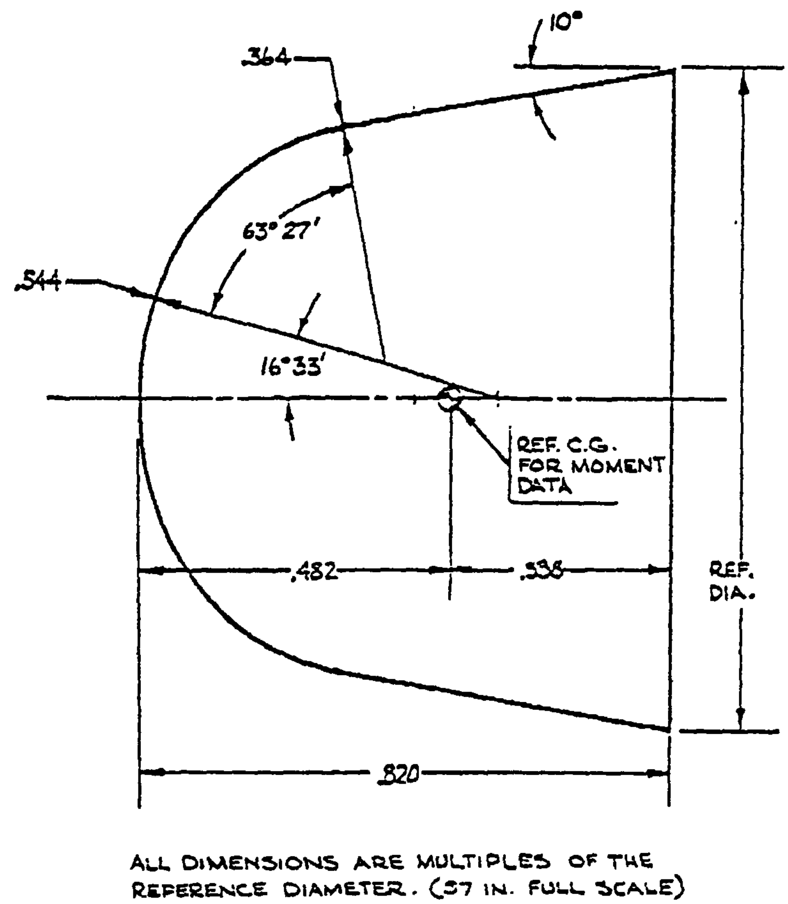

Figure 3.4-1, Sample Canister Assembly
(French and Blanchard, 1985)

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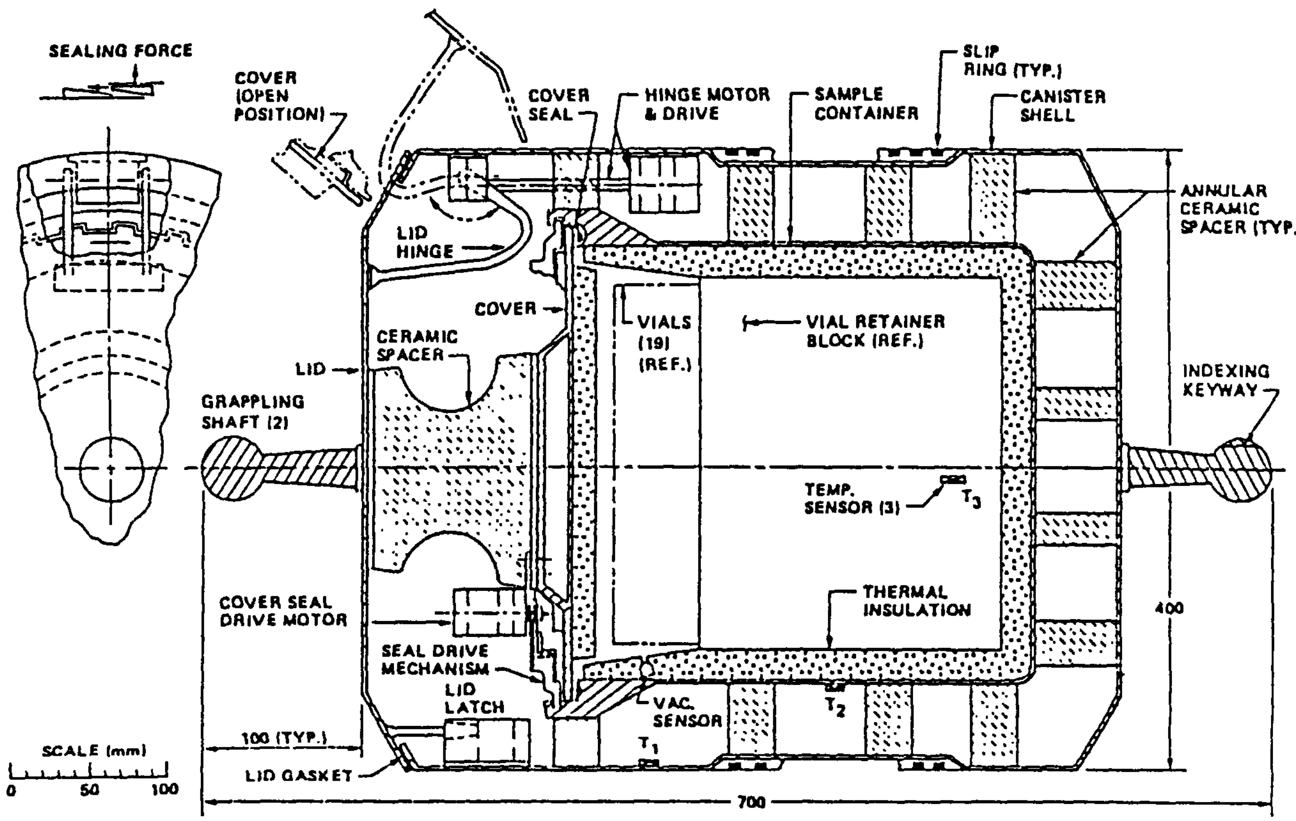
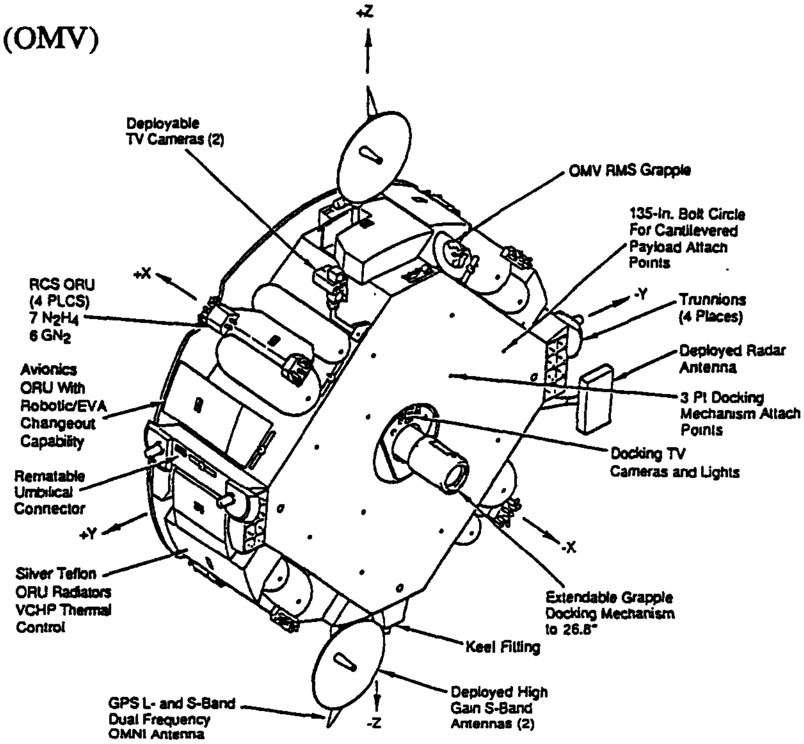
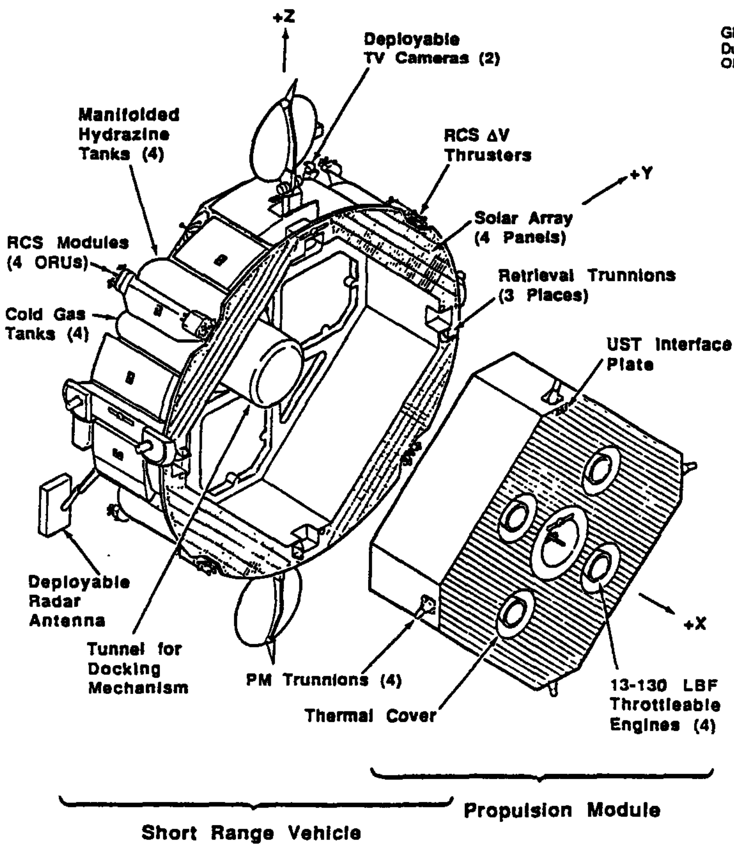


**Figure 3.5-1, Orbital Maneuvering Vehicle (OMV)
(User's Guide, 1987)**



OMV CONFIGURATION: VIEW OF FRONT FACE



OMV CONFIGURATION: VIEW OF BACK FACE

Figure 3.6-1, Canister Pallet
(Simonds, 1988)

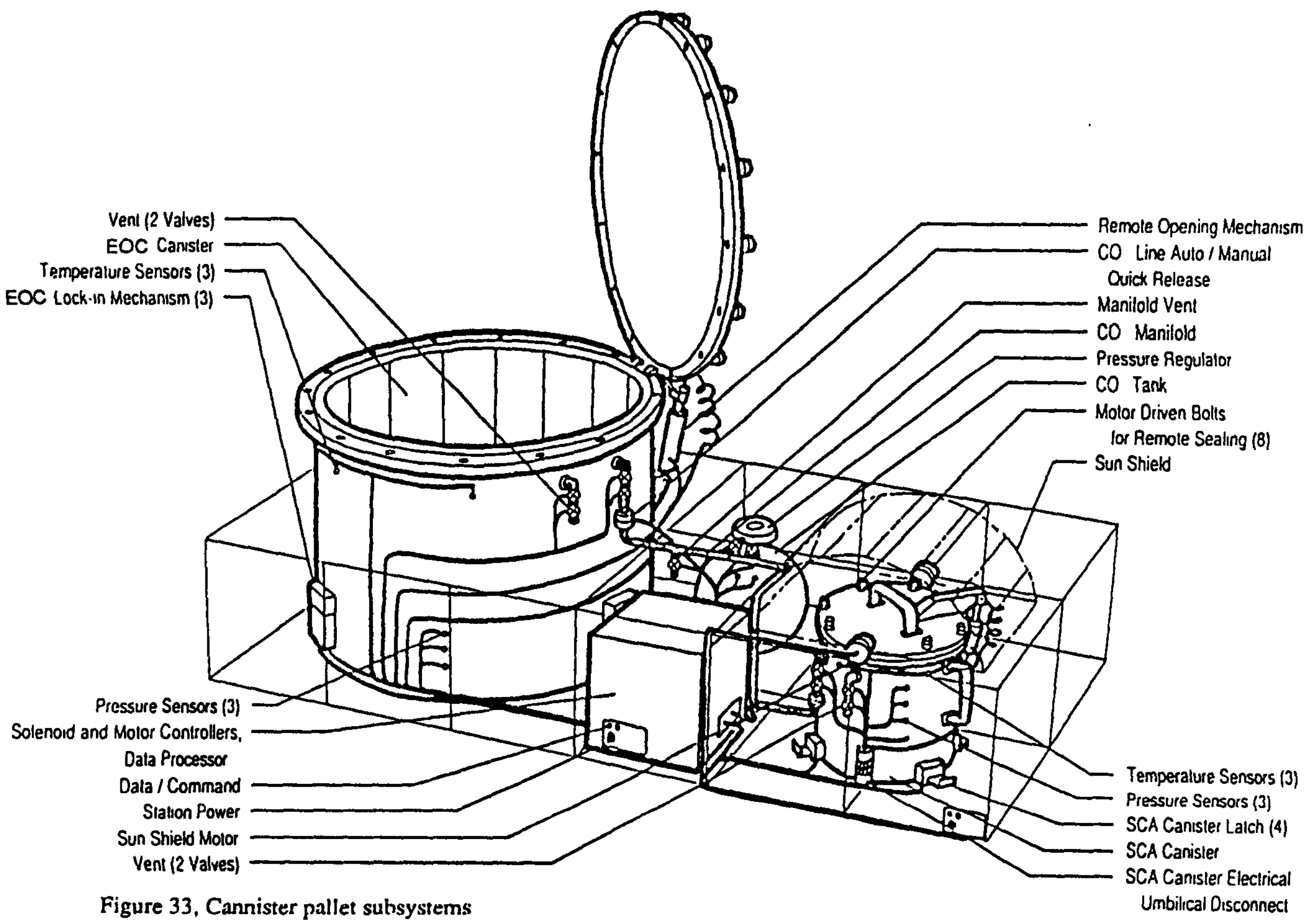


Figure 33, Cannister pallet subsystems

4.0 Comparable Operations in Each Sequence

This report presents two different methods of assessing the risk of various types of failures of the earth return phase of the mission. The first method is to compare the nominal operational sequences of each option.

Table **4.0-1** shows the top level sequence for several options. A rough comparison of the complexity of the options can be seen by comparing the steps in each sequence. Some steps, such as a shuttle launch, are really far more complex in terms of sequential steps than is shown here, but the general trend is correct. The sequence is for a single mission only. A dual mission has additional steps in some options, such as refueling the OMV.

Several key points can be inferred from Table 4.0-1. First, the first five steps are common to all options. Thus to a first approximation, the probability that these events go nominally does not affect the relative risk of the options. The second inference is that the Space Station based options require nearly twice as many steps as those partly dependent on the Shuttle, and those depending on the Shuttle have nearly twice as many steps as direct entry.

Thus, to bring the complex Space Station based options to a similar level of reliability as the shuttle based or direct entry option will require significant extra redundancy and other risk reduction techniques. Similarly, bringing the shuttle based options up to the level of reliability of the simpler direct entry case will require significant effort. Sections 5 and 6 of this report provide detail on the individual steps and how they link together in both nominal and off-nominal missions.

Table 4.0-1, Top Level Sequence for Return Options

Aerocapture to Space Station	Propulsive Capture to Station	Aerocapture to Shuttle	Propulsive Capture to Shuttle	Direct Entry to Surface
1. Midcourse correction	→	→	→	→
2. SRC goes on batteries	→	→	→	→
3. SRC and ERV separate	→	→	→	→
4. ERV thruster fires to miss Earth	→	→	→	→
5. Nav. Update	→	→	→	→
6. Aerocapture	6. Insertion Burns, (2 Stages)	6. Aerocapture	6. Insertion Burns, (2 Stages)	6. Entry
7. Perigee Raise	7. Despin	7. Perigee Raise	7. Despin	7. Shroud Release
8. Shuttle Launch with OMV and canister pallet (4 burns)	→	8. Shuttle Launch with canister pallet (4 burns)	→	8. Drogue Deployment
9. Shuttle Rendez. with station (10 burns)	→	9. Shuttle rendez. with SRC (10 burns)	→	9. Main Chute Deployment
10. Shuttle prox. ops.	→	10. RMS grapples SRC	→	10. Air Snatch
11. Canister pallet and OMV placed on truss	→	11. SRC placed in SRC canister	→	11. SRC placed in SRC canister
12. OMV Deployed	→	12. SCA removed from SRC	→	12. SCA removed from SRC
13. OMV Rendezvous with SRC (10 burns)	→	13. SCA placed in SCA canister	→	13. SCA placed in SCA canister
14. OMV prox. ops./ docks with SRC	→	14. Shuttle deorbit	→	14. Aircraft lands
15. OMV/SRC rendez. with Sta.(10 burns)	→	15. Shuttle lands	→	
16. OMV/SRC prox. ops.	→			
17. OMV/SRC placed on truss	→			
18. SRC placed in SRC canis.	→			
19. SCA removed from SRC	→			
20. SRC placed in SRC canis.	→			
21. Shuttle Launch (4 burns)	→			
22. Shuttle Rendez. with Sta. (10 burns)	→			
23. Shuttle Prox. Ops.	→			
24. Canister pallet placed in payload bay	→			
25. Shuttle deorbit	→			
26. Shuttle lands	→			
Total No. of Operations (1 burn counts as one operation): 68	69	27	28	14

5.0 Fault Trees

The second, more comprehensive method of risk analysis used in this report involves constructing a logic network for a sequence of events, nominal and off-nominal, for each option. The events lump together into nodes or big events, the complex series of mechanical, electronic and software operations that take place during each event. In general, redundant ways to accomplish the same function are not visible in the networks. For example using multiple computers with voting or having ground based calculation backing up flight computers does not appear in on the network. Instead the redundancy is taken into account in the probability estimates for each event. These estimates are discussed in section 6 of this report.

The following fault trees describe the major events and their possible results. The trees are not totally comprehensive. Inclusion of all possible fault paths is not possible or desirable in this study. Many highly improbable paths exist, that due to lack of resources or detailed knowledge of the systems involved are not covered. Coverage of all possible paths also leads to such a large tree that comprehension is difficult.

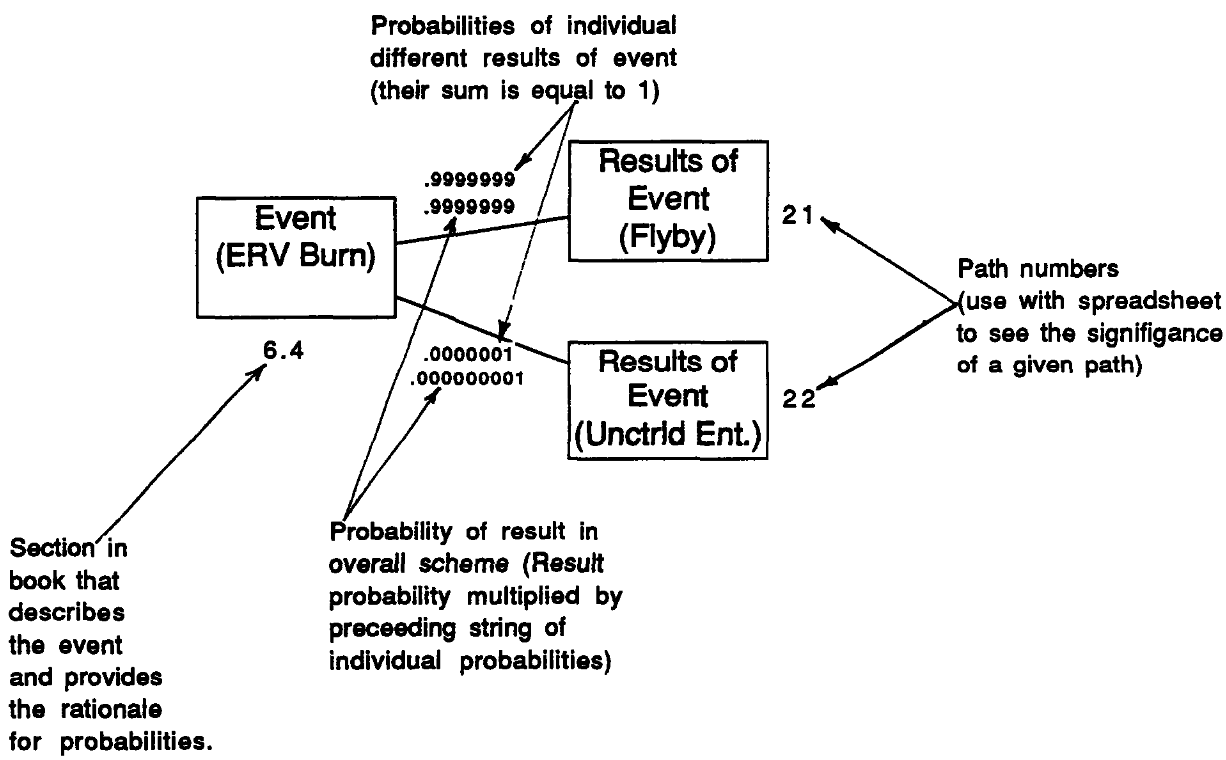
The approach used in this analysis is to define the sequence of events that occur in both nominal and off-nominal mission profiles. The events are exclusively those which are directly related to mission loss. The issues addressed in this analysis are focused on the relative merits of the direct entry, aerocapture, and propulsive capture approaches and whether it is better to attempt orbital rendezvous with the Space Shuttle or Freedom Space Station. Given the limited resources for this study and the preliminary level of definition of most of the Earth return options, the analysis was organized to focus on the differences between scenarios. Thus the fault trees showing the different mission options were built from a series of common elements, wherever possible and reasonable.

The fault trees are designed to show the sequence for recovery of a single SRC. The sequence for recovery for a second SRC will vary considerably depending on the spacing between the two SRC's in terms of time of arrival at Earth orbital altitude and orbital phasing with respect to each other and the Freedom Space Station. Only the direct entry approach is insensitive to the SRC relative timing, assuming that the two missions a separated by enough time for the air snatch and ground forces to redeploy.

Figure 5.0-1 shows how the probabilities are accounted for. Following each event are up to three paths, each with two probability numbers. The upper number is the probability that this particular result, rather than the other one or two listed, will occur. Adding up all the upper numbers after a given event should give 1.0. The lower numbers are the overall probabilities that this particular event will occur in the whole tree. They are the upper numbers for each line, multiplied all together, back to the start of the tree. Adding up all the lower numbers for the final events in each sequence gives 1.0.

Figures 5.1-1, 5.2-1, 5.3-1, etc. show the fault trees for the various options. Following each fault tree is a table, Tables 5.1-1, 5.2-1, etc. Each table shows the final probabilities of all the different paths through a tree, grouped such that the significant paths are easy to identify. Following these tables are another set of tables, Tables 5.1-2, 5.2-2, etc. These tables show the Lotus 1-2-3 spreadsheet calculations used to calculate the probabilities. Each row is a path through the tree. All the numbers in the row are multiplied together to give the final probability for that path. Events which do not occur in that particular path are represented with a 1.0 in the string of numbers multiplied together.

Figure 5.0-1, Explanation of Fault Tree Events



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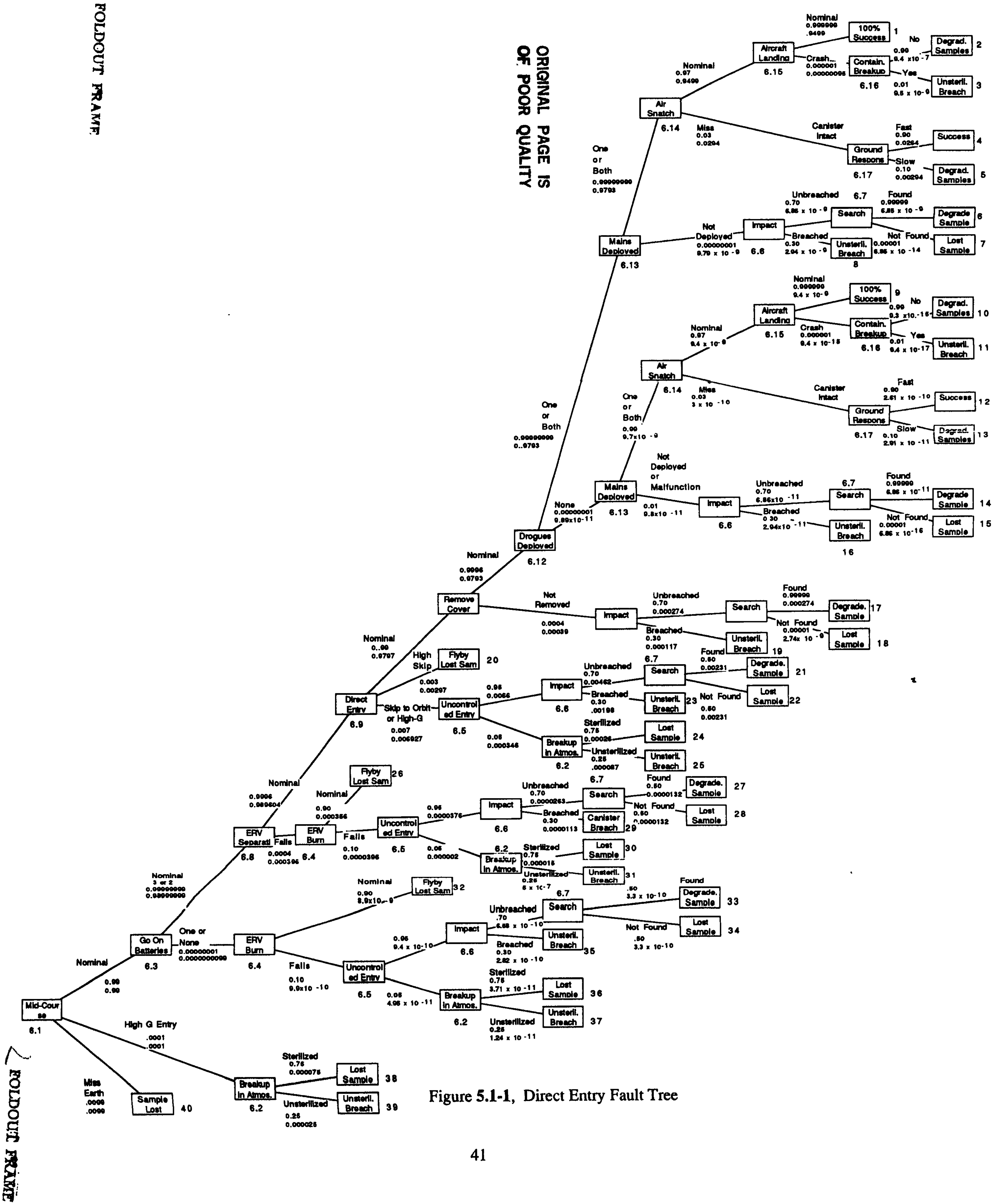

Figure 5.1-1, Direct Entry Fault Tree

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Table 5.1-1, Direct Entry Fault Tree Path Probabilities

Path #	100 % Success	Degraded Sample	Can. Breach (Sample Re-covrd or in theory rcvrable)	Can. Breach (Sample Dstroyed)	Unsteril. Lost Sample (on Earth)	Lost Sample (in Space)	Sterilized Lost Sample (on Earth)
1	0.94994						
2		9.40E-07					
3			9.50E-09				
4	0.02644						
5		0.00294					
6		6.86E-09					
7					6.86E-14		
8			2.94E-09				
9	9.40E-09						
10		9.31E-15					
11			9.40E-17				
12	2.62E-10						
13		2.91E-11					
14		6.86E-11					
15					6.86E-16		
16			2.94E-11				
17		0.00027					
18					2.74E-09		
19			0.00012				
20						0.00297	
21		0.00230					
22					0.00230		
23			0.00197				
24							0.00026
25				8.66E-05			
26						0.00036	
27		1.32E-05					
28					1.32E-05		
29			1.13E-05				
30							1.48E-06
31				4.95E-07			
32						8.91E-09	
33		3.29E-10					
34					3.29E-10		
35			2.82E-10				
36							3.71E-11
37				1.24E-11			
38							7.50E-05
39				2.50E-05			
40						0.00990	
41							
42							
Totals =	0.97638	0.00553	0.00210	0.00011	0.00232	0.01323	0.00034

Check Sum = 1.00000 Total of Canister Breached = 0.0045316824

Figure 5.1-2, Direct Entry Fault Tree Calculations

	Event->	Mid C.	Brk-up	Batt. On	ERV Burn	U.Entry Low A.	No Ch. Impact	Srch No Zn.	Srch in Zn.	ERV Sep.	Entry Direct	Aero-Captr	Remve Covr	Drgue Deply	Mains Deply	Air Snatch	Aircft Landng	Con.Brk Acft Cr	Grnd Rspn							
	Ref.	6.1	6.2	6.3	6.4	6.5	6.6	6.7	6.7	6.8	6.9	6.10	6.11	6.12	6.13	6.14	6.15	6.16	6.17							
	Nomin.	0.99	0.75	0.9999	0.9	0.95	0.3	0.5	0.9999	0.9996	0.99	0.99	0.9996	0.9999	0.9999	0.97	0.9999	0.99	0.9							
	Alt. 1	0.0001	0.25	1E-08	0.1	0.05	0.7	0.5	1E-05	0.0004	0.003	0.005	0.0004	1E-08	1E-08	0.03	1E-06	0.01	0.1							
	Alt. 2	0.0099	0	0	0	0	0	0	0	0	0.007	0.005	0	0	0	0	0	0	0	100 % Success	Degraded Sample	Can. Breach (Sample Re-covrd or in theory rcvrable)	Can. Breach (Sample Dstroyed)	Unsteril. Lost Sample (on Earth)	Lost Sample (in Space)	Sterilized Lost Sample (on Earth)
	Chk Sum	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000							
Path #	Event #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18							
1		0.99	1	0.9999	1	1	1	1	1	0.9996	0.99	1	0.9996	0.9999	0.9999	0.97	0.9999	1	1	0.94994						
2		0.99	1	0.9999	1	1	1	1	1	0.9996	0.99	1	0.9996	0.9999	0.9999	0.97	1E-06	0.99	1		9.40E-07					
3		0.99	1	0.9999	1	1	1	1	1	0.9996	0.99	1	0.9996	0.9999	0.9999	0.97	1E-06	0.01	1			9.50E-09				
4		0.99	1	0.9999	1	1	1	1	1	0.9996	0.99	1	0.9996	0.9999	0.9999	0.03	1	1	0.9	0.02644						
5		0.99	1	0.9999	1	1	1	1	1	0.9996	0.99	1	0.9996	0.9999	0.9999	0.03	1	1	0.1		0.00294					
6		0.99	1	0.9999	1	1	0.7	1	0.9999	0.9996	0.99	1	0.9996	0.9999	1E-08	1	1	1	1		6.86E-09					
7		0.99	1	0.9999	1	1	0.7	1	1E-05	0.9996	0.99	1	0.9996	0.9999	1E-08	1	1	1	1					6.86E-14		
8		0.99	1	0.9999	1	1	0.3	1	1	0.9996	0.99	1	0.9996	0.9999	1E-08	1	1	1	1			2.94E-09				
9		0.99	1	0.9999	1	1	1	1	1	0.9996	0.99	1	0.9996	1E-08	0.99	0.97	0.9999	1	1	9.40E-09						
10		0.99	1	0.9999	1	1	1	1	1	0.9996	0.99	1	0.9996	1E-08	0.99	0.97	1E-06	0.99	1		9.31E-15					
11		0.99	1	0.9999	1	1	1	1	1	0.9996	0.99	1	0.9996	1E-08	0.99	0.97	1E-06	0.01	1			9.40E-17				
12		0.99	1	0.9999	1	1	1	1	1	0.9996	0.99	1	0.9996	1E-08	0.99	0.03	1	1	0.9	2.62E-10						
13		0.99	1	0.9999	1	1	1	1	1	0.9996	0.99	1	0.9996	1E-08	0.99	0.03	1	1	0.1		2.91E-11					
14		0.99	1	0.9999	1	1	0.7	1	0.9999	0.9996	0.99	1	0.9996	1E-08	0.01	1	1	1	1		6.86E-11					
15		0.99	1	0.9999	1	1	0.7	1	1E-05	0.9996	0.99	1	0.9996	1E-08	0.01	1	1	1	1					6.86E-16		
16		0.99	1	0.9999	1	1	0.3	1	1	0.9996	0.99	1	0.9996	1E-08	0.01	1	1	1	1			2.94E-11				
17		0.99	1	0.9999	1	1	0.7	1	0.9999	0.9996	0.99	1	0.0004	1	1	1	1	1	1		0.00027					
18		0.99	1	0.9999	1	1	0.7	1	1E-05	0.9996	0.99	1	0.0004	1	1	1	1	1	1					2.74E-09		
19		0.99	1	0.9999	1	1	0.3	1	1	0.9996	0.99	1	0.0004	1	1	1	1	1	1			0.00012				
20		0.99	1	0.9999	1	1	1	1	1	0.9996	0.003	1	1	1	1	1	1	1	1						0.00297	
21		0.99	1	0.9999	1	0.95	0.7	0.5	1	0.9996	0.007	1	1	1	1	1	1	1	1		0.00230					
22		0.99	1	0.9999	1	0.95	0.7	0.5	1	0.9996	0.007	1	1	1	1	1	1	1	1					0.00230		
23		0.99	1	0.9999	1	0.95	0.3	1	1	0.9996	0.007	1	1	1	1	1	1	1	1			0.00197				
24		0.99	0.75	0.9999	1	0.05	1	1	1	0.9996	0.007	1	1	1	1	1	1	1	1							0.00026
25		0.99	0.25	0.9999	1	0.05	1	1	1	0.9996	0.007	1	1	1	1	1	1	1	1				8.66E-05			
26		0.99	1	0.9999	0.9	1	1	1	1	0.0004	1	1	1	1	1	1	1	1	1						0.00036	
27		0.99	1	0.9999	0.1	0.95	0.7	0.5	1	0.0004	1	1	1	1	1	1	1	1	1		1.32E-05					
28		0.99	1	0.9999	0.1	0.95	0.7	0.5	1	0.0004	1	1	1	1	1	1	1	1	1					1.32E-05		
29		0.99	1	0.9999	0.1	0.95	0.3	1	1	0.0004	1	1	1	1	1	1	1	1	1			1.13E-05				
30		0.99	0.75	0.9999	0.1	0.05	1	1	1	0.0004	1	1	1	1	1	1	1	1	1							1.48E-06
31		0.99	0.25	0.9999	0.1	0.05	1	1	1	0.0004	1	1	1	1	1	1	1	1	1				4.95E-07			
32		0.99	1	1E-08	0.9	1	1	1	1	1	1	1	1	1	1	1	1	1	1						8.91E-09	
33		0.99	1	1E-08	0.1	0.95	0.7	0.5	1	1	1	1	1	1	1	1	1	1	1		3.29E-10					
34		0.99	1	1E-08	0.1	0.95	0.7	0.5	1	1	1	1	1	1	1	1	1	1	1					3.29E-10		
35		0.99	1	1E-08	0.1	0.95	0.3	1	1	1	1	1	1	1	1	1	1	1	1			2.82E-10				
36		0.99	0.75	1E-08	0.1	0.05	1	1	1	1	1	1	1	1	1	1	1	1	1							3.71E-11
37		0.99	0.25	1E-08	0.1	0.05	1	1	1	1	1	1	1	1	1	1	1	1	1				1.24E-11			
38		0.0001	0.75	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1							7.50E-05
39		0.0001	0.25	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1				2.50E-05			
40		0.0099	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1						0.00990	
41		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1							
42		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1							
Totals =																				0.97638	0.00553	0.00210	0.00011	0.00232	0.01323	0.00034

Check Sum = 1.00000

Total of Canister Breached =0.00453168

ORIGINAL PAGE IS OF POOR QUALITY

5.2 Aerocapture to Freedom Space Station with Processing, Orbiter Return

The tree for Aerocapture with Freedom Space Station Processing is shown in Figure 5.2-1. It is the most complex of the mission scenarios with 73 individual paths. Many of the major branches of this scenario are associated with the consequences of slow response of the OMV. The event referred to as OMV deployment includes the complete sequence which will put an OMV on the Station. The current OMV (User's Guide, 1987) and Freedom Space Station (SSP 30256) baseline do not maintain an OMV permanently at the Freedom Space Station. Thus OMV deployment includes the launch of the OMV in the Shuttle. Because the SRC cannot maintain thermal control of the sample beyond the life of the power system, currently defined as batteries rated at 90 day lifetime, hiatus in Shuttle launches as occurred after the 51-L accident will result in loss of thermal control of the sample. A similar series of adverse consequences result if the OMV has an on-orbit failure and cannot retrieve the SRC. If the retrieval by the OMV is very slow, the SRC orbit will decay and the SRC will reenter the atmosphere without control, resulting in complete mission loss.

The sequence for recovery of a second aerocaptured SRC to the Freedom Space Station may require refueling or replacing a propulsion module in the OMV on-orbit.

