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SRB WATER IMPACT VELOCITY TRADE STUDY

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16. ABSTRACT

Updated loads imposed on the Space Shuttle Solid Rocket Booster (SRB) resulted in water impact attrition rates of 10 percent or more for the aft structure. The most obvious solution to this problem, to reinforce the aft structure, was undesirable due to the status of design drawings, schedule impacts, and the risk of failure at drogue chute deployment. Any weight increase to solve the water impact problem would make the parachute attrition problem worse.

Reducing the vertical impact velocity by enlarging the three clustered parachutes was technically feasible and essentially solved both attrition problems. The lower velocity reduced the water impact loads and the increased weight of the parachutes moved the center of gravity forward to reduce the risk of parachute induced attrition. This memorandum records the results of the attrition/cost studies which formulated the data base for the recommendation to reduce the SRB nominal vertical water impact velocity to 85 feet per second.

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SRB WATER IMPACT VELOCITY TRADE STUDY

I. INTRODUCTION

Updated loads imposed on the Space Shuttle Solid Rocket Booster (SRB) resulted in water impact attrition rates of 10 percent or more for the aft structure (table 1). The most obvious solution to this problem, to reinforce the aft structure, was undesirable due to the status of design drawings, schedule impacts, and another source of attrition: the risk of failure at drogue chute deployment. This is strongly driven by any aft movement in the center of gravity (c.g.) at reentry and the most probable c.g. for the baselined configuration was further aft than desirable. Any weight increase to solve the water impact problem would make the parachute attrition problem worse.

Reducing the vertical impact velocity by enlarging the three clustered parachutes was technically feasible and essentially solved both attrition problems. The lower velocity reduced the water impact loads and the increased weight of the parachutes moved the c.g. forward to reduce the risk of parachute induced attrition. This technical memo records the results of the attrition/cost studies which formulated the data base for the recommendation to reduce the SRB nominal vertical water impact velocity to 85 feet per second.

II. BACKGROUND

The SRB is designed for recovery at sea and reuse. Parachutes are deployed to decelerate the vehicle. The vehicle, as it enters the water, passes through a complex series of separate loading events from the initial impact loads applied to the nozzle through cavity collapse and slapdown, to maximum submergence hydrostatic pressure load. These loads have been determined for a wide range of water impact conditions through a series of scale model drop tests.

The structural capabilities of the SRB to resist each of the water impact loads were established and attrition rates determined in order to design the SRB for optimum program cost. In general, this was an iterative process adjusting capabilities through hardware modification, testing or refined analysis. The lowest program cost lies somewhere between the extremes of a structure not designed for water impact and thus experiencing a high attrition, and the one designed for the worst case load with a factor of safety, and thus requiring a high unit cost to achieve low attrition. Since there are no crew safety considerations after separation, failures are purely economic and the traditional factor of safety and worst case loads are inappropriate. Instead, a cost optimization approach defines the design.

Figure 1 is a flow diagram of a design optimization of the SRB for water impact. It illustrates the relationship between the design, loads, attrition costs, and program factors which went into this decision. An optimization such as this was performed on the initial SRB configuration (4/11/73) and loads with the result that 100 ft/sec was chosen as the optimum design.

III. LOADS

The load parameters utilized for the attrition assessment are documented in SE-019-057-2H, "Space Shuttle Solid Rocket Booster Design Loads, Revision A, September 12, 1975." They are appropriate for the SRB configuration of figure 3. All motor case analyses include the superimposed thermally induced vacuum shown in figure 4.

The loads in SE-019-057-2H have increased due to two factors:

The current configuration has been changed considerably in the aft end. Since the vehicle enters the water aft end first, it is very sensitive to the flair angle of the aft skirt and the length of the nozzle.

New drop tests have been performed. Because of concern over the loads applied to the nozzle area, much more elaborate instrumentation was installed in this area of the drop test model and forces and moments, as well as pressures, were measured. Pressure scaling and horizontal motion were also introduced into the tests for greater fidelity. Figure 2 is an illustration of the change in the critical cavity collapse load due to these two effects.

IV. ATTRITION

Attrition rate as utilized herein is defined as the percentage loss or damage to the SRM or SRB subassembly which would result in replacement or repair. In general, it is equivalent to the percentage of missions in which a water impact load exceeds the structural capability.

Attrition of a subsystem can be induced through several sources:

a. The structural elements of that subsystem may fail due to excessive water impact loads.

b. The subsystem may be lost as a result of failure of some other subsystem which induces a "cascading" failure of adjacent subsystems.

c. The subsystem may be lost due to the loss of entire SRB's, i.e., sinkage causes a loss of the electrical subsystem.

The replacement quantity is determined by an attrition computer program which includes the effects of turnaround time, mission model, maximum uses a structure can experience, and other factors. It can be approximated by twice (two SRB's per flight) the number of flight missions times the attrition rate.

A. COMPUTER PROGRAM "SPLASH"

The computer program "SPLASH"[1] (SRB Probabilistic Loads for Attrition of Subsystem Hardware) was utilized to assess the attrition rates of the SRB subassemblies. This program is a Monte Carlo analysis which treats the meteorological factors (wind, sea, etc.) and the strength of each element probabilistically. Each critical load condition is programmed as a table of loads input as a function of vertical velocity (V_V), horizontal velocity (V_H), and water impact angle (θ). For each Monte Carlo trial, a water impact condition (V_V, V_H, θ) is randomly selected and the set of loads is computed by interpolation from the tables. The probability of strength is included in the analysis to increase or decrease the effective load.

B. STRUCTURAL CAPABILITIES

The structural capability of a structure is that load which will cause damage that is uneconomical to repair. This may be the onset of yielding, in the case of structures that require critical alignment to assemble, or it may be ultimate, fracture or stability type loading. The capability is established with no reduction due to factors of safety, in effect with a factor of safety of 1.0.

Capabilities were established for loads on all structures directly subjected to failure due to water impact. Capabilities were also established for loads which result in sinkage and thus loss of an entire SRB. Tables 3 and 4 list the capabilities used to establish attrition rates for the selection of the design vertical impact velocity.

The structural capabilities used for this study were provided by Thiokol Corporation for the SRM (case and nozzle), by Strength Analysis Branch, Structures and Propulsion Laboratory, for the SRB (frustum, aft skirt, and systems tunnel),

1. Counter, Duane N.: SPLASH Evaluation of SRB Designs: NASA TM X-64910; MSFC, Alabama

Propulsion and Control Branch, Structures and Propulsion Laboratory, for the TVC system, and Control Mechanisms Branch, Electronics and Control Laboratory, for the actuators.

C. STATISTICAL VARIATION OF STRENGTH

The statistical variation of strength accounts for the fact that for the majority of the time, a structure will actually be stronger than the stress analyst predicts and that occassionally (10 percent of the time) the structure will be weaker than predicted. This effect is due to a number of things: Conservatism in analysis, errors in manufacturing or analysis, variations in material properties, assumed load paths, etc. It has been quantified, based upon a number of Saturn tests [2] and is included in the SPLASH program (figure 5). Computations are made both with and without this effect. The SPLASH program uses this distribution of strength to derate the loads. There are several distributions included, depending on what type of testing is done. The so-called standard test is a test of a prototype structure to the design load. This weeds out the population of design defects and reduces the attrition from that obtained when no test is planned. In some cases, the attrition benefits are so low or the test is so expensive that the test is not cost effective.

There are also distributions for proof test and no test. The appropriate distribution was used for each structure, depending upon the existing test planned by SRB Program Management.

The influence on attrition of performing structural verification testing is illustrated in figure 17 for the V_V = 85 feet per second condition. The curve labeled "Random Strength not Included" is the probability of occurrence of the loads with no derating for probability of strength. Curves labeled "Std. Test" and "No Test" show comparatively the effects on attrition of the strength probability distribution for these options.

Table 2 lists those SRB structural assemblies for which structural verification testing is currently planned, and indicates the probability of strength distribution utilized in the attrition assessments.

D. FRUSTUM AND FORWARD SKIRT

Water impact attrition of the frustum and forward skirt did not affect the vertical velocity trade study. The frustum assembly descends on the drogue parachute and thus is not affected by changes in the mains design to achieve lower impact

[2] Thomas, Jerrell, and Hanagud, S.: Reliability - Based Econometrics of Aerospace Structural Systems: Design Criteria and Test Options, NASA TM D-7647, Jund 1974

velocity of the SRB. The frustum capability to withstand parachute loads is a critical factor in the determination of the losses of entire SRB's. This source of attrition is covered in the section on loss of entire SRB's.

The forward skirt does not affect the vertical velocity trade because it does not have any subassemblies critical for water impact. The forward skirt was itself affected by the vertical velocity change since structure within the forward skirt was modified to support the larger main parachute.

E. SYSTEMS TUNNEL

The systems tunnel water impact attrition was not included in the vertical velocity trade study. The baseline design had very low attrition and was relatively insensitive to vertical velocity. This is particularly true since the forward section is sensitive to slapdown which decreases with vertical velocity, and the aft section is sensitive to cavity collapse which increases with vertical velocity. In addition, the systems tunnel cost is small relative to the other elements.

F. FORWARD MOTOR CASE SEGMENTS

The forward segments of the SRM are structurally critical for the slapdown water impact condition. This condition occurs during the terminal pitching of the vehicle in the water to a horizontal position after maximum penetration.

The peak external pressure was selected as the parameter which best represented the structural influence of these forward segments to the slapdown pressure distributions. In general, the peak pressure decreases with increased vertical velocity.

The matrix of peak slapdown pressures, as a function of the entry angle theta and the vertical and horizontal impact velocities, is shown in table 5. This matrix is the input of loads to the "SPLASH" program for the attrition assessment. The structural capabilities of the SRM for this loading are shown in table 3. These capabilities were established by Thiokol Corporation using the nonlinear analysis option of the program "STAGS." The most critical loading intensity and axial location was used within the envelope of horizontal velocity up to 45 feet per second and water impact angle between plus and minus 5 degrees. The motor case attrition rates versus peak slapdown pressure capability are shown in figure 6 for vertical impact velocities of 80, 90, and 100 feet per second. Figure 11 shows attrition versus vertical velocity. For cost studies, the attrition was assumed to affect two segments; however, it was further assumed that if the loadings exceeded the capability of the segment by 10 percent, an entire SRM would be lost due to sinkage.

G. AFT MOTOR CASE SEGMENTS

The aft motor case segments are structurally critical for the cavity collapse water impact condition. The maximum penetration or "submergence" pressure load is significant but not as critical as cavity collapse. The submergence input matrix is shown in table 6. Submergence and cavity collapse attrition rates can be compared by examining figure 11.

For the cavity collapse condition, peak external pressure was selected as the parameter which best represents the influence of the water impact load on the SRM aft segments. In general, the peak pressure decreases with a decrease in vertical velocity. (Figure 11) SE-019-057-2H states that the cavity collapse load should be evaluated with the pressure distribution shifted up to 1/4 case diameter (D) forward or aft. Early evaluations considered the pressure shifted to the worst location in the ±D/4 range. Reevaluation showed that the shift was probabilistic and that there was an equal probability of the peak being anywhere in the ±D/4 range (figure 7). A special version of SPLASH was written to accept three matrices of loads for the nominal and ±D/4 shifts and to interpolate between them for a randomly located peak.

A comparison between using the peak pressures in the worst location (using the data in table 7) and considering the probability of axial location of the peak (using the data in table 8) is illustrated in figure 8. The structural capability of the SRM for this loading is shown in table 3. These capabilities were established by Thiokol using the nonlinear analysis option of the computer program "STAGS" for the conditions shown.

Figure 9 shows the attrition rates of the segments for vertical velocities of 80, 85, 90, and 100 feet per second versus differential pressure capability, and figure 10 shows the effect of beefing up the case wall thickness.

Due to the sensitivity of the aft segments capability to the cavity collapse loading intensities, probabilities of peak load longitudinal positioning, and the nonlinear buckling response to the loads, other parametric variations are being evaluated to refine the attrition assessment.

H. AFT SKIRT

The critical water impact condition for the aft skirt is cavity collapse, as it is with the motor case. The assessment of the attrition was performed in phases in accordance with refinements in load, capability, and structural beef-up potential. The aft skirt is subject to forward and aft shifts of the load peak similar to the motor case.

Initial evaluation was with the worst case location of the peak within the ±D/4 shift range. The load matrix is shown in table 9. Phase 2 evaluated the effect of shifting the peak with an equal probability of it lying anywhere in the ±D/4 band. The load peak was assumed to fall at station 1877.43 nominally as shown in the loads book with the ±D/4 shifts made from that location. The input to SPLASH is shown in table 10 and the shifts are illustrated in figure 12.

Phase 3 included the radial (clocking) probability of the orientation of the aft skirt with the peak falling at or near one of the thrust posts. Another special modification of SPLASH was made which incorporated the clocking capability shown in figure 13 and a random orientation of the cavity collapse peak relative to that capability.

Figure 14 shows a comparison of these phases of refinement in the aft skirt analysis and the resulting reduction in attrition as conservatism is removed.

Figures 15 and 16 show the structural capability with respect to the cavity collapse differential pressure versus structural beef-up, based on a yield and ultimate criterion. The yield criterion was utilized for the aft skirt attrition. The ultimate criterion was utilized for attrition of the TVC.

Consideration was given to strengthening the aft skirt to reduce the attrition rate. Curve A represents beefing up the weakest areas of the rings and skin as required to obtain equal capability. Curve B represents beefing up the skin all the way to 165 psi capability and beefing up the rings to any desired intermediate point. Curve B was generated because it would be much more expensive to change the skin at some later date than to change the rings.

SRB Project Management narrowed the choices to two options: Making no structural modifications or adding pounds to the skin by introducing small integral stiffeners (the skin would then be good for 165 psi), and adding 80 pounds to the aft and aft intermediate rings. This point is located on curve B of figure 18. The decision was made not to beef up the aft skirt because of weight margin and c.g. effects. Management concluded that weight, schedule, and cost constraints dictated no modification.

Consideration has also been given to the advantages of a structural test on the aft skirt. Since a test during the development phase will uncover any design weaknesses, the attrition probability is improved by conducting a test. However, the cost of the test may out weigh the benefits attained. Figure 17 illustrates the advantage, and figure 18 shows the cost benefits attainable from a test.

Figure 19 shows the attrition assessment versus the cavity collapse differential pressure capability for vertical impact velocities of 80, 85, 90, and 100 feet per second.

Figure 20 shows the aft skirt baseline attrition versus impact vertical velocity.

Compensation has been included for all conceived conservatism such that it represents the most realistic assessment of the aft skirt attrition. With the conservatism removed, the attrition rate at 100 ft/sec is still clearly unacceptable. Improvement is obtainable from any reduction in the vertical velocity and significant improvement results from reductions all the way to 80 ft/sec.

I. NOZZLE AND ACTUATORS

Attritions for the nozzle and actuators were difficult to determine because of the lack of definitive analyses of the dynamic response of the nozzle at water impact. Static analyses were used to bracket the problem and dynamic analyses by Thiokol were utilized in approximating the capability.

The actuator attrition was based upon the probability of occurrence of a 250K static reaction in the plane of the actuator assuming the flexseal had infinite axial and lateral stiffnesses. The clocking probability effect, the probability that the applied load was not in line with the actuator, was included. The nozzle attrition was based upon the probability of occurrence of a nozzle moment, which causes a static reaction of 300K in the plane of the actuator. The installation geometry is illustrated in figure 21, the load matrix is given in table 11, and the attrition curves are illustrated in figure 22.

J. TVC POWER SUPPLY

The TVC power supply is sensitive to two sources of attrition. The power supply can be damaged by direct water impingement or it can be damaged as a result of an aft skirt failure. The TVC power supply installation is shown in figure 23. Figure 24 shows the resulting capability versus attrition for velocities of 80, 85, and 100 ft/sec.

The failure rate for the power supply resulting from aft skirt failures was judged to be one-half the failure rate for the aft skirt. At all velocities, the cascading failures resulting from aft skirt failures are dominant.

K. SUBSYSTEM ATTRITION SUMMARY

The attrition rates of all SRM and SRB subsystems are summarized in table 13. These are exclusive of the "entire SRB" rates in the following section or of any "general attrition" caused by transportation accidents, in flight failures, etc. The attrition rates at 100 ft/sec and 90 ft/sec are considered unacceptable.

L. LOSS OF ENTIRE SRB

There are three significant risks of incurring loss of an entire SRB:

o Failure of drogue chute and/or frustum or fwd skirt structure due to excessive dynamic pressure at drogue chute deployment.

o Failure to maintain buoyancy due to damage to forward SRM segments during slapdown, especially leakage of buckled clevis joints.

o Inability to plug the SRM nozzle due to damage of nozzle metal parts from initial impact pressure.