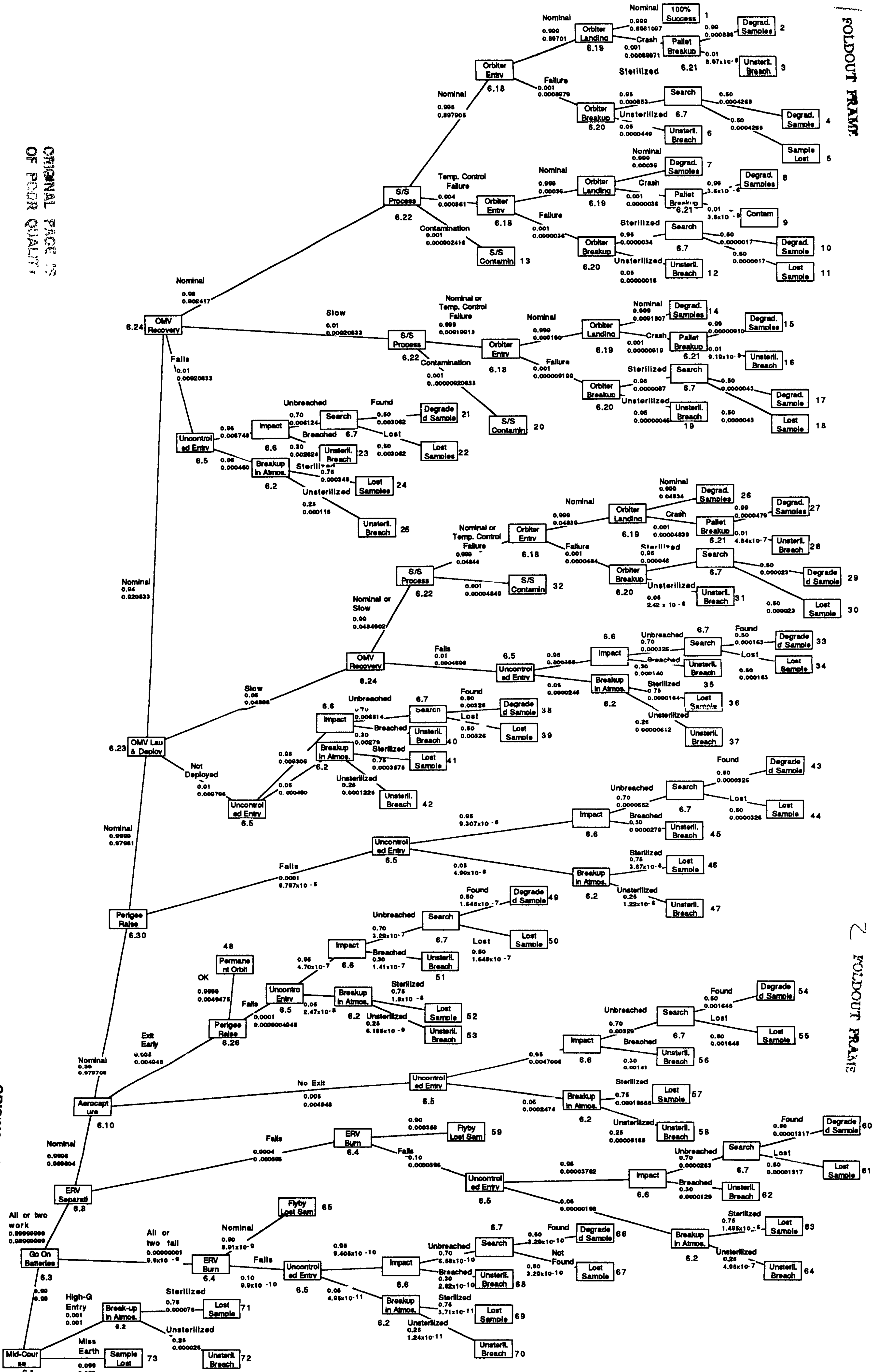

Figure 5.2-1, Aerocapture to Freedom Space Station Fault Tree

Table 5.2-1, Aerocapture to Freedom Space Station Fault Tree Path Probabilities

Path #	100 % Success	Degraded Sample	Can. Breach (Sample Recov or in theory recoverable)	Can. Breach (Sam. destro	Unsterilized Lost Sample (on Earth)	Lost Sample (in Space)	Sterilized Lost Sample (on Earth)	Space Station Contamin.	Permanent Orbit
1	0.89611								
2		0.00089							
3			8.97E-06						
4		0.00043							
5							0.00043		
6				4.49E-05					
7		0.00360							
8		3.57E-06							
9			3.61E-08						
10		1.71E-06							
11							1.71E-06		
12				1.80E-07					
13								0.00090	
14		0.00918							
15		9.10E-06							
16			9.19E-08						
17		4.37E-06							
18							4.37E-06		
19				4.60E-07					
20								9.21E-06	
21		0.00306							
22					0.00306				
23			0.00262						
24							0.00035		
25				0.00012					
26		0.04835							
27		0.00005							
28			4.84E-07						
29		2.30E-05							
30							2.30E-05		
31				2.42E-06					
32								4.85E-05	
33		0.00016							
34					0.00016				
35			0.00014						
36							1.84E-05		
37				6.12E-06					
38		0.00326							
39					0.00326				
40			0.00279						
41							0.00037		
42				0.00012					
43		3.26E-05							
44					3.26E-05				
45			2.79E-05						
46							3.67E-06		
47				1.22E-06					
48									0.00495
49		1.65E-07							
50					1.65E-07				
51			1.41E-07						
52							1.86E-08		

Table 5.2-1, Aerocapture to Freedom Space Station Fault Tree Path Probabilities, Continued

Path #	100 % Success	Degraded Sample	Can. Breach (Sample Recov or in theory recoverable)	Can. Breach (Sam. destro	Unsterilized Lost Sample (on Earth)	Lost Sample (in Space)	Sterilized Lost Sample (on Earth)	Space Station Contamin.	Permanent Orbit
53				6.19E-09					
54		0.00165							
55					0.00165				
56			0.00141						
57							0.00019		
58				6.19E-05					
59						0.00036			
60		1.32E-05							
61					1.32E-05				
62			1.13E-05						
63							1.48E-06		
64				4.95E-07					
65						8.91E-09			
66		3.29E-10							
67					3.29E-10				
68			2.82E-10						
69							3.71E-11		
70				1.24E-11					
71							7.50E-05		
72				2.50E-05					
73						0.00990			
Totals =	0.89611	0.07071	0.00701	0.00038	0.00817	0.01026	0.00145	0.00096	0.00495

Check Sum = 1.0000 Totals of Canister Breached = 0.0156

Table 5.2-2, Aerocapture to Freedom Space Station Fault Tree Calculations

Event->	Mid C.	Brk-up	Batt. On	ERV Burn	U.Entry Low A.	No Ch. Impact	Srch No Zn.	Srch in Zn.	ERV Sep.	Entry Direct	Aero-Captr	Reeve Covr	Drgue Deply	Mains Deply	Air Snatch	Aircft Landng	Con.Brk Acft Cr	Grnd Rspn	Orb. Entry	Orb. Lands	Orb.Ent Brkup	Pallet Brkup	Sp Sta Proc.	OMV Deplyd	OMV Rcvry	SCA Can Impact	Perige Raise	1stEOI Burn	2ndEOI Burn	Despin
Ref.	6.1	6.2	6.3	6.4	6.5	6.6	6.7	6.7	6.8	6.9	6.10	6.11	6.12	6.13	6.14	6.15	6.16	6.17	6.18	6.19	6.20	6.21	6.22	6.23	6.24	6.25	6.26	6.27	6.28	6.29
Nomin.	0.99	0.75	0.9999	0.9	0.95	0.3	0.5	0.9999	0.9996	0.99	0.99	0.9996	0.9999	0.9999	0.97	0.9999	0.99	0.9	0.999	0.999	0.95	0.99	0.995	0.94	0.98	0.1	0.9999	0.9993	0.9994	0.9997
Alt. 1	0.0001	0.25	1E-08	0.1	0.05	0.7	0.5	1E-05	0.0004	0.003	0.005	0.0004	1E-08	1E-08	0.03	1E-06	0.01	0.1	0.001	0.001	0.05	0.01	0.004	0.05	0.01	0.9	0.0001	0.0007	0.0006	0.0003
Alt. 2	0.0099	0	0	0	0	0	0	0	0	0.007	0.005	0	0	0	0	0	0	0	0	0	0	0	0.001	0.01	0.01	0	0	0	0	0
Chk Sum	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Path # Event # ->	1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
1	0.99	1	0.9999	1	1	1	1	1	0.9996	1	0.99	1	1	1	1	1	1	1	0.999	0.999	1	1	0.995	0.94	0.98	1	0.9999	1	1	1
2	0.99	1	0.9999	1	1	1	1	1	0.9996	1	0.99	1	1	1	1	1	1	1	0.999	0.001	1	0.99	0.995	0.94	0.98	1	0.9999	1	1	1
3	0.99	1	0.9999	1	1	1	1	1	0.9996	1	0.99	1	1	1	1	1	1	1	0.999	0.001	1	0.01	0.995	0.94	0.98	1	0.9999	1	1	1
4	0.99	1	0.9999	1	1	1	0.5	1	0.9996	1	0.99	1	1	1	1	1	1	1	0.001	1	0.95	1	0.995	0.94	0.98	1	0.9999	1	1	1
5	0.99	1	0.9999	1	1	1	0.5	1	0.9996	1	0.99	1	1	1	1	1	1	1	0.001	1	0.95	1	0.995	0.94	0.98	1	0.9999	1	1	1
6	0.99	1	0.9999	1	1	1	1	1	0.9996	1	0.99	1	1	1	1	1	1	1	0.001	1	0.05	1	0.995	0.94	0.98	1	0.9999	1	1	1
7	0.99	1	0.9999	1	1	1	1	1	0.9996	1	0.99	1	1	1	1	1	1	1	0.999	0.999	1	1	0.004	0.94	0.98	1	0.9999	1	1	1
8	0.99	1	0.9999	1	1	1	1	1	0.9996	1	0.99	1	1	1	1	1	1	1	0.999	0.001	1	0.99	0.004	0.94	0.98	1	0.9999	1	1	1
9	0.99	1	0.9999	1	1	1	1	1	0.9996	1	0.99	1	1	1	1	1	1	1	0.999	0.001	1	0.01	0.004	0.94	0.98	1	0.9999	1	1	1
10	0.99	1	0.9999	1	1	1	0.5	1	0.9996	1	0.99	1	1	1	1	1	1	1	0.001	1	0.95	1	0.004	0.94	0.98	1	0.9999	1	1	1
11	0.99	1	0.9999	1	1	1	0.5	1	0.9996	1	0.99	1	1	1	1	1	1	1	0.001	1	0.95	1	0.004	0.94	0.98	1	0.9999	1	1	1
12	0.99	1	0.9999	1	1	1	1	1	0.9996	1	0.99	1	1	1	1	1	1	1	0.001	1	0.05	1	0.004	0.94	0.98	1	0.9999	1	1	1
13	0.99	1	0.9999	1	1	1	1	1	0.9996	1	0.99	1	1	1	1	1	1	1	1	1	1	1	0.001	0.94	0.98	1	0.9999	1	1	1
14	0.99	1	0.9999	1	1	1	1	1	0.9996	1	0.99	1	1	1	1	1	1	1	0.999	0.999	1	1	0.999	0.94	0.01	1	0.9999	1	1	1
15	0.99	1	0.9999	1	1	1	1	1	0.9996	1	0.99	1	1	1	1	1	1	1	0.999	0.001	1	0.99	0.999	0.94	0.01	1	0.9999	1	1	1
16	0.99	1	0.9999	1	1	1	1	1	0.9996	1	0.99	1	1	1	1	1	1	1	0.999	0.001	1	0.01	0.999	0.94	0.01	1	0.9999	1	1	1
17	0.99	1	0.9999	1	1	1	0.5	1	0.9996	1	0.99	1	1	1	1	1	1	1	0.001	1	0.95	1	0.999	0.94	0.01	1	0.9999	1	1	1
18	0.99	1	0.9999	1	1	1	0.5	1	0.9996	1	0.99	1	1	1	1	1	1	1	0.001	1	0.95	1	0.999	0.94	0.01	1	0.9999	1	1	1
19	0.99	1	0.9999	1	1	1	1	1	0.9996	1	0.99	1	1	1	1	1	1	1	0.001	1	0.05	1	0.999	0.94	0.01	1	0.9999	1	1	1
20	0.99	1	0.9999	1	1	1	1	1	0.9996	1	0.99	1	1	1	1	1	1	1	1	1	1	1	0.001	0.94	0.01	1	0.9999	1	1	1
21	0.99	1	0.9999	1	0.95	0.7	0.5	1	0.9996	1	0.99	1	1	1	1	1	1	1	1	1	1	1	1	0.94	0.01	1	0.9999	1	1	1
22	0.99	1	0.9999	1	0.95	0.7	0.5	1	0.9996	1	0.99	1	1	1	1	1	1	1	1	1	1	1	1	0.94	0.01	1	0.9999	1	1	1
23	0.99	1	0.9999	1	0.95	0.3	1	1	0.9996	1	0.99	1	1	1	1	1	1	1	1	1	1	1	1	0.94	0.01	1	0.9999	1	1	1
24	0.99	0.75	0.9999	1	0.05	1	1	1	0.9996	1	0.99	1	1	1	1	1	1	1	1	1	1	1	1	0.94	0.01	1	0.9999	1	1	1
25	0.99	0.25	0.9999	1	0.05	1	1	1	0.9996	1	0.99	1	1	1	1	1	1	1	1	1	1	1	1	0.94	0.01	1	0.9999	1	1	1
26	0.99	1	0.9999	1	1	1	1	1	0.9996	1	0.99	1	1	1	1	1	1	1	0.999	0.999	1	1	0.999	0.05	0.99	1	0.9999	1	1	1
27	0.99	1	0.9999	1	1	1	1	1	0.9996	1	0.99	1	1	1	1	1	1	1	0.999	0.001	1	0.99	0.999	0.05	0.99	1	0.9999	1	1	1
28	0.99	1	0.9999	1	1	1	1	1	0.9996	1	0.99	1	1	1	1	1	1	1	0.999	0.001	1	0.01	0.999	0.05	0.99	1	0.9999	1	1	1
29	0.99	1	0.9999	1	1	1	0.5	1	0.9996	1	0.99	1	1	1	1	1	1	1	0.001	1	0.95	1	0.999	0.05	0.99	1	0.9999	1	1	1
30	0.99	1	0.9999	1	1	1	0.5	1	0.9996	1	0.99	1	1	1	1	1	1	1	0.001	1	0.95	1	0.999	0.05	0.99	1	0.9999	1	1	1
31	0.99	1	0.9999	1	1	1	1	1	0.9996	1	0.99	1	1	1	1	1	1	1	0.001	1	0.05	1	0.999	0.05	0.99	1	1	1	1	1
32	0.99	1	0.9999	1	1	1	1	1	0.9996	1	0.99	1	1	1	1	1	1	1	1	1	1	1	0.001	0.05	0.99	1	1	1	1	1
33	0.99	1	0.9999	1	0.95	0.7	0.5	1	0.9996	1	0.99	1	1	1	1	1	1	1	1	1	1	1	1	0.05	0.01	1	0.9999	1	1	1
34	0.99	1	0.9999	1	0.95	0.7	0.5	1	0.9996	1	0.99	1	1	1	1	1	1	1	1	1	1	1	1	0.05	0.01	1	0.9999	1	1	1
35	0.99	1	0.9999	1	0.95	0.3	1	1	0.9996	1	0.99	1	1	1	1	1	1	1	1	1	1	1	1	0.05	0.01	1	0.9999	1	1	1
36	0.99	0.75	0.9999	1	0.05	1	1	1	0.9996	1	0.99	1	1	1	1	1	1	1	1	1	1	1	1	0.05	0.01	1	0.9999	1	1	1
37	0.99	0.25	0.9999	1	0.05	1	1	1	0.9996	1	0.99	1	1	1	1	1	1	1	1	1	1	1	1	0.05	0.01	1	0.9999	1	1	1
38	0.99	1	0.9999	1	0.95	0.7	0.5	1	0.9996	1	0.99	1	1	1	1	1	1	1	1	1	1	1	1	0.01	1	1	0.9999	1	1	1
39	0.99	1	0.9999	1	0.95	0.7	0.5	1	0.9996	1	0.99	1	1	1	1	1	1	1	1	1	1	1	1	0.01	1	1	0.9999	1	1	1
40	0.99	1	0.9999	1	0.95	0.3	1	1	0.9996	1	0.99	1	1	1	1	1	1	1	1	1	1	1	1	0.01	1	1	0.9999	1	1	1
41	0.99	0.75	0.9999	1	0.05	1	1	1	0.9996	1	0.99	1	1	1	1	1	1	1	1	1	1	1	1	0.01	1	1	0.9999	1	1	1
42	0.99	0.25	0.9999	1	0.05	1	1	1	0.9996	1	0.99	1	1	1	1	1	1	1	1	1	1	1	1	0.01	1	1	0.9999	1	1	1
43	0.99	1	0.9999	1	0.95	0.7	0.5	1	0.9996	1	0.99	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.0001	1	1	1
44	0.99	1	0.9999	1	0.95	0.7	0.5	1	0.9996	1	0.99	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.0001	1	1	1

Table 5.2-2, Aerocapture to Freedom Space Station Fault Tree Calculations, Continued

Path #	Event->	Mid C.	Brk-up	Batt. On	ERV Burn	U.Entry Low A.	No Ch. Impact	Srch No Zn.	Srch in Zn.	ERV Sep.	Entry Direct	Aero- Captr	Reave Covr	Drgue Deply	Mains Deply	Air Snatch	Aircft Landng	Con.Brk Acft Cr	Grnd Rspn	Orb. Entry	Orb. Lands	Orb.Ent Brkup	Pallet Brkup	Sp Sta Proc.	OMV Deplyd	OMV Rcvry	SCA Can Impact	Perige Raise	1stEOI Burn	2ndEOI Burn	Despin
	Ref.	6.1	6.2	6.3	6.4	6.5	6.6	6.7	6.7	6.8	6.9	6.10	6.11	6.12	6.13	6.14	6.15	6.16	6.17	6.18	6.19	6.20	6.21	6.22	6.23	6.24	6.25	6.26	6.27	6.28	6.29
	Nomin.	0.99	0.75	0.9999	0.9	0.95	0.3	0.5	0.9999	0.9996	0.99	0.99	0.9996	0.9999	0.9999	0.97	0.9999	0.99	0.9	0.999	0.999	0.95	0.99	0.995	0.94	0.98	0.1	0.9999	0.9993	0.9994	0.9997
	Alt. 1	0.0001	0.25	1E-08	0.1	0.05	0.7	0.5	1E-05	0.0004	0.003	0.005	0.0004	1E-08	1E-08	0.03	1E-06	0.01	0.1	0.001	0.001	0.05	0.01	0.004	0.05	0.01	0.9	0.0001	0.0007	0.0006	0.0003
	Alt. 2	0.0099	0	0	0	0	0	0	0	0	0.007	0.005	0	0	0	0	0	0	0	0	0	0	0	0.001	0.01	0.01	0	0	0	0	0
	Chk Sum	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Path #	Event #	-> 1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
45		0.99	1	0.9999	1	0.95	0.3	1	1	0.9996	1	0.99	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.0001	1	1	1
46		0.99	0.75	0.9999	1	0.05	1	1	1	0.9996	1	0.99	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.0001	1	1	1
47		0.99	0.25	0.9999	1	0.05	1	1	1	0.9996	1	0.99	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.0001	1	1	1
48		0.99	1	0.9999	1	1	1	1	1	0.9996	1	0.005	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.9999	1	1	1
49		0.99	1	0.9999	1	0.95	0.7	0.5	1	0.9996	1	0.005	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.0001	1	1	1
50		0.99	1	0.9999	1	0.95	0.7	0.5	1	0.9996	1	0.005	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.0001	1	1	1
51		0.99	1	0.9999	1	0.95	0.3	1	1	0.9996	1	0.005	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.0001	1	1	1
52		0.99	0.75	0.9999	1	0.05	1	1	1	0.9996	1	0.005	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.0001	1	1	1
53		0.99	0.25	0.9999	1	0.05	1	1	1	0.9996	1	0.005	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.0001	1	1	1
54		0.99	1	0.9999	1	0.95	0.7	0.5	1	0.9996	1	0.005	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
55		0.99	1	0.9999	1	0.95	0.7	0.5	1	0.9996	1	0.005	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
56		0.99	1	0.9999	1	0.95	0.3	1	1	0.9996	1	0.005	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
57		0.99	0.75	0.9999	1	0.05	1	1	1	0.9996	1	0.005	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
58		0.99	0.25	0.9999	1	0.05	1	1	1	0.9996	1	0.005	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
59		0.99	1	0.9999	0.9	1	1	1	1	0.0004	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
60		0.99	1	0.9999	0.1	0.95	0.7	0.5	1	0.0004	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
61		0.99	1	0.9999	0.1	0.95	0.7	0.5	1	0.0004	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
62		0.99	1	0.9999	0.1	0.95	0.3	1	1	0.0004	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
63		0.99	0.75	0.9999	0.1	0.05	1	1	1	0.0004	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
64		0.99	0.25	0.9999	0.1	0.05	1	1	1	0.0004	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
65		0.99	1	1E-08	0.9	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
66		0.99	1	1E-08	0.1	0.95	0.7	0.5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
67		0.99	1	1E-08	0.1	0.95	0.7	0.5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
68		0.99	1	1E-08	0.1	0.95	0.3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
69		0.99	0.75	1E-08	0.1	0.05	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
70		0.99	0.25	1E-08	0.1	0.05	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
71		0.0001	0.75	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
72		0.0001	0.25	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
73		0.0099	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Totals =

Table 5.2-2, Aerocapture to Freedom Space Station Fault Tree Calculations, Continued

	Shutle Ascnt 6.30	Sh.Rnd &RMS C 6.31									100 % Success	Degraded Sample	Can. Breach (Sample Re-covrd or in theory rcvrable)	Can. Breach (Sample Destroyed)	Unsterilized Lost Sample (on Earth)	Lost Sample (in Space)	Sterilized Lost Sample (on Earth)	Space Station Contain.	Permanent Orbit
	0.9	0.999	1	1	1	1	1	1	1	1									
	0.05	0.001	0	0	0	0	0	0	0	0									
	0.05	0	0	0	0	0	0	0	0	0									
	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000									
Path #	30	31	32	33	34	35	36	37	38	39									
1	1	1	1	1	1	1	1	1	1	1	0.89611								
2	1	1	1	1	1	1	1	1	1	1		0.00089							
3	1	1	1	1	1	1	1	1	1	1			8.97E-06						
4	1	1	1	1	1	1	1	1	1	1		0.00043							
5	1	1	1	1	1	1	1	1	1	1							0.00043		
6	1	1	1	1	1	1	1	1	1	1				4.49E-05					
7	1	1	1	1	1	1	1	1	1	1		0.00360							
8	1	1	1	1	1	1	1	1	1	1		3.57E-06							
9	1	1	1	1	1	1	1	1	1	1			3.61E-08						
10	1	1	1	1	1	1	1	1	1	1		1.71E-06							
11	1	1	1	1	1	1	1	1	1	1							1.71E-06		
12	1	1	1	1	1	1	1	1	1	1				1.80E-07					
13	1	1	1	1	1	1	1	1	1	1								0.00090	
14	1	1	1	1	1	1	1	1	1	1		0.00918							
15	1	1	1	1	1	1	1	1	1	1		9.10E-06							
16	1	1	1	1	1	1	1	1	1	1			9.19E-08						
17	1	1	1	1	1	1	1	1	1	1		4.37E-06							
18	1	1	1	1	1	1	1	1	1	1							4.37E-06		
19	1	1	1	1	1	1	1	1	1	1				4.60E-07					
20	1	1	1	1	1	1	1	1	1	1								9.21E-06	
21	1	1	1	1	1	1	1	1	1	1		0.00306							
22	1	1	1	1	1	1	1	1	1	1					0.00306				
23	1	1	1	1	1	1	1	1	1	1			0.00262						
24	1	1	1	1	1	1	1	1	1	1							0.00035		
25	1	1	1	1	1	1	1	1	1	1				0.00012					
26	1	1	1	1	1	1	1	1	1	1		0.04835							
27	1	1	1	1	1	1	1	1	1	1		0.00005							
28	1	1	1	1	1	1	1	1	1	1			4.84E-07						
29	1	1	1	1	1	1	1	1	1	1		2.30E-05							
30	1	1	1	1	1	1	1	1	1	1							2.30E-05		
31	1	1	1	1	1	1	1	1	1	1				2.42E-06					
32	1	1	1	1	1	1	1	1	1	1								4.85E-05	
33	1	1	1	1	1	1	1	1	1	1		0.00016							
34	1	1	1	1	1	1	1	1	1	1					0.00016				
35	1	1	1	1	1	1	1	1	1	1			0.00014						
36	1	1	1	1	1	1	1	1	1	1							1.81E-05		
37	1	1	1	1	1	1	1	1	1	1				6.12E-06					
38	1	1	1	1	1	1	1	1	1	1		0.00326							
39	1	1	1	1	1	1	1	1	1	1					0.00326				
40	1	1	1	1	1	1	1	1	1	1			0.00279						
41	1	1	1	1	1	1	1	1	1	1							0.00037		
42	1	1	1	1	1	1	1	1	1	1				0.00012					
43	1	1	1	1	1	1	1	1	1	1		3.26E-05							
44	1	1	1	1	1	1	1	1	1	1					3.26E-05				

Table 5.2-2, Aerocapture to Freedom Space Station Fault Tree Calculations, Continued

	Shutle Ascnt 6.30	Sh.Rnd &RMS C 6.31																		
	0.9	0.999	1	1	1	1	1	1	1	1										
	0.05	0.001	0	0	0	0	0	0	0	0										
	0.05	0	0	0	0	0	0	0	0	0	100 %	Degraded	Can. Breach	Can. Breach	Unsterilized	Lost	Sterilized	Space	Permanent
	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	Success	Sample	(Sample Re- covrd or in theory rcvrable)	(Sample Destroyed)	Lost Sample (on Earth)	Sample (in Space)	Lost Sample (on Earth)	Station Contain.	Orbit
Path #	30	31	32	33	34	35	36	37	38	39									
45	1	1	1	1	1	1	1	1	1	1			2.79E-05						
46	1	1	1	1	1	1	1	1	1	1							3.67E-06		
47	1	1	1	1	1	1	1	1	1	1				1.22E-06					
48	1	1	1	1	1	1	1	1	1	1									0.00495
49	1	1	1	1	1	1	1	1	1	1		1.65E-07							
50	1	1	1	1	1	1	1	1	1	1					1.65E-07				
51	1	1	1	1	1	1	1	1	1	1			1.41E-07						
52	1	1	1	1	1	1	1	1	1	1							1.86E-08		
53	1	1	1	1	1	1	1	1	1	1				6.19E-09					
54	1	1	1	1	1	1	1	1	1	1		0.00165							
55	1	1	1	1	1	1	1	1	1	1					0.00165				
56	1	1	1	1	1	1	1	1	1	1			0.00141						
57	1	1	1	1	1	1	1	1	1	1							0.00019		
58	1	1	1	1	1	1	1	1	1	1				6.19E-05					
59	1	1	1	1	1	1	1	1	1	1						0.00036			
60	1	1	1	1	1	1	1	1	1	1		1.32E-05							
61	1	1	1	1	1	1	1	1	1	1					1.32E-05				
62	1	1	1	1	1	1	1	1	1	1			1.13E-05						
63	1	1	1	1	1	1	1	1	1	1							1.48E-06		
64	1	1	1	1	1	1	1	1	1	1				4.95E-07					
65	1	1	1	1	1	1	1	1	1	1						8.91E-09			
66	1	1	1	1	1	1	1	1	1	1		3.29E-10							
67	1	1	1	1	1	1	1	1	1	1					3.29E-10				
68	1	1	1	1	1	1	1	1	1	1			2.82E-10						
69	1	1	1	1	1	1	1	1	1	1							3.7125E-11		
70	1	1	1	1	1	1	1	1	1	1				1.24E-11					
71	1	1	1	1	1	1	1	1	1	1							7.50E-05		
72	1	1	1	1	1	1	1	1	1	1				2.50E-05					
73	1	1	1	1	1	1	1	1	1	1						0.00990			
Totals =										Totals	0.89611	0.07071	0.00701	0.00038	0.00817	0.01026	0.00145	0.00096	0.00495

Check Sum = 1.0000 Totals of Canister Breached = 0.0156

5.3 Aerocapture to LEO, Shuttle Recovery with RMS from LEO

The fault tree for aerocapture to a Space Shuttle has 9 fewer branches than to the Freedom Space Station due to the elimination of the OMV recovery phase, for a total of 64 branches.

The recovery of a second SRC to the Space Shuttle places the most stringent demands on SRC orbital timing and targeting, because the Orbiter can only remain in orbit approximately 10 days.

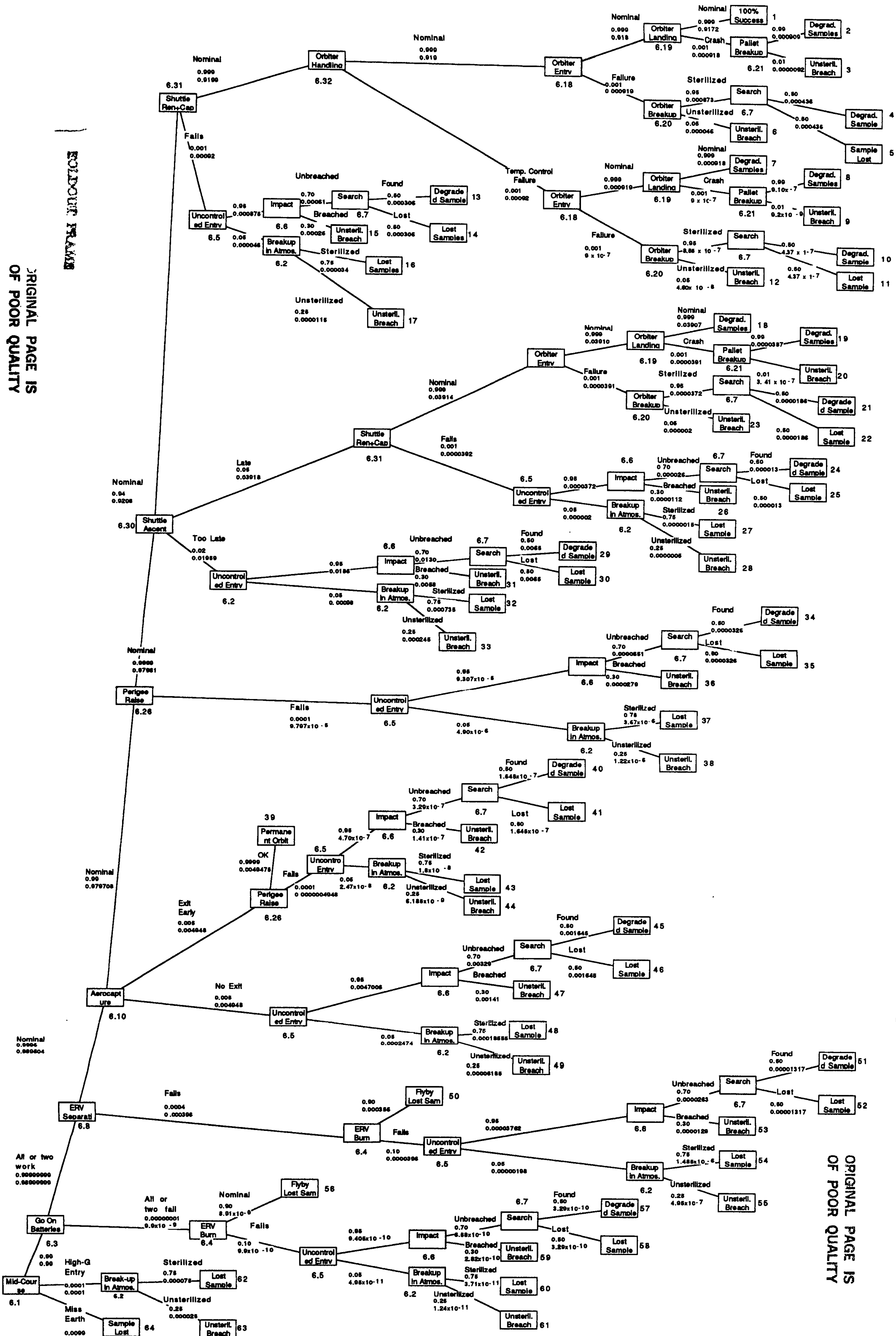

Figure 5.3-1, Aerocapture to Shuttle Fault Tree

Table 5.3-1, Aerocapture to Shuttle Fault Tree Path Probabilities

Path #	100 % Success	Degraded Sample	Can. Breach (Sample Re-covrd or in theory rcvrable)	Can. Breach (Sample Destroyed)	Unsterilized Lost Sample (on Earth)	Lost Sample (in Space)	Sterilized Lost Smple (on Earth)	Space Station Contamin.	Permanent Orbit
1	0.91716								
2		0.00091							
3			9.18E-06						
4		0.00044							
5							0.00044		
6				4.59E-05					
7		0.00092							
8		9.10E-07							
9			9.19E-09						
10		4.37E-07							
11							4.37E-07		
12				4.60E-08					
13		0.00031							
14					0.00031				
15			0.00026						
16							3.45E-05		
17				1.15E-05					
18		0.03907							
19		3.87E-05							
20			3.91E-07						
21		1.86E-05							
22							1.86E-05		
23				1.96E-06					
24		1.30E-05							
25					1.30E-05				
26			1.12E-05						
27							1.47E-06		
28				4.90E-07					
29		0.00651							
30					0.00651				
31			0.00558						
32							0.00073		
33				0.00024					
34		3.26E-05							
35					3.26E-05				
36			2.79E-05						
37							3.67E-06		
38				1.22E-06					
39									0.00495
40		1.65E-07							
41					1.65E-07				
42			1.41E-07						
43							1.86E-08		
44				6.19E-09					
45		0.00165							
46					0.00165				
47			0.00141						
48							0.00019		
49				6.19E-05					
50						0.00036			
51		1.32E-05							
52					1.32E-05				

Table 5.3-1, Aerocapture to Shuttle Fault Tree Path Probabilities, Continued

Path #	100 % Success	Degraded Sample	Can. Breach (Sample Re-covrd or in theory rcvrable)	Can. Breach (Sample Destroyed)	Unsterilized Lost Sample (on Earth)	Lost Sample (in Space)	Sterilized Lost Smple (on Earth)	Space Station Contamin.	Permanent Orbit
53			1.13E-05						
54							1.48E-06		
55				4.95E-07					
56						8.91E-09			
57		3.29E-10							
58					3.29E-10				
59			2.82E-10						
60							3.71E-11		
61				1.24E-11					
62							7.50E-05		
63				2.50E-05					
64						0.00990			
Totals =	0.91716	0.04991	0.00732	0.00039	0.00852	0.01026	0.00149	0.00000	0.00495

Check Sum = 1.0000 Totals of Canister Breached = 0.0162

Table 5.3-2, Aerocapture to Shuttle Fault Tree Calculations

Event->	Mid C.	Brk-up	Batt. On	ERV Burn	U.Entry Low A.	No Ch. Impact	Srch No Zn.	Srch in Zn.	ERV Sep.	Entry Direct	Aero- Captr	Remve Covr	Drgue Deply	Mains Deply	Air Snatch	Aircft Landng	Con.Brk Acft Cr	Grnd Rspn	Orb. Entry	Orb. Lands	Orb.Ent Brkup	Pallet Brkup	Sp Sta Proc.	OMV Deplyd	OMV Rcvry	SCA Can Impact	Perige Raise	1stEOI Burn	2ndEOI Burn	Despin
Ref.	6.1	6.2	6.3	6.4	6.5	6.6	6.7	6.7	6.8	6.9	6.10	6.11	6.12	6.13	6.14	6.15	6.16	6.17	6.18	6.19	6.20	6.21	6.22	6.23	6.24	6.25	6.26	6.27	6.28	6.29
Nomin.	0.99	0.75	0.9999	0.9	0.95	0.3	0.5	0.9999	0.9996	0.99	0.99	0.9996	0.9999	0.9999	0.97	0.9999	0.99	0.9	0.999	0.999	0.95	0.99	0.995	0.94	0.98	0.1	0.9999	0.9993	0.9994	0.9997
Alt. 1	0.0001	0.25	1E-08	0.1	0.05	0.7	0.5	1E-05	0.0004	0.003	0.005	0.0004	1E-08	1E-08	0.03	1E-06	0.01	0.1	0.001	0.001	0.05	0.01	0.004	0.05	0.01	0.9	0.0001	0.0007	0.0006	0.0003
Alt. 2	0.0099	0	0	0	0	0	0	0	0	0.007	0.005	0	0	0	0	0	0	0	0	0	0	0	0.001	0.01	0.01	0	0	0	0	0
Chk Sum	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Path # Event # ->	1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
1	0.99	1	0.9999	1	1	1	1	1	0.9996	1	0.99	1	1	1	1	1	1	1	0.999	0.999	1	1	1	1	1	1	0.9999	1	1	1
2	0.99	1	0.9999	1	1	1	1	1	0.9996	1	0.99	1	1	1	1	1	1	1	0.999	0.001	1	0.99	1	1	1	1	0.9999	1	1	1
3	0.99	1	0.9999	1	1	1	1	1	0.9996	1	0.99	1	1	1	1	1	1	1	0.999	0.001	1	0.01	1	1	1	1	0.9999	1	1	1
4	0.99	1	0.9999	1	1	1	0.5	1	0.9996	1	0.99	1	1	1	1	1	1	1	0.001	1	0.95	1	1	1	1	1	0.9999	1	1	1
5	0.99	1	0.9999	1	1	1	0.5	1	0.9996	1	0.99	1	1	1	1	1	1	1	0.001	1	0.95	1	1	1	1	1	0.9999	1	1	1
6	0.99	1	0.9999	1	1	1	1	1	0.9996	1	0.99	1	1	1	1	1	1	1	0.001	1	0.05	1	1	1	1	1	0.9999	1	1	1
7	0.99	1	0.9999	1	1	1	1	1	0.9996	1	0.99	1	1	1	1	1	1	1	0.999	0.999	1	1	1	1	1	1	0.9999	1	1	1
8	0.99	1	0.9999	1	1	1	1	1	0.9996	1	0.99	1	1	1	1	1	1	1	0.999	0.001	1	0.99	1	1	1	1	0.9999	1	1	1
9	0.99	1	0.9999	1	1	1	1	1	0.9996	1	0.99	1	1	1	1	1	1	1	0.999	0.001	1	0.01	1	1	1	1	0.9999	1	1	1
10	0.99	1	0.9999	1	1	1	0.5	1	0.9996	1	0.99	1	1	1	1	1	1	1	0.001	1	0.95	1	1	1	1	1	0.9999	1	1	1
11	0.99	1	0.9999	1	1	1	0.5	1	0.9996	1	0.99	1	1	1	1	1	1	1	0.001	1	0.95	1	1	1	1	1	0.9999	1	1	1
12	0.99	1	0.9999	1	1	1	1	1	0.9996	1	0.99	1	1	1	1	1	1	1	0.001	1	0.05	1	1	1	1	1	0.9999	1	1	1
13	0.99	1	0.9999	1	0.95	0.7	0.5	1	0.9996	1	0.99	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.9999	1	1	1
14	0.99	1	0.9999	1	0.95	0.7	0.5	1	0.9996	1	0.99	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.9999	1	1	1
15	0.99	1	0.9999	1	0.95	0.3	1	1	0.9996	1	0.99	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.9999	1	1	1
16	0.99	0.75	0.9999	1	0.05	1	1	1	0.9996	1	0.99	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.9999	1	1	1
17	0.99	0.25	0.9999	1	0.05	1	1	1	0.9996	1	0.99	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.9999	1	1	1
18	0.99	1	0.9999	1	1	1	1	1	0.9996	1	0.99	1	1	1	1	1	1	1	0.999	0.999	1	1	1	1	1	1	0.9999	1	1	1
19	0.99	1	0.9999	1	1	1	1	1	0.9996	1	0.99	1	1	1	1	1	1	1	0.999	0.001	1	0.99	1	1	1	1	0.9999	1	1	1
20	0.99	1	0.9999	1	1	1	1	1	0.9996	1	0.99	1	1	1	1	1	1	1	0.999	0.001	1	0.01	1	1	1	1	0.9999	1	1	1
21	0.99	1	0.9999	1	1	1	0.5	1	0.9996	1	0.99	1	1	1	1	1	1	1	0.001	1	0.95	1	1	1	1	1	0.9999	1	1	1
22	0.99	1	0.9999	1	1	1	0.5	1	0.9996	1	0.99	1	1	1	1	1	1	1	0.001	1	0.95	1	1	1	1	1	0.9999	1	1	1
23	0.99	1	0.9999	1	1	1	1	1	0.9996	1	0.99	1	1	1	1	1	1	1	0.001	1	0.05	1	1	1	1	1	1	1	1	1
24	0.99	1	0.9999	1	0.95	0.7	0.5	1	0.9996	1	0.99	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.9999	1	1	1
25	0.99	1	0.9999	1	0.95	0.7	0.5	1	0.9996	1	0.99	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.9999	1	1	1
26	0.99	1	0.9999	1	0.95	0.3	1	1	0.9996	1	0.99	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.9999	1	1	1
27	0.99	0.75	0.9999	1	0.05	1	1	1	0.9996	1	0.99	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.9999	1	1	1
28	0.99	0.25	0.9999	1	0.05	1	1	1	0.9996	1	0.99	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.9999	1	1	1
29	0.99	1	0.9999	1	0.95	0.7	0.5	1	0.9996	1	0.99	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.9999	1	1	1
30	0.99	1	0.9999	1	0.95	0.7	0.5	1	0.9996	1	0.99	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.9999	1	1	1
31	0.99	1	0.9999	1	0.95	0.3	1	1	0.9996	1	0.99	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.9999	1	1	1
32	0.99	0.75	0.9999	1	0.05	1	1	1	0.9996	1	0.99	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.9999	1	1	1
33	0.99	0.25	0.9999	1	0.05	1	1	1	0.9996	1	0.99	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.9999	1	1	1
34	0.99	1	0.9999	1	0.95	0.7	0.5	1	0.9996	1	0.99	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.0001	1	1	1
35	0.99	1	0.9999	1	0.95	0.7	0.5	1	0.9996	1	0.99	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.0001	1	1	1
36	0.99	1	0.9999	1	0.95	0.3	1	1	0.9996	1	0.99	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.0001	1	1	1
37	0.99	0.75	0.9999	1	0.05	1	1	1	0.9996	1	0.99	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.0001	1	1	1
38	0.99	0.25	0.9999	1	0.05	1	1	1	0.9996	1	0.99	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.0001	1	1	1
39	0.99	1	0.9999	1	1	1	1	1	0.9996	1	0.005	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.9999	1	1	1
40	0.99	1	0.9999	1	0.95	0.7	0.5	1	0.9996	1	0.005	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.0001	1	1	1
41	0.99	1	0.9999	1	0.95	0.7	0.5	1	0.9996	1	0.005	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.0001	1	1	1
42	0.99	1	0.9999	1	0.95	0.3	1	1	0.9996	1	0.005	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.0001	1	1	1
43	0.99	0.75	0.9999	1	0.05	1	1	1	0.9996	1	0.005	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.0001	1	1	1
44	0.99	0.25	0.9999	1	0.05	1	1	1	0.9996	1	0.005	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.0001	1	1	1

Table 5.3-2, Aerocapture to Shuttle Fault Tree Calculations, Continued

Event->	Mid C.	Brk-up	Batt. On	ERV Burn	U.Entry Low A.	No Ch. Impact	Srch No Zn.	Srch in Zn.	ERV Sep.	Entry Direct	Aero-Captr	Remve Covr	Drgue Deply	Mains Deply	Air Snatch	Aircft Landng	Con.Brk Acft Cr	Grnd Rspn	Orb. Entry	Orb. Lands	Orb.Ent Brkup	Pallet Brkup	Sp Sta Proc.	OMV Deplyd	OMV Rcvry	SCA Can Impact	Perige Raise	1stEOI Burn	2ndEOI Burn	Despin
Ref.	6.1	6.2	6.3	6.4	6.5	6.6	6.7	6.7	6.8	6.9	6.10	6.11	6.12	6.13	6.14	6.15	6.16	6.17	6.18	6.19	6.20	6.21	6.22	6.23	6.24	6.25	6.26	6.27	6.28	6.29
Nomin.	0.99	0.75	0.9999	0.9	0.95	0.3	0.5	0.9999	0.9996	0.99	0.99	0.9996	0.9999	0.9999	0.97	0.9999	0.99	0.9	0.999	0.999	0.95	0.99	0.995	0.94	0.98	0.1	0.9999	0.9993	0.9994	0.9997
Alt. 1	0.0001	0.25	1E-08	0.1	0.05	0.7	0.5	1E-05	0.0004	0.003	0.005	0.0004	1E-08	1E-08	0.03	1E-06	0.01	0.1	0.001	0.001	0.05	0.01	0.004	0.05	0.01	0.9	0.0001	0.0007	0.0006	0.0003
Alt. 2	0.0099	0	0	0	0	0	0	0	0	0.007	0.005	0	0	0	0	0	0	0	0	0	0	0	0.001	0.01	0.01	0	0	0	0	0
Chk Sum	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Path # Event # ->	1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
45	0.99	1	0.9999	1	0.95	0.7	0.5	1	0.9996	1	0.005	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
46	0.99	1	0.9999	1	0.95	0.7	0.5	1	0.9996	1	0.005	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
47	0.99	1	0.9999	1	0.95	0.3	1	1	0.9996	1	0.005	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
48	0.99	0.75	0.9999	1	0.05	1	1	1	0.9996	1	0.005	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
49	0.99	0.25	0.9999	1	0.05	1	1	1	0.9996	1	0.005	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
50	0.99	1	0.9999	0.9	1	1	1	1	0.0004	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
51	0.99	1	0.9999	0.1	0.95	0.7	0.5	1	0.0004	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
52	0.99	1	0.9999	0.1	0.95	0.7	0.5	1	0.0004	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
53	0.99	1	0.9999	0.1	0.95	0.3	1	1	0.0004	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
54	0.99	0.75	0.9999	0.1	0.05	1	1	1	0.0004	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
55	0.99	0.25	0.9999	0.1	0.05	1	1	1	0.0004	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
56	0.99	1	1E-08	0.9	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
57	0.99	1	1E-08	0.1	0.95	0.7	0.5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
58	0.99	1	1E-08	0.1	0.95	0.7	0.5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
59	0.99	1	1E-08	0.1	0.95	0.3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
60	0.99	0.75	1E-08	0.1	0.05	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
61	0.99	0.25	1E-08	0.1	0.05	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
62	0.0001	0.75	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
63	0.0001	0.25	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
64	0.0099	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Totals =

Table 5.3-2, Aerocapture to Shuttle Fault Tree Calculations, Continued

Path #	Shutle Ascnt 6.30	Sh.Rnd &RMS C 6.31			Orbiter Handeling 6.32						100 % Success	Degraded Sample	Can. Breach (Sample Re-covrd or in theory rcvrable)	Can. Breach (Sample Destroyed)	Unsterilized Lost Sample (on Earth)	Lost Sample (in Space)	Sterilized Lost Smple (on Earth)	Space Station Contain.	Permanent Orbit
	0.94	0.999	1	1	0.999	1	1	1	1	1									
	0.04	0.001	0	0	0.001	0	0	0	0	0									
	0.02	0	0	0	0	0	0	0	0	0									
	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000									
	30	31	32	33	34	35	36	37	38	39									
1	0.94'	0.999	1	1	0.999	1	1	1	1	1	0.91716								
2	0.94	0.999	1	1	0.999	1	1	1	1	1		0.00091							
3	0.94	0.999	1	1	0.999	1	1	1	1	1			9.18E-06						
4	0.94	0.999	1	1	0.999	1	1	1	1	1		0.00044							
5	0.94	0.999	1	1	0.999	1	1	1	1	1							0.00044		
6	0.94	0.999	1	1	0.999	1	1	1	1	1				4.59E-05					
7	0.94	0.999	1	1	0.001	1	1	1	1	1		0.00092							
8	0.94	0.999	1	1	0.001	1	1	1	1	1		9.10E-07							
9	0.94	0.999	1	1	0.001	1	1	1	1	1			9.19E-09						
10	0.94	0.999	1	1	0.001	1	1	1	1	1		4.37E-07							
11	0.94	0.999	1	1	0.001	1	1	1	1	1							4.37E-07		
12	0.94	0.999	1	1	0.001	1	1	1	1	1				4.60E-08					
13	0.94	0.001	1	1	1	1	1	1	1	1		0.00031							
14	0.94	0.001	1	1	1	1	1	1	1	1					0.00031				
15	0.94	0.001	1	1	1	1	1	1	1	1			0.00026						
16	0.94	0.001	1	1	1	1	1	1	1	1							3.45E-05		
17	0.94	0.001	1	1	1	1	1	1	1	1				1.15E-05					
18	0.04	0.999	1	1	1	1	1	1	1	1		0.03907							
19	0.04	0.999	1	1	1	1	1	1	1	1		3.87E-05							
20	0.04	0.999	1	1	1	1	1	1	1	1			3.91E-07						
21	0.04	0.999	1	1	1	1	1	1	1	1		1.86E-05							
22	0.04	0.999	1	1	1	1	1	1	1	1							1.86E-05		
23	0.04	0.999	1	1	1	1	1	1	1	1				1.96E-06					
24	0.04	0.001	1	1	1	1	1	1	1	1		1.30E-05							
25	0.04	0.001	1	1	1	1	1	1	1	1					1.30E-05				
26	0.04	0.001	1	1	1	1	1	1	1	1			1.12E-05						
27	0.04	0.001	1	1	1	1	1	1	1	1							1.47E-06		
28	0.04	0.001	1	1	1	1	1	1	1	1				4.90E-07					
29	0.02	1	1	1	1	1	1	1	1	1		0.00651							
30	0.02	1	1	1	1	1	1	1	1	1					0.00651				
31	0.02	1	1	1	1	1	1	1	1	1			0.00558						
32	0.02	1	1	1	1	1	1	1	1	1							0.00073		
33	0.02	1	1	1	1	1	1	1	1	1				0.00024					
34	1	1	1	1	1	1	1	1	1	1		3.26E-05							
35	1	1	1	1	1	1	1	1	1	1					3.26E-05				
36	1	1	1	1	1	1	1	1	1	1			2.79E-05						
37	1	1	1	1	1	1	1	1	1	1							3.67E-06		
38	1	1	1	1	1	1	1	1	1	1				1.22E-06					
39	1	1	1	1	1	1	1	1	1	1									0.00495
40	1	1	1	1	1	1	1	1	1	1		1.65E-07							
41	1	1	1	1	1	1	1	1	1	1					1.65E-07				
42	1	1	1	1	1	1	1	1	1	1			1.41E-07						
43	1	1	1	1	1	1	1	1	1	1							1.86E-08		
44	1	1	1	1	1	1	1	1	1	1				6.19E-09					

Table 5.3-2, Aerocapture to Shuttle Fault Tree Calculations, Continued

	Shutle Ascnt 6.30	Sh.Rnd &RMS C 6.31			Orbiter Handeling 6.32						100 % Success	Degraded Sample	Can. Breach (Sample Re-covrd or in theory rcvrable)	Can. Breach (Sample Destroyed)	Unsterilized Lost Sample (on Earth)	Lost Sample (in Space)	Sterilized Lost Sple (on Earth)	Space Station Contamin.	Permanent Orbit
	0.94	0.999	1	1	0.999	1	1	1	1	1									
	0.04	0.001	0	0	0.001	0	0	0	0	0									
	0.02	0	0	0	0	0	0	0	0	0									
	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000									
Path #	30	31	32	33	34	35	36	37	38	39									
45	1	1	1	1	1	1	1	1	1	1		0.00165							
46	1	1	1	1	1	1	1	1	1	1					0.00165				
47	1	1	1	1	1	1	1	1	1	1			0.00141						
48	1	1	1	1	1	1	1	1	1	1							0.00019		
49	1	1	1	1	1	1	1	1	1	1				6.19E-05					
50	1	1	1	1	1	1	1	1	1	1						0.00036			
51	1	1	1	1	1	1	1	1	1	1		1.32E-05							
52	1	1	1	1	1	1	1	1	1	1					1.32E-05				
53	1	1	1	1	1	1	1	1	1	1			1.13E-05						
54	1	1	1	1	1	1	1	1	1	1							1.48E-06		
55	1	1	1	1	1	1	1	1	1	1				4.95E-07					
56	1	1	1	1	1	1	1	1	1	1						8.91E-09			
57	1	1	1	1	1	1	1	1	1	1		3.29E-10							
58	1	1	1	1	1	1	1	1	1	1					3.29E-10				
59	1	1	1	1	1	1	1	1	1	1			2.82E-10						
60	1	1	1	1	1	1	1	1	1	1							3.71E-11		
61	1	1	1	1	1	1	1	1	1	1				1.24E-11					
62	1	1	1	1	1	1	1	1	1	1							7.50E-05		
63	1	1	1	1	1	1	1	1	1	1				2.50E-05					
64	1	1	1	1	1	1	1	1	1	1						0.00990			
Totals =											0.91716	0.04991	0.00732	0.00039	0.00852	0.01026	0.00149	0.00000	0.00495

Check Sum = 1.0000 Totals of Canister Breached = 0.0162

5.4 Propulsive Capture to Freedom Space Station with Repackaging and Orbiter Return

The mission sequence for propulsive capture to the Freedom Space Station is significantly simpler than aerocapture, with 43 paths (Figure 5.4-1). However, all of the branches associated with the OMV deployment and recovery are identical to those of aerocapture, resulting in similar overall probabilities.

The sequence for recovery of a second propulsively captured SRC to the Freedom Space Station may require refueling the OMV on-orbit.

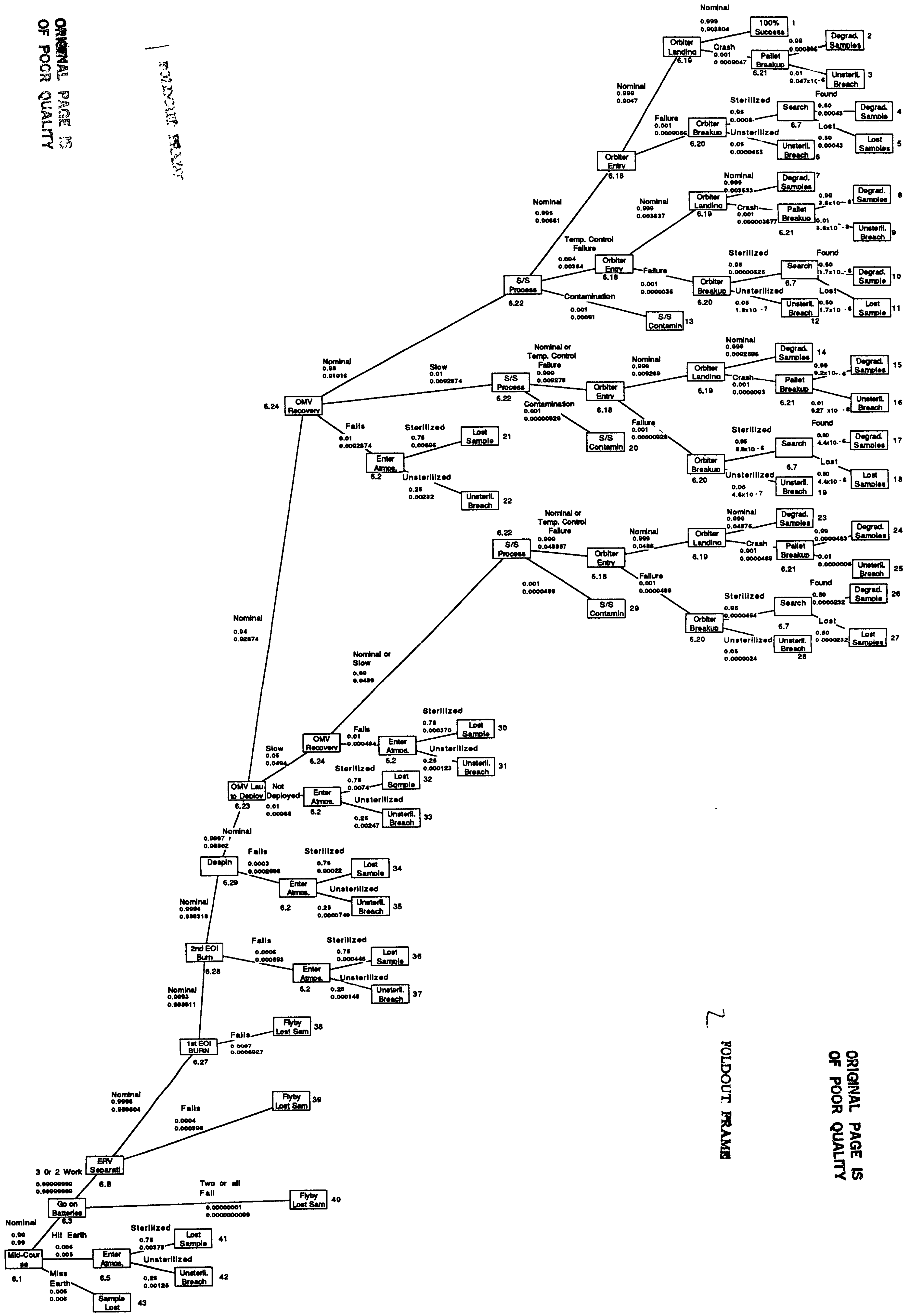

Figure 5.4-1, Propulsive Capture to Freedom Space Station Fault Tree

Table 5.4-1, Propulsive Capture to Freedom Space Station Fault Tree Path Probabilities

Path #	100 % Success	Degraded Sample	Can. Breach (Sample Recovrd or in theory rcvrable)	Can. Breach (Sample Destroyed)	Unsterilized Lost Sample (on Earth)	Lost Sample (in Space)	Sterilized Lost Smple (on Earth)	Space Station Contamin.
1	0.90380							
2		0.00090						
3			9.05E-06					
4		0.00043						
5							0.00043	
6				4.53E-05				
7		0.00363						
8		3.60E-06						
9			3.64E-08					
10		1.73E-06						
11							1.73E-06	
12				1.82E-07				
13								0.00091
14		0.00926						
15		9.18E-06						
16			9.27E-08					
17		4.41E-06						
18							4.41E-06	
19				4.64E-07				
20								9.29E-06
21							0.00697	
22				0.00232				
23		0.04876						
24		4.83E-05						
25			4.88E-07					
26		2.32E-05						
27							2.32E-05	
28			2.44E-06					
29								4.89E-05
30							0.00037	
31				0.00012				
32							0.00741	
33				0.00247				
34							0.00022	
35				7.41E-05				
36							0.00045	
37				0.00015				
38						0.00069		
39						0.00040		
40						9.90E-09		
41							0.00375	
42				0.00125				
43						0.00500		
Totals =	0.90380	0.06307	0.00001	0.00643	0.00000	0.00609	0.01962	0.00097

Check Sum = 1 Totals of Canister Breached = 0.0064

Table 5.4-2, Propulsive Capture to Freedom Space Shuttle Fault Tree Calculations

Event->	Mid C.	Brk-up	Batt. On	ERV Burn	U.Entry Low A.	No Ch. Impact	Srch No Zn.	Srch in Zn.	ERV Sep.	Entry Direct	Aero-Captr	Reeve Covr	Drgue Deply	Mains Deply	Air Snatch	Aircft Landng	Con.Brk Acft Cr	Grnd Rspn	Orb. Entry	Orb. Lands	Orb.Ent Brkup	Pallet Brkup	Sp Sta Proc.	OMV Deplyd	OMV Rcvry	SCA Can Impact	Perige Raise	1stEOI Burn	2ndEOI Burn	Despin
Ref.	6.1	6.2	6.3	6.4	6.5	6.6	6.7	6.7	6.8	6.9	6.10	6.11	6.12	6.13	6.14	6.15	6.16	6.17	6.18	6.19	6.20	6.21	6.22	6.23	6.24	6.25	6.26	6.27	6.28	6.29
Nomin.	0.99	0.75	0.9999	0.9	0.95	0.3	0.5	0.9999	0.9996	0.99	0.99	0.9996	0.9999	0.9999	0.97	0.9999	0.99	0.9	0.999	0.999	0.95	0.99	0.995	0.94	0.98	0.1	0.9999	0.9993	0.9994	0.9997
Alt. 1	0.005	0.25	1E-08	0.1	0.05	0.7	0.5	1E-05	0.0004	0.003	0.005	0.0004	1E-08	1E-08	0.03	1E-06	0.01	0.1	0.001	0.001	0.05	0.01	0.001	0.05	0.01	0.9	0.0001	0.0007	0.0006	0.0003
Alt. 2	0.005	0	0	0	0	0	0	0	0	0.007	0.005	0	0	0	0	0	0	0	0	0	0	0	0.004	0.01	0.01	0	0	0	0	0
Chk Sum	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Path # / Event #	-> 1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
1	0.99	1	0.9999	1	1	1	1	1	0.9996	1	1	1	1	1	1	1	1	1	0.999	0.999	1	1	0.995	0.94	0.98	1	1	0.9993	0.9994	0.9997
2	0.99	1	0.9999	1	1	1	1	1	0.9996	1	1	1	1	1	1	1	1	1	0.999	0.001	1	0.99	0.995	0.94	0.98	1	1	0.9993	0.9994	0.9997
3	0.99	1	0.9999	1	1	1	1	1	0.9996	1	1	1	1	1	1	1	1	1	0.999	0.001	1	0.01	0.995	0.94	0.98	1	1	0.9993	0.9994	0.9997
4	0.99	1	0.9999	1	1	1	0.5	1	0.9996	1	1	1	1	1	1	1	1	1	0.001	1	0.95	1	0.995	0.94	0.98	1	1	0.9993	0.9994	0.9997
5	0.99	1	0.9999	1	1	1	0.5	1	0.9996	1	1	1	1	1	1	1	1	1	0.001	1	0.95	1	0.995	0.94	0.98	1	1	0.9993	0.9994	0.9997
6	0.99	1	0.9999	1	1	1	1	1	0.9996	1	1	1	1	1	1	1	1	1	0.001	1	0.05	1	0.995	0.94	0.98	1	1	0.9993	0.9994	0.9997
7	0.99	1	0.9999	1	1	1	1	1	0.9996	1	1	1	1	1	1	1	1	1	0.999	0.999	1	1	0.004	0.94	0.98	1	1	0.9993	0.9994	0.9997
8	0.99	1	0.9999	1	1	1	1	1	0.9996	1	1	1	1	1	1	1	1	1	0.999	0.001	1	0.99	0.004	0.94	0.98	1	1	0.9993	0.9994	0.9997
9	0.99	1	0.9999	1	1	1	1	1	0.9996	1	1	1	1	1	1	1	1	1	0.999	0.001	1	0.01	0.004	0.94	0.98	1	1	0.9993	0.9994	0.9997
10	0.99	1	0.9999	1	1	1	0.5	1	0.9996	1	1	1	1	1	1	1	1	1	0.001	1	0.95	1	0.004	0.94	0.98	1	1	0.9993	0.9994	0.9997
11	0.99	1	0.9999	1	1	1	0.5	1	0.9996	1	1	1	1	1	1	1	1	1	0.001	1	0.95	1	0.004	0.94	0.98	1	1	0.9993	0.9994	0.9997
12	0.99	1	0.9999	1	1	1	1	1	0.9996	1	1	1	1	1	1	1	1	1	0.001	1	0.05	1	0.004	0.94	0.98	1	1	0.9993	0.9994	0.9997
13	0.99	1	0.9999	1	1	1	1	1	0.9996	1	1	1	1	1	1	1	1	1	1	1	1	1	0.001	0.94	0.98	1	1	0.9993	0.9994	0.9997
14	0.99	1	0.9999	1	1	1	1	1	0.9996	1	1	1	1	1	1	1	1	1	0.999	0.999	1	1	0.999	0.94	0.01	1	1	0.9993	0.9994	0.9997
15	0.99	1	0.9999	1	1	1	1	1	0.9996	1	1	1	1	1	1	1	1	1	0.999	0.001	1	0.99	0.999	0.94	0.01	1	1	0.9993	0.9994	0.9997
16	0.99	1	0.9999	1	1	1	1	1	0.9996	1	1	1	1	1	1	1	1	1	0.999	0.001	1	0.01	0.999	0.94	0.01	1	1	0.9993	0.9994	0.9997
17	0.99	1	0.9999	1	1	1	0.5	1	0.9996	1	1	1	1	1	1	1	1	1	0.001	1	0.95	1	0.999	0.94	0.01	1	1	0.9993	0.9994	0.9997
18	0.99	1	0.9999	1	1	1	0.5	1	0.9996	1	1	1	1	1	1	1	1	1	0.001	1	0.95	1	0.999	0.94	0.01	1	1	0.9993	0.9994	0.9997
19	0.99	1	0.9999	1	1	1	1	1	0.9996	1	1	1	1	1	1	1	1	1	0.001	1	0.05	1	0.999	0.94	0.01	1	1	0.9993	0.9994	0.9997
20	0.99	1	0.9999	1	1	1	1	1	0.9996	1	1	1	1	1	1	1	1	1	1	1	1	1	0.001	0.94	0.01	1	1	0.9993	0.9994	0.9997
21	0.99	0.75	0.9999	1	1	1	1	1	0.9996	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.94	0.01	1	1	0.9993	0.9994	0.9997
22	0.99	0.25	0.9999	1	1	1	1	1	0.9996	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.94	0.01	1	1	0.9993	0.9994	0.9997
23	0.99	1	0.9999	1	1	1	1	1	0.9996	1	1	1	1	1	1	1	1	1	0.999	0.999	1	1	0.999	0.05	0.99	1	1	0.9993	0.9994	0.9997
24	0.99	1	0.9999	1	1	1	1	1	0.9996	1	1	1	1	1	1	1	1	1	0.999	0.001	1	0.99	0.999	0.05	0.99	1	1	0.9993	0.9994	0.9997
25	0.99	1	0.9999	1	1	1	1	1	0.9996	1	1	1	1	1	1	1	1	1	0.999	0.001	1	0.01	0.999	0.05	0.99	1	1	0.9993	0.9994	0.9997
26	0.99	1	0.9999	1	1	1	0.5	1	0.9996	1	1	1	1	1	1	1	1	1	0.001	1	0.95	1	0.999	0.05	0.99	1	1	0.9993	0.9994	0.9997
27	0.99	1	0.9999	1	1	1	0.5	1	0.9996	1	1	1	1	1	1	1	1	1	0.001	1	0.95	1	0.999	0.05	0.99	1	1	0.9993	0.9994	0.9997
28	0.99	1	0.9999	1	1	1	1	1	0.9996	1	1	1	1	1	1	1	1	1	0.001	1	0.05	1	0.999	0.05	0.99	1	1	0.9993	0.9994	0.9997
29	0.99	1	0.9999	1	1	1	1	1	0.9996	1	1	1	1	1	1	1	1	1	1	1	1	1	0.001	0.05	0.99	1	1	0.9993	0.9994	0.9997
30	0.99	0.75	0.9999	1	1	1	1	1	0.9996	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.05	0.01	1	1	0.9993	0.9994	0.9997
31	0.99	0.25	0.9999	1	1	1	1	1	0.9996	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.05	0.01	1	1	0.9993	0.9994	0.9997
32	0.99	0.75	0.9999	1	1	1	1	1	0.9996	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.01	1	1	1	0.9993	0.9994	0.9997
33	0.99	0.25	0.9999	1	1	1	1	1	0.9996	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.01	1	1	1	0.9993	0.9994	0.9997
34	0.99	0.75	0.9999	1	1	1	1	1	0.9996	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.9993	0.9994	0.0003
35	0.99	0.25	0.9999	1	1	1	1	1	0.9996	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.9993	0.9994	0.0003
36	0.99	0.75	0.9999	1	1	1	1	1	0.9996	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.9993	0.0006	1
37	0.99	0.25	0.9999	1	1	1	1	1	0.9996	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.9993	0.0006	1
38	0.99	1	0.9999	1	1	1	1	1	0.9996	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.0007	1	1
39	0.99	1	0.9999	1	1	1	1	1	0.0004	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
40	0.99	1	1E-08	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
41	0.005	0.75	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
42	0.005	0.25	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
43	0.005	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Totals =																														

Table 5.4-2, Propulsive Capture to Freedom Space Shuttle Fault Tree Calculations, Continued

	Shutle Ascnt	Sh.Rnd &RMS C																
	6.30	6.31																
	0.94	0.999	1	1	1	1	1	1	1	1								
	0.04	0.001	0	0	0	0	0	0	0	0								
	0.02	0	0	0	0	0	0	0	0	0	100 % Success	Degraded Sample	Can. Breach (Sample Re-covrd or in theory rcvrable)	Can. Breach (Sample Destroyed)	Unsterilized Lost Sample (on Earth)	Lost Sample (in Space)	Sterilized Lost Smple (on Earth)	Space Station Contamin.
	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000								
Path #	30	31	32	33	34	35	36	37	38	39								
1	1	1	1	1	1	1	1	1	1	1	0.90380							
2	1	1	1	1	1	1	1	1	1	1		0.00090						
3	1	1	1	1	1	1	1	1	1	1			9.05E-06					
4	1	1	1	1	1	1	1	1	1	1		0.00043						
5	1	1	1	1	1	1	1	1	1	1							0.00043	
6	1	1	1	1	1	1	1	1	1	1				4.53E-05				
7	1	1	1	1	1	1	1	1	1	1		0.00363						
8	1	1	1	1	1	1	1	1	1	1		3.60E-06						
9	1	1	1	1	1	1	1	1	1	1			3.64E-08					
10	1	1	1	1	1	1	1	1	1	1		1.73E-06						
11	1	1	1	1	1	1	1	1	1	1							1.73E-06	
12	1	1	1	1	1	1	1	1	1	1				1.82E-07				
13	1	1	1	1	1	1	1	1	1	1								0.00091
14	1	1	1	1	1	1	1	1	1	1		0.00926						
15	1	1	1	1	1	1	1	1	1	1		9.18E-06						
16	1	1	1	1	1	1	1	1	1	1			9.27E-08					
17	1	1	1	1	1	1	1	1	1	1		4.41E-06						
18	1	1	1	1	1	1	1	1	1	1							4.41E-06	
19	1	1	1	1	1	1	1	1	1	1				4.64E-07				
20	1	1	1	1	1	1	1	1	1	1								9.29E-06
21	1	1	1	1	1	1	1	1	1	1							0.00697	
22	1	1	1	1	1	1	1	1	1	1				0.00232				
23	1	1	1	1	1	1	1	1	1	1		0.04876						
24	1	1	1	1	1	1	1	1	1	1		4.83E-05						
25	1	1	1	1	1	1	1	1	1	1			4.88E-07					
26	1	1	1	1	1	1	1	1	1	1		2.32E-05						
27	1	1	1	1	1	1	1	1	1	1							2.32E-05	
28	1	1	1	1	1	1	1	1	1	1			2.44E-06					
29	1	1	1	1	1	1	1	1	1	1								4.89E-05
30	1	1	1	1	1	1	1	1	1	1							0.00037	
31	1	1	1	1	1	1	1	1	1	1				0.00012				
32	1	1	1	1	1	1	1	1	1	1							0.00741	
33	1	1	1	1	1	1	1	1	1	1				0.00247				
34	1	1	1	1	1	1	1	1	1	1							0.00022	
35	1	1	1	1	1	1	1	1	1	1				7.41E-05				
36	1	1	1	1	1	1	1	1	1	1							0.00045	
37	1	1	1	1	1	1	1	1	1	1				0.00015				
38	1	1	1	1	1	1	1	1	1	1						0.00069		
39	1	1	1	1	1	1	1	1	1	1						0.00040		
40	1	1	1	1	1	1	1	1	1	1						9.90E-09		
41	1	1	1	1	1	1	1	1	1	1							0.00375	
42	1	1	1	1	1	1	1	1	1	1				0.00125				
43	1	1	1	1	1	1	1	1	1	1						0.00500		
Totals =		Check Sum = 1.0000									0.90380	0.06307	0.00001	0.00643	0.00000	0.00609	0.01962	0.00097

Totals of Canister Breached = 0.0064

6.0 Probability Estimates for Failures

In section 5, fault trees are presented for four mission options. Each one of these fault trees has a series of branch points or events. In all the trees, there are only a limited number of events. This section discusses each of these events in some detail, and explains the rational for the numbers chosen.

6.1 Event: **Last Midcourse Correction** - This is the last in what may be a series of midcourse corrections from Mars to Earth. It is assumed that each correction targets have been proposed in which the ERV/SRC is targeted to miss Earth and only after separation from the ERV does the SRC make a burn that will result in the proper entry trajectory. This idea reduces the risk of canister breach some small amount since failures during the last midcourse, ERV/SRC separation, and initial SRC operation cannot result in breach, only sample loss. However, this scheme may cost weight since the SRC gets power from the ERV and it is desirable to keep the two vehicles together for as long as possible to reduce the mass of the SRC. The closer the last midcourse is made to Earth, the more propellant is used.

Possible Results: **Nominal Trajectory** (aligned for proper Earth entry) or sufficiently normal such that the normal mission sequence can be followed, resulting in chute opening for direct entry, no break-up or burn-up for aerocapture and no atmospheric entry for propulsive capture.

High Off-Nominal Trajectory resulting in a steeper than normal entry and high g's. For the direct entry case, high g capsule breakup results. Trajectories resulting in anything less than capsule breakup are accounted for in the Nominal path for direct entry.

For the aerocapture case, this would be an entry steep enough to result in break-up. An entry from which an exit from the atmosphere is not possible, but during which the SRC remains intact is handled along the nominal path.

For propulsive capture, this case includes any off-nominal trajectory resulting in significant atmospheric entry and burn-up in a few orbits or less.

Miss Earth - The trajectory either misses Earth entirely or is so shallow that a skip occurs. The vehicle continues on into interplanetary space and the probability of it returning and hitting Earth with any live organism is considered small enough to be ignored. Some analysis predicting the probability of the vehicle hitting the Earth at some distant point in the future is desirable to confirm this assumption. This path is always assumed to result in a lost sample and no sample canister breach.

Probabilities:

Nominal Trajectory - 0.99 - (Merkhofer, 1977), based on similar systems at JPL.

Highly Off-Nominal Trajectory (entry and break or burn-up) - 0.005 for propulsive capture.

0.0001 - for direct entry and aerocapture.

The chance of something happening other than a nominal trajectory is 1.0 - 0.99 = 0.01. Given a trajectory that is targeted for Earth or very near Earth (the "edge" of Earth) in the first place, and the most likely failures resulting is no last midcourse burn (rather than a wildly erratic burn) an estimate of 50% of the 0.01 is chosen for the propulsive capture. If the propulsive capture vehicle enters the atmosphere to any significant extent, it will burn up in a few orbits. Detailed trajectory analysis is needed to confirm this probability guess. Merkhofer and Yen before him estimated a probability of 0.0001 (Merkhofer, 1977) for this event. This result is a function of the trajectory and dispersions. Merkhofer assumed the ERV/SRC would be targeted away from Earth for most of the return trajectory however.

For direct entry and aerocapture, the capsule must enter the Earth's atmosphere at an angle steep enough to result in sufficient gs or heating such that the capsule breaks up. Initial calculations concerning an Apollo shaped capsule with a diameter in the range of 2 meters and a mass on the order of 400 kg indicate that it might require 200 gs or so to break up. This would require an entry angle of 20 degrees or more, depending on the entry velocity. This angle seems large and perhaps difficult to achieve, leading to the guess that break-up will be unlikely, maybe 1 chance in 100. Trajectory analysis is needed to confirm this estimation. Given that the chance of achieving this trajectory is 1 in 100 and that the chance of being off-nominal at all of .01, .01/100 = .0001

Miss Earth - 0.005 for propulsive capture based on 1.0 - 0.99 -.005.

0.0099 for aerocapture and direct entry based on 1.0 - 0.99 - 0.0001 = 0.0099.

6.2 Event: **Break-up in Atmosphere** - Following an entry at a steep angle and high gs or entry with no heat shield in the propulsive capture case, the vehicle breaks up in the atmosphere. G and aero forces, and melting are assumed to cause the break-up. Following break-up, the sample canister is assumed to be breached. The chief question of interest becomes whether or not the sample and sample contaminated hardware will be sterilized. For estimation purposes, assume the sample is dumped from its container, shortly before entry. The sample consists of small rocks, sand, silt and many size particles.