All three of these risks are vertical velocity dependent.

Failures associated with drogue chute deployment are determined by a Monte Carlo analysis of the loads on the parachute as a function of reentry dynamics. They are affected by attitude velocity and altitude at deployment. These are, in turn, affected by the center of dynamic pressure (c.p.) and c.p. of the reentering SRB. A detail analysis of this attrition rate was performed and reported by Systems Dynamics Laboratory. The critical factor is attrition as a function of c.g. since any change in the parachute size alters the c.g. by increasing the weight forward. Attrition as a function of c.g. is shown in figure 25.

The c.g. used for the study considered the present baseline design and all the proposed changes under consideration. The changes were classified as probable or improbable and all the probable changes were used to compute a "potential" c.g. and therefore, a potential parachute or c.g. attrition. Both the present and potential c.g. effects are shown in table 14.

Failure to maintain buoyance or "sinkage" attrition was determined through the slapdown load probability. Buoyancy analyses have determined that the SRB will remain afloat if air is entrapped in the forward-most segment of the SRB. The only known cause of a leak in this area is the slapdown load. There has been no analysis determining what load will cause a leak in this area. The slapdown capability is stability limited by the onset of buckling. Presumably a higher load is required to generate a leak producing crack or fracture. In the absence of definitive analysis, a capability of 110 percent of the slapdown capability was assumed, determined by the ratio of ultimate to yield strength of D6AC case material.

Inability to plug the nozzle is the source of total SRB attrition due to the required retrieval mode. A remotely controlled device is maneuvered into the nozzle and an expandable component seals the interior by expanding against the motor case aft segment. Compressed air dewaters the SRM, causing it to rotate from the spar buoy mode to the log mode. If the nozzle is severely damaged by water impact, the nozzle plug will be unable to enter and perform the dewatering operation. In this event, it is technically feasible to tow an SRB in the spar buoy mode at a reduced rate, but it will extend too far below the surface to be towed into the channel at the refurbishment site. It must, therefore, be considered lost. It will have to be sunk as a menace to navigation unless some alternate means of dewatering is devised.

For the purpose of this study, it was assumed as high as one half the damaged nozzles could result in failure to plug and dewater, hense a loss of the SRB.

The "best guess" total attrition rate of entire SRB's was determined by summing the slapdown induced sinkage, the mean of present and potential c.g. attrition, and the nozzle pluggability attrition. These results are tabulated in table 14.

V. PROGRAM COSTS

Costs for the trades were determined using total program costs of flight hardware and spares as stated in the current cost per flight document. The costs in table 16 are differential costs for water impact attrition. These are costs incurred during the operational phase of the program because water impact attrition is nonzero. They include all the effects of wearout, learning, turnaround time, and traffic model, but they do not include inflation effects. All the costs are in FY 1975 dollars.

VI. RESULTS AND CONCLUSIONS

The attrition rates of all assemblies subject to water impact damage are summarized in table 14, and the associated costs in table 15. The costs are illustrated in the bar chart of figure 26. The loss of an entire SRB is a strong driver and tends to overshadow the other costs. The costs of increasing the parachute size and attrition of the forward SRM segments are the only costs that increase with decreasing velocity and tend to form a "bucket" in the curve.

Both table 15 and figure 26 illustrate that the minimum cost is near 80 ft/sec but that the benefit of 80 ft/sec over 85 ft/sec is small relative to the benefit of 85 ft/sec over 100 ft/sec. It is probably beyond the accuracy of the costs to determine a benefit in 80 ft/sec over 85 ft/sec.

The data in table 15 also illustrates that the optimization is obtainable without the use of the "entire SRB" attrition costs. This is particularly beneficial to a decision since the "entire SRB" attrition is based more on judgement than the other attrition rates.

There are other factors than hardware cost which influence a decision to change the vertical velocity. As the attrition becomes greater the problems of manufacturing a larger quantity begin to influence the facilities required for manufacturing and thus require early year funding to build greater manufacturing capability. Table 16 illustrates the number of units required for the two most critical hardware elements. Table 17 illustrates the resulting peak manufacturing rates in comparison to the capabilities.

Table 18 illustrates the key factors which were considered in making the decision. Since only water impact attrition could be costed, the other factors had to be considered relatively using judgement alone. The c.g. location was the most compelling no-cost factor since it tends to be more of a risk than an attrition factor. There was a probability that all SRB's could be lost with a c.g. greater than 59 percent of the vehicle length. Both current (the upper figure) and potential c.g. locations are shown. Note that at 85 ft/sec the potential c.g. falls below 59 percent.

The weight margin is a valuable commodity, and because of the nonlinearity of the parachute weight versus vertical velocity curve, the reduction from 85 ft/sec to 80 ft/sec is more expensive than from 90 ft/sec to 85 ft/sec.

The aft skirt production rate could be a critical factor if early funding to provide new facilities was required. This is a likely problem at 100 ft/sec, but at 90 ft/sec the facility is just adequate for the required production rate.

It was concluded that the costs and attrition associated with 100 ft/sec were unacceptable and that reduction to at least 90 ft/sec was required. Reduction to 85 ft/sec was cost effective and provided a very desirable margin for the parachute attrition but the further decrease to 80 ft/sec was not worth the added weight.

VII. RECOMMENDATIONS

The recommendation was made and accepted to baseline a nominal water impact velocity of 85 ft/sec.

SRB ELEMENT	ATTRITION	
	4/11/73 CONFIG. LOADS	CURRENT BASELINE LOADS
AFT SKIRT	1%	20%
AFT SEGMENTS	1.6%	9.5%
FWD SEGMENTS	0.5%	1.3%
NOZZLE*	0.3%	7%
TVC ACTUATOR	0.8%	12.5%
TVC POWER SUPPLY	0.5%	10%

*BASED ON 1600—LB SNUBBER DESIGN CAPABILITY

TABLE 1. COMPARATIVE EFFECTS ON ATTRITION OF WATER IMPACT LOAD/CONFIGURATION REVISION FOR A VERTICAL VELOCITY OF 100 FEET PER SECOND

TABLE 2 PLANNED STRUCTURAL TESTING OPTION FOR ATTRITION STUDIES

ASSEMBLY	PLANNED TESTING
FRUSTUM	YES
SRM FORWARD SEGMENT	YES
SRM AFT SEGMENT	YES
SYSTEMS TUNNEL	NO
AFT SKIRT	NO
TVC POWER	NO
ACTUATORS	NO
NOZZLE	NO

TABLE 3 SRM NONLINEAR STRUCTURAL ANALYSIS (STAGS) REFERENCE CAPABILITIES FOR WATER RECOVERY

VERTICAL VELOCITY	CONDITION	P (PSIG)	t (IN)	F. S. (EIGEN)	CAP. * (20 MISSION)	CAP. * (10 MISSION)	POTENTIAL LOSS OF SRM **
	$V_V/V_H/Q$				(PSIG)	(PSIG)	(PSIG)
SLAPDOWN							
80	80/45/–5	41.0	0.497	0.90	36.9		40.6
			0.5015			38.4	
85	85/45/–5	38.8	0.497	0.97	37.64		41.4
			0.5015			39.2	
100	100/45/–5	34.4	0.497	1.17	40.25		44.3
						41.9	
CAVITY COLLAPSE							
80	80/15/–5	175	0.511	1.06	185.5		
			0.5155			192.9	
100	100/30/+5	250	0.511	0.75	187.5		
			0.5155			195.0	

* TWO SEGMENT ATTRITION
** LOSS ENTIRE SRM (1.1 X 20 MISSION CAPBAILITY)

TABLE 4. SRB WATER IMPACT CAPABILITIES FOR ATTRITION ASSESSMENT AND HARDWARE EFFECTED

ASSEMBLY	CONDITION	CAPABILITY	HARDWARE ATTRITION EFFECT
FRUSTUM, AFT RING , SEP. MOTORS	IMPACT, ΔP IMPACT, ACCELERATION	62.5 PSIG – YIELD 75 g – ULTIMATE	FRUSTUM FRUSTUM
SYSTEMS TUNNEL, FORWARD , AFT	SLAPDOWN, ΔP CAVITYCOLLAPSE ΔP	– PSIG - BUCKLING – PSIG - BUCKLING	2 SEGMENTS 2 SEGMENTS
AFT SKIRT, AFT RING	CAVITY COLLAPSE, ΔP	109 PSIG – YIELD	AFT SKIRT
TVC POWER, BRACKETS	IMPACT, ΔP	72 PSIG – ULTIMATE*	TVC POWER SUPPLY
ACTUATORS	IMPACT,	– ULTIMATE	2 ACTUATORS
NOZZLE	IMPACT,	– ULTIMATE	BEARING RUBBER SHIMS COMPLIANCE RING HOUSING METAL PARTS

*OR ONE–HALF THE AFT SKIRT YIELD STRENGTH ATTRITION (EQUAL AFT SKIRT ULTIMATE ATTRITION) WHICHEVER IS GREATEST.

TABLE 5 SRM FORWARD SEGMENTS WATER IMPACT SLAPDOWN PRESSURE (PSIG) INPUT MATRIX

CONDITION			MATRIX
V_V (FT/SEC)	V_H (FT/SEC)	THETA (DEGREES)	PRESSURE (PSIG)
80.	0.	−10.	.13000 + 02
80.	0.	−5.	.00000
80.	0.	0.	.00000
80	0.	5.	.00000
80.	0.	10.	.13000 + 02
80.	15.	−10.	.18000 + 02
80.	15.	−5.	.12000 + 02
80.	15.	0.	.80000 + 01
80.	15.	5.	.12000 + 02
80.	15.	10.	.18000 + 02
80.	30.	−10.	.27000 + 02
80.	30.	−5.	.25000 + 02
80.	30.	0.	.21000 + 02
80.	30.	5.	.25000 + 02
80.	30.	10.	.27000 + 02
80.	45.	−10.	.46000 + 02
80.	45.	−5.	.41000 + 02
80.	45.	0.	.31000 + 02
80.	45.	5.	.41000 + 02
80.	45.	10.	.46000 + 02
80.	60.	−10.	.60000 + 02
80.	60.	−5.	.41000 + 02
80.	60.	0.	.31000 + 02
80.	60.	5.	.41000 + 02
80.	60.	10.	.60000 + 02
100.	0.	−10.	.11000 + 02
100.	0.	−5.	.60000 + 01
100.	0.	0.	.60000 + 01
100.	0.	5.	.60000 + 01
100.	0.	10.	.11000 + 02
100.	15.	−10.	.18000 + 02
100.	15.	−5.	.14000 + 02
100.	15.	0.	.10000 + 02
100.	15.	5.	.14000 + 02
100.	15.	10.	.18000 + 02
100.	30.	−10.	.27000 + 02
100	30.	−5.	.22000 + 02
100.	30.	0.	.15000 + 02

CONDITION			MATRIX
V_V (FT/SEC)	V_H (FT/SEC)	THETA (DEGREES)	PRESSURE (PSIG)
100.	30.	5.	.22000 + 02
100.	30.	10.	.27000 + 02
100.	45.	−10.	.40000 + 02
100.	45.	−5.	.34000 + 02
100.	45.	0.	.23000 + 02
100.	45.	5.	.34000 + 02
100.	45.	10.	.40000 + 02
100.	60.	−10.	.58000 + 02
100.	60.	−5.	.45000 + 02
100.	60.	0.	.34000 + 02
100.	60.	5.	.45000 + 02
100.	60.	10.	.58000 + 02
120.	0.	−10.	.50000 + 01
120.	0.	−5.	.50000 + 01
120.	0.	0.	.00000
120.	0.	5.	.50000 + 01
120.	0.	10.	.50000 + 01
120.	15.	−10.	.15000 + 02
120.	15.	−5.	.12500 + 02
120.	15.	0.	.70000 + 01
120.	15.	5.	.12500 + 02
120.	15.	10.	.15000 + 02
120.	30.	−10.	.27000 + 02
120.	30.	5.	.20000 + 02
120.	30.	0.	.16000 + 02
120.	30.	5.	.20000 + 02
120.	30.	10.	.27000 + 02
120.	45.	−10.	.41000 + 02
120.	45.	−5.	.31000 + 02
120.	45.	0.	.21000 + 02
120.	45.	5.	.31000 + 02
120.	45.	10.	.41000 + 02
120.	60.	−10.	.56000 + 02
120.	60.	−5.	.41000 + 02
120.	60.	0.	.28000 + 02
120.	60.	5.	.41000 + 02
120.	60.	10.	.56500 + 02

TABLE 6 SRM AFT SEGMENTS WATER IMPACT SUBMERGENCE PRESSURE (PSIG) INPUT MATRIX

CONDITION			MATRIX	CONDITION			MATRIX
V_V (FT/SEC)	V_H (FT/SEC)	THETA (DEGREES)	PRESSURE (PSIG)	V_V (FT/SEC)	V_H (FT/SEC)	THETA (DEGREES)	PRESSURE (PSIG)
80.	0.	−10.	.16420 + 02	100.	45.	−10.	.13180 + 02
80.	0.	−5.	.19290 + 02	100.	45.	−5.	.14550 + 02
80.	0.	0.	.21800 + 02	100.	45.	0.	.16350 + 02
80.	0.	5.	.19740 + 02	100.	45.	5.	.18120 + 02
80.	0.	10.	.16420 + 02	100.	45.	10.	.20710 + 02
80.	15.	−10.	.13730 + 02	100.	60.	−10.	.12180 + 02
80.	15.	−5.	.16950 + 02	100.	60.	−5.	.13570 + 02
80.	15.	0.	.19630 + 02	100.	60.	0.	.14880 + 02
80.	15.	5.	.21360 + 02	100.	60.	5.	.17630 + 02
80.	15.	10.	.19140 + 02	100.	60.	10.	.19770 + 02
80.	30.	−10.	.12770 + 02	120.	0.	−10.	.19450 + 02
80.	30.	−5.	.14280 + 02	120.	0.	−5.	.21990 + 02
80.	30.	0.	.16200 + 02	120.	0.	0.	.23580 + 02
80.	30.	5.	.18000 + 02	120.	0.	5.	.23330 + 02
80.	30.	10.	.20260 + 02	120.	0.	10.	.20100 + 02
80.	45.	−10.	.10900 + 02	120.	15.	−10.	.17190 + 02
80.	45.	−5.	.12500 + 02	120.	15.	−5.	.20630 + 02
80.	45.	0.	.13610 + 02	120.	15.	0.	.22880 + 02
80.	45.	5.	.15950 + 02	120.	15.	5.	.24900 + 02
80.	45.	10.	.18640 + 02	120.	15.	10.	.23170 + 02
80.	60.	−10.	.94300 + 01	120.	30.	−10.	.15880 + 02
80.	60.	−5.	.11080 + 02	120.	30.	−5.	.17140 + 02
80.	60.	0.	.12290 + 02	120.	30.	0.	.18370 + 02
80.	60.	5.	.14720 + 02	120.	30.	5.	.21010 + 02
80.	60.	10.	.17000 + 02	120.	30.	10.	.23820 + 02
100.	0.	−10.	.18160 + 02	120.	45.	−10.	.15460 + 02
100.	0.	−5.	.20390 + 02	120.	45.	−5.	.17100 + 02
100.	0.	0.	.22240 + 02	120.	45.	0.	.18240 + 02
100.	0.	5.	.22170 + 02	120.	45.	5.	.20370 + 02
100.	0.	10.	.18030 + 02	120.	45.	10.	.23170 + 02
100.	15.	−10.	.15460 + 02	120.	60.	−10.	.14440 + 02
100.	15.	−5.	.18560 + 02	120.	60.	−5.	.15610 + 02
100.	15.	0.	.21250 + 02	120.	60.	0.	.18070 + 02
100.	15.	5.	.23150 + 02	120.	60.	5.	.20880 + 02
100.	15.	10.	.21200 + 02	120.	60.	10.	.22720 + 02
100.	30.	−10.	.14110 + 02				
100.	30.	−5.	.15950 + 02				
100.	30.	0.	.17310 + 02				
100.	30.	5.	.19480 + 02				
100.	30.	10.	.22240 + 02				

TABLE 7 SRM AFT SEGMENTS CAVITY COLLAPSE PEAK DIFFERENTIAL PRESSURE (ΔP, PSIG) SHIFTED FORWARD (WORST CASE LOCATION)