This event occurs because the aerobraking or reentry vehicle entered the Earth's atmosphere either more rapidly than designed or due to an uncontrolled entry where the vehicle entered with the heat shield in the incorrect orientation. The result is the destruction of the vehicle and the exposure of the SCA to the atmosphere. The SCA is a light weight structure and will be subjected to temperatures in excess of alloy melting temperature. The sample will undoubtedly be lost. The issue is whether the entry heating will be adequate to sterilize the sample by thermally decomposing any complex organic molecules, such as DNA.

Possible Results: **Sterilized** - All parts of the sample are heated to a temperature at which sterilization is almost certain for small life forms carrying genetic information in long chain molecules. This temperature is estimated to be in the range of 200°C for a few minutes. If the SCA canister remains in large pieces for part of the entry it will be aerodynamically heated to the degree that complete sterilization can occur.

Unsterilized - Some of the sample is not heated sufficiently to sterilize it and it lands on the Earth's surface, resulting in contamination. The only way that the sample can escape sterilization is if the sample containing tubes are breached rapidly and the fine grained Martian soil is released into the upper atmosphere. The material will then be slowed down, but the fine particle size allows radiation and convective cooling at a rate rapid enough that sterilization may not be complete. The preservation of organic material in fine cosmic dust particles indicates that such a process is possible on fine grained material.

Probabilities:

Sterilized - 0.75 - If the capsule can be designed to contain the sample until it has been heated sufficiently to sterilize the sample, sterilization may work. This will probably result in some weight penalty due to replacing aluminum alloy with Inconel for example. The probability is somewhat arbitrarily picked. Analysis can probably determine if it is possible to build a SRC/container that will sterilize in all situations. If it is possible then this number can be much closer to 1.0.

Unsterilized - 0.25 - Small dust particles have been shown to not experience significant heating during entry. If the sample is released from the container, prior to being sterilized by the heat, then contamination may be assumed to occur.

6.3 Event: **Go On Batteries** - The SRC will be powered by the ERV until four hours before Earth entry, or Earth Orbit Insertion (EOI) burn, depending on the option. At this point the SRC will go on its internal battery power and separate from the ERV. The SRC internal power system is currently planned to use three separate battery packs, providing a total of 150 % of the required power. One battery pack can be lost and have no effect on the mission. If two are lost, only 50% of the required power is available.

Possible Results: **Three or Two Battery Packs Function** - This results in a nominal mission with 150 or 100 % of required power.

One or No Battery Packs Function - With no internal power, the mission is certain to fail for the aerocapture and propulsive capture options. The direct entry option, if designed properly and given enough mass, might be able to enter and impact the Earth's surface, reasonably intact, but the seals on the canister are likely to be broken, resulting in possible contamination. In addition, lack of control will probably result in a large error ellipse on the ground. For these reasons, in the event of no power, it would be desirable to not separate the ERV and SRC and between the two of them, try to arrange a burn that would cause them to miss Earth. The feasibility of this is a function of the trajectory and the mass that can be added. This requires study, but is generally assumed to be possible and is the nominal plan assumed for this calculation. This is assumed to occur for all three options and to occur in the event of no power or just one battery available.

In the event only one battery pack functions, only 50% of the power requirement of the vehicle is available. The mission will be degraded, though it is difficult to predict how much. At some point the vehicle will run out of power. For the cases resulting in Earth parking orbits, power loss may occur after establishment of the orbit. It then becomes more difficult to locate (no transponder) and capture (no attitude control) the vehicle. For the direct entry case, insufficient power may be available to ignite pyros or parachute mortars or run a locator beacon. In any event, the risk of contamination will be increased, and the nominal procedure is assumed to be an ERV/SRC burn using ERV power to miss Earth. More study is required to determine if this is indeed the best course of action.

Looking at the probabilities below, the probability of one or no batteries functioning is so small, that whatever happens after such a failure will be very improbable, thus the branch following this failure is not very important.

Probabilities:

One or No Battery Packs Function - 0.00000001 - (1 x 10^-8) Given a probability of failure of one battery of .0001 (a reliability of 0.9999), the probability of two out is calculated to be (.0001)^2 x (1-.0001)^(3-2) = 1 x 10^-8. The probability of three out is (.0001)^3 x (1-.0001)^(3-3) = 1 x 10^-12. 1 x 10^-8 + 1 x 10^-12 = (approx.) 1 x 10^-8.

The reliability of a single battery is an estimate. A single battery is assumed to be at least as reliable as a single pyro unit, estimated to have a reliability of 0.9999 (Vaughn and Graves, 1988). Better estimates can undoubtedly be located.

Three or Two Battery Packs Function - 0.99999999 - This is the residual left over after the calculation above is performed.

6.4 Event: **ERV/SRC Burn to Miss Earth** - Given a failure of two or more battery packs or failure of the ERV to separate, the ERV/SRC combination must make a burn that allows it to miss Earth. Propulsion on both the ERV and SRC can be used. In the event of SRC battery failure, ERV power can be used.

Possible Results: **Nominal Burn** - The ERV/SRC makes an adequate burn and misses Earth resulting in a lost sample. The probability of the vehicle returning and impacting Earth in the future is assumed to be so small as to be negligible, but this requires analysis to confirm.

Burn Fails - The burn is not made or is inadequate to miss Earth. There are a number of possibilities following such an occurrence, but the inability to make such a burn implies a serious problem and an uncontrolled entry at a relatively shallow angle is assumed to result. More possible results could also be mapped, but the probability of this whole branch is so low that the effort would be wasted.

Probabilities:

Nominal Burn - 0.9 - Given one failure another may be more probable.

Burn Fails - 0.10 - The residual.

6.5 Event: **Uncontrolled, Low-angle Entry** - The vehicle, due to lack of power, an attached ERV, or other failure, makes an uncontrolled entry. This event occurs when the aerodynamic SRC, either that designed for aerobraking or for direct entry, enters the atmosphere without any attitude control. The vehicle may either orient itself so that it is aerodynamically braked and eventually hits the Earth, or the vehicle may break up due to high loads or orientation in a direction without the heat shield in the proper direction. The vehicle can probably be designed to survive an uncontrolled entry. A Discoverer type capsule could be used. The Discoverer design (see Fig. 3.3-2) orients itself in an aerodynamically stable position without active control. The uncontrolled capsule will have a much larger landing foot-print, perhaps on the order of 10 x 30 nm as opposed to an ellipse on the order of 2 x 5 or so (Apollo numbers). Designing a nominally controlled capsule to survive uncontrolled entry will probably come at some cost in mass.

Probable Results: **Intact to the Surface** - If the vehicle orients itself in the correct direction and remains at least partially intact, then the SRC Canister will impact the Earth. The impact is of an intact SRC. Subsequent branches cover whether the SRC is breached or not and whether it is found if it is unbreached. In any case the sample's thermal control is lost. The best that can happen is that the sample is found intact just warm.

Breakup in atmosphere - The vehicle breaks up in the atmosphere for any number of causes and the SRC does not reach the surface of the Earth intact. The breakup in the atmosphere branch refers to breaking up the SRC Canister.

Probabilities:

Intact to the Surface - 0.95 - For direct entry and aerocapture. If the weight penalty can be paid, a capsule can probably be designed to survive intact to the ground. This number assumes most of that penalty will be paid. For a given design, this number is testable.

Break-up in Atmosphere - 0.05 - for direct entry and aerocapture, the residual.

6.6 Event: **Surface Impact with No Chute** - The main chutes fails to deploy or malfunctions significantly resulting in a high velocity impact with the Earth's surface.

Possible Results: **Sample Canister Breached** - The impact results in rupture of the sample container. In water, contamination will certainly occur following this. On land, it may well occur.

Sample Canister Unbreached - The impact does not rupture the sample container. The sample is contained.

Probabilities:

Sample Canister Breached - 0.30 - A breach in the sample container can be avoided by careful packaging and addition of materials to absorb the energy of the impact. This may cost weight however. Balsa is one candidate energy absorber, causing an estimated weight penalty on the order of 10 kg. Another concept involves placing the sample in a tough, flexible bag that would contain it while all the metal around it is deformed. The energy absorption system is easily testable and could be well developed at the cost of capsule mass. On the other hand, the seals of the canister are likely to be fragile. Contamination is defined hereas as little as a loss of seal integrity and exposure of some of the sample to air.

Terminal velocity of the capsule is estimated to be in the range of 210 ft/sec. Peak decelerations are estimated to range from 2,000 g's (water landing) to 4,000 gs (landing on rock) based on an analysis to estimate water landing loads. The program was modified to estimate land landing loads.

The 0.30 number is a guess. Testing can determine this number precisely.

Sample Canister Unbreached - 0.70 - See above, 1.0 - 0.30 = 0.70.

6.7 Event: **Search for SRC on Earth** -This event is the search for an SRC which has landed without parachutes and not been breached. The search would not be aided by any radio beacon due to the fact that the vehicle would not be equipped with one durable enough to survive a hard landing. A land landing is assumed because the primary requirements are to find the sample and not contaminate the Earth. Land landings offer the best chance for both of these. A land area can even conceivably be sterilized in the event of a breach of the sample container.

Two different cases must be noted. In one case, the impact follows failures on-orbit resulting in an uncontrolled entry or other failures resulting in landing in a randomly determined area. Decay of a parking orbit is a good example of this kind of failure. The capsule will be much more difficult to find in this case.

The other case involves failures on the nominal trajectory, after entry, such as a parachute failure. The nominal landing zone would still be used. The vehicle would just hit hard.

Probable
Results: **SRC and Canister Found** - If the intact SRC is found, the sample will have been warmed above the required -40°C, assuming that it lands in areas other than the Antarctica, Greenland or the Arctic regions of Eurasia or North America during the winter. A nominal landing zone would be in a Southwestern U.S. desert, in the Midwest U.S. wheat fields or in the Central Soviet Union.

SRC and Canister Not Found - If the sample is not found it obviously has no value and adds to the risk of contamination.

Probabilities:

SRC and Canister Found - 0.50 - For the random landing. The SRC will be tracked prior to entry by NASA, NORAD and its Soviet equivalent. Thus the impact location will be estimated within an ellipse a few miles wide and at most a few tens of miles long, within an area of a few hundred square miles. If the SRC lands in the ocean it can easily be lost. If it lands in a flat area with either little vegetation or row crops the probability of discovery is very high. If, on the other hand it lands in a forest or jungle it may not be found. Since the oceans occupy 70 percent of the Earth's surface and forest and jungle cover about a third of the land, the probability of discovery is about 20% if the landing area is randomly chosen.

The above philosophy is based on experience with searches that may be rather poorly funded compared to what would be expected for this search. Given the sample is in a known area, land or water, the search will continue until the searchers run out of money. Ignoring factors associated with time-consuming searches such as theft of the sample by non-government searchers, and burial of the sample with sediment, the probability of finding the sample goes up with the money and time spent. A search like the one conducted for nuclear warheads lost in the Mediterranean could be expected and the probability of finding it is assumed to be significantly better than 20%.
0.99999 - for landing in the nominal landing zone. The nominal landing zone will be on land in a cleared area. Given adequate time and money, and baring simple theft and other strange misfortune, it is difficult to conceive of losing the sample.

SRC and Canister Not Found - 0.50 - For the random case, the residual.

0.00001 - For the targeted case. The residual.

6.8 Event: **ERV Separation** - Based on internal or ground commands the ERV and the SRC will separate approx. four hours prior to Earth entry. This event is a function of the correct functioning of the data and communications systems, both redundant, and a minimum of 3 pyros.

Possible Results: **Nominal Separation** - The command is sent, all three pyros fire, and nominal separation occurs. At the present time, the ERV is assumed to enter the Earth's atmosphere for all but the propulsive capture case, and no further attention is paid to it. The probability of contamination of the ERV is assumed to be very small. A sterile transfer is to have taken place in Mars orbit. Any detected anomaly in this transfer would be cause to leave the vehicle in Mars orbit.

Failure to Separate - At least one of the three pyros does not fire and the two vehicles do not separate. Following this failure, an attempt is made to do a burn that causes the vehicle to miss Earth.

Probabilities:

Nominal Separation - 0.9996 - Each pyro is assumed to have a reliability of 0.9999. The probability of at least one failing is (.9999)^3 = 0.9997. An additional 1 chance in a thousand is thrown in to account for failures of the data/com/-power distribution/etc.

Failure to Separate - 0.0004 - The residual.

6.9 Event: **Direct Entry** - For the direct entry option, the vehicle enters the atmosphere at any angle shallow enough to avoid break-up, predicted to be anything less than 20 degrees.

Possible Results: **Nominal Entry** is a controlled entry leading to the nominal sequence.

High Skip is an entry at such a shallow angle that the vehicle skips out and misses Earth. Other reasons for a high skip and miss might include a guidance or navigation failure of some kind such that the vehicle is guided out of the atmosphere.

Skip to Orbit or High Gamma Entry - These cases, though radically different, have the same result, an uncontrolled entry.

In the skip to orbit, the vehicle skips out, but enough energy is lost to put it in an elliptical orbit. The orbit will pass through the atmosphere at each perigee and will therefore decay quickly to an unplanned landing.
In the high gamma entry, the entry will be far too steep due to some failure, resulting in high gs and loss of control.

Probabilities:

Nominal Entry - 0.99 - This is an estimate, subject to dispute. Historical data from past programs resulting in entries could be researched to come up with a better number.

High Skip - 0.003 - The residual probability remaining after nominal entry is 0.01. The high skip is felt to be somewhat less likely than the alternative, resulting in an uncontrolled entry and is therefore assigned 30 % of the residual.

Skip to Orbit or High Gamma Entry - .007 - The other 70 % of the residual (0.01 - 0.003).

6.10 Event: **Aerocapture Maneuver** - The SRC goes into the atmosphere and dissipates enough energy to enter an orbit with apogee near the Freedom Space Station orbit. After exiting the atmosphere and reaching apogee, a circularization burn raises the perigee out of the atmosphere.

Possible Results: **Nominal** - The SRC enters and exits the atmosphere on a trajectory close enough to nominal to enable circularization in a near Freedom Space Station orbit.

Exit Early - The SRC leaves the atmosphere before dissipating enough energy to get the apogee low enough to allow retrieval by the OMV. If the vehicle's perigee can be raised out of the atmosphere, the SRC will go into a long term, but perhaps inaccessible orbit.

Unplanned Entry - The SRC enters the atmosphere and dissipates too much energy, resulting in an inability to exit the atmosphere or an apogee that is too low, resulting in entry in a few orbits or tens of orbits.

Probabilities:

Nominal - 0.99 - an estimate, subject to dispute. The aerocapture maneuver is at least as complicated as the midcourse, which has a referenced 0.99 success estimate.

Exit Early - 0.005 - one half of the residual.

Unplanned Entry - 0.005 - the other half of the residual.

6.11 Event: **Remove Cover** - Prior to release of the drogue chutes during direct entry, a cover or shroud, covering the chutes is assumed to be released by three pyrotechnic devices. The release of the cover reduces the hung weight and uncovers the chutes.

Possible
Results: **Nominal** - The pyrotechnic devices fire as planned and the cover is removed.
Cover Not Removed - Due to signal or pyro failures, the cover does not come off. The chutes can therefore not deploy and the capsule hits the ground at a high velocity.

Probabilities:
Nominal - 0.9996 - Given a reliability for a single pyro unit of 0.9999 (Vaughn and Graves, 1988), the reliability for the system is (0.9999)^3 = 0.9997. An additional .0001 is subtracted to account for reliability in the system sending the signal to the pyros.

Cover Not Removed - 0.0004 - the residual.

6.12 Event: **Drogue Deployed** - Two redundant, mortar-deployed drogue chutes may be used to stabilize the capsule and slow its descent rate some, prior to opening the main chutes. In Apollo, the drogues were deployed at 25,000 ft. and the mains at 12,000 ft. Prior to deployment of the mains the drogues were cut away.

Possible
Results: **One or Both Drogues Deployed** - At least one drogue is deployed as planned. The system is designed for one drogue deployment as a nominal case. The second drogue is redundant.

No Drogues Deployed - If for some reason no drogue chutes deploy, the capsule may be tumbling, and will certainly be going faster when the main chutes deploy. If the mains can be designed to take the dynamic pressure without the drogues, the probability that they will deploy is still very high. It is assumed the main chutes can be designed to take this dynamic pressure and that some weight penalty will result.

Probabilities:
One or Both Drogues Deploy - 0.99999999 - The military currently has roughly one malfunction per 10,000 live jumps with the T-10 chute. Fatalities are 1 per one million jumps. The malfunction probability is therefore 0.0001. With two redundant chutes, the probability is (0.0001) ^2 = 0.00000001. The probability of success is the residual. It has been estimated that the reliability of the standard military chute could be substantially increased by better packing. On the other hand, the MRSR chute will never be tested and developed to the degree the military chute system has been, and must survive the space environment for three years or more. Apollo testing showed chutes could remain packed for four years without degradation however (Kiker, 1988).

No Drogues Deploy - 0.00000001 - See above.

6.13 Event: **Main Chutes Deployed** - Two mortar-deployed, redundant main canopies are assumed to deploy somewhere around 10,000 ft. The deployment mechanism is assumed to be an atmospheric pressure switch firing the mortars and the drogue cutaway pyro simultaneously. The pressure switch must be armed by the sequencing logic at some point higher in the trajectory and power must be provided to the initiators.

Failure to cut away the drogues will result in some small increase in the probability of malfunction of the mains, but this is ignored here. The main chutes are assumed to be designed to be deployable even in the absence of one or both drogues. It is assumed they will be able to take the greater dynamic pressure due to the higher airspeed.

Possible Results: **One or Both Mains Deployed** - The main chutes are assumed to be redundant. If at least one successfully deploys, a normal landing is assumed to take place.

No Mains Deploy - Failure of both main chutes to deploy will result in a high velocity landing.

Probabilities:
One or Both Mains Deployed - 0.99999999 - See discussion for drogue chutes.

0.99 - if no drogues deploy (Kiker, 1988). Failure of at least one drogue to deploy will significantly reduce the chance of a successful main chute deployment, however, if the system is properly designed, successful main chute deployment can still be made quite probable. If at least one drogue does not deploy, the capsule will be going much faster at main chute deployment and may also have some tumbling motions that might lead to a malfunction in the mains.

No Mains Deploy - 0.00000001 - The residual.

0.01 - if no drogues deploy. The residual.

6.14 Event: **Air Snatch** - In order to reduce the chance of contamination as much as possible and increase the chances of maintaining the required thermal conditions (-40° C), the SRC, hanging from one or more chutes, will be snatched in the air by a large aircraft and brought on board using a technique developed over a long period of time for military film canisters. Even if the air snatch is missed, a relatively nominal landing on land is anticipated, with a somewhat greater chance of the sample warming up.

Possible Results: **Success** - The SRC is swung into the interior of the aircraft and placed in a biological containment canister capable of providing thermal control to the sample.

Miss - The SRC makes a land landing, with no breaching of the sample, given at least one functional chute. Given a rapid ground response and location of the capsule before it gets too warm, the mission can still be a complete success.

Probabilities:

Success - 0.97 - This is approximately the success rate for military air snatch operations (Kiker, 1988).
Miss - 0.03 - The residual.

6.15 Event: **Aircraft Landing** - Following successful air snatch and onboard containment and thermal control of the sample, the aircraft flies to a designated location and unloads the sample for ground transport to an analysis laboratory.

Possible
Results: **Nominal** - The aircraft returns and lands without incident.

Crash - The aircraft crashes between successful snatch and landing. The sample may or may not be breached.

Probabilities:

Nominal - 0.999999 - There is roughly one fatal accident in one million aircraft operations (takeoff or landing) in the U.S. air carrier fleet (Merkhofer, 1971). The sample carrying aircraft should do at least this well.

Crash - 0.000001 - The residual.

6.16 Event: **Container Breakup in Aircraft Crash** - In the event of an aircraft accident, most probably related to landing, the SRC will be in a thick-walled, thermal controlled containment.

Possible
Results: **Container Breakup - Yes** - the containment is broken and the sample is exposed to the air and thermal control is lost. Contamination is therefore considered to have occurred.

Container Breakup - No - The containment remains intact, but it is assumed that thermal control is lost and the sample warms up to some extent.

Probabilities:

Container Breakup - Yes - 0.01 - The sample container can be heavy and strong (half-inch steel). A well designed container can survive a substantial crash.

Container Breakup - No - 0.99 - The residual. Even if the container does not breakup, thermal control is assumed to be lost.

6.17 Event: **Ground Response to Air Snatch Miss** - In the event an air snatch is missed, the ground personnel must quickly find and thermally control the sample.

Possible
Results: **Fast Response** - The sample is quickly recovered before thermal limits are exceeded. This is far more difficult to do at sea than on land due to the high heat capacity and thermal conductivity of water.

Slow Response - The ground cannot find the sample and plug in thermal control before it warms up.

Probabilities:
Fast Response - 0.9 - Helicopters can back up the main recovery aircraft and quickly locate and direct ground vehicles to the sample. The recovery aircraft can also do the same.

Slow Response - 0.1 - The residual.

6.18 Event: **Orbiter Entry** - This event is the combination of all of the events that occur from the time the orbiter begins to undock with the Freedom Space Station until it begins final approach for landing.

Possible
Results: **Nominal Entry** - The next event is landing.

Orbiter Breakup during entry - The SRC Canister would be exposed to the airstream after breakup occurred. Following breakup, if the sample container is properly designed, it may sterilize the sample with heating prior to releasing it. If breakup occurs after the heating phase of entry, the sample will not be sterilized, however the container will still hold it.

Probabilities:
Nominal entry - 0.999 - The Orbiter has made 24 successful entries in 24 attempts. Other than failures of the thermal protection system, the entry phase has a high degree of redundancy.

Crash or Orbiter Breakup during Entry - 0.001 - This sort of event could occur due to either a guidance or control failure or possibly a critical high temperature black tile coming off during launch. This sort of failure has been considered in Orbiter design, and the design has been certified as part of the Orbiter reevaluation following the 51-L incident.

6.19 Event: **Orbiter Lands** - Following a successful deorbit and entry the Orbiter lands. A variety of failures are possible, ranging from the landing gear's failure to deploy or a hard landing, resulting in gear collapse to a flight control failure.

Probable
Results: **Nominal** - The successful landing of the orbiter terminates the mission and results in the delivery of the sample to a waiting team of curation and scientific personnel.

Crash - A crash should not normally result in the canister pallet breaking loose from the trunnion and keel fittings. The pallet is designed to remain in place even following a crash as are all orbiter payloads.

Probabilities:

Nominal - 0.999 - The flight record is for 24 successful landings for 24 attempts following orbital flights and 6 successes for 6 attempts during the Approach and Landing Tests.

Crash - 0.001 - The residual probability.

6.20 Event: **Orbiter Breakup on Entry** - The event is the destruction of the Orbiter due to a TPS burn through, malfunction, or operational error. The event results in the exposing of the SRC Canister to the airstream. The canister will be heated to high temperatures. The canister and associated debris will hit the Earth at high subsonic velocities. The sample has certainly been degraded at this point, the only question is whether or not it has been sterilized.

Probable Results: **Sample Sterilized** - The sample container is heated either as a whole or after breaking up to temperatures that decompose complex organic molecules (such as DNA) that are critical for the Martian pathogens to reproduce.

Sample Not Sterilized - The sample container is broken up and parts of the clay and fine sand portions of the sample are aerodynamically slowed before they are heated to sterilizing temperatures.

Probabilities:

Sample Sterilized - 0.95 - Hard data is not available that can be used to estimate this probability. However, the most likely scenario is that the SRC container would be designed to withstand high aerodynamic and heating loads. In our study of MRSR requirements affecting Freedom Space Station (Simonds, 1988) it was recommended that the SRC Canister be made of Inconel 718 which maintains its strength at temperatures in excess of 900°C.

Sample Not Sterilized - 0.05 - The residual.

6.21 Event: **Pallet Breakup following Orbiter crash landing** - As a result of a crash landing thermal control of the sample will certainly be lost, since the ground crew's top priority will be the rescue of the crew.

Probable Results: **Degraded Sample** - A degraded, that is a warm sample will result from the loss of thermal control. However, the SRC and the SRC Canister should remain intact.

Canister Breach - The sample canister, inside the SCA and SCA canister, is breached.

Probabilities:

Degraded Sample - 0.99 - This is the likely event since the pallet is designed to not break loose from the orbiter during a crash and the SCA Canister is designed to withstand impact loads. The probability is estimated at 0.99 to cover the possibility of loads in excess of those for which the SCA canister is designed.

Canister Breach - 0.01 - The residual.

6.22 Event: **SRC Docking and Freedom Space Station Processing** - This event encompasses a series of operations covering the docking of the OMV, placing of the SRC in the SRC canister on the truss mounted pallet, and transfer of the SCA from the SRC to the SCA canister. The baseline level of processing considered in this scenario is simply repackaging of the SCA from the SRC into the SCA canister, mounted on the pallet, attached to the Freedom Space Station Truss. This scenario was developed by Eagle Engineering (Simonds, 1988). This event is unique in that it is possible to contaminate the Freedom Space Station without damaging the sample, since the probable paths for contamination are due to malfunctions in the sample handling in Mars Orbit.

The steps in SRC docking and processing the sample on the Freedom Space Station include:

Docking of the OMV, placing of the SRC in the SRC canister on the truss mounted pallet.

Removing the SCA from the SRC and placing the SCA in the actively cooled SCA canister, mounted on the same pallet mounted on the truss. The SCA canister cooling system may keep the sample within specifications with a simple sun shade.

Placing the complete SRC canister and SCA canister and the attached pallet in the Orbiter payload bay.

Supplying the pallet with any utilities from the Orbiter, and preparing the Orbiter for deorbit.

Possible Results: **No contamination of Freedom Space Station** - The nominal case.

Contamination of Freedom Space Station - This case assumes that Mars dust has somehow gotten outside the SCA in the SRC. This dust has then found its way to the Freedom Space Station itself. This can be due to contamination of the exterior of the SRC due to an undetected sterile transfer failure in Mars orbit or some other failure.

Loss of Sample Thermal Control - Due to a system failure or human error, the sample becomes too warm. Measures can probably be taken to reduce this probability to a small number, but some expense may be involved. For the simple repackaging scenario proposed here, the sample is assumed to use passive thermal control measures with a sun shade. A detailed thermal analysis is required however to make sure this will work.

Probabilities:

No contamination of Freedom Space Station - 0.995 - (Really 0.999 if the loss of thermal control case, 0.004, is included) Extreme precautions are going to be taken to confine the SRC canister, thus the probability that the station is contaminated is arbitrarily set at 999%. The real danger may be failure of the sterile transfer in Mars orbit and contamination of the exterior of the SRC. Numerous redundancies can be designed into the handling process at the Station, making the probability of contamination very low.

Contamination of Freedom Space Station - 0.001 - Freedom Space Station contamination probability is arbitrarily set at 0.001.

Loss of Thermal Control - 0.004 - This number is subject to dispute.

6.23 Event: **OMV Launched and Deployed** - This event is the single most important event influencing the overall probability of getting a degraded sample for the aerocapture and propulsive capture to the Freedom Space Station options. This event encompasses the complete process of getting the OMV from Earth to leaving the Freedom Space Station on the way to picking up the SRC. This aspect of the mission assumes that the OMV is attached to the Freedom Space Station, not the Orbiter. As of the date of preparation of this report, this assumption is contrary to the NASA Freedom Space Station baseline. The OMV does not have a place to park on the Freedom Space Station. For a variety of reasons, however, parking the OMV at the Freedom Space Station is the preferred method for use of the OMV with the Freedom Space Station for this case. There is effectively no way to bring the SRC to the Freedom Space Station without the OMV. Getting the OMV deployed on-orbit involves the following steps:

a) Preparation and Checkout of the OMV at KSC
b) Mounting the OMV in the Orbiter
c) Launching the Orbiter
d) Rendezvous of the Orbiter with the Freedom Space Station
e) Transfer of the OMV to the Freedom Space Station
f) Checkout of the OMV on the Freedom Space Station
g) Maintenance and repair of the OMV, including refueling the OMV for the recovery of the second SRC (these calculations only address one mission however)
h) Deployment of the OMV from the Freedom Space Station

Probable Results: **Nominal** - The nominal case is that the OMV is ready to retrieve the SRC within the time that it can maintain thermal control of the sample on-orbit. This time period may be as little as three orbits or as long as 90 days.

Slow Deployment - Slow deployment means an OMV deployment that is not in time to retrieve the SRC within the thermal control of the sample. It is assumed that passive thermal control of the SRC without attitude control is not possible. It is further assumed that a spin stabilized SRC would not be stable in the correct orientation with the Sample container pointed away from the Sun to maintain thermal control.

Not Deployed - Not Deployed means that the OMV cannot be deployed to retrieve the SRC within the orbital lifetime of the SRC. Thus the SRC does an uncontrolled reentry. See section 6.24 and section 11.0 for estimates of the orbital lifetime of the SRC.

Probabilities:

Nominal - 0.94 - The nominal case is essentially the probability of the normal functioning of the Shuttle program for some period of time prior to and during the OMV deployment. This number is basically the residual left over after the two estimates that follow.

Slow Deployment - 0.05 - Prudent mission planning would manifest the OMV on a Shuttle flight to the Freedom Space Station in advance of the SRC arrival at least one logistics flight earlier than needed, that is somewhere between 90 and 180 days prior to earth orbit insertion. Thus only a complete halting of Shuttle launches as occurred after 51-L could prevent deployment. The OMV should be readily maintained on-orbit, assuming that adequate spares are available. Thus the probability of slow deployment is almost totally that of a 51-L type hiatus in Shuttle launches. The probability of that event is assigned a value of 0.05. If every flight had a 0.99 ascent success probability, then five flights would have an ascent success probability of $(0.99)^5 = 0.95$. Five flights represent some time frame on the order of a year or less in which a 51-L type accident could slow deployment of the OMV.

Not Deployed - 0.01 - The most likely event to prevent the deployment of the OMV is its loss during a Shuttle launch. There is only one OMV planned at this time. This event has been assigned a probability of 0.01. This number assumes the probability of a successful Shuttle ascent is 0.99.

6.24 Event: **OMV Recovery** - The OMV recovery sequence begins when the OMV is undocked from the Freedom Space Station and ends when the OMV and recovered SRC enter the proximity operations volume around the Freedom Space Station. The process involves the following steps:

a) Getting an adequate state vector for the SRC.
b) Having the SRC rotation rates within the abilities of the OMV to dock with it.
c) Loading the OMV with the proper state vectors and burn calculating algorithms.
d) Deploying the OMV.
f) Orienting the OMV and commencing a burn sequence. As many as 10 burns may be needed.
g) Having the OMV proximity operation sensors lock on the SRC.
h) Matching the OMV and SRC attitude rates.
g) Docking the OMV and SRC.
h) Reorienting the combined SRC and OMV and beginning a series of burns back to the Freedom Space Station (10 burns).
i) Entering the Freedom Space Station proximity operations volume.
j) Docking with the Freedom Space Station.

Probable
Results: **Nominal** - The nominal case involves a complex series of navigation and state vector updates, propulsive maneuvers and proximity operations, the majority of which are ground controlled. The OMV will be controlled from the Freedom Space Station when it is within a certain minimum range.

Slow Recovery - Slow recovery means an OMV recovery that does not permit the SRC to maintain thermal control of the sample. It is assumed that passive thermal control of the SRC, lacking attitude control, is not possible. It is further assumed that a spin stabilized SRC would not be stable in the correct orientation with the sample container pointed away from the Sun to maintain thermal control.

No Recovery - Means that the recovery can not be completed within the orbital lifetime of the SRC. Thus the SRC does an uncontrolled reentry. The following brief table (computed using Richter, 1966) gives an idea of the orbital lifetime of a small satellite based on the 1962 standard atmosphere. The atmosphere model is near worst case. In the conclusions and recommendations section (11.0), a 1972 atmosphere model is used with variations for the solar cycle to get a better idea of the lifetimes involved. Changes in the solar flux, which vary with the sunspot cycle, can increase the density by a factor of 10 and bring the vehicle in much quicker. The ballistic number of the vehicle (W/Cd*A) is assumed to be on the order of 18, using a weight of 800 lbs, a Cd of 1.8 and an area of 24 ft sq., based on a 5.6 ft (1.7 m) diameter Apollo shape.

Apogee Altitude nm	Perigee Altitude nm	Lifetime/Ballistic Number day/(lb/ft sq.)	Orbit Lifetime days
250	250	20	360
230	230	10	180
220	220	7	126
150	150	0.8	14
290	190	9	162
290	100	0.6	11
250	80	0.25	5
250	70	0.10	2

Probabilities:

Nominal - 0.98 - The best data base for such a series of automated/ground controlled rendezvous and docking maneuvers are the Soviet's experience docking with Salut and Mir. They have experienced approximately 6 serious problems where vehicles either missed docking, or docking operations had to be aborted because closing rates were too high. However, most of the missions were eventually completed. A 0.98 success rate is assumed. It can be argued that to do the MRSR mission with Mars orbit rendezvous as is currently planned, the U.S. will have to develop a good system for near totally automated rendezvous.

Slow Recovery - 0.01 - The OMV is designed to perform satellite servicing missions that are similar to recovering the SRC. The principle reason for a slow recovery might be SRC tumbling which would require development of special procedures to complete the recovery. Given the decay times shown above, there will be little time to develop new techniques or hardware to catch the sample if something goes wrong.

No Recovery - 0.01 - The OMV has a high level of redundancy to complete its mission and the recovery of the SRC should not be significantly different from other satellite servicing missions for which the OMV is designed. Thus the probability of 0.01 is assigned to no recovery. Multiple OMVs could also be placed at the Freedom Space Station. Only one OMV is currently planned however.

6.25 Event: **SCA Canister Impact** - The impact of the SCA canister at a high velocity, into the Earth following breakup of the Orbiter during descent to landing. The possibility of breakup of the Orbiter following entry has not been considered in the calculations or the fault trees. Orbiter breakup during entry is assumed to result in a sterilized sample if the SCA canister holds together long enough (in theory recoverable) or an unsterilized sample scattered in the upper atmosphere if the canister melts or breaks up. Breakup after entry was considered improbable enough to be ignored in the most recent iterations of the fault trees and this section is therefore not used, but is included here for future reference.

Probable Results: **Unbreached SCA Canister** - This event is the case where the SCA canister, made of Inconel 718, is able to stand a high velocity impact. It is dented but the seals stay intact. The result will be a warm sample that can be found.

Breached SCA Canister - This case is the one where the SCA Canister seals are broken by the impact. The sample may be simply exposed to air or perhaps scattered over the surface.

Probabilities:

Unbreached SRC Canister - 0.10 - The canister may be designed to withstand high impact loads. If the canister is encased in a large amount of low density debris from the SRC, then it may hit at a low enough velocity that it remains intact, however this is assumed to be unlikely.

Breached SRC Canister - 0.90 - Impact at high velocity will probably break the seals.

6.26 Event: **Perigee Raise Maneuver** - Once the aerocapture maneuver is complete, the perigee of the orbit must be raised. If this is not done, the orbit will decay shortly, probably within the next orbit or two. See the table is section 6.24 for an idea of how fast orbits with low perigee decay.

Possible Results: **Nominal** - Perigee is raised out of the atmosphere as planned.

Fails (Entry) - Without the perigee raise maneuver, the vehicle will enter and impact the surface of the Earth within an orbit or two.

Probabilities:

Nominal - 0.9999 - This burn uses the SRC hydrazine system and is assumed to have a high level of redundancy in thrusters, etc. This number is subject to dispute.

Fails (Entry) - 0.0001 - The residual.

6.27 Event: **First Propulsive EOI Burn** - For the propulsive capture case, given the configuration described in section 3.2, spinning two-stage solids, the first burn uses four STAR 14A small solid rocket motors, spinning around an axis to level out thrust inequalities. The second stage uses two STAR 14As. First stage consists of the burn of the first four and release of the four with pyro units. Other designers have proposed using small liquid motors to accomplish the same task.

The SRC is also spun up by the ERV. Therefore, 7 events must happen, the ERV must be properly oriented, the SRC spun up and then released, and the four STAR 14As must fire. The staging is considered part of the second burn event however, because failure to stage will probably result in a high elliptical parking orbit.

Possible Results: **Nominal Burn** - The four first stage motors all burn nominally. The vehicle is accurately pointed, spun up, and released.

Failures Resulting in a Flyby - The SRC could be improperly oriented, or not spun up. Failure to spin up would result in an improper orientation and probably tumbling at the time of the burn, or in effect, no burn. Failure of one of the motors to burn might also result in tumbling.

Failures Resulting in a Capture or Entry - There are undoubtedly some failure modes resulting in an Earth entry (an unlucky orientation failure at spinup, and a failure to sense it and stop the burn), or in capture into a high ellipse, but these are assumed to be of such low probability that they can be ignored here.

Probabilities:

Nominal Burn - 0.9993 - Seven events, an orientation, a spinup, a pyrotechnic release, and four motor firings, all with a 0.9999 reliability result in a (0.9999)^7 reliability when required to all work. The actual reliability of the motor should be acquired.

Failures Resulting in a Flyby - 0.0007 - The residual.

6.28 Event: **Second Propulsive EOI Burn** - This follows the first burn of four STAR 14As. The four spent motors must be staged and the last two STAR 14As must burn to complete the insertion into low Earth orbit. Six things must happen.

Possible
Results: **Nominal Burn** - The four spent motors stage, and the two remaining motors burn without incident. The vehicle is then inserted into a low Earth orbit on the order of 500 km circular (270 nm).

Failure to Stage or Burn - Failure to stage or burn should result in placement of the vehicle in an elliptical orbit. It is assumed the first stage burn will place the vehicle in an elliptical orbit. The second stage burn is needed to reduce the apogee of the ellipse to within range of the OMV. It is assumed that any failure in the second stage burn will result in the vehicle being out of range of the OMV. This assumption requires analysis to verify. The orbit will have a perigee around 500 km but with any one of a variety of apogees. Orbital lifetime can be from a few years on up.