CONDITION			MATRIX	CONDITION			MATRIX
V_V (FT/SEC)	V_H (FT/SEC)	THETA (DEGREES)	PRESSURE (PSIG)	V_H (FT/SEC)	V_V (FT/SEC)	THETA (DEGREES)	PRESSURE (PSIG)
80.	0.	−10.	.14500 + 03	100	30.	0.	.24500 + 03
80.	0.	−5.	.15000 + 03	100.	30.	5.	.25500 + 03
80.	0.	0.	.10200 + 03	100.	30.	10.	.11800 + 03
80.	0.	5.	.15000 + 03	100.	45.	−10.	.80000 + 02
80.	0.	10.	.14500 + 03	100.	45.	−5.	.11000 + 03
80.	15.	−10.	.12000 + 03	100.	45.	0.	.15000 + 03
80.	15.	−5.	.17500 + 03	100.	45.	5.	.24000 + 03
80.	15.	0.	.16500 + 03	100.	45.	10.	.25200 + 03
80.	15.	5.	.82000 + 02	100.	60.	−10.	.40000 + 02
80.	15	10.	.17000 + 03	100.	60.	−5.	.70000 + 02
80.	30.	−10.	.10000 + 03	100.	60.	0.	.00000
80.	30.	−5.	.13200 + 03	100.	60.	5.	.11500 + 03
80.	30.	0.	.16500 + 03	100.	60.	10.	.15000 + 03
80.	30.	5.	.18500 + 03	120.	0.	−10.	.28500 + 03
80.	30.	10.	.95000 + 02	120.	0.	−5.	.26500 + 03
80	45.	−10.	.45000 + 02	120.	0.	0.	.15000 + 03
[illegible]	45.	−5.	.65000 + 02	120.	0.	5.	.26500 + 03
80.	45.	0.	.13000 + 03	120.	0.	10.	.28500 + 03
80.	45.	5.	.15500 + 03	120.	15.	−10.	.21000 + 03
80.	45.	10.	.18200 + 03	120.	15.	−5.	.33000 + 03
80.	60.	−10.	.80000 + 02	120.	15.	0.	.28500 + 03
80.	60.	−5.	.70000 + 02	120.	15.	5.	.14000 + 03
80.	60.	0.	.70000 + 02	120.	15.	10.	.26000 + 03
80.	60.	5.	.10500 + 03	120.	30.	−10.	.14500 + 03
80.	60.	10.	.15000 + 03	120.	30.	−5.	.20500 + 03
100.	0.	−10.	.21400 + 03	120.	30.	0.	.32000 + 03
100.	0.	−5.	.20000 + 03	120.	30.	5.	.30200 + 03
100.	0.	0.	.12500 + 03	120.	30.	10.	.15000 + 03
100.	0.	5.	.20000 + 03	120.	45.	−10.	.10000 + 03
100.	0.	10.	.21400 + 03	120.	45.	−5.	.13000 + 03
100.	15.	−10.	.18000 + 03	120.	45.	0.	.18000 + 03
100.	15.	−5.	.24200 + 03	120.	45.	5.	.31500 + 03
100.	15.	0.	21800 + 03	120.	45.	10.	.30200 + 03
100.	15.	5.	.10800 + 03	120.	60.	−10.	.80000 + 02
100.	15.	10.	.19800 + 03	120.	60.	−5.	.10000 + 03
100.	30.	−10.	.10000 + 03	120.	60.	0.	.13500 + 03
100.	30.	−5.	.16500 + 03	120.	60.	5.	.20000 + 03
				120.	60.	10.	.30000 + 03

TABLE 8 SRM AFT SEGMENTS CAVITY COLLAPSE DIFFERENTIAL PRESSURE (ΔP) MATRICES FOR ASSESSMENT OF PROBABILITY OF AXIAL LOCATION

CONDITION			LOAD DIFFERENTIAL PRESSURE (PSIG)		
V_V (FT/SEC)	V_H (FT/SEC)	THETA (DEGREES)	MATRIX 1	MATRIX 2	MATRIX 3
80.	0.	−10.	.14500 + 03	.14000 + 03	.14500 + 03
80	0.	−5.	.15000 + 03	.10500 + 03	.13000 + 03
80.	0.	0.	.70000 + 02	.95000 + 02	.10000 + 03
80	0	5.	15000 + 03	.10500 + 03	.13000 + 03
80.	0.	10.	.10500 + 03	.14000 + 03	.14500 + 03
80.	15	−10.	.12000 + 03	.10000 + 03	.65000 + 02
80.	15	−5.	.15000 + 03	.17500 + 03	.15000 + 03
80	15	0.	.14500 + 03	.16500 + 03	.12000 + 03
80	15	5.	.75000 + 02	.80000 + 02	.60000 + 02
80	15.	10.	.13000 + 03	.17000 + 03	.12500 + 03
80	30.	−10.	.85000 + 02	.10000 + 03	.75000 + 02
80	30.	−5	.11000 + 03	12500 + 03	.10000 + 03
80	30	0	.16500 + 03	.16000 + 03	.11000 + 03
80	30	5.	.16000 + 03	.18500 + 03	.11500 + 03
80	30	10	.75000 + 02	95000 + 02	.65000 + 02
80	45	−10	.45000 + 02	30000 + 02	.00000
80	45	−5	.65000 + 02	.50000 + 02	.50000 + 02
80	45.	0	.13000 + 03	11000 + 03	.60000 + 02
80	45	5.	.15500 + 03	.15000 + 03	.11000 + 03
80.	45	10	.15500 + 03	.18000 + 03	.13000 + 03
80	60	−10.	80000 + 02	.10000 + 02	.00000
80	60	−5	70000 + 02	20000 + 02	.00000
80	60	0	.70000 + 02	50000 + 02	.30000 + 02
80	60	5.	10500 + 03	.95000 + 02	.70000 + 02
80	60	10	.15000 + 03	15000 + 03	.12000 + 03
100	0	−10	.17500 + 03	21500 + 03	.20500 + 03
100	0.	−5	.13000 + 03	.15000 + 03	.20000 + 03
100	0.	0	.10000 + 03	.12500 + 03	.12500 + 03
100	0	5	.13000 + 03	15000 + 03	.20000 + 03
100	0	10.	.17500 + 03	.21500 + 03	.20500 + 03
100	15	−10	15000 + 03	.18000 + 03	.13000 + 03
100	15	−5	.21000 + 03	.24000 + 03	.16500 + 03
100	15	0	.20500 + 03	.21500 + 03	.18500 + 03
100	15	5	.95000 + 02	.10500 + 03	.70000 + 02
100	15	10	.14500 + 03	.17000 + 03	.20000 + 03
100	30	−10.	.10000 + 03	.95000 + 02	.65000 + 02
100	30	−5	.14500 + 03	.16500 + 03	.12000 + 03

CONDITION			LOAD DIFFERENTIAL PRESSURE (PSIG)		
V_V (FT/SEC)	V_H (FT/SEC)	THETA (DEGREES)	MATRIX 1	MATRIX 2	MATRIX 3
100.	30.	0.	.21500 + 03	.24500 + 03	.14500 + 03
100.	30.	5.	.21500 + 03	.25500 + 03	.21500 + 03
100.	30.	10.	.10000 + 03	.11500 + 03	.10000 + 03
100.	45.	−10.	.80000 + 02	.60000 + 02	.35000 + 02
100.	45.	−5.	.11000 + 03	.10000 + 03	.65000 + 02
100.	45.	0.	.13000 + 03	.15000 + 03	.11000 + 03
100.	45.	5.	.21500 + 03	.24000 + 03	.17000 + 03
100.	45.	10.	.21500 + 03	.25200 + 03	.17000 + 03
100.	60.	−10.	.40000 + 02	.20000 + 02	.00000
100.	60.	−5.	.70000 + 02	.20000 + 02	.00000
100.	60.	0.	.11500 + 03	.10500 + 03	.50000 + 02
100.	60.	5.	.15000 + 03	.15000 + 03	.13000 + 03
100.	60.	10.	.16500 + 03	.20000 + 03	.15000 + 03
120.	0.	−10.	.23000 + 03	.28500 + 03	.23000 + 03
120.	0.	−5.	.22000 + 03	.26500 + 03	.24000 + 03
120.	0.	0.	.13000 + 03	.15000 + 03	.15000 + 03
120.	0.	5.	.22000 + 03	.26500 + 03	.24000 + 03
120.	0.	10.	.23000 + 03	.28500 + 03	.23000 + 03
120.	15.	−10.	.19500 + 03	.21500 + 03	.20000 + 03
120.	15.	−5.	.30000 + 03	.33000 + 03	.28000 + 03
120.	15.	0.	.22500 + 03	.28500 + 03	.22500 + 03
120.	15.	5.	.13000 + 03	.14500 + 03	.13000 + 03
120.	15.	10.	.23500 + 03	.25500 + 03	.25000 + 03
120.	30.	−10.	.14500 + 03	.14000 + 03	.12500 + 03
120.	30.	−5.	.20000 + 03	.20000 + 03	.16500 + 03
120.	30.	0.	.28500 + 03	.32000 + 03	.28500 + 03
120.	30.	5.	.25000 + 03	.30000 + 03	.25000 + 03
120.	30.	10.	.14500 + 03	.15000 + 03	.15000 + 03
120.	45.	−10.	.11000 + 03	11000 + 03	.85000 + 02
120.	45.	−5.	.13000 + 03	.11500 + 03	.10000 + 03
120.	45.	0.	.18000 + 03	.16500 + 03	.15000 + 03
120.	45.	5.	.28000 + 03	.30500 + 03	.26000 + 03
120.	45.	10.	.26500 + 03	.30500 + 03	.23000 + 03
120.	60.	−10	[illegible]	.65000 + 02	.45000 + 02
120.	60.	[illegible]	[illegible]	[illegible]	.65000 + 02
120.	60.	[illegible]	[illegible]	.11500 + 03	.95000 + 02
120.	60.	[illegible]	[illegible]	.20000 + 03	.17500 + 03
120.	60.	10.	.23000 + 03	.30000 + 03	.30000 + 03

TABLE 9 SRB AFT SKIRT CAVITY COLLAPSE PEAK DIFFERENTIAL PRESSURE (ΔP, PSIG) SHIFTED TO CRITICAL AXIAL LOCATION

CONDITION			MATRIX	CONDITION			MATRIX
V_V (FT/SEC)	V_H (FT/SEC)	THETA (DEGREES)	PRESSURE (PSIG)	V_V (FT/SEC)	V_H (FT/SEC)	THETA (DEGREES)	PRESSURE (PSIG)
80	0.	−10.	.86000 + 02	100.	30.	5.	.19900 + 03
80	0.	− 5.	90000 + 02	100.	30.	10.	10000 + 03
80	0.	0.	74000 + 02	100.	45.	−10.	.90000 + 02
80.	0.	5.	.91000 + 02	100.	45.	−5.	.96000 + 02
80.	0.	10.	.86000 + 02	100.	45.	0.	10500 + 03
80	15.	−10	10800 + 03	100.	45.	5.	.19000 + 03
80.	15.	− 5.	.13100 + 03	100.	45.	10.	.21000 + 03
80	15.	0.	12500 + 03	100.	60.	−10.	.69000 + 02
80.	15.	5.	.62000 + 02	100.	60.	− 5.	.94000 + 02
80.	15.	10	.94000 + 02	100.	60.	0.	.81000 + 02
80	30.	−10.	79000 + 02	100.	60.	5.	.99000 + 02
80	30	− 5.	10000 + 03	100	60.	10.	.14100 + 03
80	30.	0.	.12500 + 03	120.	0.	−10.	.21100 + 03
80.	30	5.	13300 + 03	120.	0.	− 5.	.19700 + 03
80	30	10.	79000 + 02	120.	0.	0.	12500 + 03
80	45	−10	80000 + 02	120	0.	5.	.44000 + 02
80	45	− 5	80000 + 02	120.	0	10.	.21100 + 03
80	45	0	93000 + 02	120.	15.	−10.	.16800 + 03
80	45	5.	90000 + 02	120.	15.	− 5.	.25600 + 03
80	45	10.	14500 + 03	120.	15.	0.	.21700 + 03
80	60	−10	.77000 + 02	120.	15.	5.	.10400 + 03
80	60	− 5.	88000 + 02	120.	15.	10.	.19600 + 03
80	60	0.	86000 + 02	120.	30	−10.	.77000 + 02
80	60	5	61000 + 02	120	30.	− 5.	.15300 + 03
80	60	10.	86000 + 02	120.	30.	0.	.24600 + 03
100	0.	−10.	15300 + 03	120.	30	5.	.23300 + 03
100	0.	− 5.	14600 + 03	120.	30	10.	.13000 + 03
100	0	0	10200 + 03	120	45.	−10.	.83000 + 02
100	0	5	14700 + 03	120.	45.	− 5.	.94000 + 02
100	0	10	15300 + 03	120	45.	0.	.14600 + 03
100	15.	−10	13300 + 03	120	45	5	.27800 + 03
100	15.	− 5	18700 + 03	120.	45.	10.	.25200 + 03
100	15.	0	16300 + 03	120	60.	−10.	.76000 + 02
100	15	5	.86000 + 02	120.	60	− 5	78000 + 02
100	15	10	11500 + 03	120.	60.	0.	.90000 + 02
100	30	−10	94000 + 02	120.	60.	5.	.13400 + 03
100	30	− 5.	12600 + 03	120.	60.	10.	.17800 + 03
100	30	0.	19500 + 03				

TABLE 10 SRB AFT SKIRT CAVITY COLLAPSE PEAK DIFFERENTIAL PRESSURE (ΔP, PSIG) MATRICES FOR ASSESSMENT OF PROBABILITY OF AXIAL LOCATION

CONDITION			LOAD DIFFERENTIAL PRESSURE (PSIG)		
V_V (FT/SEC)	V_H (FT/SEC)	THETA (DEGREES)	MATRIX 1	MATRIX 2	MATRIX 3
80.	0.	−10	.10000 + 01	.26000 + 02	56000 + 02
80.	0.	− 5.	.50000 + 01	.30000 + 02	.60000 − 02
80	0	0.	19000 + 02	.39000 + 02	54000 + 02
80	0	5.	60000 + 01	.31000 + 02	.61000 + 02
80	0	10.	10800 + 01	.26000 + 02	.56000 + 02
80.	15.	−10.	.35000 + 02	.11000 + 03	.10000 + 03
80.	15.	− 5	11000 + 02	.56000 + 02	.12100 + 03
80	15	0.	.15000 + 02	.85000 + 02	.11000 + 03
80.	15	5.	29000 + 02	.39000 + 02	.49000 + 02
80.	15	10.	10000 + 01	.81000 + 02	.86000 + 02
80.	30.	−10.	.29000 + 02	54000 + 02	.64000 + 02
80.	30	− 5.	23000 + 02	.68000 + 02	83000 + 02
80.	30	0.	.52000 + 02	13200 + 03	12200 + 03
80.	30.	5	13000 + 02	.88000 + 02	.10800 + 03
80.	30	10	.24000 + 02	.39000 + 02	.59000 + 02
80	45	−10.	63000 + 02	.38000 + 02	33000 + 02
80.	45.	− 5	35000 + 02	80000 + 02	.55000 + 02
80.	45.	0	.23000 + 02	.10300 + 03	78000 + 02
80.	45.	5.	−.20000 + 01	88000 + 02	83000 + 02
80.	45.	10.	.18000 + 02	.38000 + 02	.11300 + 03
80.	60.	−10.	82000 + 02	.62000 + 02	−.30000 + 00
80.	60.	− 5.	88000 + 02	83000 + 02	.43000 + 02
80.	60	0.	69000 + 02	.59000 + 02	.44000 + 02
80.	60	5	16000 + 02	.81000 + 02	.71000 + 02
80.	60.	10.	33000 + 02	.58000 + 02	.58000 + 02
100.	0.	−10	.13000 + 02	48000 + 02	.10900 + 03
100	0.	− 5.	.34000 + 02	46000 + 02	71000 + 02
100.	0	0	27000 + 02	.47000 + 02	.77000 + 02
100.	0.	5	−.30000 + 01	.47000 + 02	72000 + 02
100.	0.	10.	.26000 + 02	.48000 + 02	93000 + 02
100.	15.	−10.	.23000 + 02	.78000 + 02	.11300 + 03
100.	15	− 5.	.27000 + 02	.13200 + 03	15700 + 03
100.	15.	0.	40000 + 02	14000 + 03	.15500 + 03
100	15.	5	21000 + 02	51000 + 02	61000 + 02
100	15	10	50000 + 01	.55000 + 02	90000 + 02
100.	30	−10.	36000 + 02	.91000 + 02	76000 + 02
100	30.	− 5	.34000 + 02	89000 + 02	10900 + 03
100	30	0	.43000 + 02	.14300 + 03	.16300 + 03