In the fault tree and calculations it is assumed that the lifetime will be such that the vehicle will re-enter the Earth's atmosphere before it can be recovered. On the other hand, given adequate orbital life time, recovery may be possible. It will probably require an upper stage such as the Centaur or IUS matched with an OMV or other remotely controlled terminal docking device.

Probabilities:
Nominal Burn - 0.9994 - Given six events, four pyro firings for staging and two motor burns, all assumed to have a reliability of 0.9999 (Vaughn and Graves, 1988 on pyros), the probability of all these happening is (0.9999)^6 = 0.9994.

Failure to Stage or Burn - 0.0006 - The residual. Any failure in the six events is assumed to result in placement in an orbit the OMV cannot reach and eventual uncontrolled entry.

6.29 Event: **Despin** - For the propulsive capture option, following the two EOI burns discussed above, the SRC must be despun to allow capture by the OMV. "Yo-yos" or weights on a string are deployed and then cut away to decrease the angular momentum of the SRC and get the spin rate down to 5 or 6 rpm. Failure to despin, or to cut away the yo-yos is assumed to make rendezvous with the OMV not possible.

Possible
Results: **Nominal Despin** - The SRC is despun and the yo-yos cut away without incident.

Failure to Despin or Cut Away Yo-Yos - This failure results in a high spin rate, or a low spin rate with weights on strings spinning around. In either case, the OMV is assumed to be unable to capture the capsule. The orbital lifetime for a low circular orbit in the 230 to 270 nm range is on the order of 6 months to a year for high solar flux. A second or third try with improvised grabbing equipment may be possible after an initial failure.

Probabilities:

Nominal Despin - 0.9997 - A command must release the yo-yos and one, maybe two pyros must fire to the cut them away. Assuming a probability of 0.9999 for each event, (0.9999)^3 = 0.9997.

Failure to Despin or Cut Away Yo-Yos - 0.0003 - The residual.

6.30 Event: **Shuttle Ascent** - for Shuttle recovery, the Shuttle must ascend to the parking orbit within a given time frame defined by the life of the sample power supply and RCS fuel, if the sample is to be kept cold. If the sample is to be recovered at all, the Shuttle must get it before its orbit decays. For a lower Shuttle orbit (250 nm) at high sunspot times, this time period may be from less than a year to over two years, depending on the solar flux. See the decay and sunspot plots in the Conclusions and Recommendations section (11.0). The last solar maximum was around 1979-82. The high sunspot part of the 11 year cycle lasts three or four years. Plus 22 years (two cycles) gives us a maximum in 2001-2004. If the mission is launched in 1998 and lasts three years, it will return in 2001, putting it on the upswinging edge of high solar activity, expanded atmospheres, and fast orbital decay.

Possible
Results: **On-Time Ascent** - The Shuttle ascends to the parking orbit of the vehicle on time, probably somewhere between 0.1 and 90 days after the arrival of the sample in Earth orbit. It is not yet clear that the sample can keep cold for 90 days in low Earth orbit, unless it is powered and controlled the whole time.

Late Ascent - This would be ascent after the sample had run out of power or RCS fuel and therefore lost temperature control. This would be something over 90 days after the vehicle enters the parking orbit.

No Ascent - Due to a 51L type failure, the Shuttle fleet is grounded for a long period of time, making a flight within the orbital lifetime of the capsule (6 months to several years) not possible. The capsule would therefore enter uncontrolled. The Russians or a CERV system might be able to back up the Shuttle, or a longer life parking orbit could be used.

Probabilities:

On-Time Ascent - 0.94 - Even before the Challenger accident, the NSTS program had a serious problem meeting schedules. The simple ascent success record for the program is 96 % (based on 25 flights). See Table 6.30-1 below for data on other vehicles. The overall average is roughly 91% see ascent success. The on-time record for given payloads is much worse, but was not calculated here. More analysis could probably quantify the record in detail. More analysis of the MRSR orbital vehicle is also required to determine how long it can maintain power, attitude control, and altitude, waiting for a launch. The longer this is, the better the probability of making the launch becomes.

Table **6.30-1**, Launch Vehicle Ascent Success Probability
(On-time performance not considered) (Simanis and Gubby, AIAA paper 88-2627, 1988)

- Araine - 81% in 21 missions
- Atlas - 80% in 67 mission, 90% in last 20 missions
- Delta - 93% in 182 missions, 96% in last 20 missions
- Long March - 88% in 16 missions
- Titan - 96% in 137 missions, 90% in last 20 missions
- Shuttle - 96% in 25 missions
- Proton - 92%, oper. vehicle only, 85% - Proton family
- Overall average - 91.4% in 447 missions

No Ascent - 0.02 - If the Shuttle has a 0.99 chance of successful ascent, then five missions have a 0.95 chance of all being successful. In other words, if the "window" for a 51-L type accident resulting in no recovery is within five missions before the scheduled recovery launch, then the chance of it happening is around 5%. This assumes a 99 % ascent success rate for one launch. The demonstrated rate for the Shuttle is 96 %. For all other launch vehicles, U.S. and foreign, the ascent success rate is in the range of 90 %, based on many hundreds of launches. None do better than 96 %. Thus the 2 % chance of no ascent may be optimistic. On the other hand, it is hoped that special efforts will be continued which make the Shuttle program significantly safer and more reliable than other launch vehicle programs flown to date.

Late Ascent - 0.04 - The residual.

6.31 Event: **Shuttle Rendezvous and RMS Capture** - Following a successful ascent, the Shuttle must rendezvous with and capture the SRC. The rendezvous is a complicated (10 burns), but a well understood and practiced maneuver.

Possible Results: **Nominal Rendezvous and Capture** - Rendezvous and RMS capture and placement in a canister pallet are accomplished without incident.

Failure to Rendezvous or Capture - Due to failure of some system, perhaps one requiring immediate deorbit, such as a pressure vessel leak of significance or fuel cell problems, the sample is not captured.

Probabilities:

Nominal Rendezvous and Capture - 0.999 - Given a successful ascent, the Orbiter is redundant in almost all crucial systems. Even the RMS may possibly be backed up by an EVA crewman with a manned maneuvering unit, as has been demonstrated for a much larger communications satellite recovery.

Failure to Rendezvous or Capture - 0.001 - The residual

6.32 Event: **Orbiter Handling** - For the cases in which the sample is recovered directly by the Space Shuttle Orbiter remote manipulator system, the SCA will probably be removed from the SRC in the payload bay and repackaged in a sturdier container. A pallet such as proposed for the Freedom Space Station repackaging (see Figure 3.6-1) may be appropriate. Once the payload bay doors are closed, active thermal control may be required to keep the sample at -40° C. Two failures of significance are possible, loss of thermal control, and contamination of the orbiter. The contamination of the orbiter case is ignored here, to simplify some, and because it is felt to be improbable. The RMS could do all the sample manipulation and even leave the tip or part of the RMS that touches the SRC and SCA in the SRC canister.

Possible Results: **Nominal** - The SCA is repackaged without incident.

Loss of Temperature Control - Due to an orbiter or pallet systems failure, the sample is not kept cold during entry and landing.

Probabilities:

Nominal - 0.999 - This is an estimate subject to dispute.

Loss of Temperature Control - 0.001 - The residual.

7.0 Detailed Comparison of Failure Probabilities

Table 7.0-1 is a summary of the results of the probability calculations for the various options. Table 7.0-2 breaks down the numbers into even more detail. The first column in Table 7.0-1 is the sum of the second and third columns. It is the probability of returning the sample with some chance of it being too warm. The container breached column in Table 7.0-1 is the sum of the third through the sixth columns in Table 7.0-2. The container breached column represents all those failures that release the Mars sample or some small fraction of it into the Earth's biosphere.

To get a more detailed breakdown of the results, we must return to the fault tree figures and their spreadsheet summary numbers for each branch or path in section five.

Table **7.0-1**, Summary of Risk Calculation Results
(from Mid-Course to touch down)

Option	Sample Returned	100% Success	Sample Degraded	Container Breached *	Sample Lost
Direct Entry	98.15	97.64	0.55	0.45	1.36
Prop. Capture to Space Sta.	96.69	90.38	6.31	0.74	2.57
Aerocapture to to Space Sta.	96.68	89.61	7.07	1.66	1.66
Aerocapture to Shuttle	96.71	91.72	4.99	1.62	1.66

* Includes everything from a broken seal to the sample spread in the upper atmosphere. Also includes a lost unsterilized sample on Earth in a sealed container. This is the sum of the third through the sixth column in Table 7.0-2 on the next page.

Table 7.0-2, Risk Calculation Results, Detailed Breakdown (All numbers in %)

Option	100% Success	Degraded Sample	Canister Breached (Sample re-covered or in theory recoverable)	Canister Breached (Sample destroyed)	Space Sta. Contaminated with Mars dust	Unsteriliz. Lost Sample (On Earth)	Steriliz. Lost Sample (On Earth)	Lost Sample (In Space)	Permanent Orbit
Direct Entry	97.64	0.55	0.21	0.011	-	0.232	0.034	1.32	-
Aerocapture to Station	89.61	7.07	0.70	0.038	0.096	0.817	0.145	1.026	0.495
Propulsive Capture to Station	90.38	6.31	0.001	0.643	0.097	-	1.962	0.609	-
Aerocapture to Shuttle	91.72	4.99	0.73	0.039	-	0.852	0.149	1.026	0.495

8.0 Sensitivity Analysis

The results of the fault tree analysis presented in sections 5 and 6 are the same as those of the simple mission complexity analysis given in section 4. Both types of analysis conclude that the direct entry option is the most likely to be successful. However, the estimates of probability of the various off-nominal results of each event presented in section 6 may be in error by as much as a factor of ten. Therefore a sensitivity analysis was run on the fault trees to see if the conclusions would be changed if any of the estimates were significantly in error.

Sensitivity to both increases and decreases in failure probability for each event was evaluated. A complete probability analysis, actually the spread sheet for each fault tree, was recalculated after increasing each probability estimate for each off-nominal result by a factor of ten. Other runs raised the probability of each nominal event to 1.0 to essentially remove that event from the calculation. The results of these calculations are presented in Tables 8.0-1 through 8.0-4 in compressed form. The following figures show the sensitivity results in an easier to read format.

Figure 8.0-1 shows a plot of the Probability of 100% success versus the probability of canister breach for all runs increasing and decreasing the probabilities . Note that the extreme points occur for all options except direct entry. Figure 8.0-2 is a close up of the previous figure. Note that with the exception of two cases, the direct entry cases all form a cluster with a probability of 100% success of about 97.5% and a probability of canister breach of less that 1/2%. In order to clarify this point Figure 8.0-3 shows only the direct entry points. Thus the inference of the previously presented analysis that the direct entry method is preferred is confirmed. The better performance of direct entry is not sensitive to the specific values of the probability estimates.

Figures 8.0-5 through 8.0-23 are bar graphs showing in graphical form the effect of varying the individual probabilities. These plots show that only 15 of the 32 different entry events produce a significant effect when probabilities are raised or lowered. Significant effect is defined here as producing a change greater than roughly 30% of the baseline case in the probability of mission success, breach of sample, etc. Table 8.0-5 shows these fifteen events and the options that they affect.

Table 8.0-6 shows a somewhat different list of key results compiled by examining the paths or branches in the fault trees that contributed the most to failure probabilities for the various options. The results are shown in Table 8.0-6 with probabilities.

26-Jul-88

Table 8.0-1, Sensitivity Analysis for Direct Entry

New Probabilities

	Item Changed	Factor	Success	100% Success	Canister Breach	Degrade	Lost Sam.
	none		98.19	97.64	0.45	0.55	1.36
1 Mid C.	6.1 High G	x10	98.10	97.55	0.48	0.55	1.42
2 Mid C.	6.1 Miss Eart	x10	89.35	88.85	0.41	0.50	10.23
3 Mid C.	6.1 Nomin.	*	99.18	98.62	0.46	0.56	0.36
4 Brk-up	6.2 Unster.	*	98.19	97.64	0.49	0.55	1.32
5 Brk-up	6.2 Ster.	*	98.19	97.64	0.44	0.55	1.37
6 Batt	6.3 <or= 1	x10	98.19	97.64	0.45	0.55	1.36
7 Batt	6.3 >or= 2	*	98.19	97.64	0.45	0.55	1.36
8 ERV Burn	6.4 Fails	*	98.20	97.64	0.48	0.56	1.32
9 ERV Burn	6.4 Nomin.	*	98.19	97.64	0.45	0.55	1.36
10 Unc. Ent.	6.5 Brk. up	x10	98.08	97.64	0.33	0.44	1.59
11 Unc. Ent.	6.5 Nomin.	*	98.21	97.64	0.47	0.57	1.33
12 No Ch Imp	6.6 Intact	*	98.30	97.64	0.34	0.66	1.36
13 No Ch Imp	6.6 Breached	*	97.93	97.64	0.71	0.29	1.36
14 Src. No I	6.7 Lost	*	97.93	97.64	0.71	0.29	1.36
15 Src. No I	6.7 Found	*	98.42	97.64	0.22	0.78	1.36
16 Src. in I	6.7 Lost	x10	98.19	97.64	0.45	0.55	1.36
17 Src. in I	6.7 Found	*	98.19	97.64	0.45	0.55	1.36
18 ERV Sep	6.8 Fails	x10	97.85	97.29	0.47	0.56	1.68
19 ERV Sep	6.8 Nomin.	*	98.23	97.68	0.45	0.55	1.32
20 Dir Ent.	6.9 High Skip	x10	94.81	94.27	0.45	0.54	4.03
21 Dir Ent.	6.9 High-G	x10	94.03	91.42	4.38	2.61	1.59
22 Dir Ent.	6.9 Nomin.	*	98.95	98.62	0.02	0.33	1.03
23 Rem. Cov.	6.11 Fails	x10	98.09	97.29	0.56	0.80	1.36
24 Rem. Cov.	6.11 Nomin.	*	98.21	97.68	0.44	0.53	1.36
25 Drgu. Dep	6.12 Fails	x10	98.19	97.64	0.45	0.55	1.36
26 Drgu. Dep	6.12 Nomin.	*	98.19	97.64	0.45	0.55	1.36
27 Mains Dep	6.13 Fails	x10	98.19	97.64	0.45	0.55	1.36
28 Mains Dep	6.13 Nomin.	*	98.19	97.64	0.45	0.55	1.36
29 Air Snat.	6.14 Fails	x10	98.19	94.99	0.45	3.20	1.36
30 Air Snat.	6.14 Nomin.	*	98.19	97.93	0.45	0.26	1.36
31 Aircft La	6.15 Chrashes	x10	98.19	97.64	0.45	0.55	1.36
32 Aircft La	6.15 Nomin.	*	98.19	97.64	0.45	0.55	1.36
33 Aircft Cr	6.16 Con. brk.	x10	98.19	97.64	0.45	0.55	1.36
34 Aircft Cr	6.16 not broke	*	98.19	97.64	0.45	0.55	1.36
35 Grnd. Res	6.17 Slow	*	98.19	94.99	0.45	3.20	1.36
36 Grnd. Res	6.17 Nomin.	*	98.19	97.93	0.45	0.26	1.36

* Probabilities raised to 1

% Change

	Item Changed	Factor	Success	100% Success	Canister Breach	Degrade	Lost Sa
	none		0.00	0.00	0.00	0.00	0.00
1 Mid C.	6.1 High G	x10	-0.09	-0.09	6.67	0.00	4.41
2 Mid C.	6.1 Miss Eart	x10	-9.00	-9.00	-8.89	-9.09	652.21
3 Mid C.	6.1 Nomin.	*	1.01	1.00	2.22	1.82	-73.53
4 Brk-up	6.2 Unster.	*	0.00	0.00	8.89	0.00	-2.94
5 Brk-up	6.2 Ster.	*	0.00	0.00	-2.22	0.00	0.74
6 Batt	6.3 <or= 1	x10	0.00	0.00	0.00	0.00	0.00
7 Batt	6.3 >or= 2	*	0.00	0.00	0.00	0.00	0.00
8 ERV Burn	6.4 Fails	*	0.01	0.00	6.67	1.82	-2.94
9 ERV Burn	6.4 Nomin.	*	0.00	0.00	0.00	0.00	0.00
10 Unc. Ent.	6.5 Brk. up	x10	-0.11	0.00	-26.67	-20.00	16.91
11 Unc. Ent.	6.5 Nomin.	*	0.02	0.00	4.44	3.64	-2.21
12 No Ch Imp	6.6 Intact	*	0.11	0.00	-24.44	20.00	0.00
13 No Ch Imp	6.6 Breached	*	-0.26	0.00	57.78	-47.27	0.00
14 Src. No I	6.7 Lost	*	-0.26	0.00	57.78	-47.27	0.00
15 Src. No I	6.7 Found	*	0.23	0.00	-51.11	41.82	0.00
16 Src. in I	6.7 Lost	x10	0.00	0.00	0.00	0.00	0.00
17 Src. in I	6.7 Found	*	0.00	0.00	0.00	0.00	0.00
18 ERV Sep	6.8 Fails	x10	-0.35	-0.36	4.44	1.82	23.53
19 ERV Sep	6.8 Nomin.	*	0.04	0.04	0.00	0.00	-2.94
20 Dir Ent.	6.9 High Skip	x10	-3.44	-3.45	0.00	-1.82	196.32
21 Dir Ent.	6.9 High-G	x10	-4.24	-6.37	873.33	374.55	16.91
22 Dir Ent.	6.9 Nomin.	*	0.77	1.00	-95.56	-40.00	-24.26
23 Rem. Cov.	6.11 Fails	x10	-0.10	-0.36	24.44	45.45	0.00
24 Rem. Cov.	6.11 Nomin.	*	0.02	0.04	-2.22	-3.64	0.00
25 Drgu. Dep	6.12 Fails	x10	0.00	0.00	0.00	0.00	0.00
26 Drgu. Dep	6.12 Nomin.	*	0.00	0.00	0.00	0.00	0.00
27 Mains Dep	6.13 Fails	x10	0.00	0.00	0.00	0.00	0.00
28 Mains Dep	6.13 Nomin.	*	0.00	0.00	0.00	0.00	0.00
29 Air Snat.	6.14 Fails	x10	0.00	-2.71	0.00	481.82	0.00
30 Air Snat.	6.14 Nomin.	*	0.00	0.30	0.00	-52.73	0.00
31 Aircft La	6.15 Chrashes	x10	0.00	0.00	0.00	0.00	0.00
32 Aircft La	6.15 Nomin.	*	0.00	0.00	0.00	0.00	0.00
33 Aircft Cr	6.16 Con. brk.	x10	0.00	0.00	0.00	0.00	0.00
34 Aircft Cr	6.16 not broke	*	0.00	0.00	0.00	0.00	0.00
35 Grnd. Res	6.17 Slow	*	0.00	-2.71	0.00	481.82	0.00
36 Grnd. Res	6.17 Nomin.	*	0.00	0.30	0.00	-52.73	0.00

Table 8.0-2, Sensitivity Analysis for Aerocapture to Freedom Space Station

New Probabilities

	Item Changed	Factor	Success	100% Success	Canister Breached	Degraded	Lost Sam.	S.S. Contam.	Perm Orb.
	none		96.68	89.61	1.56	7.07	1.17	0.10	0.49
1 Mid C.	6.1 High-G	x10	96.59	89.53	1.58	7.06	1.24	0.10	0.49
2 Mid C.	6.1 Miss Eart	x10	87.98	81.55	1.42	6.43	10.07	0.09	0.45
3 Mid C.	6.1 Nomin.	*	97.66	90.52	1.57	7.14	0.18	0.10	0.50
4 Brk-up	6.2 Unster.	*	96.68	89.61	1.66	7.07	1.07	0.10	0.49
5 Brk-up	6.2 Ster.	*	96.68	89.61	1.52	7.07	1.20	0.10	0.49
6 Batt	6.3 <or= 1	x10	96.68	89.61	1.56	7.07	1.17	0.10	0.49
7 Batt	6.3 >or= 2	*	96.68	89.61	1.56	7.07	1.17	0.10	0.49
8 ERV Burn	6.4 Fails	*	96.69	89.61	1.58	7.08	1.14	0.10	0.49
9 ERV Burn	6.4 Nomin.	*	96.68	89.61	1.55	7.07	1.17	0.10	0.49
10 Unctrl. E	6.5 Brkup	x10	96.29	89.61	1.11	6.68	2.00	0.10	0.49
11 Unctrl. E	6.5 Impact	*	96.72	89.61	1.61	7.11	1.08	0.10	0.49
12 No Ch. Im	6.6 Breached	*	97.03	89.61	1.21	7.42	1.17	0.10	0.49
13 No Ch. Im	6.6 Intact	*	95.86	89.61	2.37	6.25	1.17	0.10	0.49
14 Src. No Z	6.7 Lost	*	95.90	89.61	2.37	6.29	1.13	0.10	0.49
15 Src. No Z	6.7 Found	*	97.46	89.61	0.74	7.85	1.21	0.10	0.49
16 ERV Sep	6.8 Fails	x10	96.35	89.29	1.57	7.06	1.49	0.10	0.49
17 ERV Sep	6.8 Nomin.	*	96.72	89.65	1.55	7.07	1.14	0.10	0.49
18 Aerocap	6.10 Early Ex.	x10	92.33	85.57	1.50	6.76	1.13	0.09	4.95
19 Aerocap	6.10 No Exit	x10	93.81	85.57	4.31	8.24	1.30	0.09	0.49
20 Aerocap	6.10 Nomin.	*	97.50	90.52	1.26	6.98	1.15	0.10	0.00
21 Orb. E.	6.18 Failure	x10	96.23	88.80	1.60	7.43	1.59	0.10	0.49
22 Orb. E.	6.18 Nomin.	*	96.73	89.70	1.55	7.03	1.13	0.10	0.49
23 Orb In.	6.19 Crash	x10	96.67	88.80	1.56	7.87	1.17	0.10	0.49
24 Orb In.	6.19 Nomin.	*	96.73	89.70	1.55	7.03	1.13	0.10	0.49
25 Orb. brk	6.20 Unsteril.	x10	96.66	89.61	1.60	7.05	1.14	0.10	0.49
26 Orb. brk	6.20 Steril.	*	96.68	89.61	1.56	7.07	1.17	0.10	0.49
27 Pal. brk	6.21 Can Brch	x10	96.67	89.61	1.56	7.06	1.17	0.10	0.49
28 Pal. brk	6.21 No Brch	*	96.68	89.61	1.56	7.07	1.17	0.10	0.49
29 S.S. Pro.	6.22 Temp Fail	x10	96.73	86.36	1.55	10.37	1.17	0.10	0.49
30 S.S. Pro.	6.22 Contam.	x10	95.38	88.36	1.55	7.02	1.14	0.96	0.49
31 S.S. Pro.	6.22 Nomin.	*	96.69	89.98	1.56	6.71	1.17	0.10	0.49
32 OMV Dep.	6.23 Fails	x10	96.69	46.70	1.55	49.99	1.17	0.10	0.49
33 OMV Dep.	6.23 Slow	x10	90.86	81.02	7.06	9.84	1.44	0.09	0.49
34 OMV Dep.	6.23 Nomin.	*	97.34	95.34	0.94	2.00	1.13	0.10	0.49
35 OMV Rec.	6.24 Slow	x10	96.67	81.37	1.55	15.30	1.17	0.10	0.49
36 OMV Rec.	6.24 Fails	x10	90.86	81.37	7.06	9.49	1.50	0.09	0.49
37 OMV Rec.	6.24 Nomin.	*	97.34	91.45	0.94	5.89	1.13	0.10	0.49

* Probabilities raised to 1

% Change

	Item Changed	Factor	Success	100% Success	Canister Breached	Degraded	Lost Sam.	S.S. Contam.	Perm Orb
	none		0.00	0.00	0.00	0.00	0.00	0.00	0.00
1 Mid C.	6.1 High-G	x10	-0.03	-0.09	1.28	-0.14	5.98	0.00	0.00
2 Mid C.	6.1 Miss Eart	x10	-9.00	-8.99	-8.97	-9.05	760.68	-10.00	-8.16
3 Mid C.	6.1 Nomin.	*	1.01	1.02	0.64	0.99	-84.62	0.00	2.04
4 Brk-up	6.2 Unster.	*	0.00	0.00	6.41	0.00	-8.55	0.00	0.00
5 Brk-up	6.2 Ster.	*	0.00	0.00	-2.56	0.00	2.56	0.00	0.00
6 Batt	6.3 <or= 1	x10	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7 Batt	6.3 >or= 2	*	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8 ERV Burn	6.4 Fails	*	0.01	0.00	1.28	0.14	-2.56	0.00	0.00
9 ERV Burn	6.4 Nomin.	*	0.00	0.00	-0.64	0.00	0.00	0.00	0.00
10 Unctrl. E	6.5 Brkup	x10	-0.40	0.00	-28.85	-5.52	70.94	0.00	0.00
11 Unctrl. E	6.5 Impact	*	0.04	0.00	3.21	0.57	-7.69	0.00	0.00
12 No Ch. Im	6.6 Breached	*	0.36	0.00	-22.44	4.95	0.00	0.00	0.00
13 No Ch. Im	6.6 Intact	*	-0.85	0.00	51.92	-11.60	0.00	0.00	0.00
14 Src. No Z	6.7 Lost	*	-0.81	0.00	51.92	-11.03	-3.42	0.00	0.00
15 Src. No Z	6.7 Found	*	0.81	0.00	-52.56	11.03	3.42	0.00	0.00
16 ERV Sep	6.8 Fails	x10	-0.34	-0.36	0.64	-0.14	27.35	0.00	0.00
17 ERV Sep	6.8 Nomin.	*	0.04	0.04	-0.64	0.00	-2.56	0.00	0.00
18 Aerocap	6.10 Early Ex.	x10	-4.50	-4.51	-3.85	-4.38	-3.42	-10.00	910.20
19 Aerocap	6.10 No Exit	x10	-2.97	-4.51	176.28	16.55	11.11	-10.00	0.00
20 Aerocap	6.10 Nomin.	*	0.85	1.02	-19.23	-1.27	-1.71	0.00	-100.00
21 Orb. E.	6.18 Failure	x10	-0.47	-0.90	2.56	5.09	35.90	0.00	0.00
22 Orb. E.	6.18 Nomin.	*	0.05	0.10	-0.64	-0.57	-3.42	0.00	0.00
23 Orb In.	6.19 Crash	x10	-0.01	-0.90	0.00	11.32	0.00	0.00	0.00
24 Orb In.	6.19 Nomin.	*	0.05	0.10	-0.64	-0.57	-3.42	0.00	0.00
25 Orb. brk	6.20 Unsteril.	x10	-0.02	0.00	2.56	-0.28	-2.56	0.00	0.00
26 Orb. brk	6.20 Steril.	*	0.00	0.00	0.00	0.00	0.00	0.00	0.00
27 Pal. brk	6.21 Can Brch	x10	-0.01	0.00	0.00	-0.14	0.00	0.00	0.00
28 Pal. brk	6.21 No Brch	*	0.00	0.00	0.00	0.00	0.00	0.00	0.00
29 S.S. Pro.	6.22 Temp Fail	x10	0.05	-3.63	-0.64	46.68	0.00	0.00	0.00
30 S.S. Pro.	6.22 Contam.	x10	-1.34	-1.39	-0.64	-0.71	-2.56	860.00	0.00
31 S.S. Pro.	6.22 Nomin.	*	0.01	0.41	0.00	-5.09	0.00	0.00	0.00
32 OMV Dep.	6.23 Fails	x10	0.01	-47.89	-0.64	607.07	0.00	0.00	0.00
33 OMV Dep.	6.23 Slow	x10	-6.02	-9.59	352.56	39.18	23.08	-10.00	0.00
34 OMV Dep.	6.23 Nomin.	*	0.68	6.39	-39.74	-71.71	-3.42	0.00	0.00
35 OMV Rec.	6.24 Slow	x10	-0.01	-9.20	-0.64	116.41	0.00	0.00	0.00
36 OMV Rec.	6.24 Fails	x10	-6.02	-9.20	352.56	34.23	28.21	-10.00	0.00
37 OMV Rec.	6.24 Nomin.	*	0.68	2.05	-39.74	-16.69	-3.42	0.00	0.00

Table 8.0-3, Sensitivity Analysis for Aerocapture to Shuttle

New Probabilities

	Item Changed		Factor	Success	100% Success	Canister Breached	Degrade	Lost Sa	Perm Orb.
	none			96.71	91.72	1.62	4.99	1.17	0.49
Mid C.	6.1	Hit Earth	x10	96.62	91.63	1.64	4.99	1.24	0.49
Mid C.	6.1	Miss Eart	x10	88.00	83.46	1.48	4.54	10.07	0.45
Mid C.	6.1	Nomin.	*	97.68	92.64	1.64	5.04	0.18	0.50
Brk-up	6.2	Unsteril.	*	96.71	91.72	1.73	4.99	1.07	0.49
Brk-up	6.2	Steril.	*	96.71	91.72	1.59	4.99	1.21	0.49
Batt	6.3	<or= 1	x10	96.71	91.72	1.62	4.99	1.17	0.49
Batt	6.3	>or= 2	*	96.71	91.72	1.62	4.99	1.17	0.49
ERV Burn	6.4	Fails	*	96.72	91.72	1.65	5.00	1.14	0.49
ERV Burn	6.4	Nomin.	*	96.71	91.72	1.62	4.99	1.18	0.49
Unctrld E	6.5	Brkup	x10	96.31	91.72	1.16	4.59	2.04	0.49
Unctrld E	6.5	Intact	*	96.76	91.72	1.67	5.04	1.08	0.49
No Ch Imp	6.6	Intact	*	97.00	91.72	1.26	5.36	1.17	0.49
No Ch Imp	6.6	Breached	*	95.86	91.72	2.48	4.14	1.17	0.49
Src. No E	6.7	Lost	*	95.90	91.72	2.48	4.18	1.13	0.49
Src. No E	6.7	Found	*	97.52	91.72	0.77	5.80	1.22	0.49
ERV Sep	6.8	Fails	x10	96.38	91.39	1.64	4.99	1.50	0.49
ERV Sep	6.8	Nomin.	*	96.74	91.75	1.62	4.99	1.14	0.49
Aerocap	6.10	Early Ex.	x10	92.32	87.55	1.56	4.77	1.17	4.95
Aerocap	6.10	No Exit	x10	93.80	87.55	4.37	6.25	1.34	0.49
Aerocap	6.10	Nomin.	*	97.52	92.64	1.32	4.88	1.16	0.00
Orb. E.	6.18	Failure	x10	96.25	90.89	1.67	5.36	1.58	0.49
Orb. E.	6.18	Nomin.	*	96.80	91.81	1.62	4.99	1.18	0.49
Orb In.	6.19	Crash	x10	96.70	90.89	1.63	5.81	1.17	0.49
Orb In.	6.19	Nomin.	*	96.71	91.81	1.62	4.90	1.17	0.49
Orb. brk	6.20	Unsteril.	x10	96.69	91.72	1.67	4.97	1.15	0.49
Orb. brk	6.20	Steril.	*	96.71	91.72	1.62	4.99	1.18	0.49
Pal. brk	6.21	Can Brch.	x10	96.70	91.72	1.63	4.98	1.17	0.49
Pal. brk	6.21	Degraded	*	96.71	91.72	1.62	4.99	1.17	0.49
Per. R	6.26	Fails	x10	96.65	91.63	1.68	5.02	1.18	0.49
Per. R	6.26	Nomin.	*	96.71	91.72	1.62	4.99	1.17	0.49
Shut. Asc	6.30	Late	x10	96.71	56.59	1.62	40.12	1.17	0.49
Shut. Asc	6.30	Too Late	x10	84.96	74.15	12.72	10.81	1.83	0.49
Shut. Asc	6.30	Nomin.	*	98.01	97.57	0.39	0.44	1.10	0.49
Shut. R&R	6.31	Fails	x10	96.13	90.89	2.17	5.24	1.21	0.49
Shut. R&R	6.31	Nomin.	*	96.77	91.81	1.56	4.96	1.17	0.49
Orb. Man	6.32	Temp Fail	x10	96.72	90.89	1.62	5.83	1.17	0.49
Orb. Man	6.32	Nomin.	*	96.71	91.81	1.62	4.90	1.17	0.49

* Probabilities raised to 1

% Change

		Item Changed		Factor	Success	100% Success	Canister Breached	Degrade	Lost Sa	Perm Orb
		none			0.00	0.00	0.00	0.00	0.00	0.00
1	Mid C.	6.1	Hit Earth	x10	-0.09	-0.10	1.23	0.00	5.98	0.00
2	Mid C.	6.1	Miss Eart	x10	-9.01	-9.01	-8.64	-9.02	760.68	-8.16
3	Mid C.	6.1	Nomin.	*	1.00	1.00	1.23	1.00	-84.62	2.04
4	Brk-up	6.2	Unsteril.	*	0.00	0.00	6.79	0.00	-8.55	0.00
5	Brk-up	6.2	Steril.	*	0.00	0.00	-1.85	0.00	3.42	0.00
6	Batt	6.3	<or= 1	x10	0.00	0.00	0.00	0.00	0.00	0.00
7	Batt	6.3	>or= 2	*	0.00	0.00	0.00	0.00	0.00	0.00
8	ERV Burn	6.4	Fails	*	0.01	0.00	1.85	0.20	-2.56	0.00
9	ERV Burn	6.4	Nomin.	*	0.00	0.00	0.00	0.00	0.85	0.00
10	Unctrld E	6.5	Brkup	x10	-0.41	0.00	-28.40	-8.02	74.36	0.00
11	Unctrld E	6.5	Intact	*	0.05	0.00	3.09	1.00	-7.69	0.00
12	No Ch Imp	6.6	Intact	*	0.30	0.00	-22.22	7.41	0.00	0.00
13	No Ch Imp	6.6	Breached	*	-0.88	0.00	53.09	-17.03	0.00	0.00
14	Src. No E	6.7	Lost	*	-0.84	0.00	53.09	-16.23	-3.42	0.00
15	Src. No E	6.7	Found	*	0.84	0.00	-52.47	16.23	4.27	0.00
16	ERV Sep	6.8	Fails	x10	-0.34	-0.36	1.23	0.00	28.21	0.00
17	ERV Sep	6.8	Nomin.	*	0.03	0.03	0.00	0.00	-2.56	0.00
18	Aerocap	6.10	Early Ex.	x10	-4.54	-4.55	-3.70	-4.41	0.00	910.20
19	Aerocap	6.10	No Exit	x10	-3.01	-4.55	169.75	25.25	14.53	0.00
20	Aerocap	6.10	Nomin.	*	0.84	1.00	-18.52	-2.20	-0.85	-100.00
21	Orb. E.	6.18	Failure	x10	-0.48	-0.90	3.09	7.41	35.04	0.00
22	Orb. E.	6.18	Nomin.	*	0.09	0.10	0.00	0.00	0.85	0.00
23	Orb In.	6.19	Crash	x10	-0.01	-0.90	0.62	16.43	0.00	0.00
24	Orb In.	6.19	Nomin.	*	0.00	0.10	0.00	-1.80	0.00	0.00
25	Orb. brk	6.20	Unsteril.	x10	-0.02	0.00	3.09	-0.40	-1.71	0.00
26	Orb. brk	6.20	Steril.	*	0.00	0.00	0.00	0.00	0.85	0.00
27	Pal. brk	6.21	Can Brch.	x10	-0.01	0.00	0.62	-0.20	0.00	0.00
28	Pal. brk	6.21	Degraded	*	0.00	0.00	0.00	0.00	0.00	0.00
29	Per. R	6.26	Fails	x10	-0.06	-0.10	3.70	0.60	0.85	0.00
30	Per. R	6.26	Nomin.	*	0.00	0.00	0.00	0.00	0.00	0.00
31	Shut. Asc	6.30	Late	x10	0.00	-38.30	0.00	704.01	0.00	0.00
32	Shut. Asc	6.30	Too Late	x10	-12.15	-19.16	685.19	116.63	56.41	0.00
33	Shut. Asc	6.30	Nomin.	*	1.34	6.38	-75.93	-91.18	-5.98	0.00
34	Shut. R&R	6.31	Fails	x10	-0.60	-0.90	33.95	5.01	3.42	0.00
35	Shut. R&R	6.31	Nomin.	*	0.06	0.10	-3.70	-0.60	0.00	0.00
36	Orb. Man	6.32	Temp Fail	x10	0.01	-0.90	0.00	16.83	0.00	0.00
37	Orb. Man	6.32	Nomin.	*	0.00	0.10	0.00	-1.80	0.00	0.00

26-Jul-88

Table 8.0-4, Sensitivity Analysis for Propulsive Capture to Freedom Space Station