CONDITION			LOAD DIFFERENTIAL PRESSURE (PSIG)		
V_V (FT/SEC)	V_H (FT/SEC)	THETA (DEGREES)	MATRIX 1	MATRIX 2	MATRIX 3
100.	30.	5	.34000 + 02	94000 + 02	.14400 + 03
100	30.	10.	32000 + 02	.57000 + 02	82000 + 02
100.	45.	−10	.36000 + 02	.81000 + 02	.66000 + 02
100.	45.	− 5.	.43000 + 02	.10300 + 03	93000 + 02
100	45.	0.	.50000 + 01	.55000 + 02	.75000 − 02
100	45.	5.	.45000 + 02	.15000 + 03	.16400 + 03
100	45.	10.	.55000 + 02	14000 + 03	.16500 + 03
100	60.	−10.	.59000 + 02	.59000 + 02	.24000 + 02
100	60.	− 5.	94000 + 02	.94000 + 02	.59000 + 02
100.	60.	0	66000 + 02	.66000 + 02	.76000 + 02
100	60.	5	22000 + 02	.22000 + 02	.11300 + 03
100.	60.	10.	.15000 + 02	.15000 + 02	.11000 + 03
120	0.	−10.	.21000 + 02	.12100 + 03	.14600 + 03
120.	0	− 5.	32000 + 02	11200 + 03	.15200 + 03
120.	0.	0.	.30000 + 02	.75000 + 02	.10000 + 03
120.	0.	5.	.44000 + 02	11400 + 03	.15400 + 03
120.	0.	10.	.21000 + 02	.12100 + 03	.14600 + 03
120.	15.	−10	.28000 + 02	.98000 + 02	.13800 + 03
120.	15.	− 5.	.46000 + 02	.17100 + 03	.20600 + 03
120.	15.	0.	32000 + 02	.10700 + 03	.15200 + 03
120	15.	5.	.39000 + 02	.79000 + 02	.99000 + 02
120.	15.	10.	.36000 + 02	.13100 + 03	.15600 + 03
120	30.	−10.	17000 + 02	.77000 + 02	.77000 + 02
120.	30.	− 5.	.43000 + 02	.14300 + 03	.14800 + 03
120.	30.	0	.36000 + 02	.17600 + 03	.21600 + 03
120.	30.	5.	.60000 + 01	.13100 + 03	.19100 + 03
120	30.	10	.55000 + 02	.10000 + 03	.11500 + 03
120	45.	−10.	.21000 + 02	81000 + 02	.81000 + 02
120	45	− 5.	.27000 + 02	.88000 + 02	92000 + 02
120.	45.	0.	.48000 + 02	.14800 + 03	.13300 + 03
120.	45.	5.	.65000 + 02	.21000 + 03	.23500 + 03
120.	45.	10.	.50000 + 02	.19000 + 03	.21000 + 03
120	60.	−10.	76000 + 02	.76000 + 02	61000 + 02
120	60.	− 5	.23000 + 02	.68000 + 02	68000 + 02
120.	60	0.	.25000 + 02	.90000 + 02	.85000 + 02
120.	60	5.	.18000 + 02	.98000 + 02	.11300 + 03
120.	60.	10.	54000 + 02	17400 − 03	.28400 + 03

TABLE 11. SRB ACTUATOR WATER IMPACT REACTION MOMENTS ($\times 10^6$ IN–LBS) INPUT MATRIX

CONDITION			MATRIX	CONDITION			MATRIX
V_V (FT/SEC)	V_H (FT/SEC)	THETA (DEGREES)	MOMENT (10^6 IN-LBS)	V_V (FT/SEC)	V_H (FT/SEC)	THETA (DEGREES)	MOMENT (10^6 IN-LBS)
80.	0.	–10.	.19760 + 02	100.	30.	5.	.13490 + 02
80.	0.	– 5.	.82400 + 01	100.	30.	10.	.60700 + 01
80.	0.	0.	.85000 + 00	100.	45.	–10.	.55890 + 02
80.	0.	5.	–.80000 –01	100.	45.	– 5.	.42120 + 02
80.	0.	10.	–.21000 + 00	100.	45.	0.	.31180 + 02
80.	15.	–10.	.20750 + 02	100.	45.	5.	.23680 + 02
80.	15.	– 5.	.13670 + 02	100.	45.	10.	.13000 + 02
80.	15.	0.	.75900 + 01	100.	60.	–10.	.65650 + 02
80.	15.	5.	.39800 + 01	100.	60.	– 5.	.52020 + 02
80.	15.	10.	.00000	100.	60.	0.	.42960 + 02
80.	30.	–10.	.25970 + 02	100.	60.	5.	.35430 + 02
80.	30.	– 5.	.21060 + 02	100.	60.	10.	.30780 + 02
80.	30.	0.	.16000 + 02	120.	0.	–10.	.48720 + 02
80.	30.	5.	.96600 + 01	120.	0.	– 5.	.24930 + 02
80.	30.	10.	.47400 + 01	120.	0.	0.	.10000 + 01
80.	45.	–10.	.34890 + 02	120.	0.	5.	–.23000 + 00
80.	45.	– 5.	.28570 + 02	120.	0.	10.	–.47000 + 00
80.	45.	0.	.23240 + 02	120.	15.	–10.	.52580 + 02
80.	45.	5.	.15920 + 02	120.	15.	– 5.	.30690 + 02
80.	45.	10.	.10310 + 02	120.	15.	0.	.14220 + 02
80.	60.	–10.	.48230 + 02	120.	15.	5.	.53400 + 01
80.	60.	– 5.	.41080 + 02	120.	15.	10.	.67100 + 00
80.	60.	0.	.33930 + 02	120.	30.	–10.	.57870 + 02
80.	60.	5.	.26740 + 02	120.	30.	– 5.	.41570 + 02
80.	60.	10.	.19150 + 02	120.	30.	0.	.24840 + 02
100.	0.	–10.	.30370 + 02	120.	30.	5.	.15980 + 02
100.	0.	– 5.	.12610 + 02	120.	30.	10.	.78400 + 01
100.	0.	0.	–.14300 + 00	120.	45.	–10.	.65830 + 02
100.	0.	5.	–.19100 + 00	120.	45.	– 5.	.57990 + 02
100.	0.	10.	–.40300 + 00	120.	45.	0.	.40280 + 02
100.	15.	–10.	.33170 + 02	120.	45.	5.	.27300 + 02
100.	15.	– 5.	.22300 + 02	120.	45.	10.	.18180 + 02
100.	15.	0.	.11880 + 02	120.	60.	–10.	.84150 + 02
100.	15.	5.	.36100 + 01	120.	60.	– 5.	.75070 + 02
100.	15.	10.	.22000 + 00	120.	60.	0.	.59710 + 02
100.	30.	–10.	.38660 + 02	120.	60.	5.	.46180 + 02
100.	30.	– 5.	.29850 + 02	120.	60.	10.	.34810 + 02
100.	30.	0.	.19620 + 02				

TABLE 12 SRB TVC POWER SUPPLY WATER IMPACT PRESSURE (PSIG) INPUT MATRIX

CONDITION			MATRIX
V_V (FT/SEC)	V_H (FT/SEC)	THETA (DEGREES)	PRESSURE (PSIG)
80.	0.	−10.	.65000 + 02
80.	0.	0.	.65000 + 02
80.	0.	10.	.65000 + 02
80.	30.	−10.	.65000 + 02
80.	30.	0.	.65000 + 02
80.	30.	10.	.65000 + 02
80.	60.	−10.	.65000 + 02
80.	60.	0.	.65000 + 02
80.	60.	10.	.65000 + 02
100.	0.	−10.	.90000 + 02
100.	0.	0.	.90000 + 02
100.	0.	10.	.90000 + 02
100.	30.	−10.	.90000 + 02
100.	30.	0.	.90000 + 02
100.	30.	10.	.90000 + 02
100.	60.	−10.	.90000 + 02
100.	60.	0.	.90000 + 02
100.	60.	10.	.90000 + 02
120.	0.	−10.	.12500 + 03
120.	0.	0.	.12500 + 03
120.	0.	10.	.12500 + 03
120.	30.	−10.	.12500 + 03
120.	30.	0.	.12500 + 03
120.	30.	10.	.12500 + 03
120.	60.	−10.	.12500 + 03
120.	60.	0.	.12500 + 03
120.	60.	10.	.12500 + 03

TABLE 13 SUMMARY OF BASELINE (10/1/75) CONFIGURATION ATTRITION RATES VERSUS VERTICAL VELOCITY (V_V)

ASSEMBLY	V_V (FT/SEC) 100	90	85	80
AFT SKIRT (NO TEST)	20.0	11.0	7.2	4.8
AFT SEG.	9.5	2.6	1.2	0.6
FWD SEG.	1.3	1.6	1.9	2.2
NOZZLE*	7.0	5.0	3.6	2.4
ACTUATORS	12.5	9	6.7	5.1
POWER SUPPLY	10	5.5	3.6	2.4

*BASED ON A 1600–LB SNUBBER DESIGN CAPABILITY; CURRENT TARGET WEIGHT IS 900 LB.

TABLE 14 ESTIMATES OF ATTRITION RATES OF ENTIRE SRB'S AS A FUNCTION OF VERTICAL VELOCITY

	100	90	85	80
● ATTRITION WHICH WOULD INCREASE THE OPTIMUM VELOCITY				
SLAPDOWN	0.6%	0.8%	1.1%	1.4%
● ATTRITION WHICH WOULD DECREASE THE OPTIMUM VELOCITY				
CG EFFECTS – PRESENT	0.0%	0.0%	0.0%	0.0%
– POTENTIAL	20.0%	2.4%	0.0%	0.0%
NOZZLE PLUGGABILITY	1.8%	1.3%	0.9%	0.6%
● BEST GUESS A. R. OF ENTIRE SRB	12.4%	3.3%	2.0%	2.0%
Δ$ ASSOCIATED WITH BEST GUESS	$377M	$96M	$57M	$57M

TABLE 15 SUMMARY OF DIFFERENTIAL PROGRAM COSTS VERSUS VERTICAL VELOCITY (V_V)

DELTA PROGRAM COST* – $M (75$)

	100 FPS Δ$'S	90 FPS Δ$'S	85 FPS Δ$'S	80 FPS Δ$'S
AFT SKIRT	37.7 M	26.0 M	16.3 M	14.0 M
AFT SRM SEGMENT	25.6	6.7	3.0	1.5
FORWARD SRM SEGMENT	2.5	3.4	4.5	6.2
NOZZLE	4.5	3.4	3.0	2.4
ACTUATORS	7.4	5.3	4.2	2.9
TVC POWER SUPPLY	24.7	13.2	8.6	5.8
SUBTOTAL	102.4	58.0	39.6	32.8
PARACHUTES	0	10.4	16.2	22
SUBTOTAL	102.4	68.4	55.8	54.8
ENTIRE SRB	377	95.7	57.2	57.2
TOTAL	479 M	164 M	113 M	112 M

* Δ TOTAL PROGRAM COST AS PRESENTED IN POP 75–2 PROJECT OPERATIONAL COST FOR 439 OPERATIONAL MISSION MODEL

TABLE 16 HARDWARE REQUIREMENT (NUMBER OF UNITS) AS A FUNCTION OF VERTICAL VELOCITY (V_V)

HARDWARE QUANTITIES

ITEM		VERTICAL IMPACT VELOCITY – FT/SEC 100	90	85	80
AFT SKIRT	ATTRITION (%)	22.9	13.9	12.4	9.8
(NO TEST, NO (BEEF–UP)	NR. UNITS REQUIRED	222	144	107	88
AFT SEGMENTS	ATTRITION (%)	13.1	5.7	4.3	5.6
	NR. UNITS REQUIRED	309	196	180	176

NOTE: ATTRITION PERCENTAGES INCLUDE WATER IMPACT COMPONENT ATTRITION PLUS 2.9% FOR GENERAL ATTRITION AND LOSS OF ENTIRE SRB'S.

TABLE 17 MANUFACTURING RATES (NUMBER OF UNITS) AS A FUNCTION OF VERTICAL VELOCITY (V_V)

MANUFACTURING RATES

	PLANNED RATE UNITS/YEAR	CURRENT MFG. CAPABILITY UNITS/YEAR	REQUIRED MFG RATE UNITS/YEAR (3)			
			V_V = 100	V_V = 90	V_V = 85	V_V = 80
AFT SKIRTS	8	16 (1)	24	16	12	11
SRM AFT SEGMENTS	90	216 (2)	124	108	99	90

NOTES:

(1) TWO SHIFT OPERATION

(2) STATED LADISH LIMITATION BASED ON 24 COMPLETE SRM CASES/YEAR X 9 SEGMENTS/CASE

(3) FOR CURRENT 60/YEAR TRAFFIC MODEL

TABLE 18 SUMMARY OF CRITICAL WATER RECOVERY EFFECTS ON SRB VERSUS WATER IMPACT VELOCITY (V_V)

COMPARISON OF IMPACT VELOCITIES

ITEM	$V_V = 90$	$V_V = 85$	$V_V = 80$	REMARKS
C. G. LOCATION (%)	58.52 59.06	58.35 58.89	58.15 58.69	CURRENT INCL. ALL PENDING CHANGES
SRB WEIGHT MARG.	2698 LB	2098 LB	1398 LB	EACH 5 FT/SEC ΔV_V CHANGES PARACHUTE WEIGHT ABOUT 600 LB.
RISK OF ENTIRE SRB LOSS	3.3%	2.0%	2.0%	LOWER VELOCITY INCREASES SLAPDOWN RISK BUT DECREASES REENTRY AND NOZZLE DAMAGE RISK.
PARACHUTE DIAMETER	116 FT	122 FT	130 FT	EACH 5 FT/SEC ΔV_V CHANGES PARACHUTE DIA ABOUT 6 FT.
AFT SKIRT PRODUCTION RATE	16/YR	12/YR	11/YR	CURRENT RATE IS 8/YR. MAXIMUM RATE IS 16/YR. FOR TOOLING (2 SHIFTS)
Δ TOTAL PROGRAM COST FOR HARDWARE	\$164 M	\$113 M	\$112 M	INCLUDES COST FOR ATTRITION OF ENTIRE SRB'S AND SRB COMPONENTS IN FY 75 DOLLARS

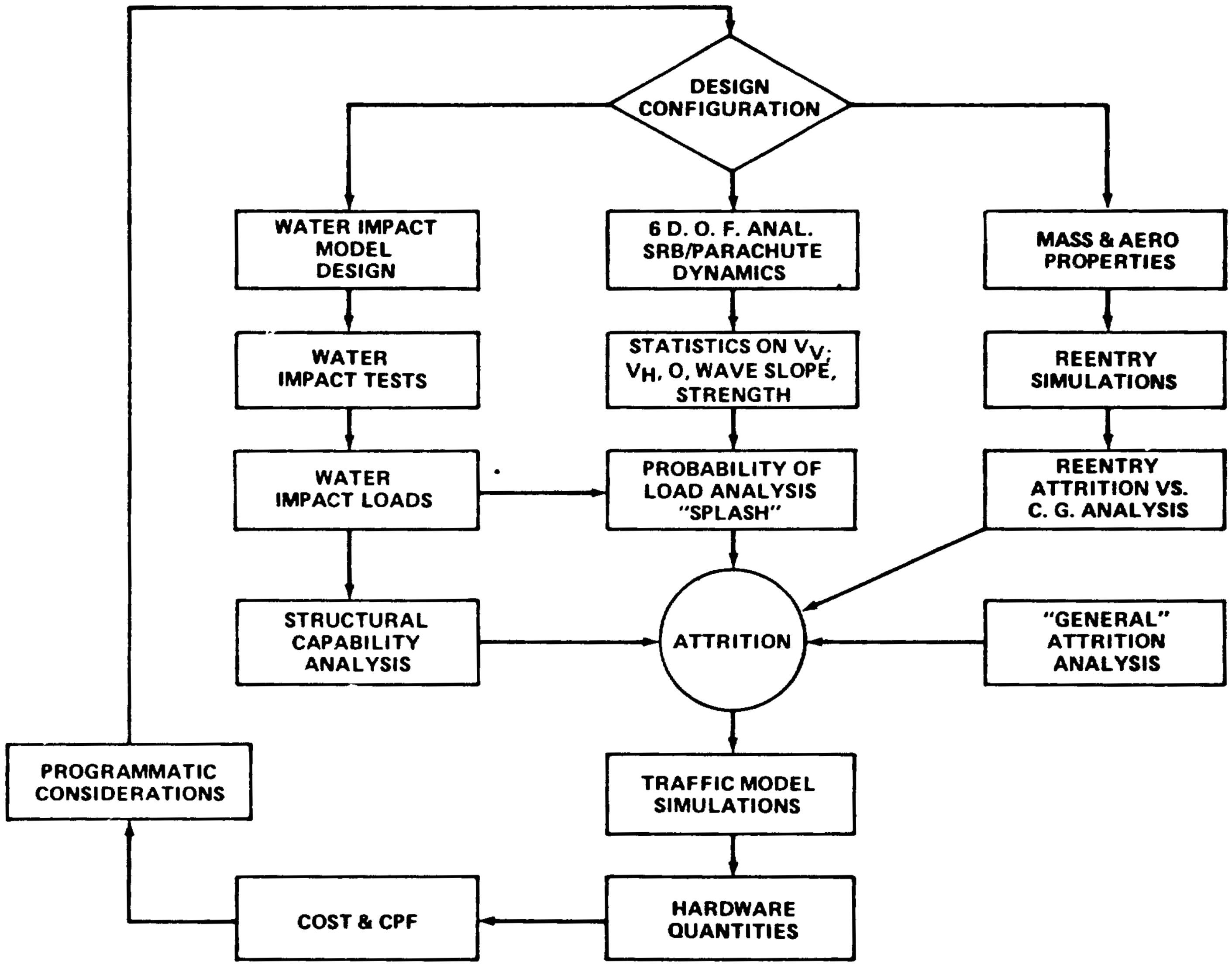
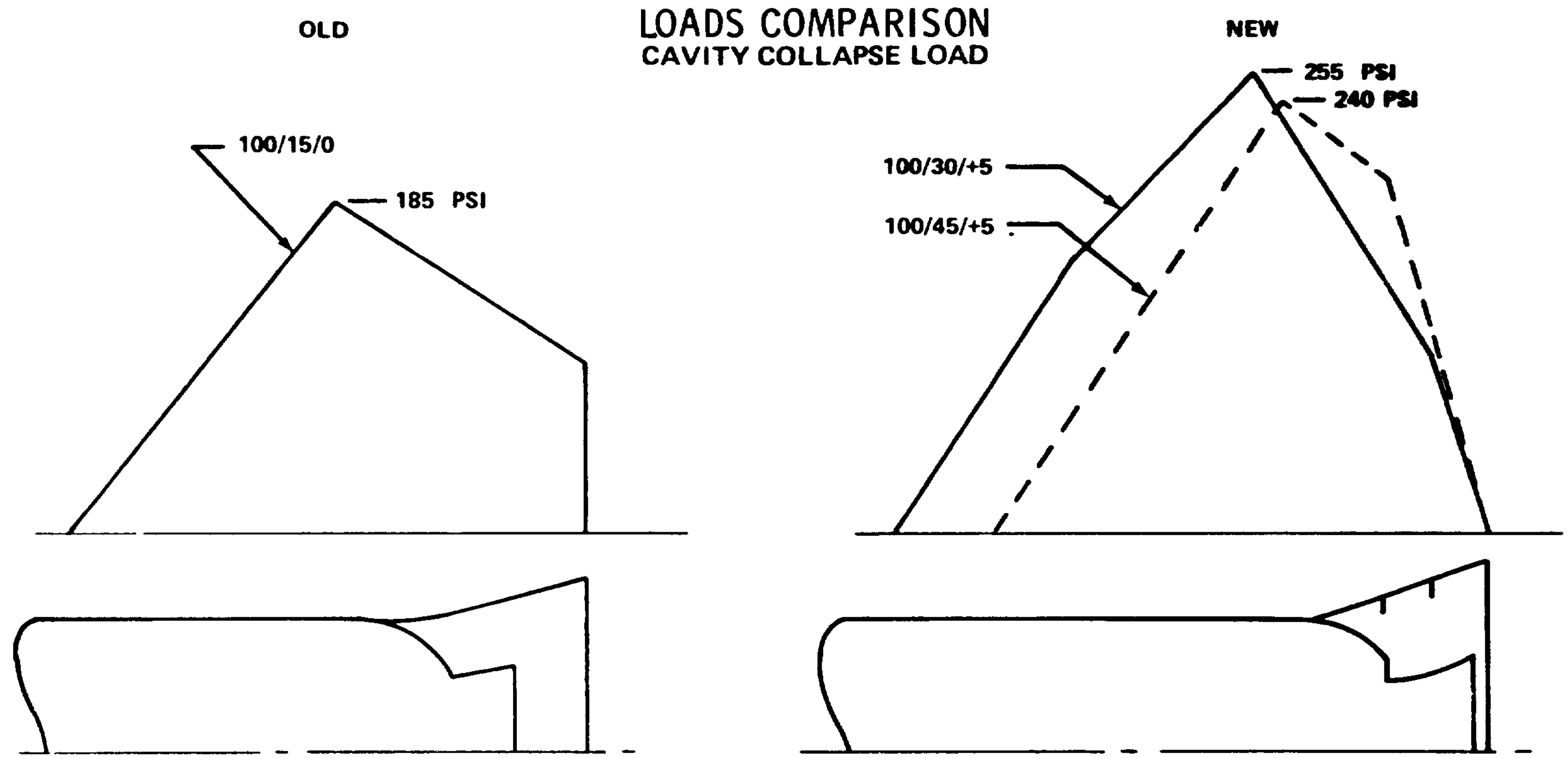
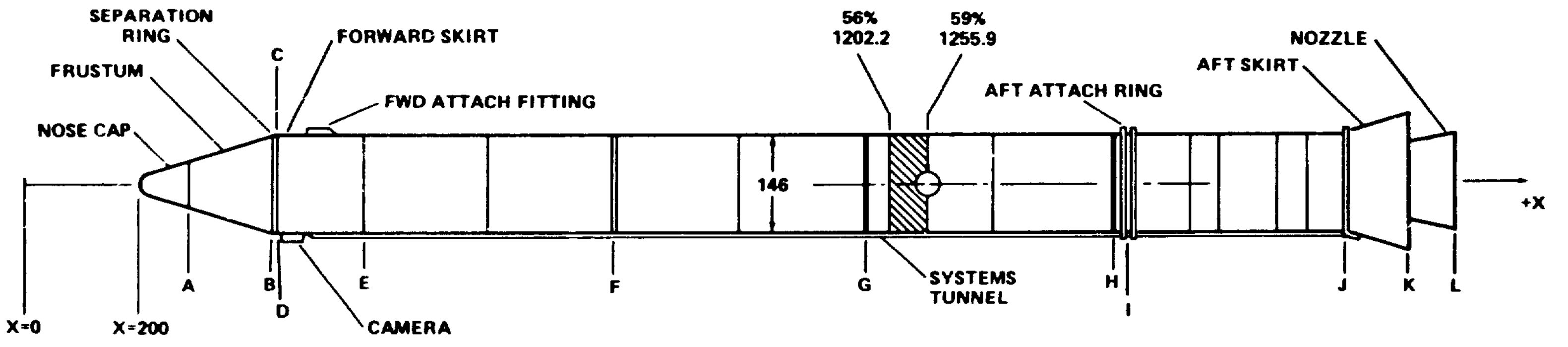


FIGURE 1. FLOW DIAGRAM OF REQUIREMENTS FOR ATTRITION ASSESSMENT FOR THE SHUTTLE SRB



- INCREASE IN PEAK PRESSURE AFFECTS AFT SRM SEGMENT
- AFT SHIFT OF LOAD PEAK AFFECTS AFT SKIRT STRUCTURE

FIGURE 2. CONFIGURATION/LOAD EFFECTS OF AFT PORTION OF SRB AT CAVITY COLLAPSE LOADING



VIEW ROTATED FOR CLARITY

LOC	DESCRIPTION	STATION
A	NOSE CAP/FRUSTUM SEPARATION PLANE	275.00
B	FRUSTUM/SEPARATION RING INTERFACE	394.875
C	SEPARATION RING SEPARATION PLANE	398.00
D	SEPARATION RING/FORWARD SKIRT INTERFACE	401.00
E	FORWARD SKIRT/SRM INTERFACE (℄ HOLES)	523.83
F	SRM FORWARD/CENTER 1 SEGMENT JOINT	851.48
G	SRM CENTER 1/CENTER 2 SE[illegible]NT JOINT	1171.48
H	SRM CENTER 2/AFT SEGMENT JOINT	1491.48
I	SRB/EXTERNAL TANK ATTAC[illegible]TATION	1511.00
J	SRM/AFT SKIRT INTERFACE (℄ HOLES)	1837.087
K	SRB AFT SKIRT AFT FACE	1930.637
L	SRM NOZZLE EXIT PLANE	[illegible]