New Probabilities

No.	Item Changed		Factor	Success	100% Success	Canister Breached	Degrade	Lost Sa	S.S. Co.
	none			96.69	90.38	0.64	6.31	2.57	0.09
1	Mid C.	6.1 Hit Earth	x10	92.29	86.27	1.75	6.02	5.07	0.09
2	Mid C.	6.1 Miss Eart	x10	92.29	86.27	0.62	6.02	6.99	0.09
3	Mid C.	6.1 Nomin.	*	97.66	91.29	0.52	6.37	1.71	0.10
4	Brk-up	6.2 Unsteril.	*	96.69	90.38	2.56	6.31	0.65	0.10
5	Brk-up	6.2 Steril.	*	96.69	90.38	0.01	6.31	3.21	0.10
6	Batt	6.3 <or= 1	x10	96.69	90.38	0.64	6.31	2.57	0.10
7	Batt	6.3 >or= 2	*	96.69	90.38	0.64	6.31	2.57	0.10
8	Src. No Z	6.7 Lost	*	96.73	90.38	0.64	6.35	2.53	0.10
9	Src. No Z	6.7 Found	*	92.99	90.38	0.64	6.27	2.61	0.10
10	ERV Sep	6.8 Fails	x10	96.33	90.05	0.64	6.28	2.92	0.10
11	ERV Sep	6.8 Nomin.	*	96.73	90.42	0.64	6.31	2.53	0.10
12	Orb. E.	6.18 Failure	x10	96.23	89.57	0.69	6.66	2.98	0.10
13	Orb. E.	6.18 Nomin.	*	96.74	90.47	0.64	6.27	2.53	0.10
14	Orb ln.	6.19 Crash	x10	96.68	89.57	0.65	7.11	2.57	0.10
15	Orb ln.	6.19 Nomin.	*	96.69	90.47	0.64	6.22	2.57	0.10
16	Orb. brk	6.20 Unsteril.	x10	96.67	90.38	0.69	6.29	2.55	0.10
17	Orb. brk	6.20 Steril.	*	96.69	90.38	0.64	6.31	2.57	0.10
18	Pal. brk	6.21 Can brch	x10	96.68	90.38	0.65	6.30	2.57	0.10
19	Pal. brk	6.21 Degraded	*	96.69	90.38	0.64	6.31	2.57	0.10
20	S.S. Pro.	6.22 Contam.	x10	95.81	89.56	0.64	6.25	2.57	0.97
21	S.S. Pro.	6.22 Temp Fail	x10	96.69	87.11	0.64	9.58	2.57	0.10
22	S.S. Pro.	6.22 Nomin.	*	96.78	90.83	0.64	5.95	2.57	0.00
23	OMV Dep.	6.23 Slow	x10	96.68	47.11	0.64	49.57	2.57	0.10
24	OMV Dep.	6.23 Fail	x10	87.90	81.73	2.84	6.17	9.17	0.09
25	OMV Dep.	6.23 Nomin.	*	97.66	96.15	0.40	1.51	1.84	0.10
26	OMV Rec.	6.24 Slow	x10	96.69	82.08	0.64	14.61	2.57	0.10
27	OMV Rec.	6.24 Fails	x10	87.90	82.08	2.84	5.82	9.17	0.09
28	OMV Rec.	6.24 Nomin.	*	97.66	92.22	0.40	5.44	1.84	0.10
29	EOI #1	6.27 Fails	x10	96.08	89.81	0.64	6.27	3.18	0.10
30	EOI #1	6.27 Nomin.	*	96.75	90.44	0.64	6.31	2.53	0.10
31	EOI #2	6.28 Fails	x10	96.16	89.89	0.78	6.27	2.97	0.10
32	EOI #2	6.28 Nomin.	*	96.74	90.43	0.63	6.31	2.53	0.10
33	Despin	6.29 Fails	x10	96.43	90.14	0.71	6.29	2.77	0.10
34	Despin	6.29 Nomin.	*	96.72	90.41	0.64	6.31	2.55	0.10

* Probabilities raised to 1

% Change

No.	Item Changed		Factor	Success	100% Success	Canister Breached	Degrade	Lost Sa	S.S. Co
	none			0.00	0.00	0.00	0.00	0.00	0.00
1	Mid C.	6.1 Hit Earth	x10	-4.55	-4.55	173.44	-4.60	128.40	0.00
2	Mid C.	6.1 Miss Eart	x10	-4.55	-4.55	-3.13	-4.60	171.98	0.00
3	Mid C.	6.1 Nomin.	*	1.00	1.01	-18.75	0.95	-33.46	11.11
4	Brk-up	6.2 Unsteril.	*	0.00	0.00	300.00	0.00	-74.71	11.11
5	Brk-up	6.2 Steril.	*	0.00	0.00	-98.44	0.00	24.90	11.11
6	Batt	6.3 <or= 1	x10	0.00	0.00	0.00	0.00	0.00	11.11
7	Batt	6.3 >or= 2	*	0.00	0.00	0.00	0.00	0.00	11.11
8	Src. No Z	6.7 Lost	*	0.04	0.00	0.00	0.63	-1.56	11.11
9	Src. No Z	6.7 Found	*	-3.83	0.00	0.00	-0.63	1.56	11.11
10	ERV Sep	6.8 Fails	x10	-0.37	-0.37	0.00	-0.48	13.62	11.11
11	ERV Sep	6.8 Nomin.	*	0.04	0.04	0.00	0.00	-1.56	11.11
12	Orb. E.	6.18 Failure	x10	-0.48	-0.90	7.81	5.55	15.95	11.11
13	Orb. E.	6.18 Nomin.	*	0.05	0.10	0.00	-0.63	-1.56	11.11
14	Orb ln.	6.19 Crash	x10	-0.01	-0.90	1.56	12.68	0.00	11.11
15	Orb ln.	6.19 Nomin.	*	0.00	0.10	0.00	-1.43	0.00	11.11
16	Orb. brk	6.20 Unsteril.	x10	-0.02	0.00	7.81	-0.32	-0.78	11.11
17	Orb. brk	6.20 Steril.	*	0.00	0.00	0.00	0.00	0.00	11.11
18	Pal. brk	6.21 Can brch	x10	-0.01	0.00	1.56	-0.16	0.00	11.11
19	Pal. brk	6.21 Degraded	*	0.00	0.00	0.00	0.00	0.00	11.11
20	S.S. Pro.	6.22 Contam.	x10	-0.91	-0.91	0.00	-0.95	0.00	977.78
21	S.S. Pro.	6.22 Temp Fail	x10	0.00	-3.62	0.00	51.82	0.00	11.11
22	S.S. Pro.	6.22 Nomin.	*	0.09	0.50	0.00	-5.71	0.00	-100.00
23	OMV Dep.	6.23 Slow	x10	-0.01	-47.88	0.00	685.58	0.00	11.11
24	OMV Dep.	6.23 Fail	x10	-9.09	-9.57	343.75	-2.22	256.81	0.00
25	OMV Dep.	6.23 Nomin.	*	1.00	6.38	-37.50	-76.07	-28.40	11.11
26	OMV Rec.	6.24 Slow	x10	0.00	-9.18	0.00	131.54	0.00	11.11
27	OMV Rec.	6.24 Fails	x10	-9.09	-9.18	343.75	-7.77	256.81	0.00
28	OMV Rec.	6.24 Nomin.	*	1.00	2.04	-37.50	-13.79	-28.40	11.11
29	EOI #1	6.27 Fails	x10	-0.63	-0.63	0.00	-0.63	23.74	11.11
30	EOI #1	6.27 Nomin.	*	0.06	0.07	0.00	0.00	-1.56	11.11
31	EOI #2	6.28 Fails	x10	-0.55	-0.54	21.88	-0.63	15.56	11.11
32	EOI #2	6.28 Nomin.	*	0.05	0.06	-1.56	0.00	-1.56	11.11
33	Despin	6.29 Fails	x10	-0.27	-0.27	10.94	-0.32	7.78	11.11
34	Despin	6.29 Nomin.	*	0.03	0.03	0.00	0.00	-0.78	11.11

Figure 8.0-1, Scatter for all Sensitivity Runs (Plot includes all points)

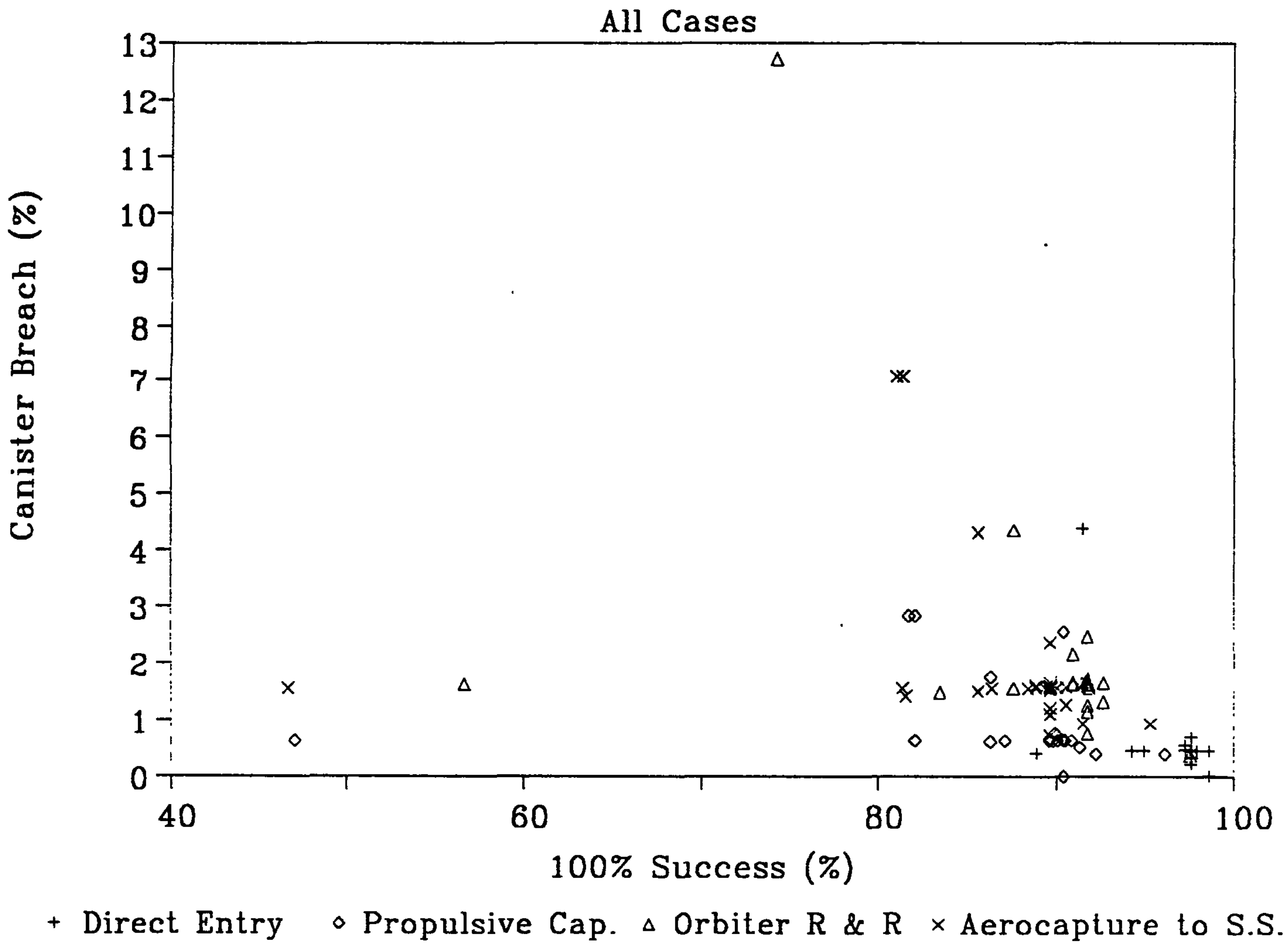

Figure 8.0-2, Scatter for All Sensitivity Runs (Plot includes most points)

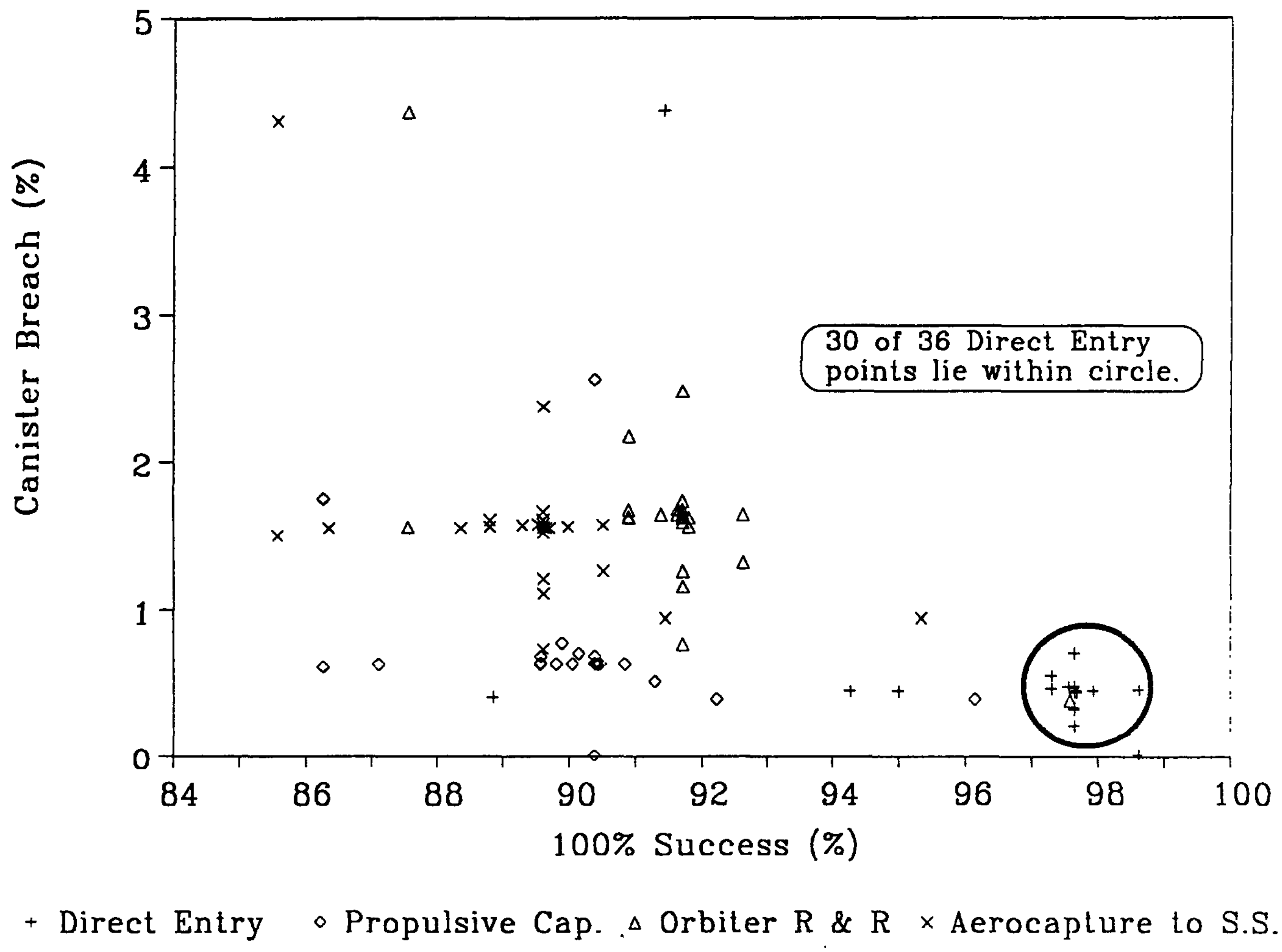

Figure 8.0-3, Scatter for Direct Entry Sensitivity Runs (Plot includes all Direct Entry points)

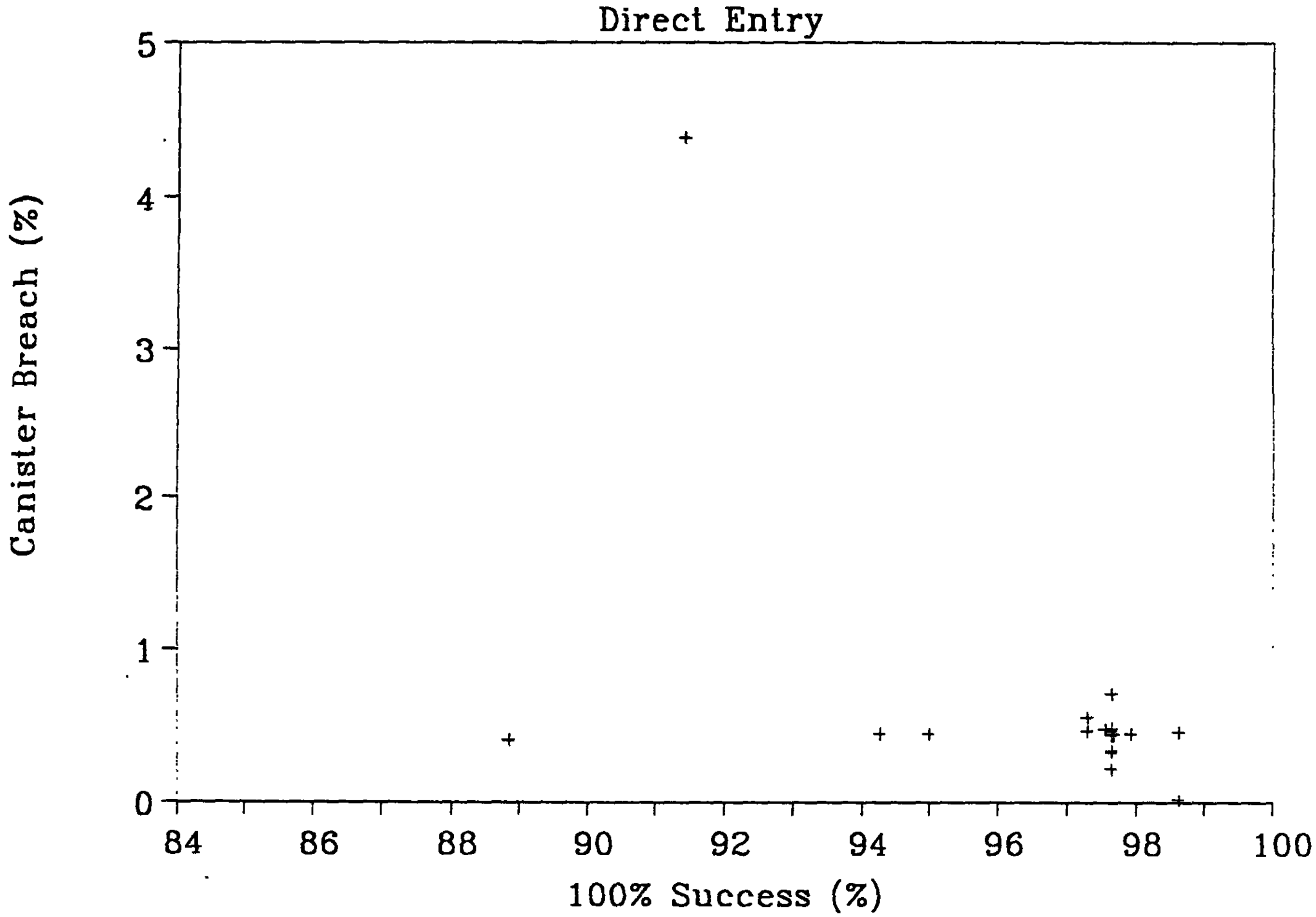

Figure 8.0-4, Sensitivity Plot for Direct Entry, Per Cent Change for Lost Sample

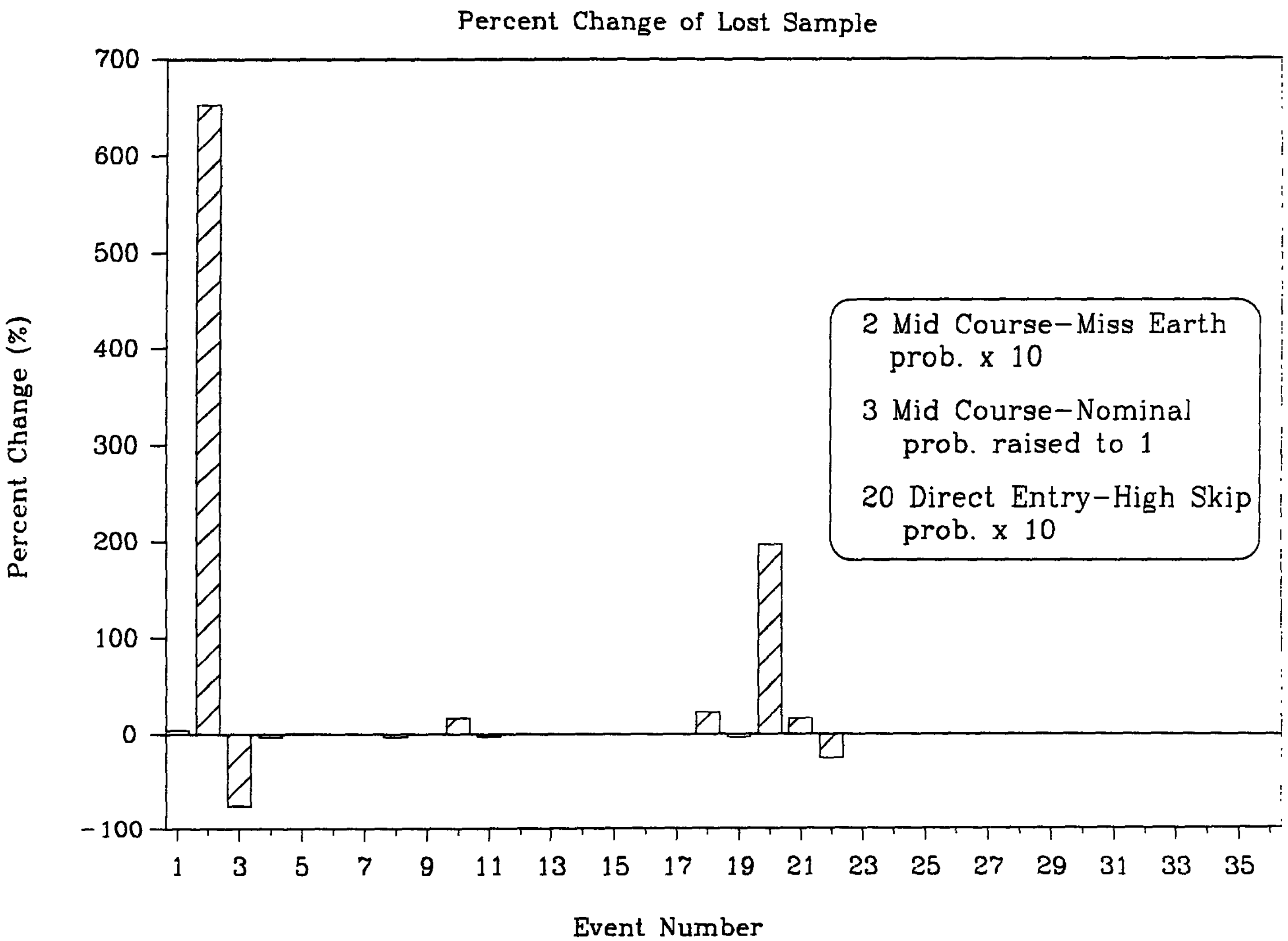

Figure 8.0-5, Sensitivity Plot for Direct Entry, Per Cent Change for Degraded Sample

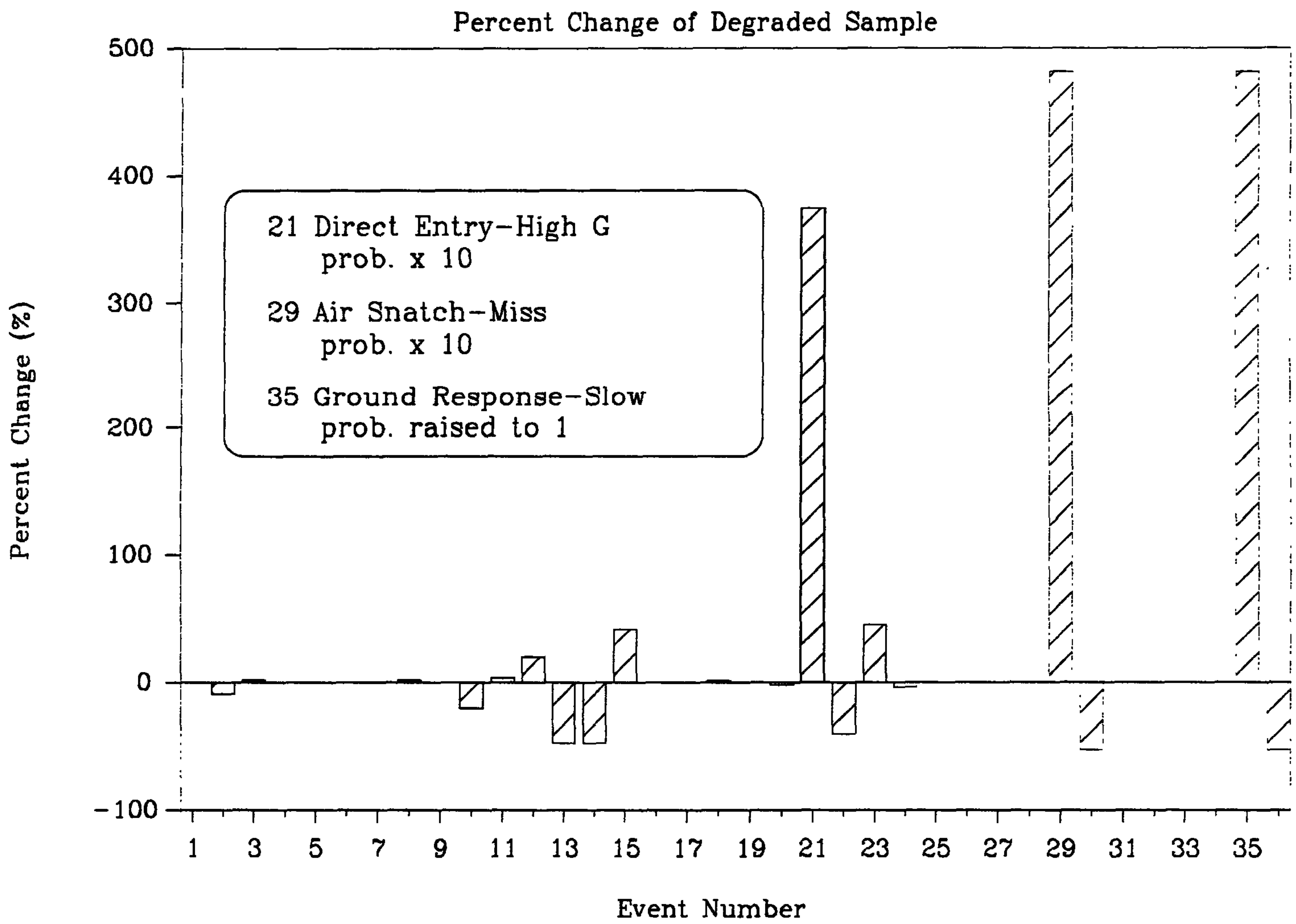

Figure 8.0-6, Sensitivity Plot for Direct Entry, Per Cent Change for 100% Success

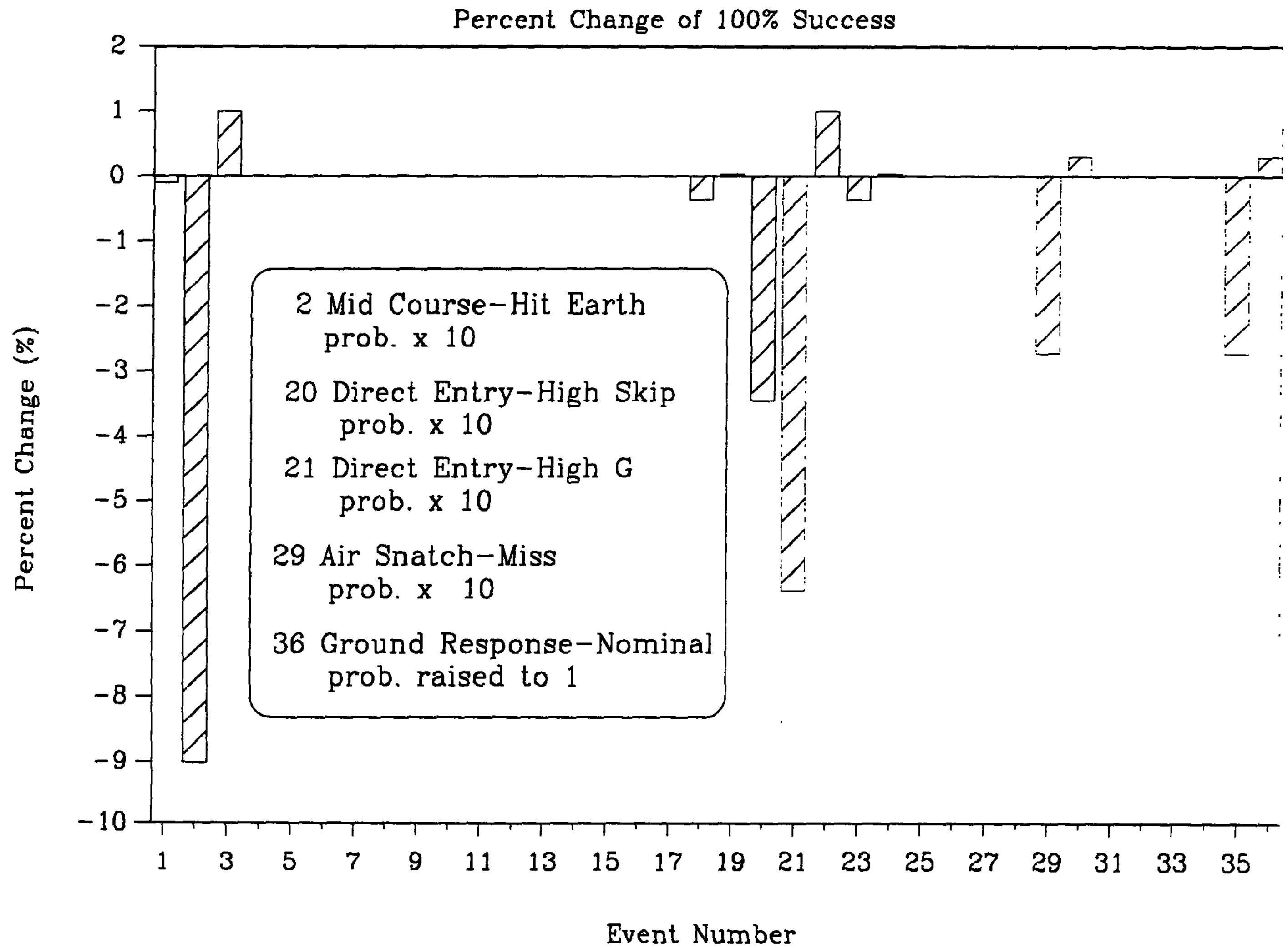

Figure 8.0-7, Sensitivity Plot for Direct Entry, Per Cent Change for Canister Breach

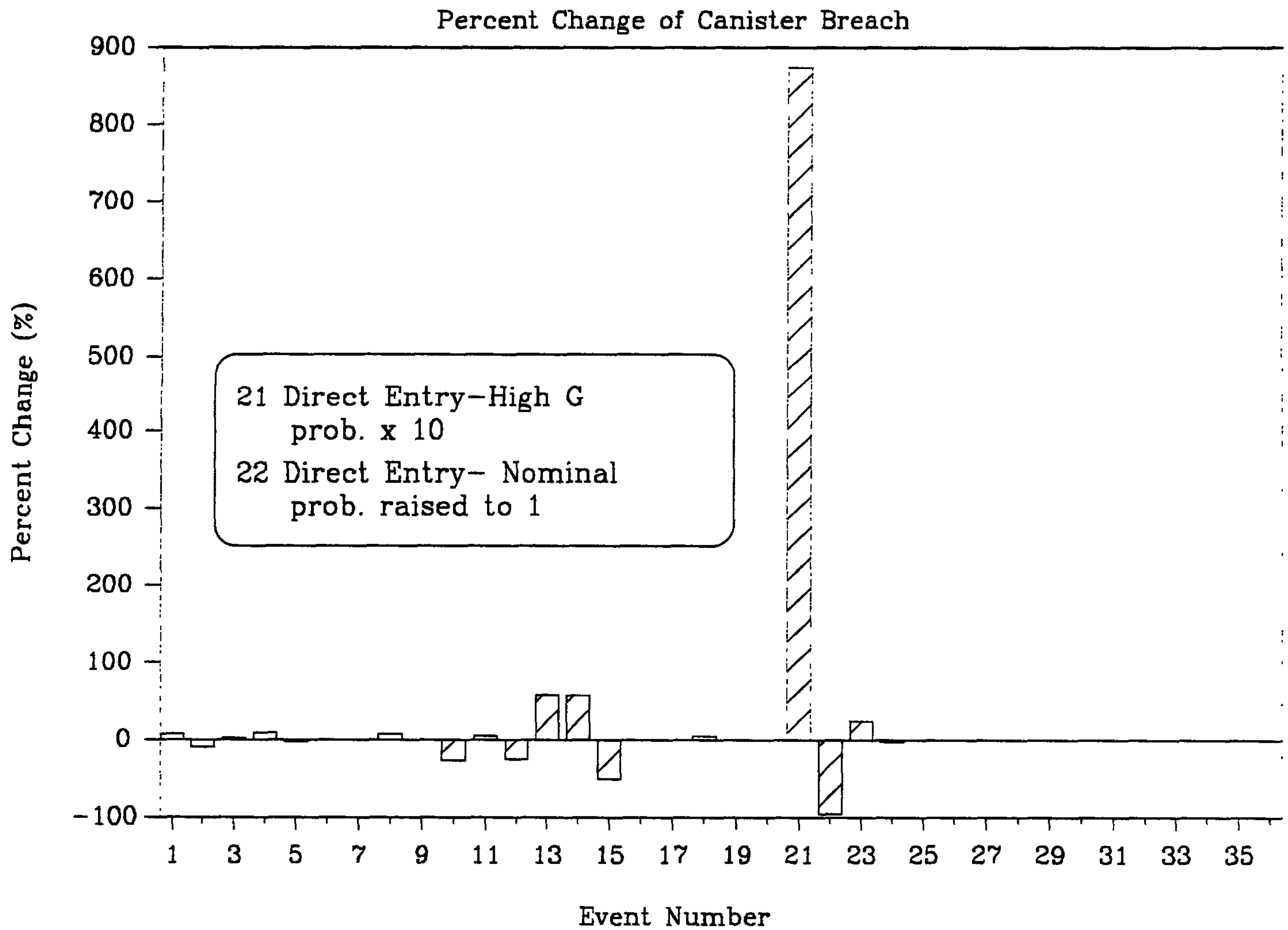

Figure 8.0-8, Sensitivity Plot for Aerocapture to the Freedom Space Station Per Cent Changed for Lost Sample

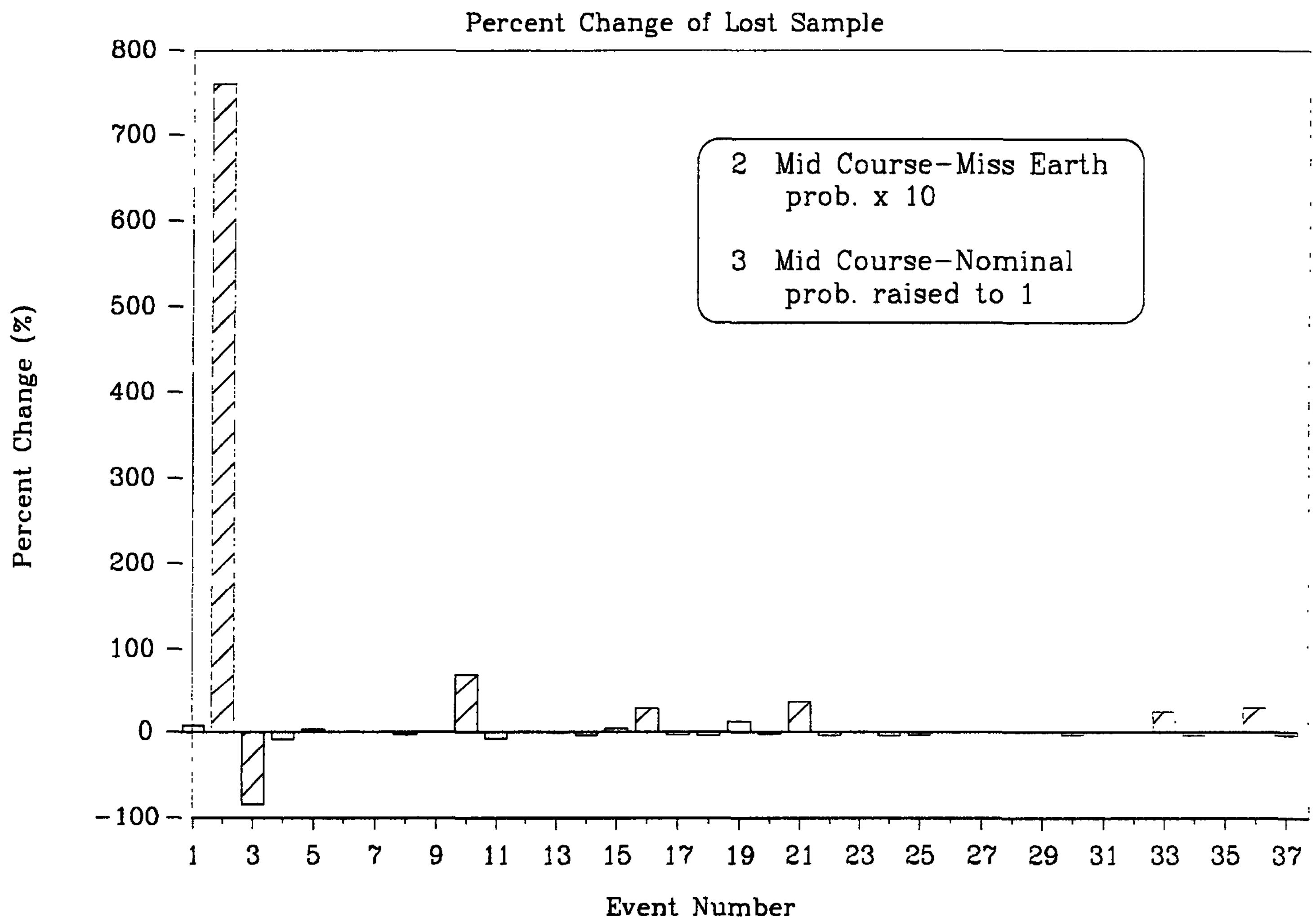

Figure 8.0-9, Sensitivity Plot for Aerocapture to the Freedom Space Station, Per Cent Change for Degraded Sample