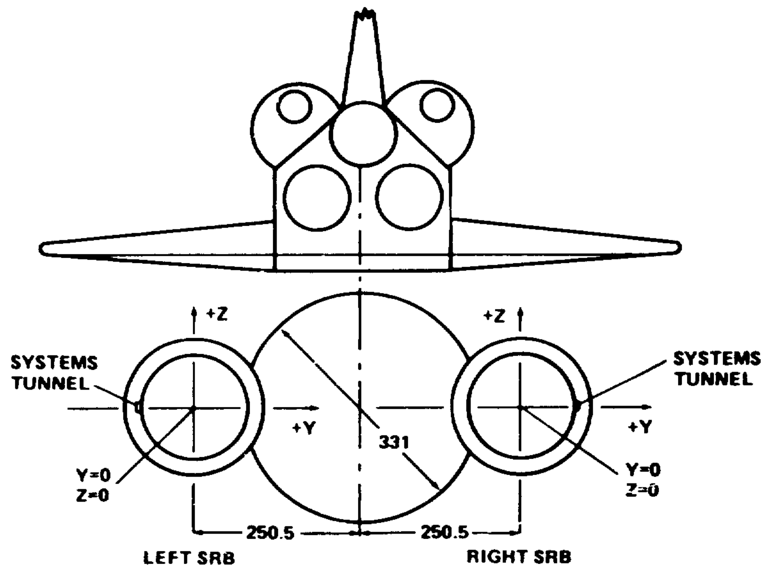


FIGURE 3. SRB VERTICAL IMPACT VELOCITY STUDY CONFIGURATION

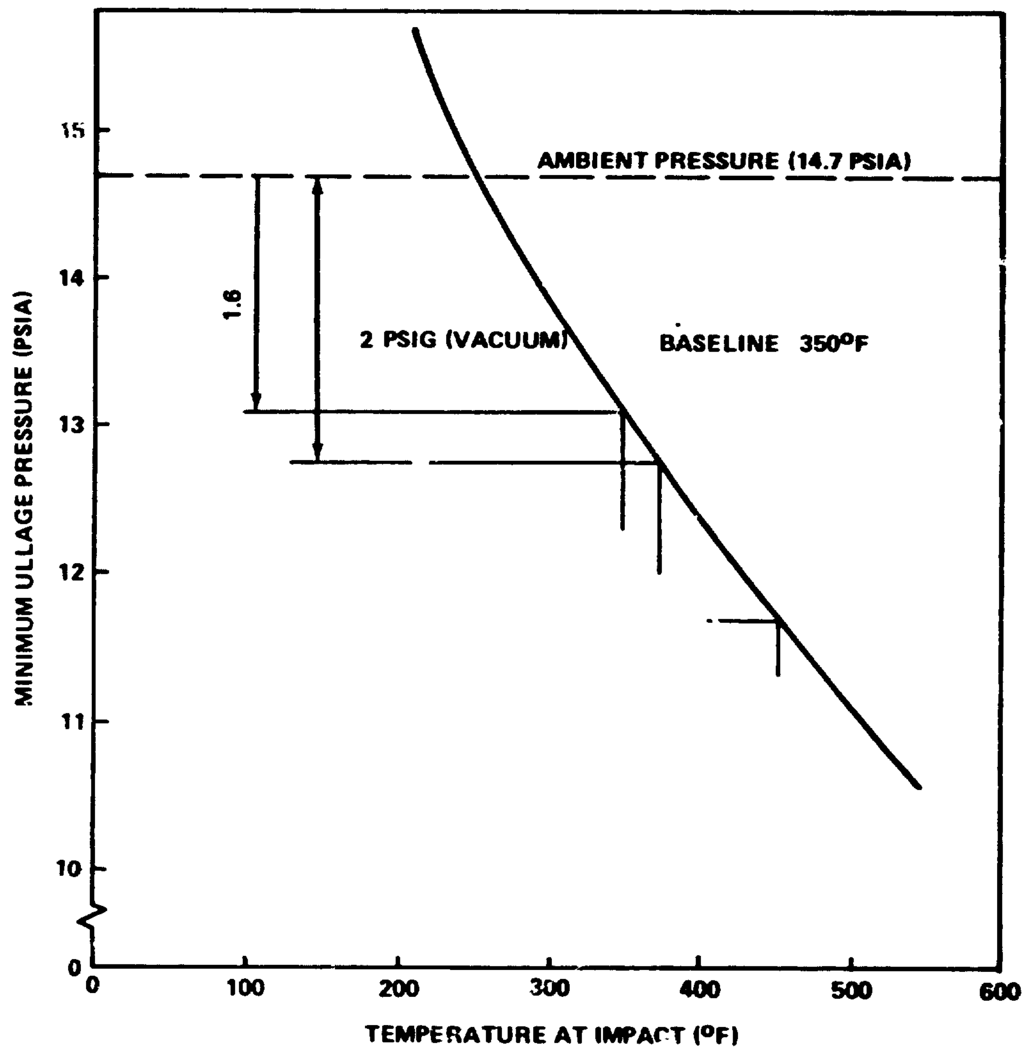


FIGURE 4. SRM ULLAGE PRESSURE AT WATER IMPACT AS A FUNCTION OF ULLAGE GAS TEMPERATURE

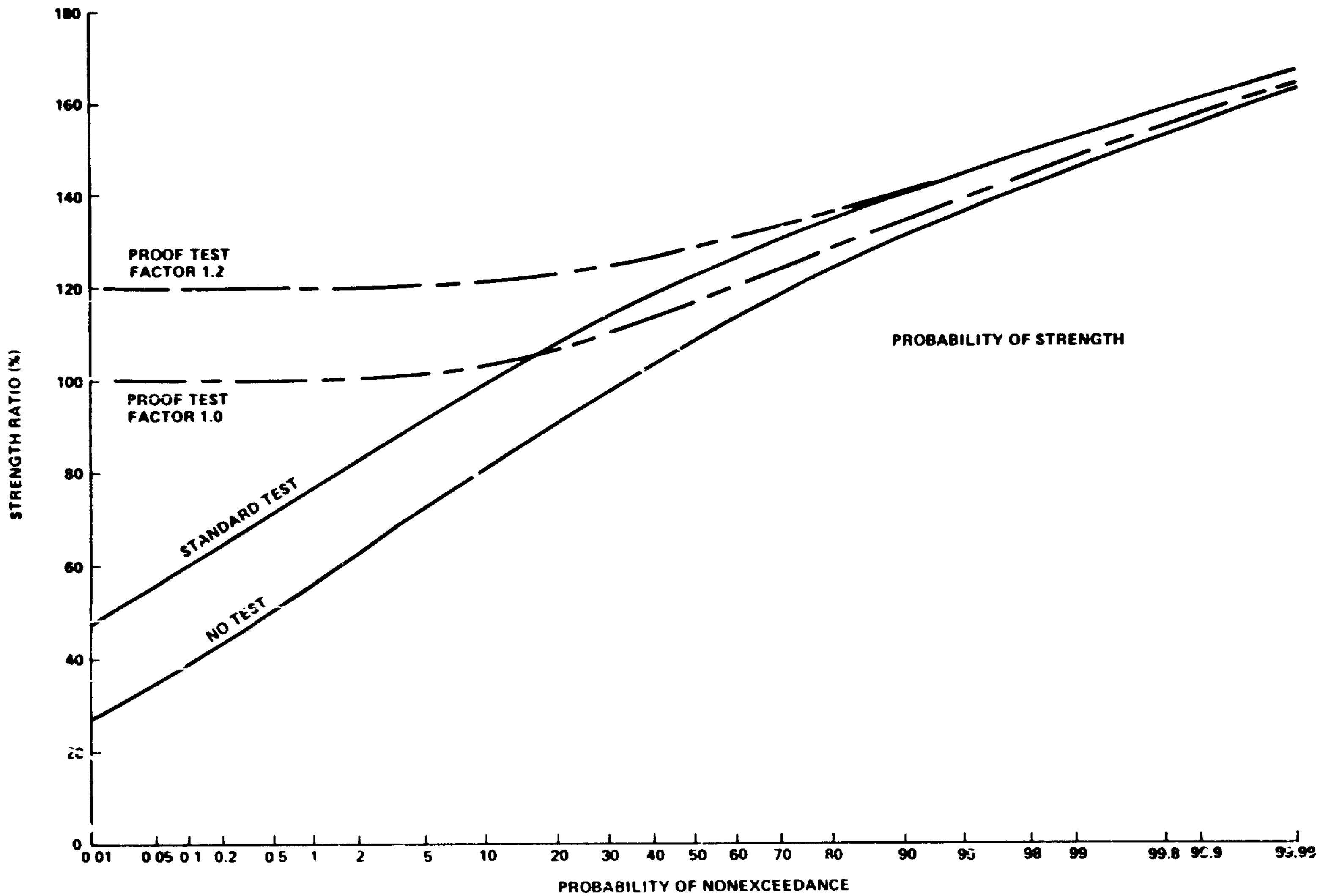


FIGURE 5. PROBABILITY OF STRENGTH AS A FUNCTION OF VERIFICATION TESTING

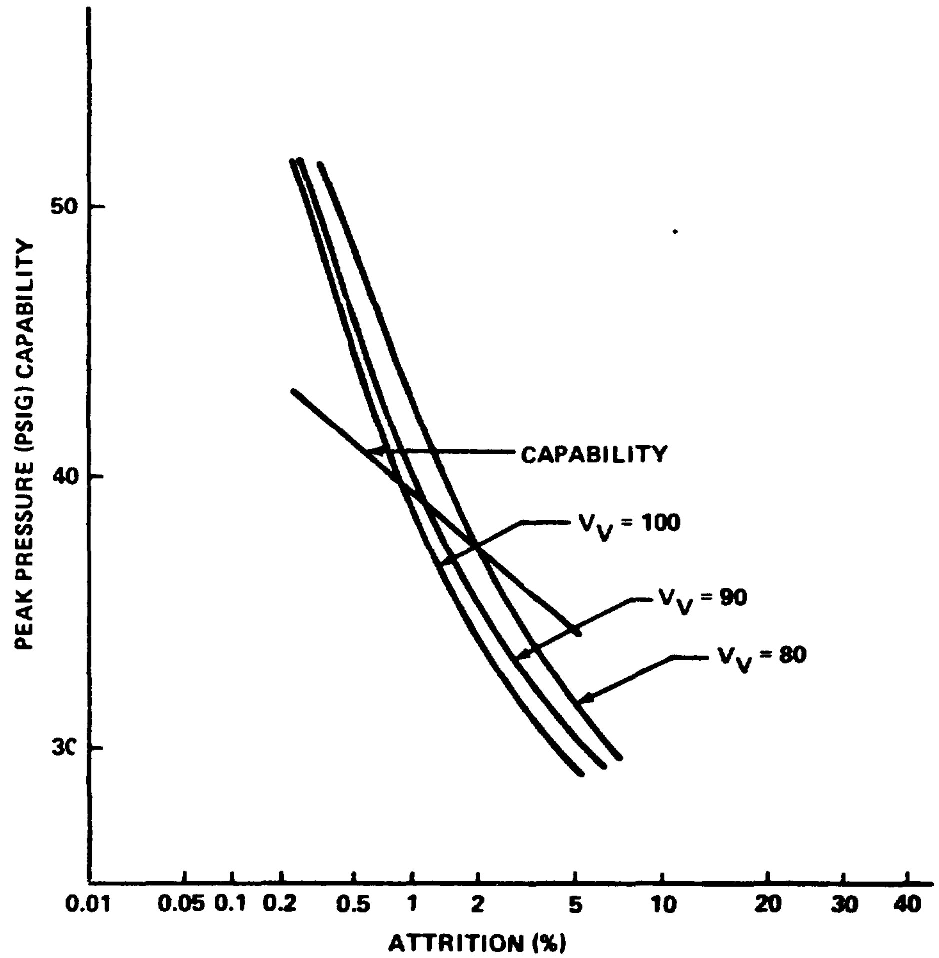


FIGURE 6 FORWARD MOTOR CASE SLAPDOWN ATTRITION VERSUS "SLAPDOWN" PEAK PRESSURE CAPABILITY

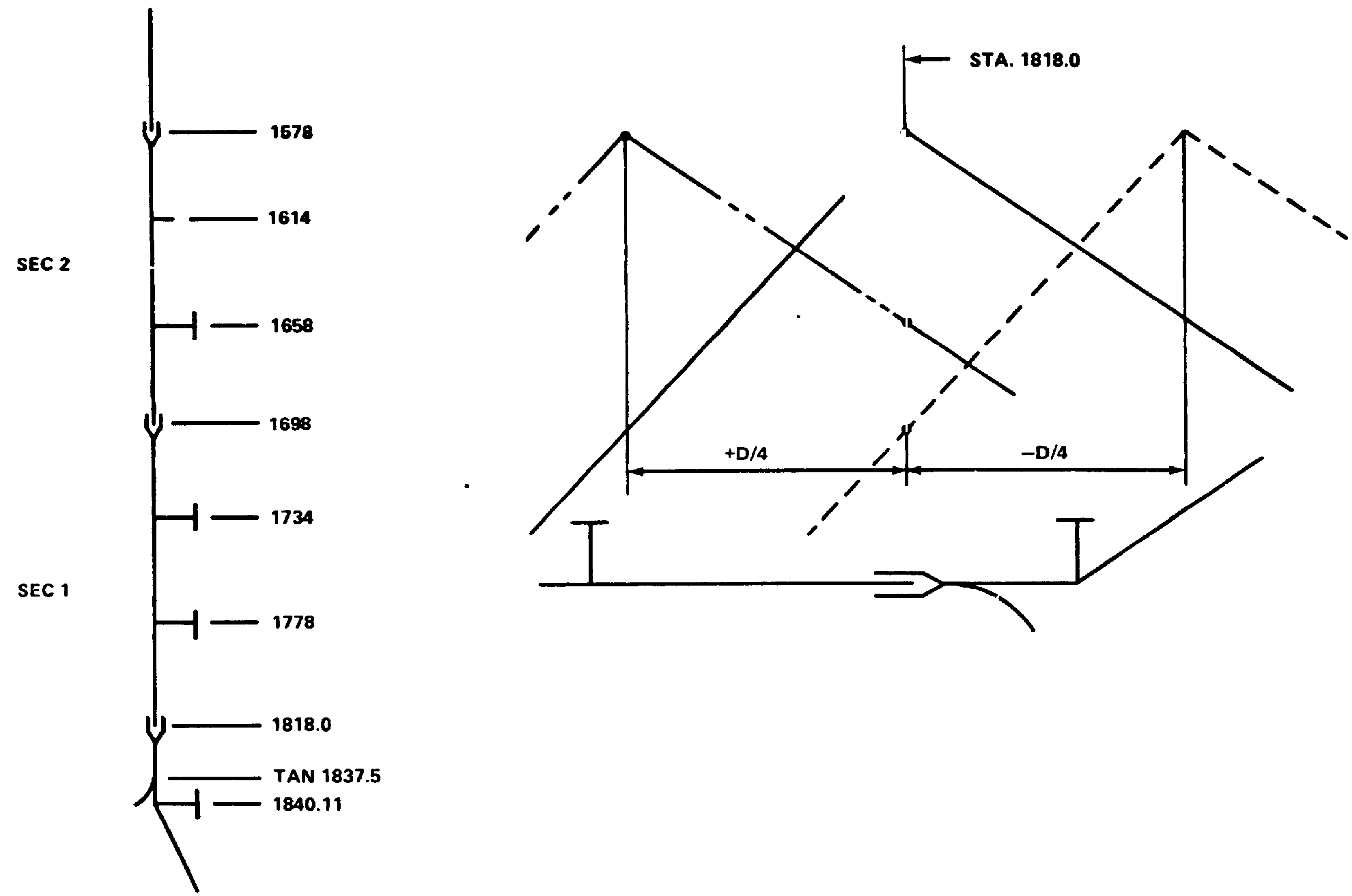


FIGURE 7 AFT MOTOR CASE LONGITUDINAL LOCATION OF LOAD PEAK
EQUAL PROBABILITY OF LOAD PEAK WITHIN ± D/4

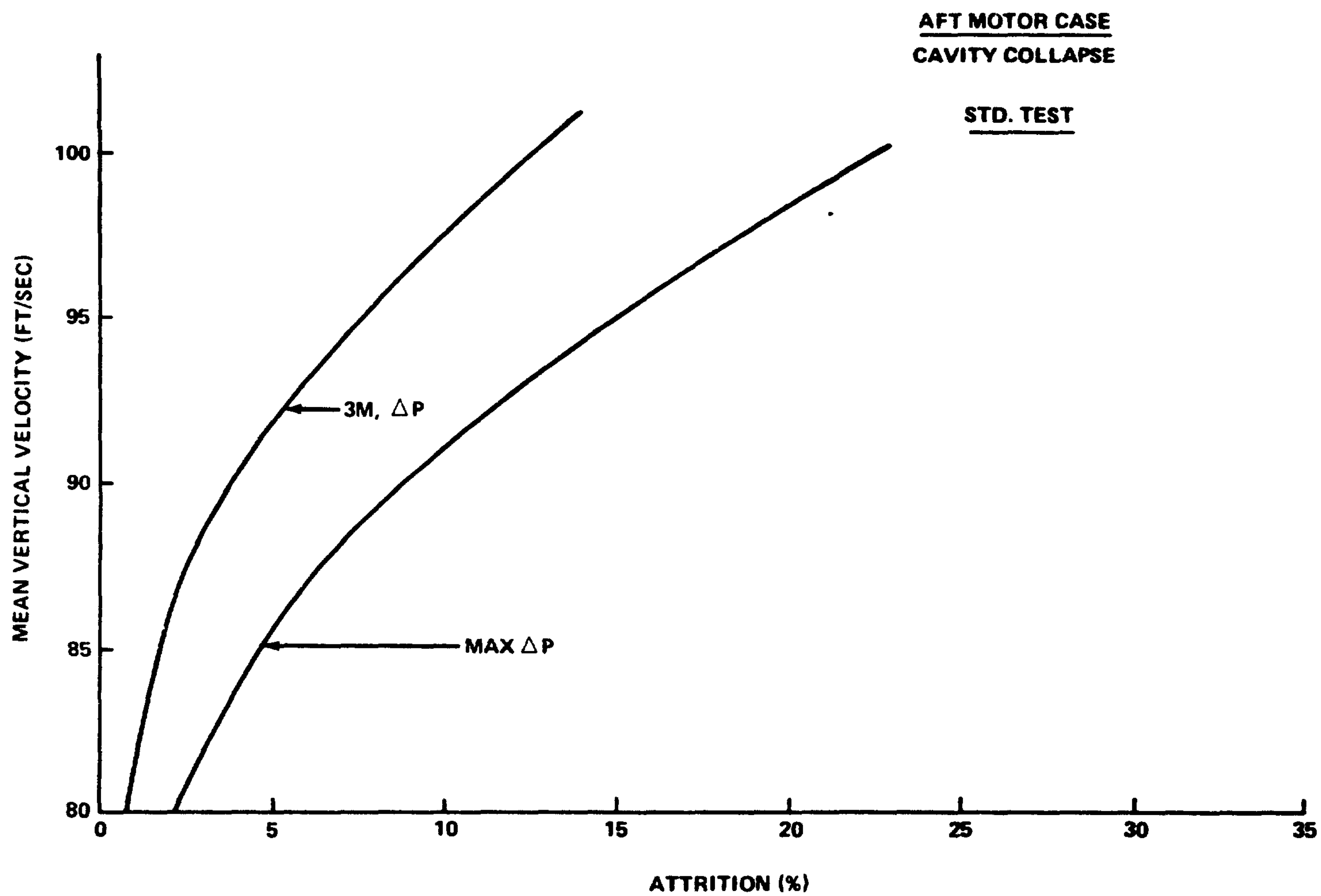


FIGURE 8 AFT MOTOR CASE CAVITY COLLAPSE ATTRITION VERSUS VERTICAL VELOCITY, DIFFERENTIAL PRESSURE METHODS, METHODOLOGY COMPARISON

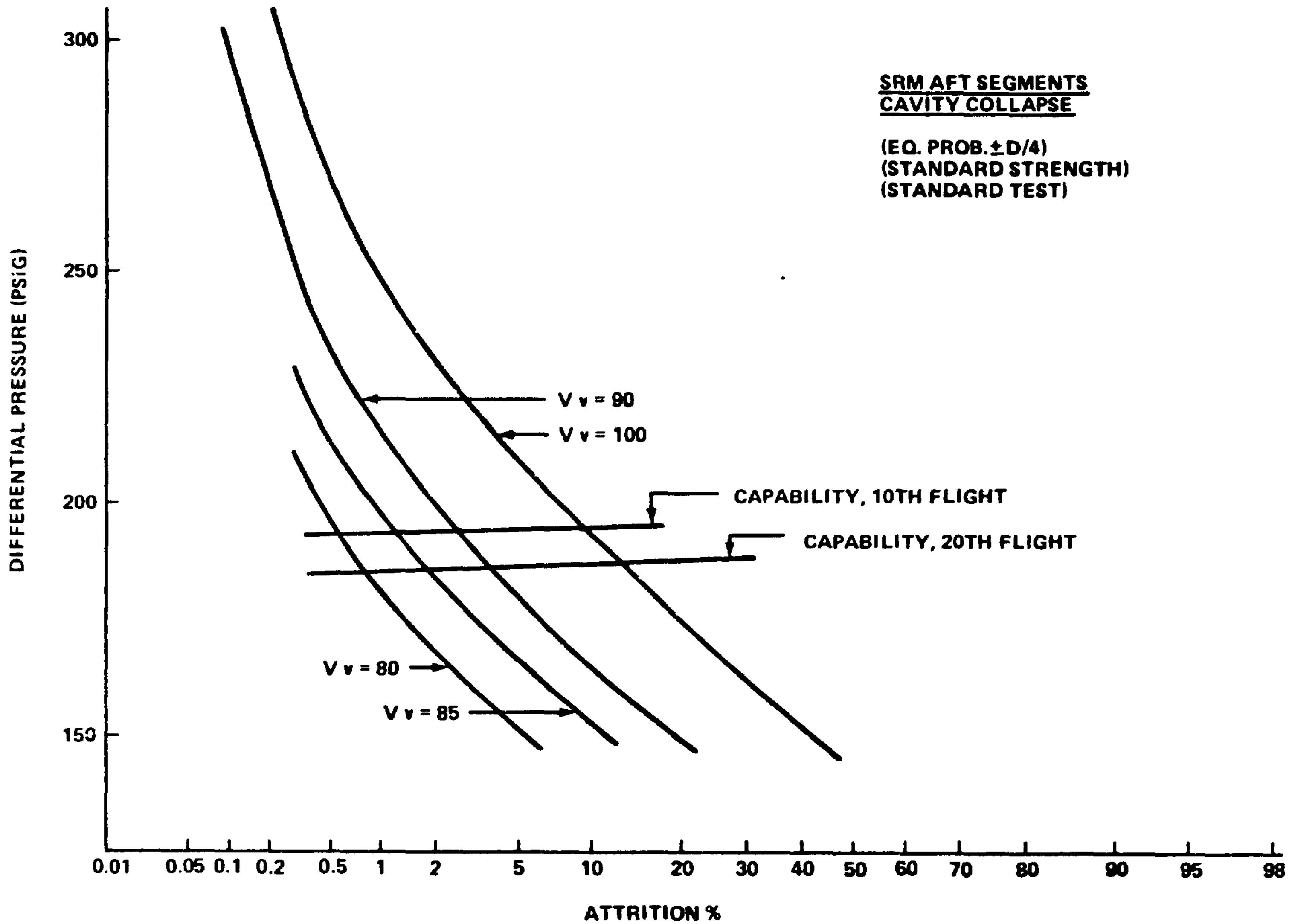


FIGURE 9 MOTOR CASE AFT SEGEMENT ATTRITION VERSUS PEAK DIFFERENTIAL PRESSURE (PSIG) CAPABILITY

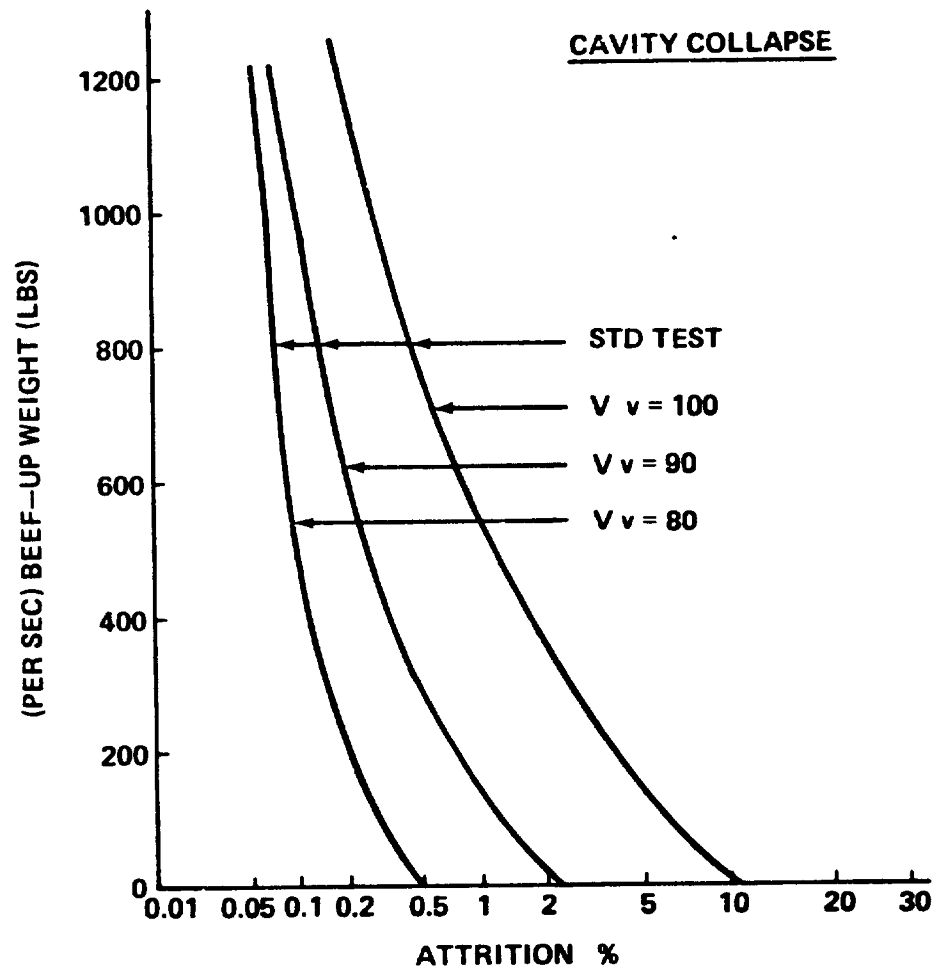


FIGURE 10 SRM AFT MOTOR CASE SEGMENTS ATTRITION VERSUS WEIGHT (BEEF–UP)

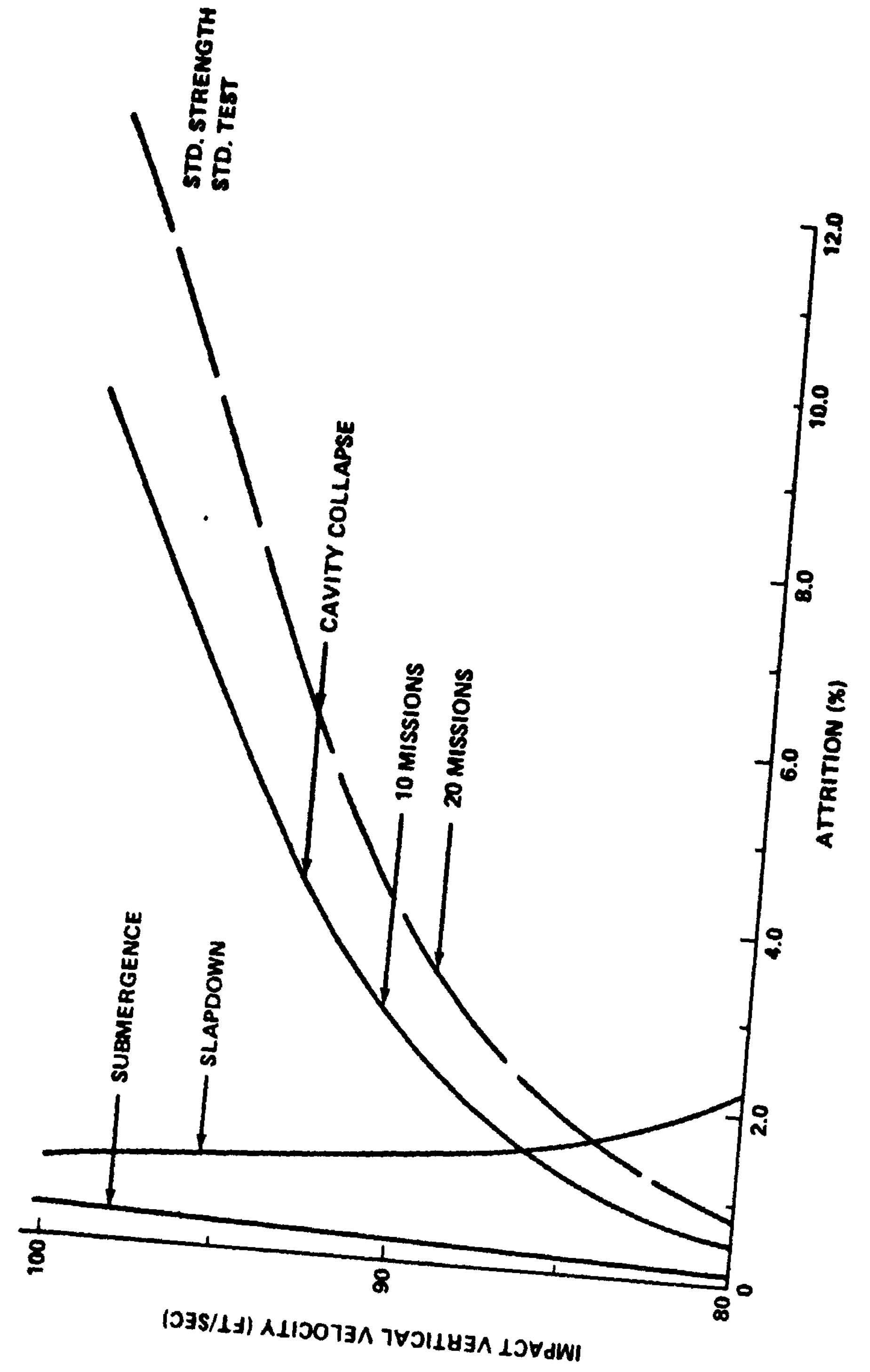


FIGURE 11. MOTOR CASE ATTRITION VERSUS WATER IMPACT VERTICAL VELOCITY (V_V)