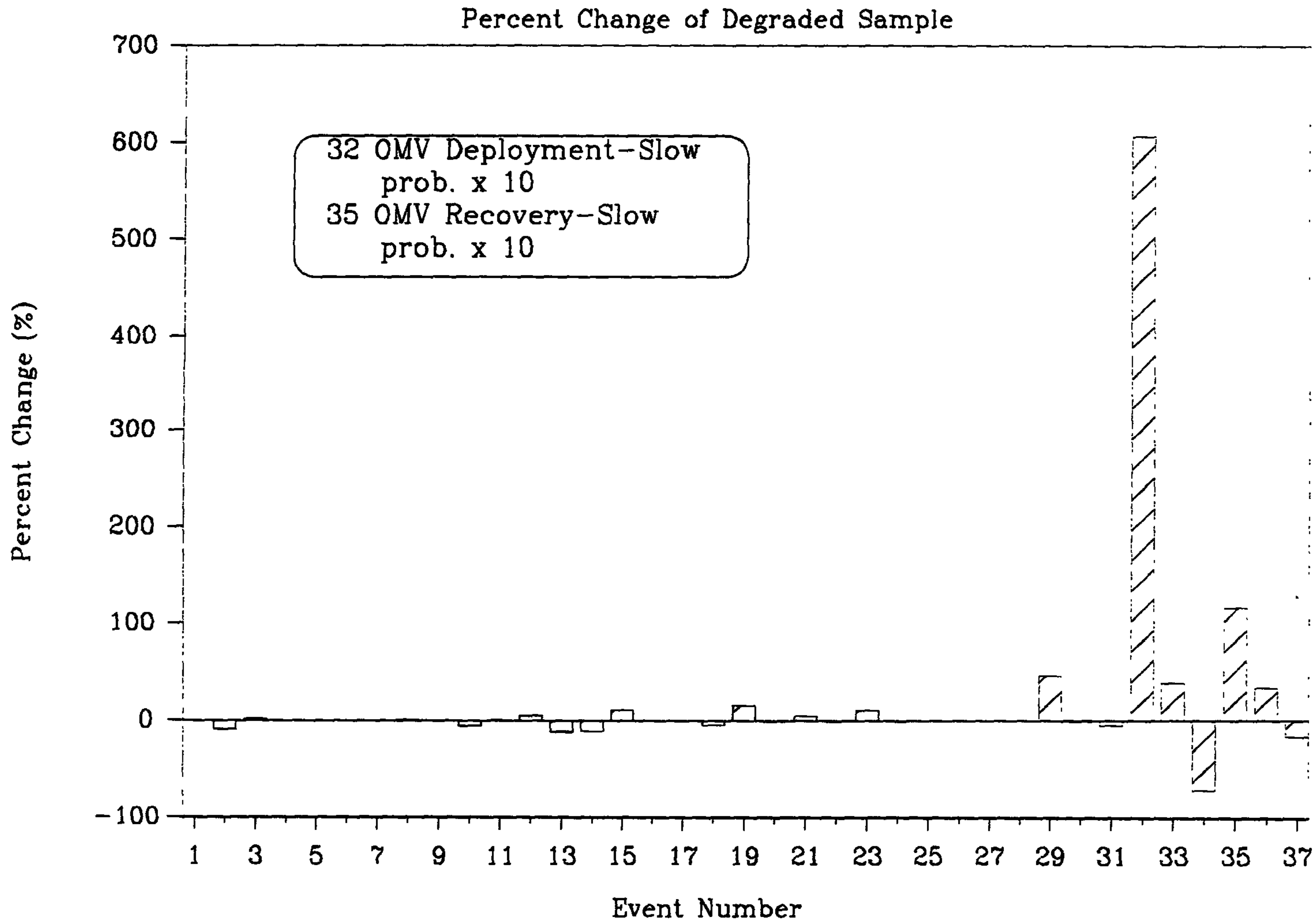

Figure 8.0-10, Sensitivity Plot for Aerocapture to the Freedom Space Station, Per Cent Change for 100% Success

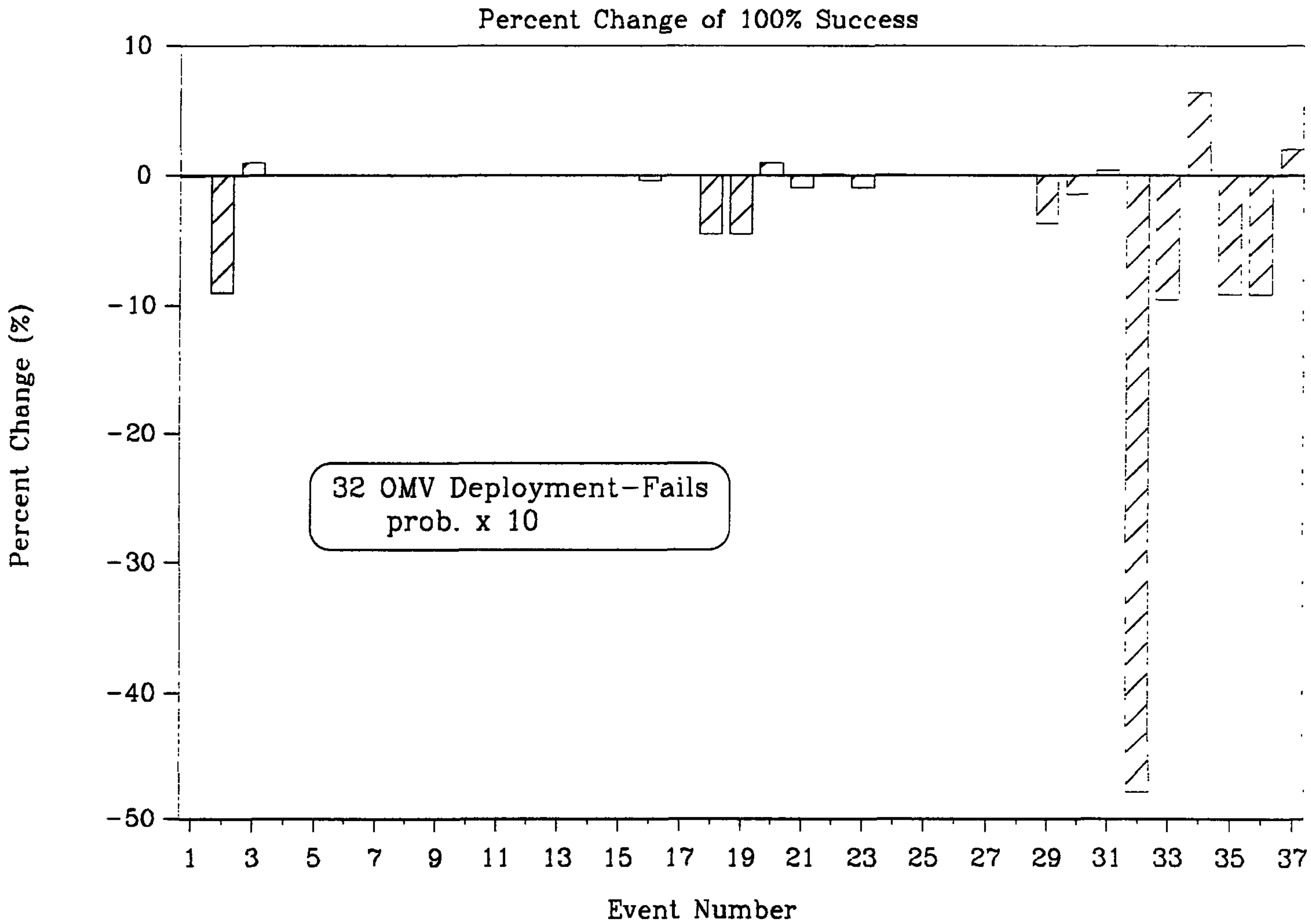

Figure 8.0-11, Sensitivity Plot for Aerocapture to the Freedom Space Station, Per Cent Change for Canister Breach

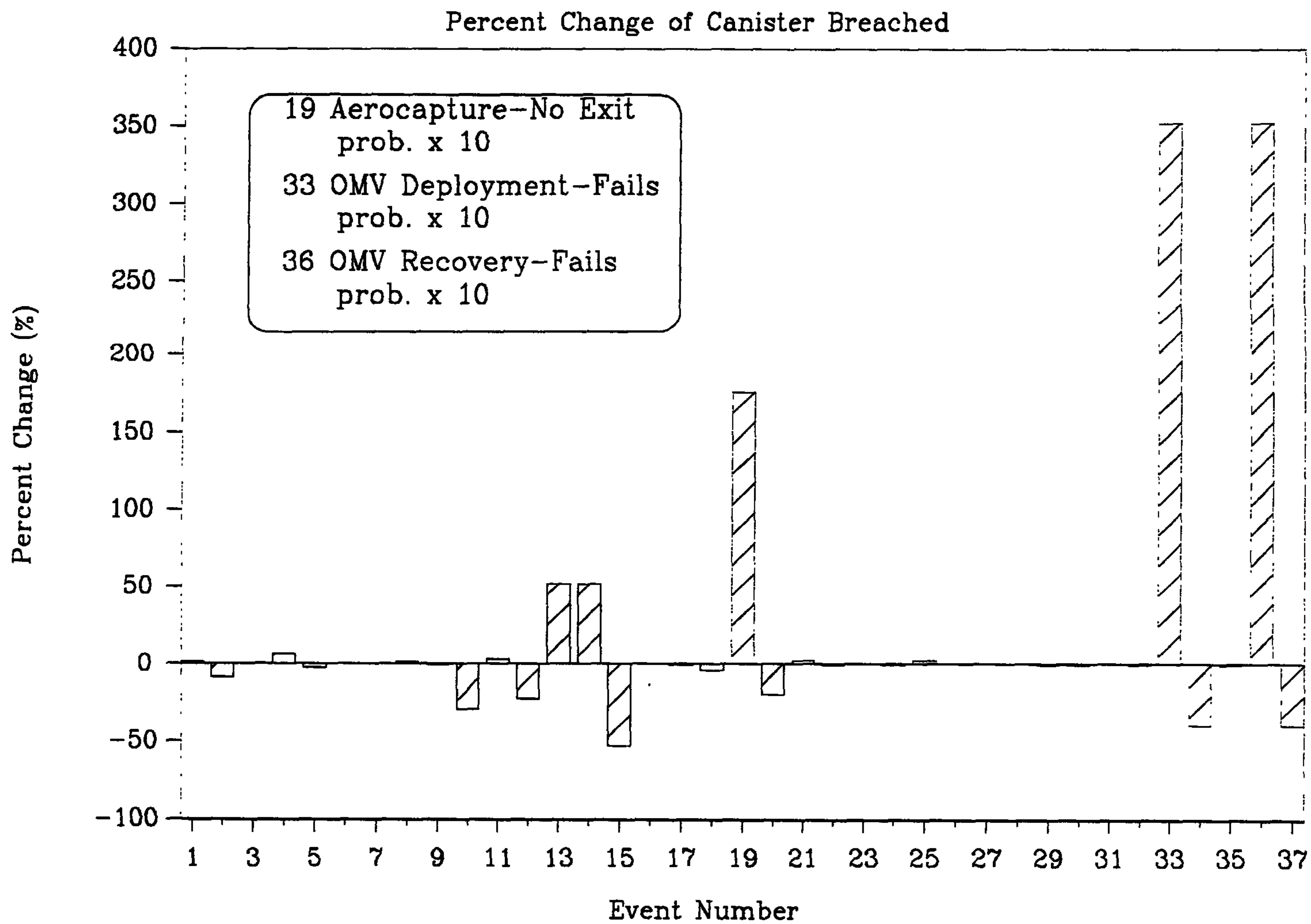

Figure 8.0-12, Sensitivity Plot for Aerocapture to the Freedom Space Station, Per Cent Change for Station Contamination

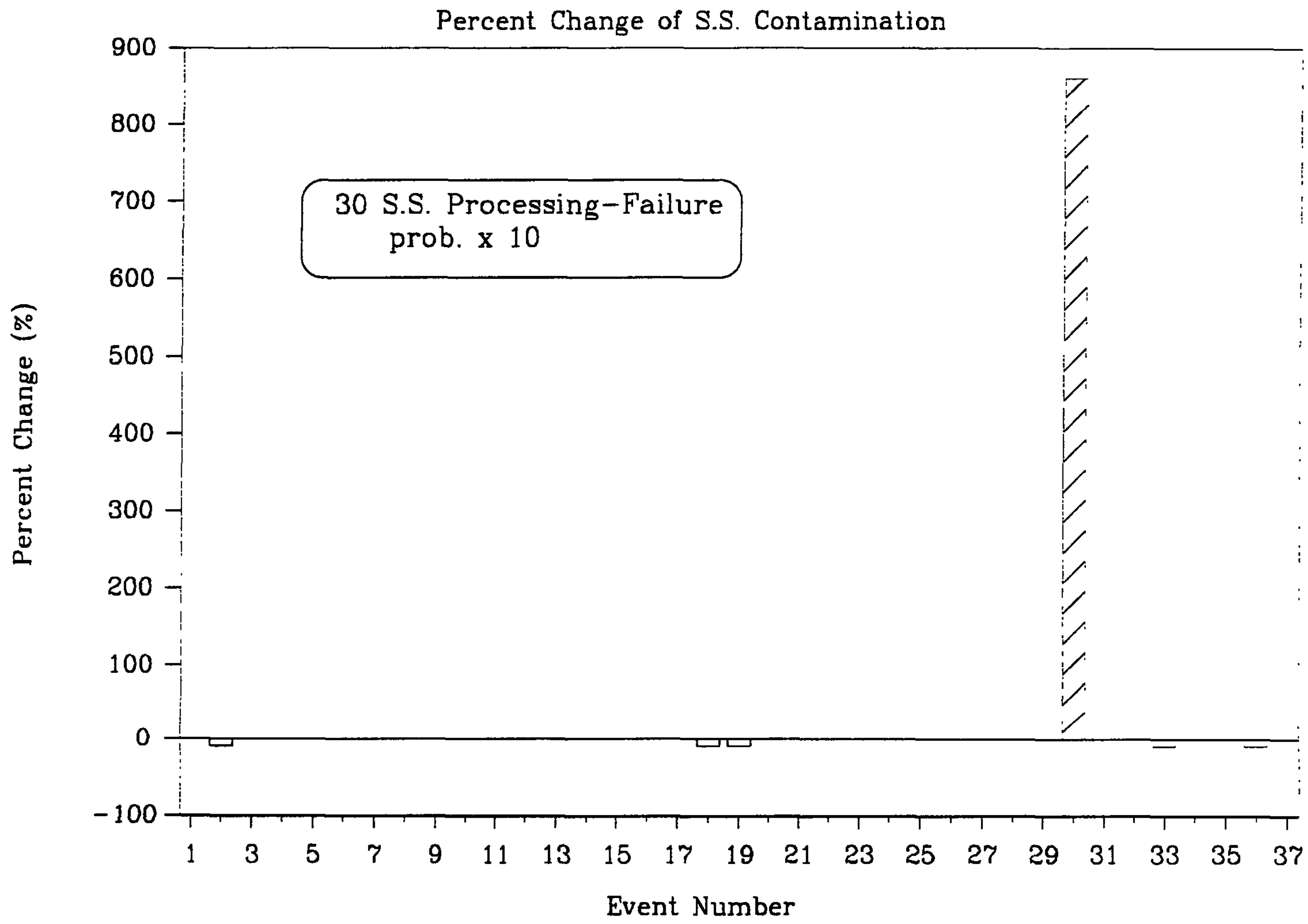

Figure 8.0-13, Sensitivity Plot for Aerocapture to the Freedom Space Station, Per Cent Change-for Permanent Orbit

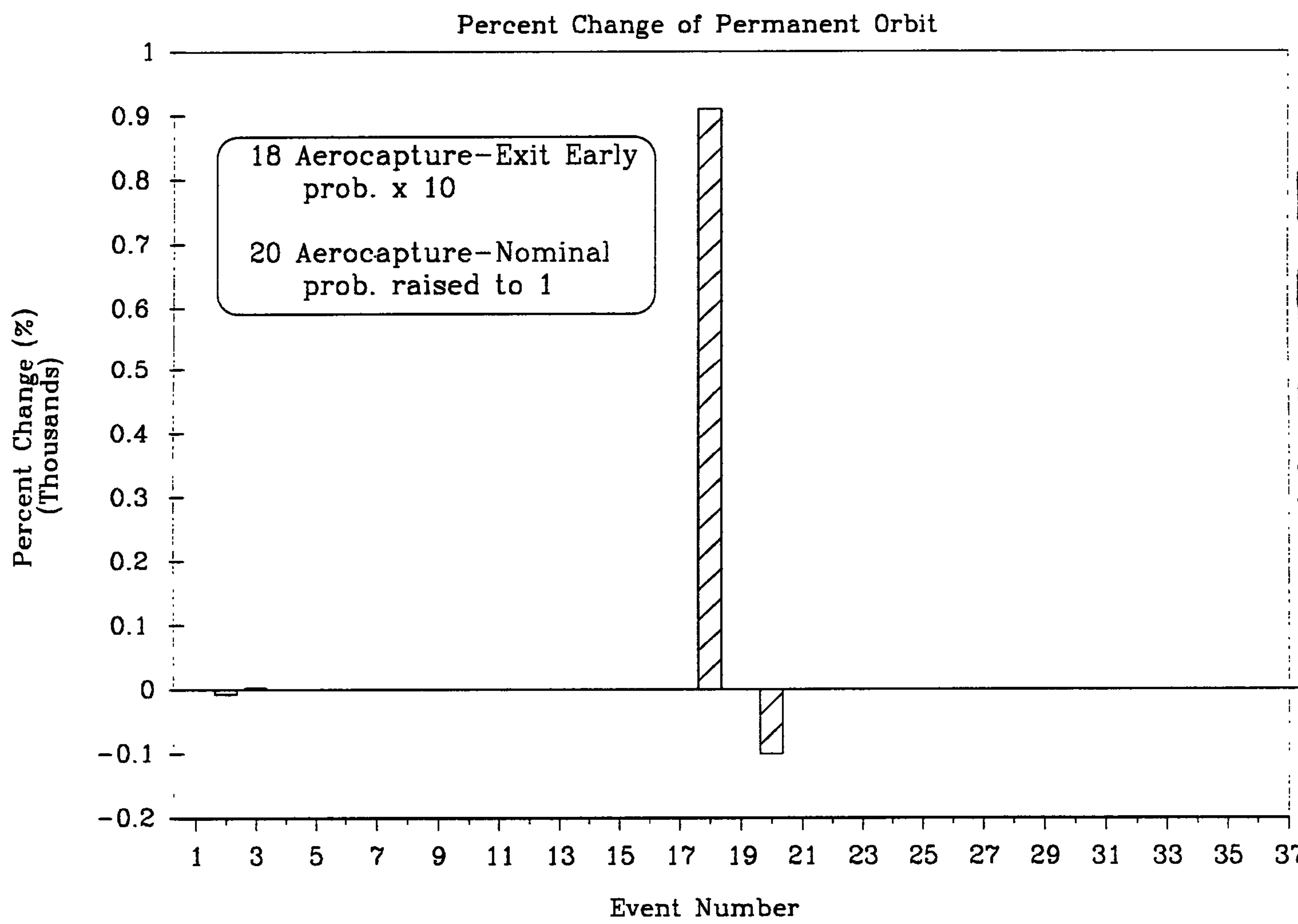

Figure 8.0-14, Sensitivity Plot for Aerocapture to the Shuttle, Per Cent Change for Lost Sample

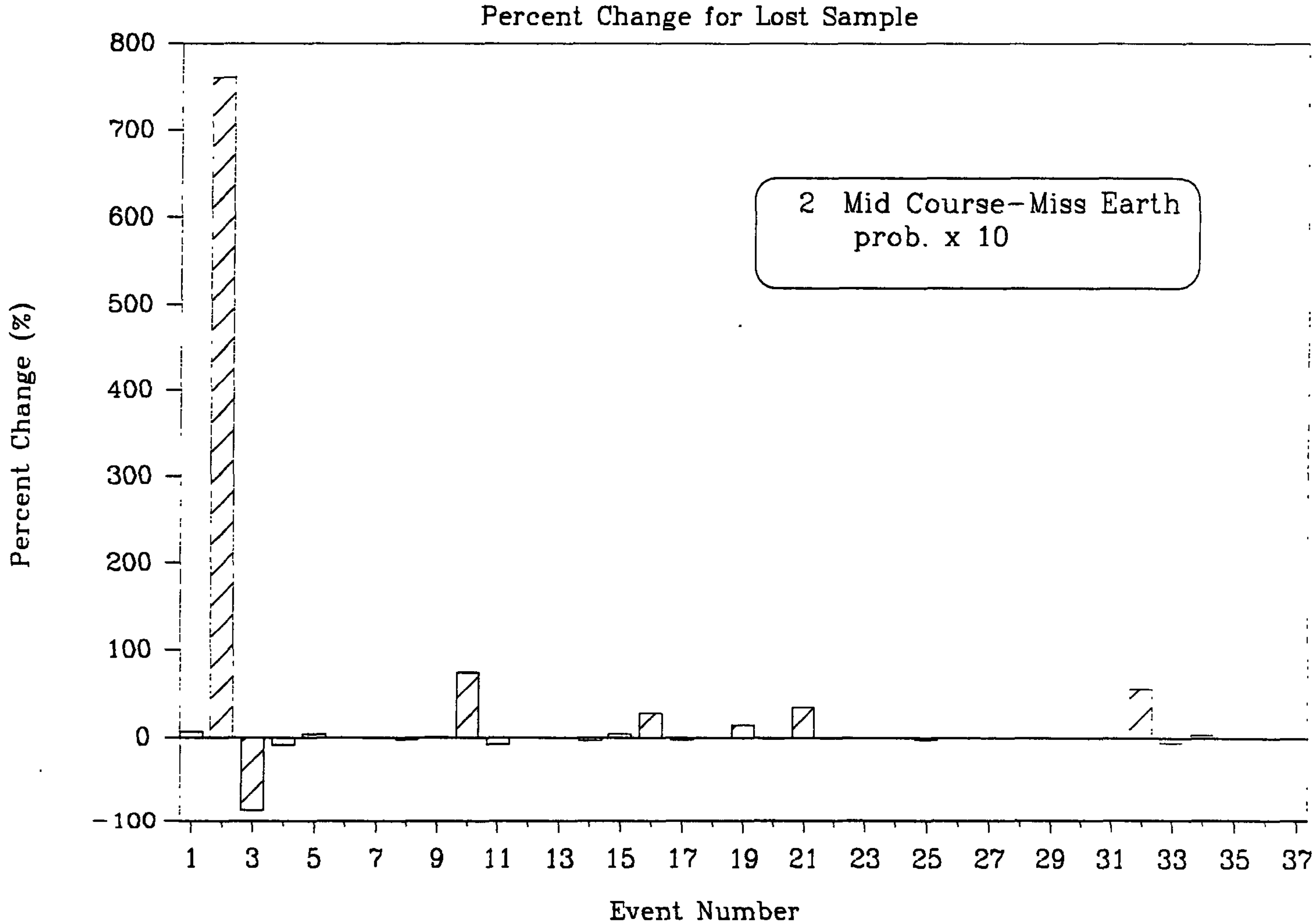

Figure 8.0-15, Sensitivity Plot for Aerocapture to the Shuttle, Per Cent Change for Degraded Sample

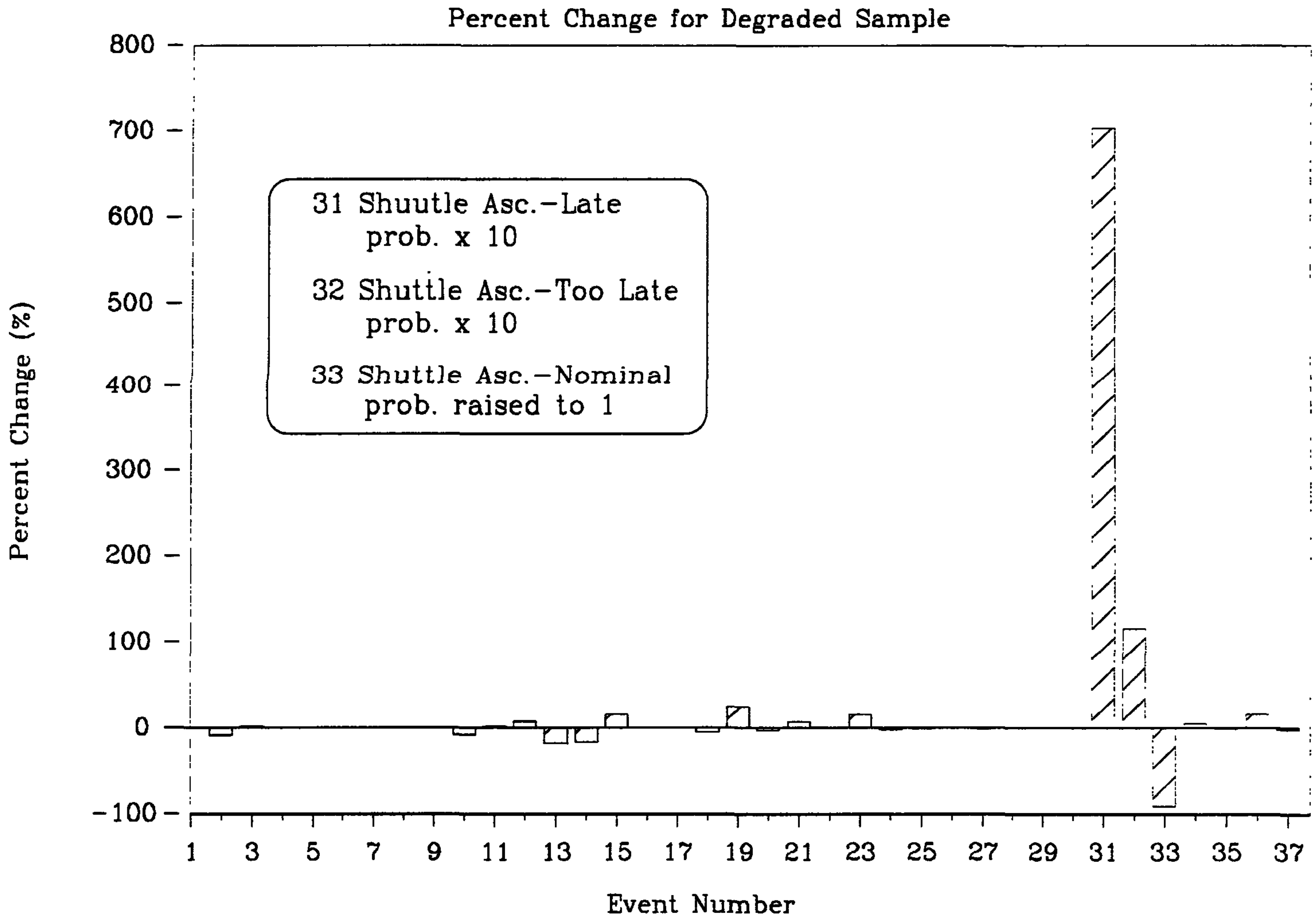

Figure 8.0-16, Sensitivity Plot for Aerocapture to the Shuttle, Per Cent Change for 100% Success

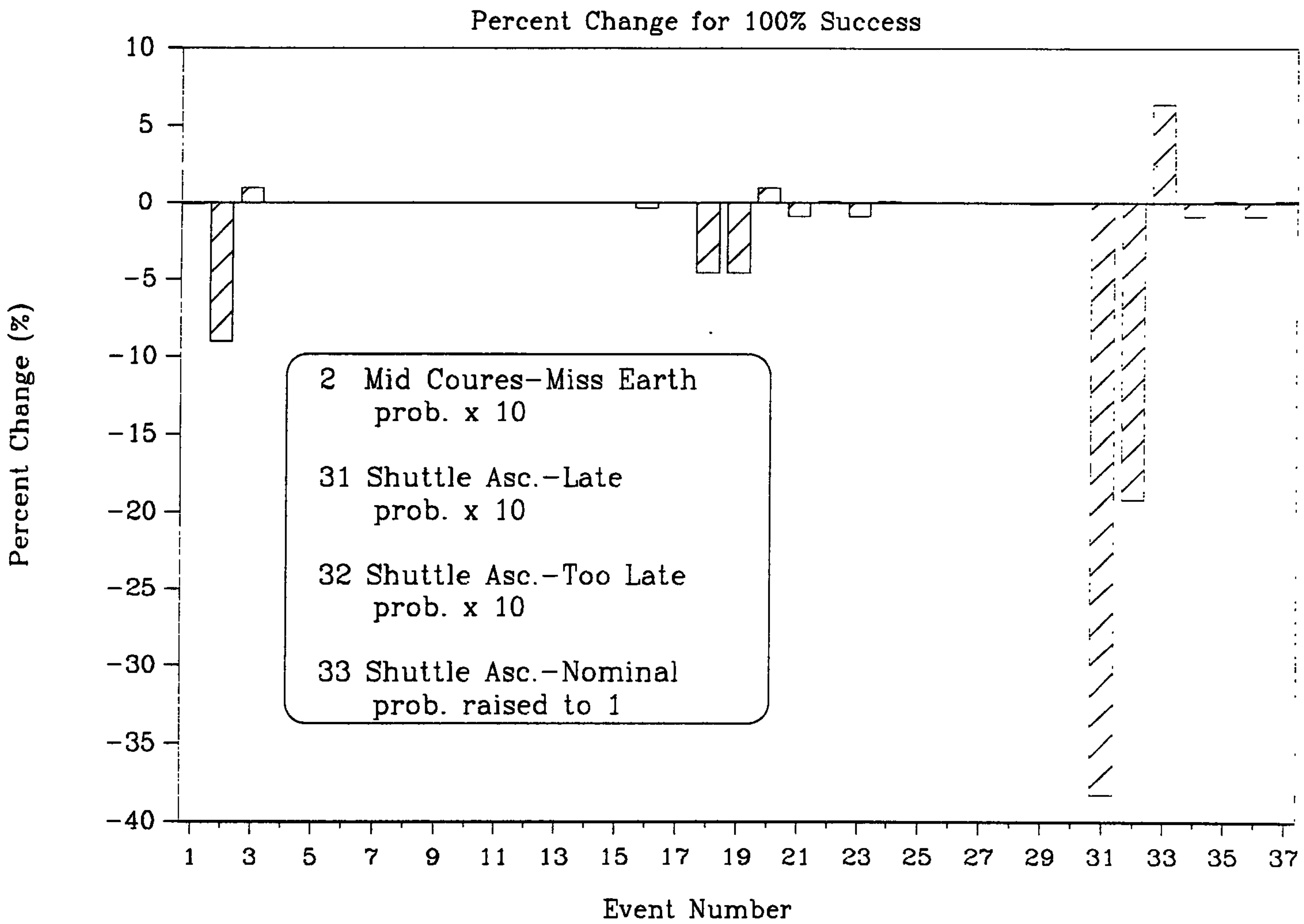

Figure 8.0-17, Sensitivity Plot for Aerocapture to the Shuttle, Per Cent Change for Canister Breached

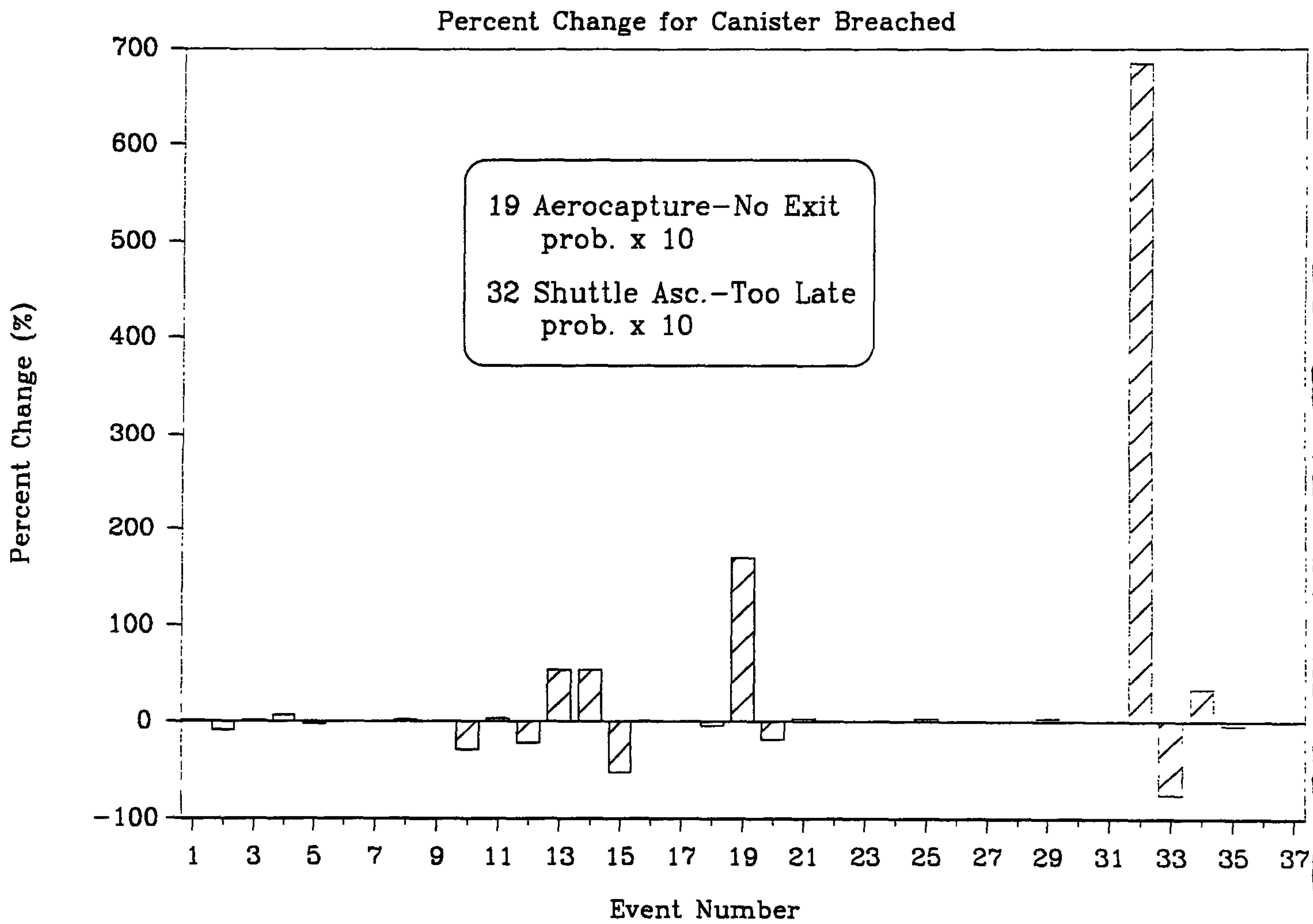

Figure **8.0-18**, Sensitivity Plot for Aerocapture to the Shuttle, Per Cent Change for Permanent Orbit

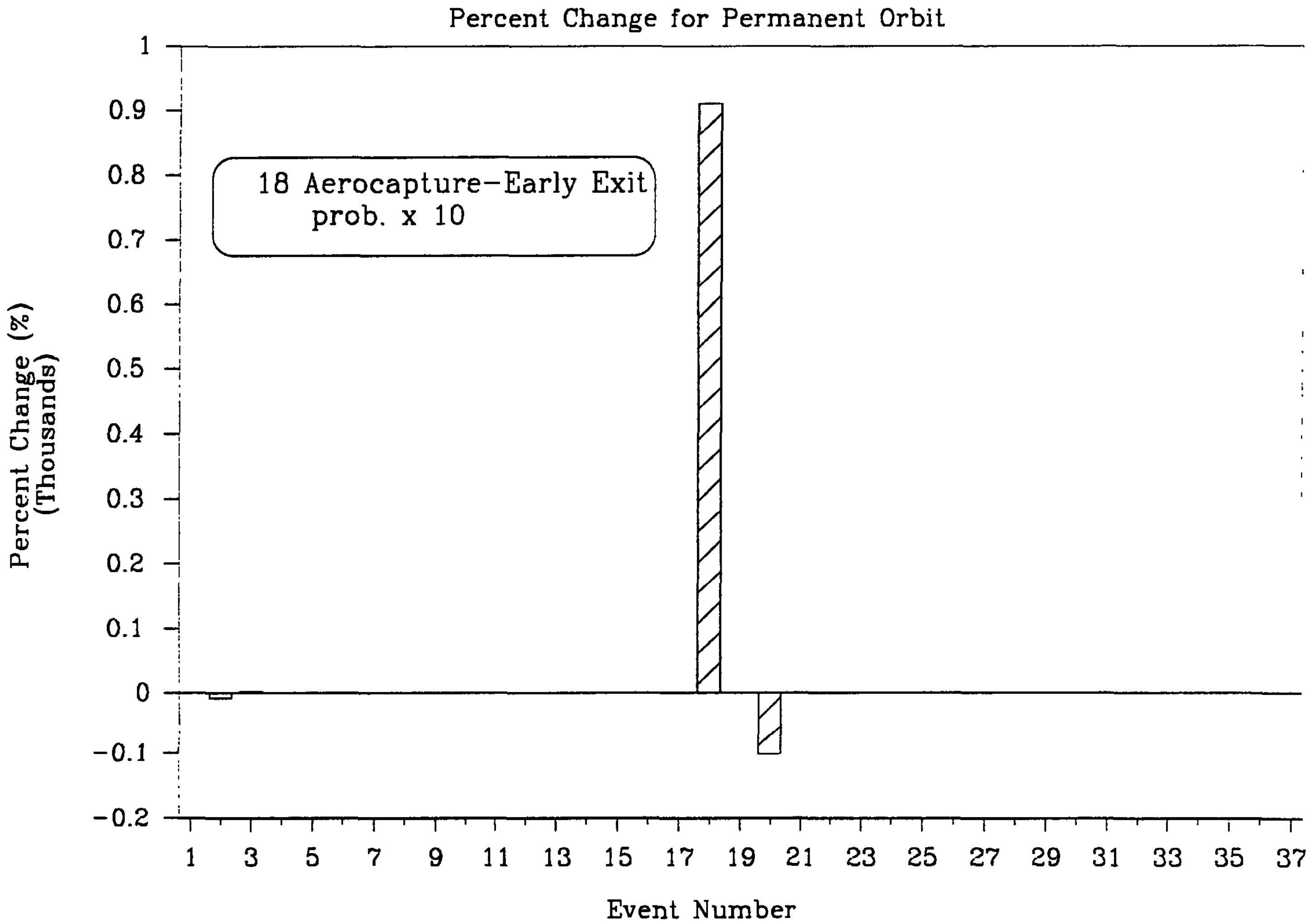

Figure 8.0-19, Sensitivity Plot for Propulsive Capture to Freedom Space Station, Per Cent Change for Lost Sample

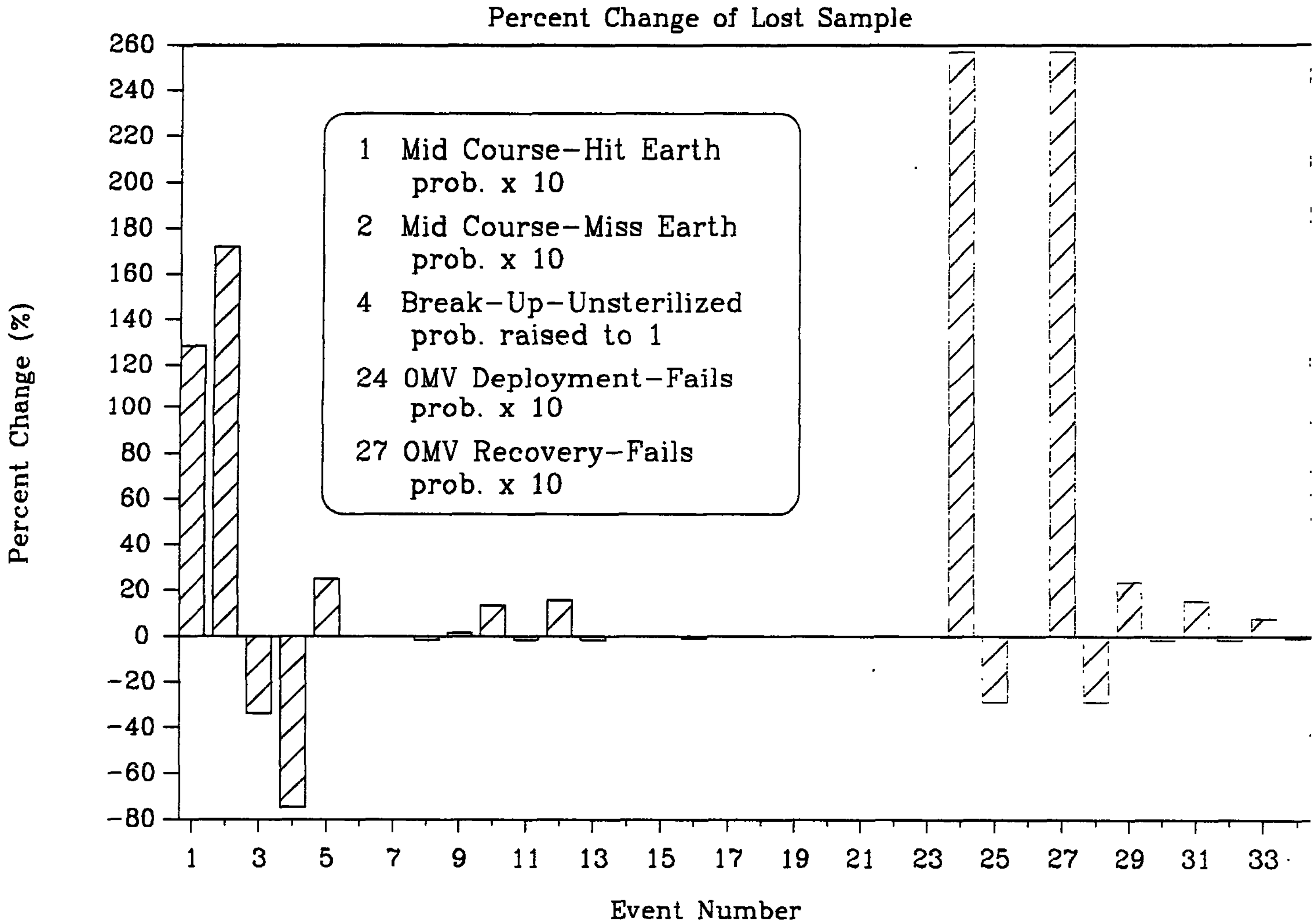

Figure 8.0-20, Sensitivity Plot for Propulsive Capture to Freedom Space Station, Per Cent Change for Sample Degraded

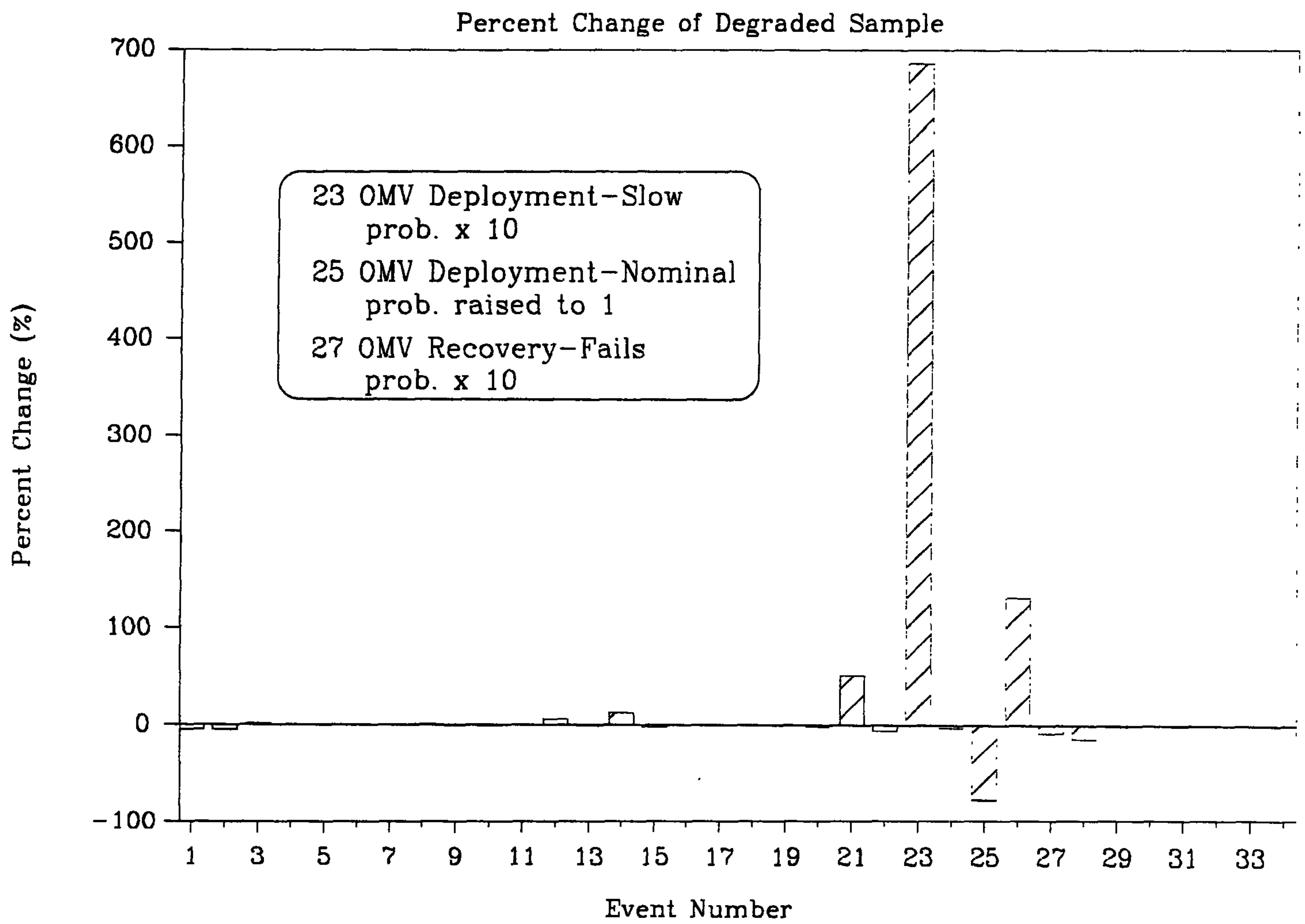

Figure 8.0-21, Sensitivity Plot for Propulsive Capture to Freedom Space Station, Per Cent Change for 100% Success

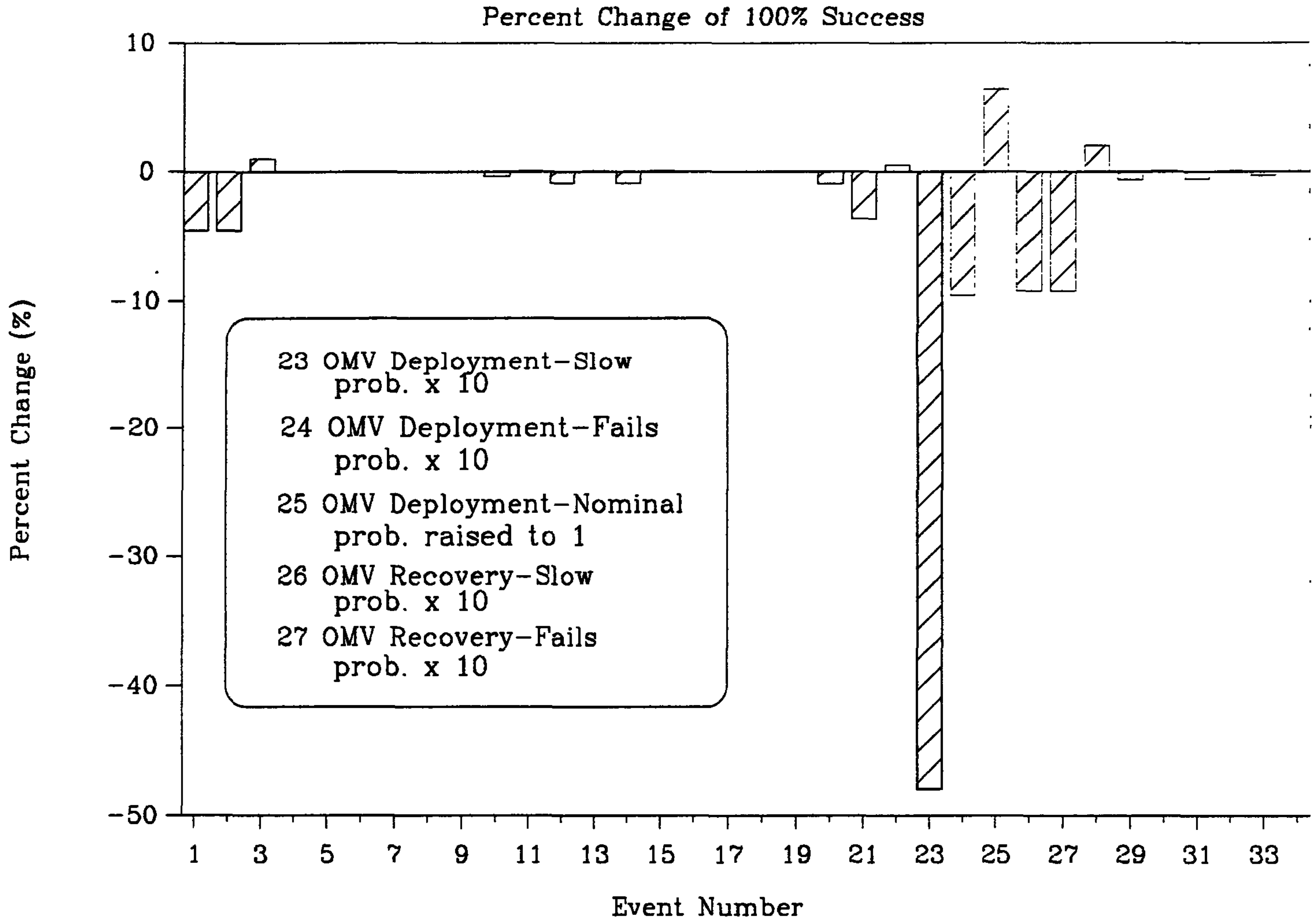

Figure 8.0-22, Sensitivity Plot for Propulsive Capture to Freedom Space Station, Per Cent Change for Canister Breach

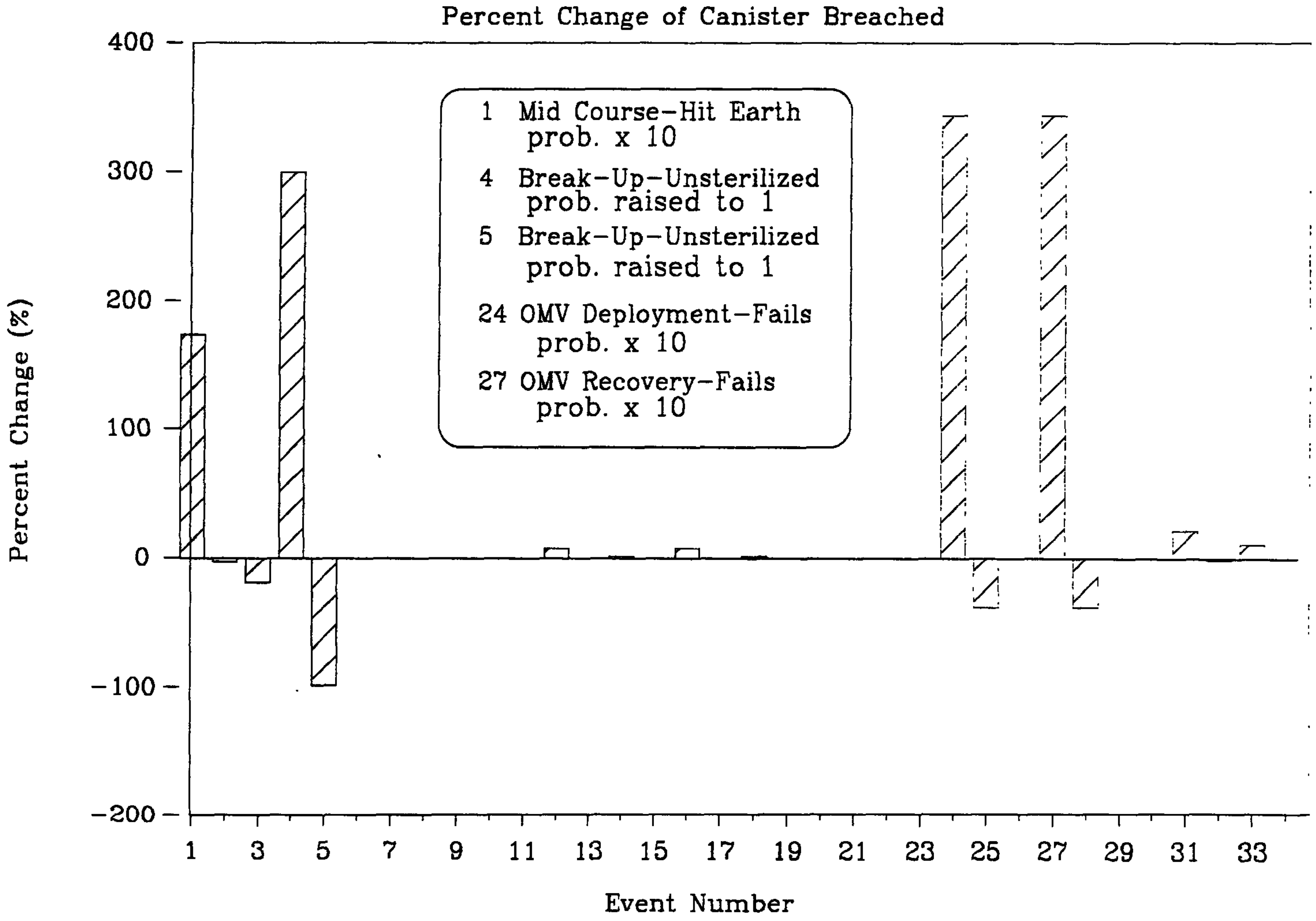

Figure 8.0-23, Sensitivity Plot for Propulsive Capture to Freedom Space Station, Per Cent Change in Station Contamination

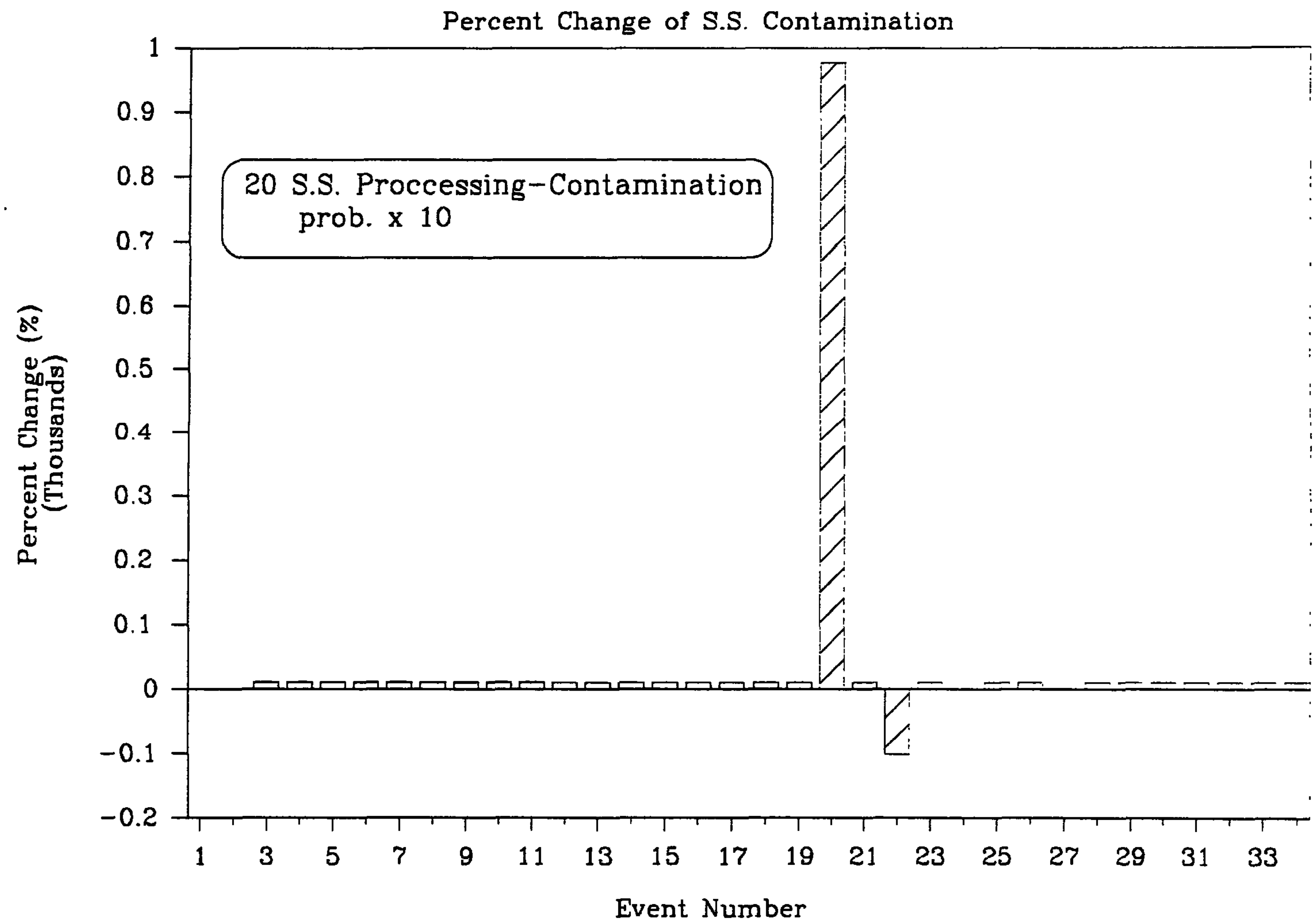

Table 8.0-5, The 15 Most Significant Events

		Option that has significant sensitivity to the Event:			
Event	Chapter	Direct Entry	Aerocap. to Sta.	Aerocap. to Shuttle	Propul. Cap. to Sta.
Mid Course	6.1	X	X	X	X
Break-up	6.2				X
Uncontrolled Entry	6.5		X	X	
No Chute Impact	6.6		X	X	
Search for SRC Out of Zone landing	6.7		X	X	
ERV Separation	6.8		X	X	
Direct Entry	6.9	X			
Aerocapture	6.10		X	X	
Air Snatch	6.14	X			
Orbiter Entry	6.18			X	
Space Sta. Proc.	6.22				X
OMV launch and departure	6.23		X		X
OMV Recovery	6.24		X		X
Shuttle Ascent	6.30			X	
Shuttle Rendez. and Recovery	6.31			X	

Table **8.0-6**, Events That Dominate Major Paths in the Fault Trees
(Nominal probability estimate shown)

1. Direct Entry

   - Successful Air snatch - 97%
   - Nominal Midcourse - 99%
   - Nominal Entry - 99%
   - Breach after no chute impact - 30%

2. Aerocapture to Orbiter

   - On-time Shuttle Ascent - 94%
   - Nominal Midcourse - 99%
   - Nominal Aerocapture - 99%
   - Breach after uncontrolled entry - 30%

3. Aerocapture to Freedom Space Station

   - OMV launch and deploy on time - 94%
   - OMV nominal recovery of SRC - 98%
   - Nominal Aerocapture - 99%
   - Nominal Midcourse - 99%

4. Propulsive Capture to Freedom Space Station

   - OMV launch and deploy on time - 94%
   - OMV nominal recovery of SRC - 98%
   - Nominal Aerocapture - 99%
   - Nominal Midcourse - 99%
   - Sterilization during uncontrl. entry - 25%

9.0 Planetary Protection Policy

At the start of this study the authors reviewed a series of documents to try to determine the official policy of the U.S. government toward return of extraterrestrial materials and possible back-contamination hazards. The policies for controlling spacecraft outbound from Earth to other planetary bodies seemed well defined, but the policy with regard to inbound flights were not adequately defined in the documents reviewed to present either design requirements or standards by which candidate designs could be evaluated.

Attitudes toward the problem are represented by two extremes:

- There is no life on Mars, don't let this issue impact the program.

- Any risk above zero is unacceptable. The benefits to the public are not worth any risk.

The authors of this study tend to be somewhere in the middle, leaning toward minimizing risk. Although the probability of living material on Mars is viewed as vanishingly small, the possibility does exist. The probability that life previously existed on Mars when it had liquid water on the surface and a more hospitable climate is much higher. One of the principle motivations to pursue a Martian sample is to find evidence of that life. It is physically impossible to return a sample in which to study past life which is 100% certain to be free of current Mars life, should it exist. Zero risk is not possible for a sample return mission. We must be willing to accept a small risk. If there is Martian life, it cannot be studied without some risk, but there are potentially great benefits from this study.

The precedents for handling extra-terrestrial materials were set in the Apollo program where biohazards were considered. Zero risk was not achievable though it was sought. The material was simply handled with equipment and procedures similar to those used to confine known deadly terrestrial pathogens in biological containment laboratories. The sample was isolated biologically as were all that came in contact with it. Such procedures can be implemented at a modest cost relative to other aspects of the mission.

There are other precedents in the handling of known terrestrial pathogens such as the remaining viable smallpox virus. Keeping some smallpox virus available for study involves some small risk to the population of Earth as a whole. However, the study of the material has been deemed to outweigh any risks associated with its presence.

What is an acceptable risk? Another way to phrase the question is - what is a risk the American public will accept. It is worthwhile mentioning that all previous sample returns (6 Apollos and 3 Lunas) were direct entries with risks on the order of or greater than those tabulated for direct entry in this report. Convincing arguments have been presented that several meteorites found on Earth came from Mars. These meteorites have fallen in all regions of the Earth including India France, Antarctica, and other locations. All arrived via direct entry and none have induced any pathologic symptoms.

Table 9.0-1 tabulates typical risks faced by the public in everyday life. An acceptable risk in the high range is roughly one in one million. This is the chance of a fatal accident on a commercial aircraft flight or roughly the chance of an individual getting struck by lightning in a year. The authors propose this as a first cut acceptable risk for releasing Martian life on Earth, to be weighed against the benefits.

Table **9.0-1**, Typical Risks
(Hutt, 1978)

- 1/4,500 - risk of death/year/indiv. in auto accid.
- 1/2,000,000 - risk of death/year/indiv. from lightning
- 1/13,000 - risk of death/year/indiv. from fall
- 1/300 - risk of death/year/indiv. from smoking

Given that the risk of breach of container in the Earth's biosphere is calculated as roughly 1/2% or 5 in 1,000 for direct entry (the best option) it must be reduced to approach 1 in 1,000,000.

One reduction factor for this risk could be a multiplier applied for the probability that Martian life exists, will be found in the sample in quantity, can survive transport, can reproduce and do damage on Earth, etc. This all seems unlikely at the moment leading the authors to propose a 1/100 or 1/1,000 multiplier. More study of this issue by an exobiologist is needed.

Other risk reduction measures are proposed in the next chapter. More work and the software developed in this study can quantify these effects on the risk of container breach.

10.0 Risk Reduction Measures

The following measures can significantly reduce the risk of sample canister breach and of back-contamination of Earth.

1. Redundant air snatch aircraft will increase the probability of a successful air snatch from 97% to 99.91%. This does not affect the chance of container breach, since the container will be designed to land unharmed with a chute, but the risk of loss of thermal control will be significantly reduced.

2. Retain ability to miss Earth as long as possible - just before entry or ERV separation. Any failure that might increase the risk of container breach would be cause to fly by.

3. Redundancy in all critical systems in the ERV and SRC. For risk of canister breach, a highly internally redundant single mission is better than a dual mission. A completely dual pair of missions may get the chance of mission success from 80% up to 96% but it will double the risk of canister breach.

4. Toughen the SCA for no seal loss in a no chute impact. Though likely to be expensive in terms of weight, this a highly testable option. Low weight options, such as placing the sample in some kind of rugged, flexible bag may also work.

5. Flight test of the direct entry or aerocapture system would increase confidence in single point failure items such as the thermal protection systems.

6. Toughen the SCA to insure sterilization in an entry breakup. A rugged SCA will retain the sample long enough for it to be sterilized by the heat of re-entry in a break-up situation.

7. Add a sterilization system in the SCA. A chemical heater (phosphorus grenade?) would be placed in the SCA to be ignited in the event of unplanned failures. The sample would be heat sterilized.

8. Add equipment (TV cameras?) to monitor the sterile transfer in Mars orbit. Any anomaly would result in cancellation of the sample return.

9. If any sign of life is seen on Mars, cancel the sample return until more secure systems are built.

10. Long life parking orbit - at least 650 km (350 nm). The OMV can retrieve 800 lbm from approximately 1,850 km (1,000 nm) orbits. This would get the orbital lifetime up to tens of years, allowing many chances to go get the sample. This will significantly reduce the risk of canister breach for the Earth orbit options, but will not affect the risk of degraded sample or overall mission success much.

    Figure 10.0-1 and 10.0-2 show decay times for ballistic numbers typical of aerocapture and propulsive capture options.

The decay times are very much a function of the solar flux/sunspot cycle and the expansion of the atmosphere that results from high flux/sunspot times which occur every eleven years and last for three or four years. The last few peak years have been 1948, 1958, 1969, and 1980. 1980 + 22 = 2002. If the mission departs in 1998, it will return roughly three years later in 2001. It will therefore arrive as sunspot activity is rising toward the peak, at the start of 3 or 4 years of high flux and expanded atmosphere. Lines number 3 and 4 in the figures are therefore applicable for lifetime prediction.

11. Redundant means to retrieve the SRC from orbit, such as an expendable with an SRC catcher of some kind would up the chance of retrieval success into the 99% range, but at great expense.

12. Permanent basing of an OMV at the Freedom Space Station will remove part of the ascent problem. The retrieval will be less dependant on an on-time launch, however a 51L accident may put the station out of action anyway. The crew may return to Earth in an emergency return device.

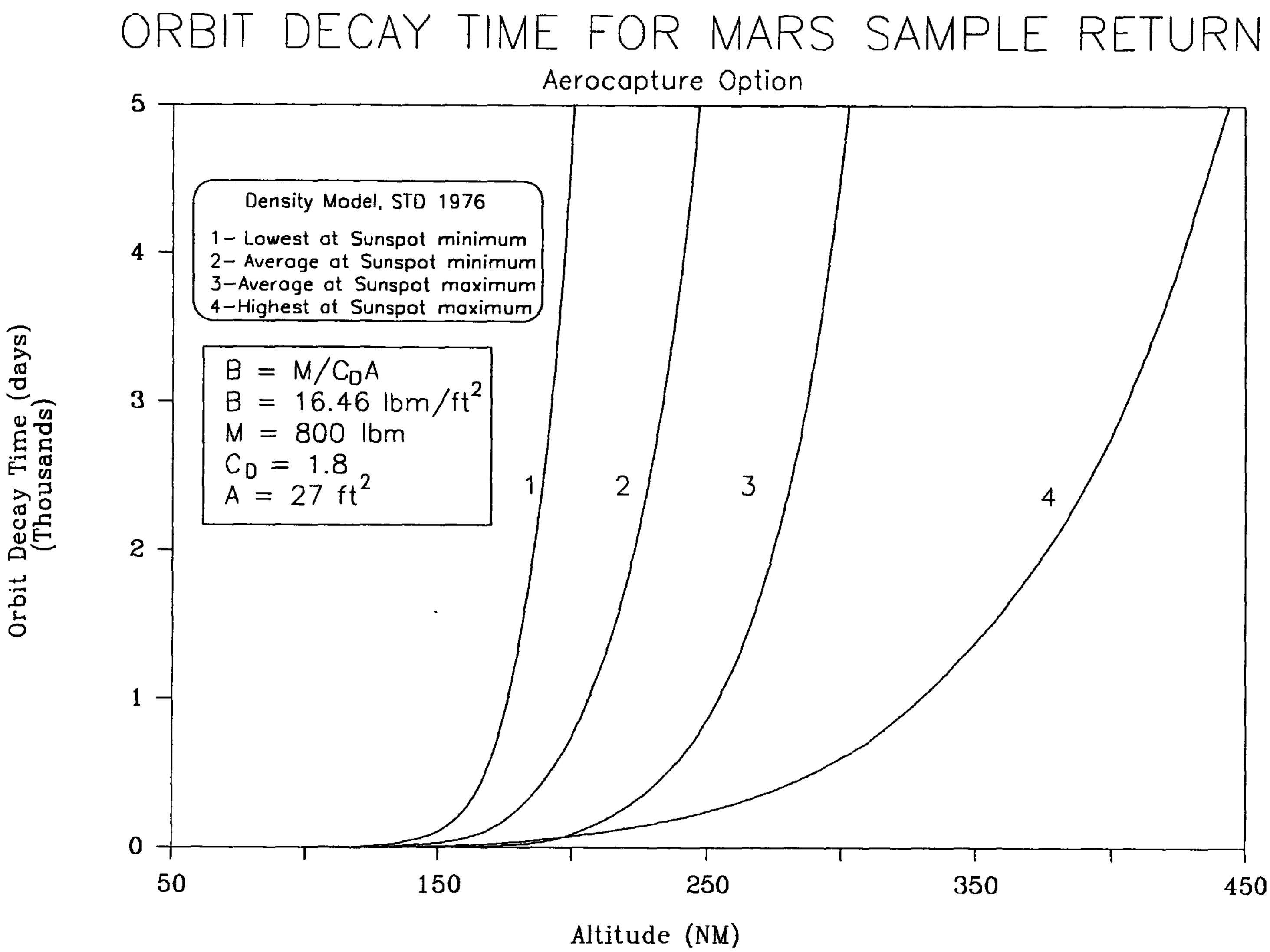

Figure 10.0-1, Orbital Decay Time, Aerocapture Option

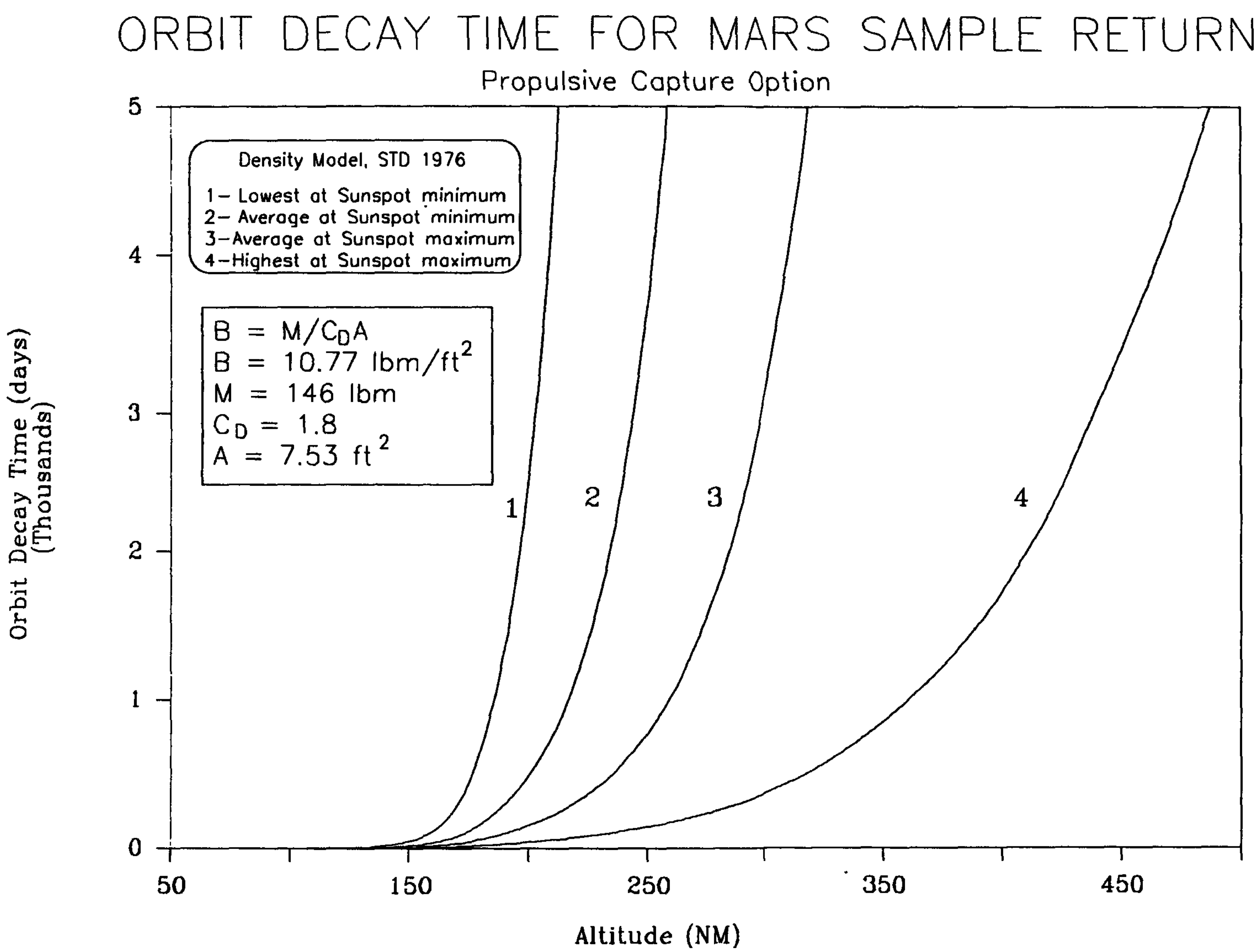

Figure 10.0-2, Orbital Decay Time, Propulsive Capture Option

11.0 Conclusions and Recommendations

The following conclusions and recommendations resulted from this study:

1. The direct entry option is the best choice of the four in all areas of comparison studied here. It has the best chance of 100% mission success, least chance of canister breach and loss of thermal control. It is the least expensive, has less program risk and is by far the simplest. All previous sample returns (6 Apollos and 3 Lunas) were direct entry missions and the public did not object. Other comparison areas, such as weight, were not addressed.

2. Measures can be taken to significantly reduce the risk of canister breach below the 0.45% calculated for direct entry. These include:

   a) Redundant subsystems in the ERV and SRC
   b) Dual main and drogue chutes (already included in the calculations)
   c) SCA capable of maintaining seals in a no chute impact
   d) Ability to flyby Earth until ERV separation
   e) Flight test for entry vehicle
   f) Redundant air snatch aircraft

3. Other measures that can reduce the probability of back-contamination for all options include:

   a) Cancellation of sample return portion of the mission if any signs of life are found on Mars.

   b) Equipment (cameras) to monitor the sterile transfer in Mars orbit. Any detected anomaly in the sterile transfer process would result in leaving the sample in Mars orbit.

4. If the options using Earth orbit parking are used, use a parking orbit with a long decay time, in the range of tens of years.

5. The orbital decay figures shown in Figures 10.0-1 and 10.0-2 are from a low-fidelity simulation. A more sophisticated decay model should be used to verify decay time versus altitude, year, and ballistic number.

6. Certain event probabilities could be improved with more research. These include:

   a) OMV launch and deployment (section 6.23) - a key event
   b) Shuttle ascent (section 6.30) - also key
   c) Go on batteries (section 6.3) - better numbers can be obtained
   d) Mid Course (section 6.1) - the probability of hitting Earth after a miss on subsequent orbits around the sun should be computed
   e) EOI burns (6.27 and 6.28) - Motor reliability can be better determined

7. If the biological material in the sample is assumed to carry its genetic information in long chain molecules, it can be heat sterilized. A heat sterilization procedure needs to be developed and agreed upon.

8. The weight penalties associated with the following proposals should be determined.

   a) Sterilization system (phosphorus grenade?) inside the sample container to be fired in the event of failures.

   b) Protection material or containment package required in order to allow the SRC to hit hard ground with no chute and not release the sample. Some very light mylar or kevlar bag may be all that is needed.

   c) Sample container that will heat the sample to the required sterilization conditions before it breaks up.

9. The probability of a vehicle's on-time ascent to LEO to retrieve the SRC is a key number unavailable at present to the authors. Simple ascent success probability is given in Table 6.29-1. Successful ascent within a specified schedule also needs to be tabulated.

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