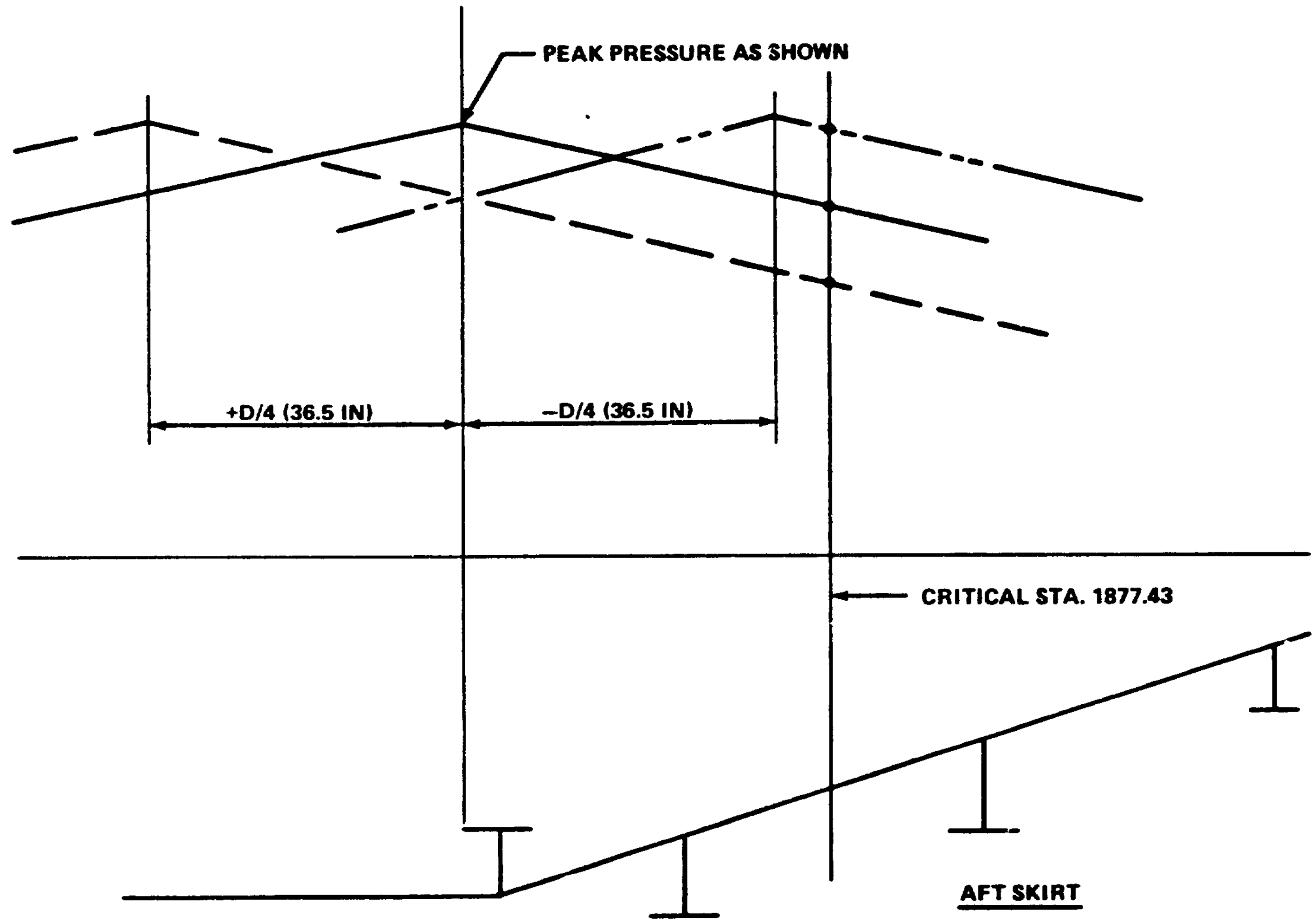


FIGURE 12. SRB AFT SKIRT CAVITY COLLAPSE LONGITUDINAL LOCATIONAL EQUAL PROBABILITY OF LOAD PEAK

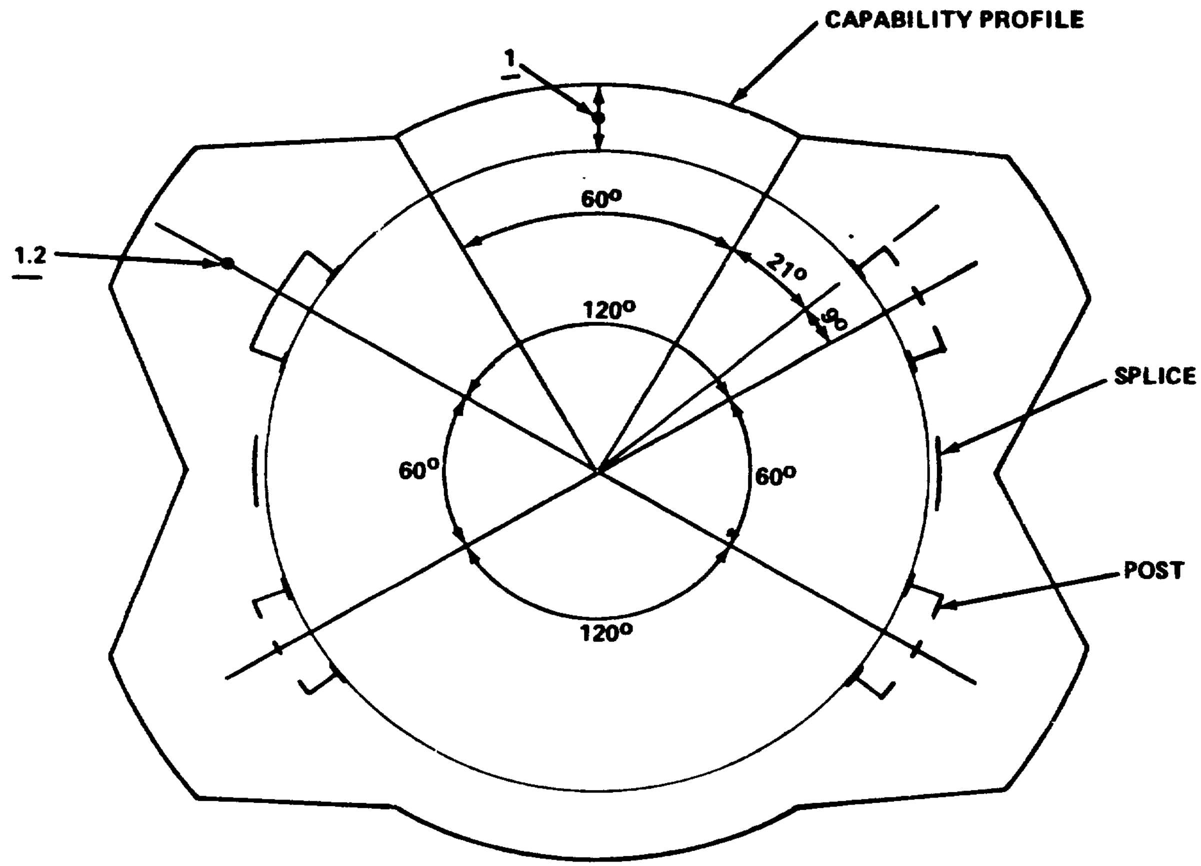


FIGURE 13. SRB AFT SKIRT RADIAL (CLOCKING) CAPABILITY DISTRIBUTION FOR CRITICAL LOAD PEAKS

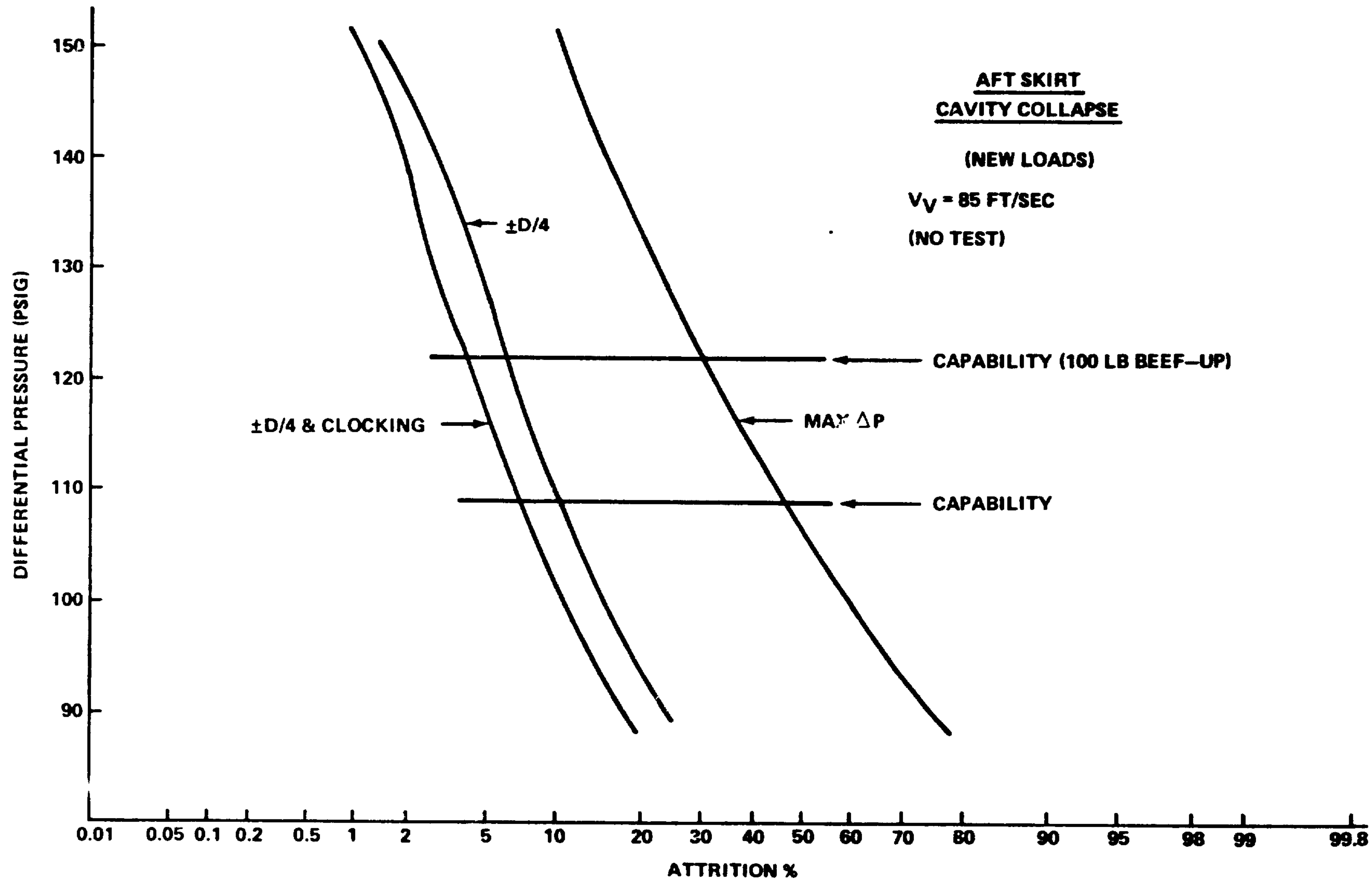


FIGURE 14 AFT SKIRT ATTRITION DETERMINATION METHODOLOGY COMPARISONS

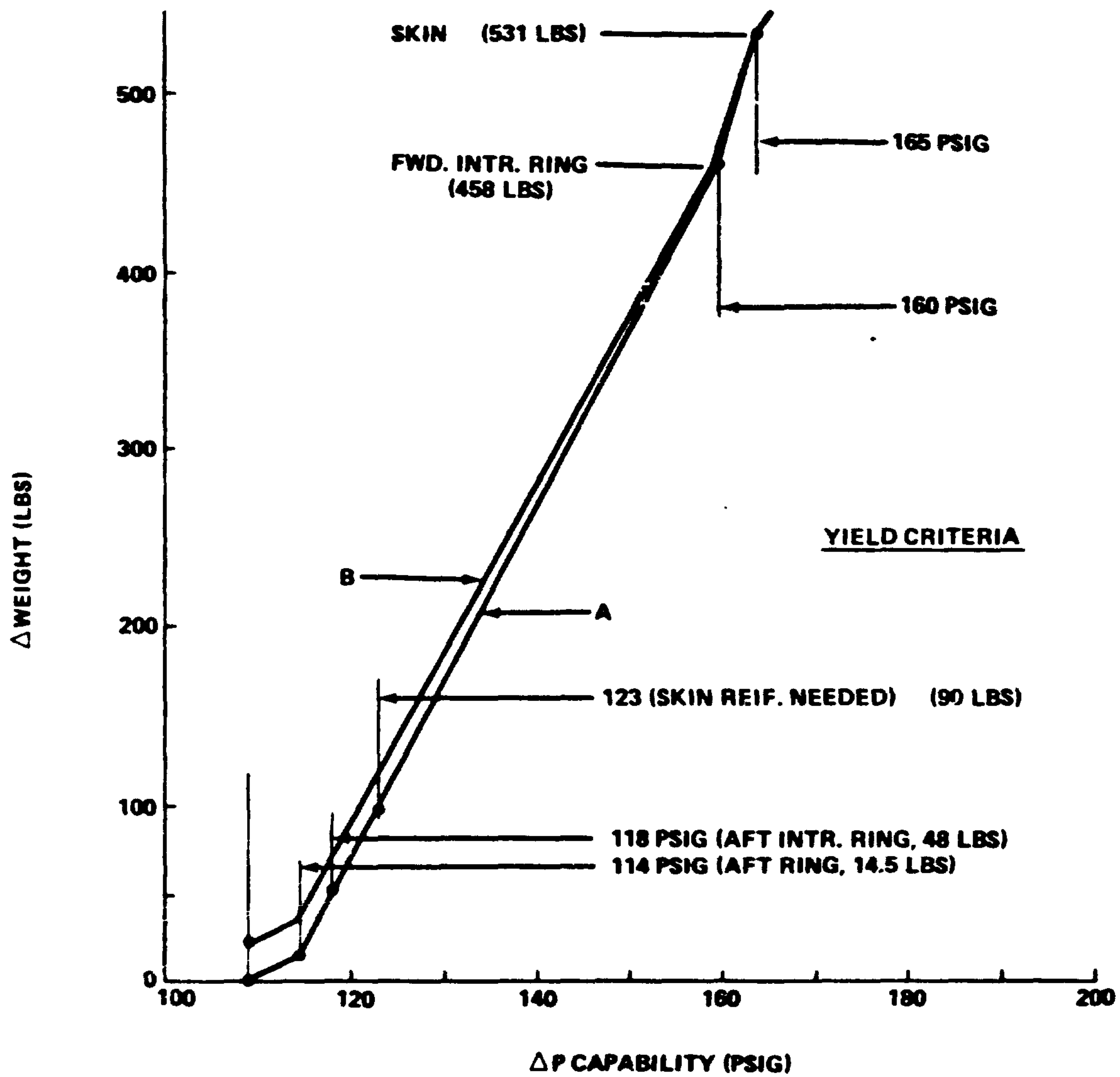


FIGURE 15 SRB AFT SKIRT DIFFERENTIAL PRESSURE CAPABILITY IMPROVEMENT VERSUS BEEF–UP WEIGHT (YIELD CRITERIA)

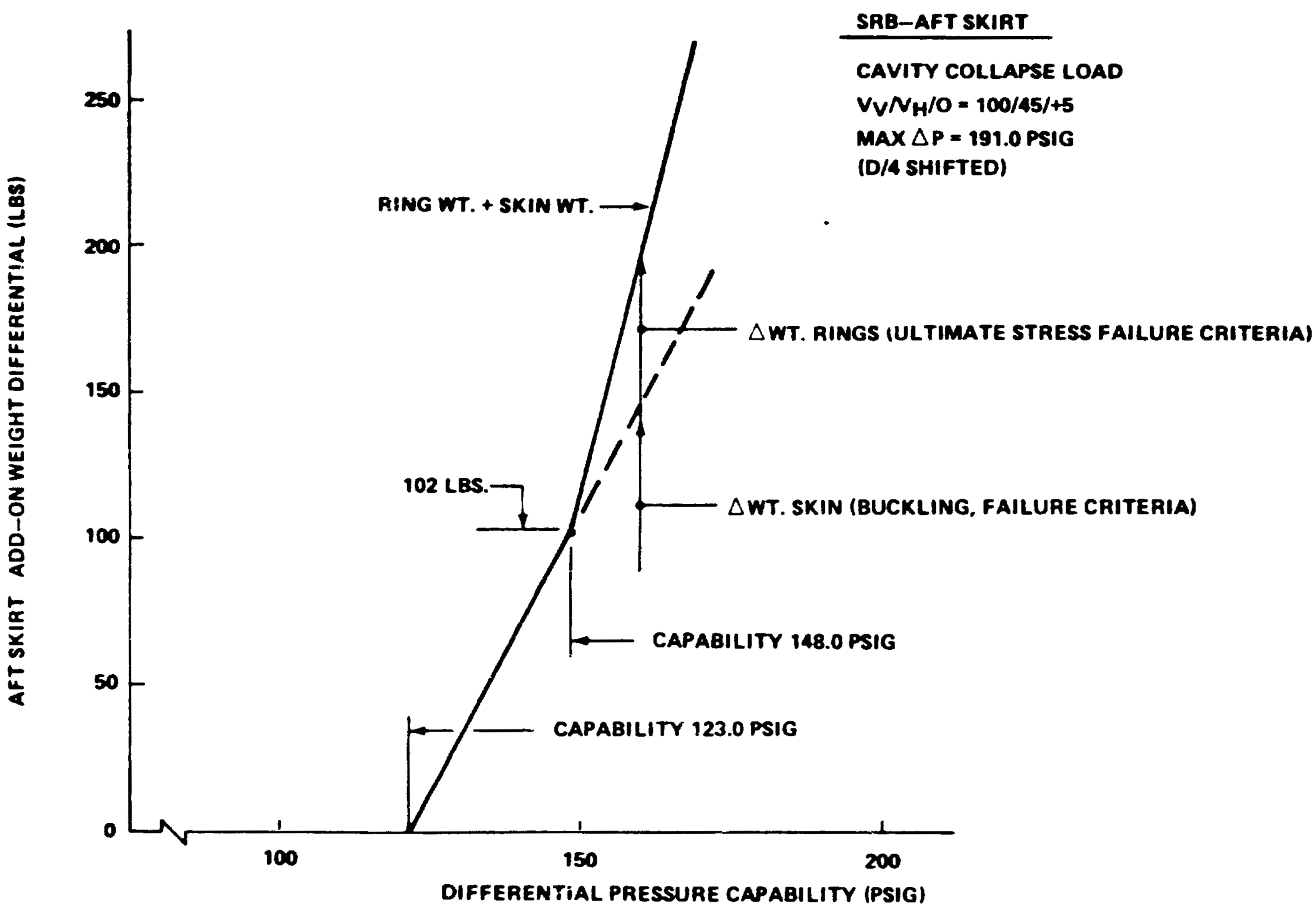


FIGURE 16 SRB AFT SKIRT DIFFERENTIAL PRESSURE CAPABILITY IMPROVEMENT VERSUS BEEF–UP WEIGHT (ULTIMATE CRITERIA)

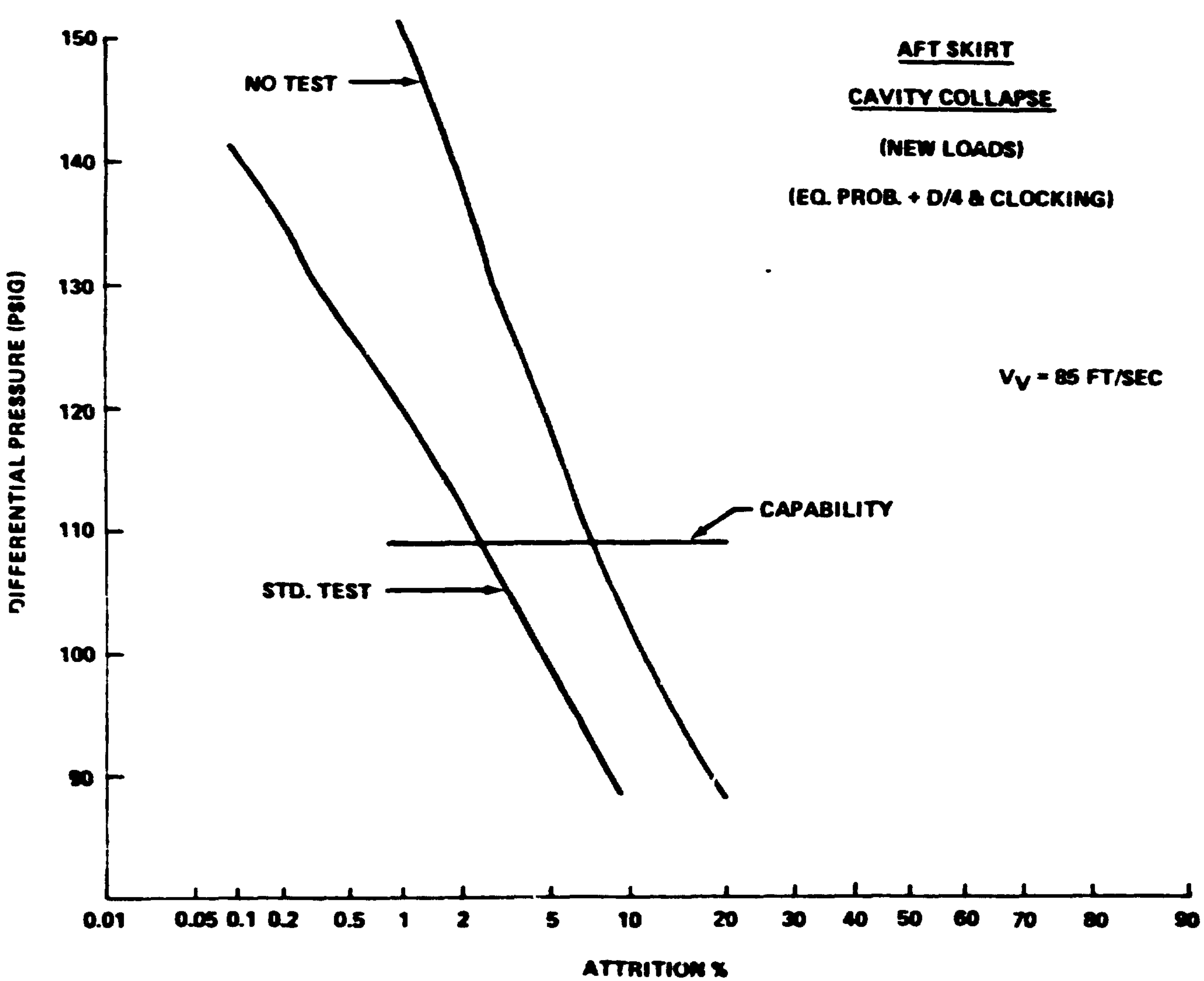


FIGURE 17 COMPARATIVE EFFECTS OF VERIFICATION TESTING AND RANDOM STRENGTH ON SRB AFT SKIRT ATTRITION

	NO TEST	TEST
ATTRITION RATE	7.2	2.3
HARDWARE REQUIRED	123	78
DELTA COST (FY 75 $)	$ 7.0M	
DELTA COST (RY $)	$11.9M	

V_V = 85 FT/SEC

FIGURE 18. COST ADVANTAGE OF A STRUCTURAL VERIFICATION TEST OF THE AFT SKIRT

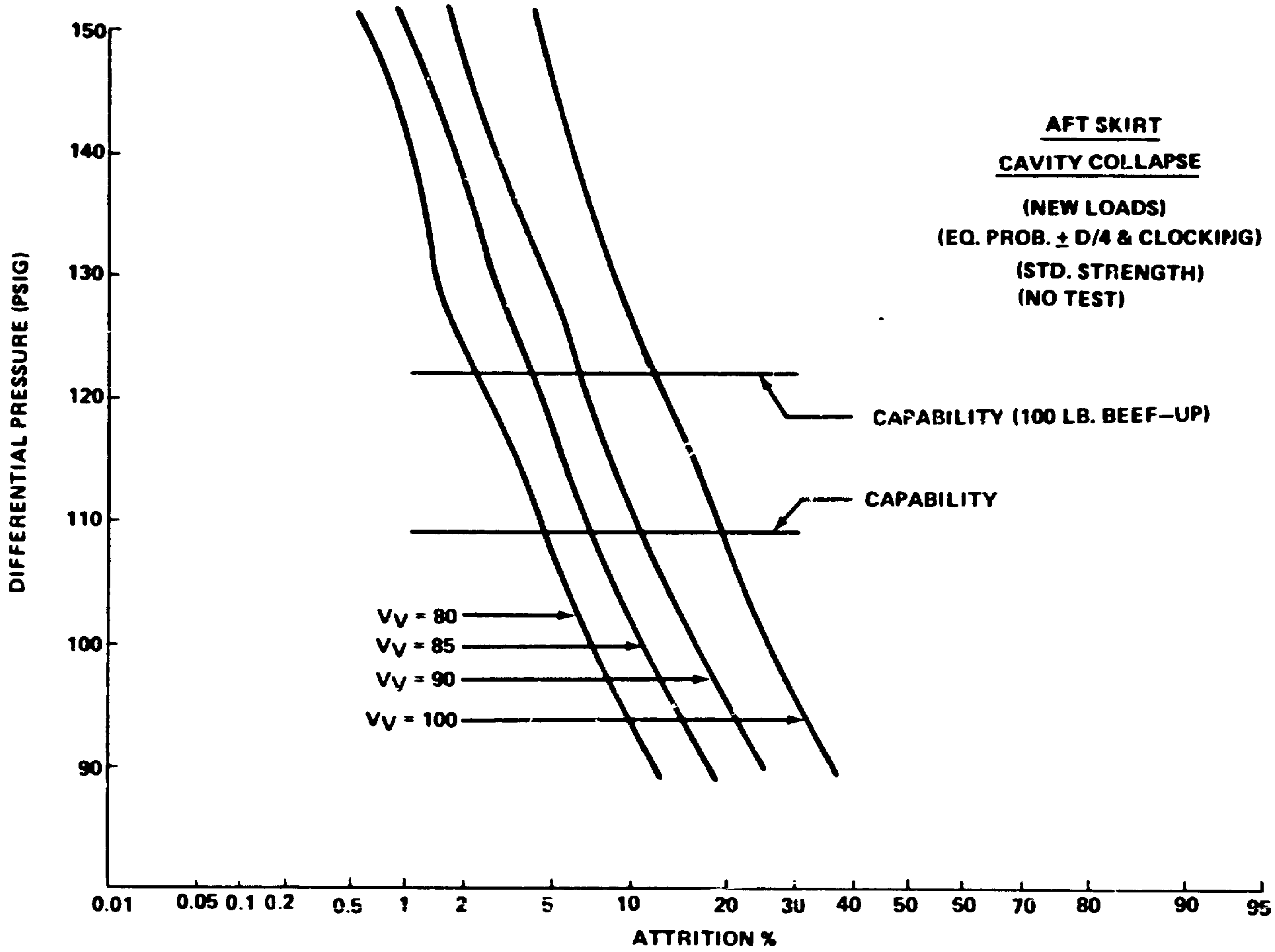


FIGURE 19. SRB AFT SKIRT ATTRITION WITH INCLUSION OF EFFECTS OF LONGITUDINAL AND RADIAL LOCATIONAL PROBABILITY OF LOAD PEAK CAPABILITY

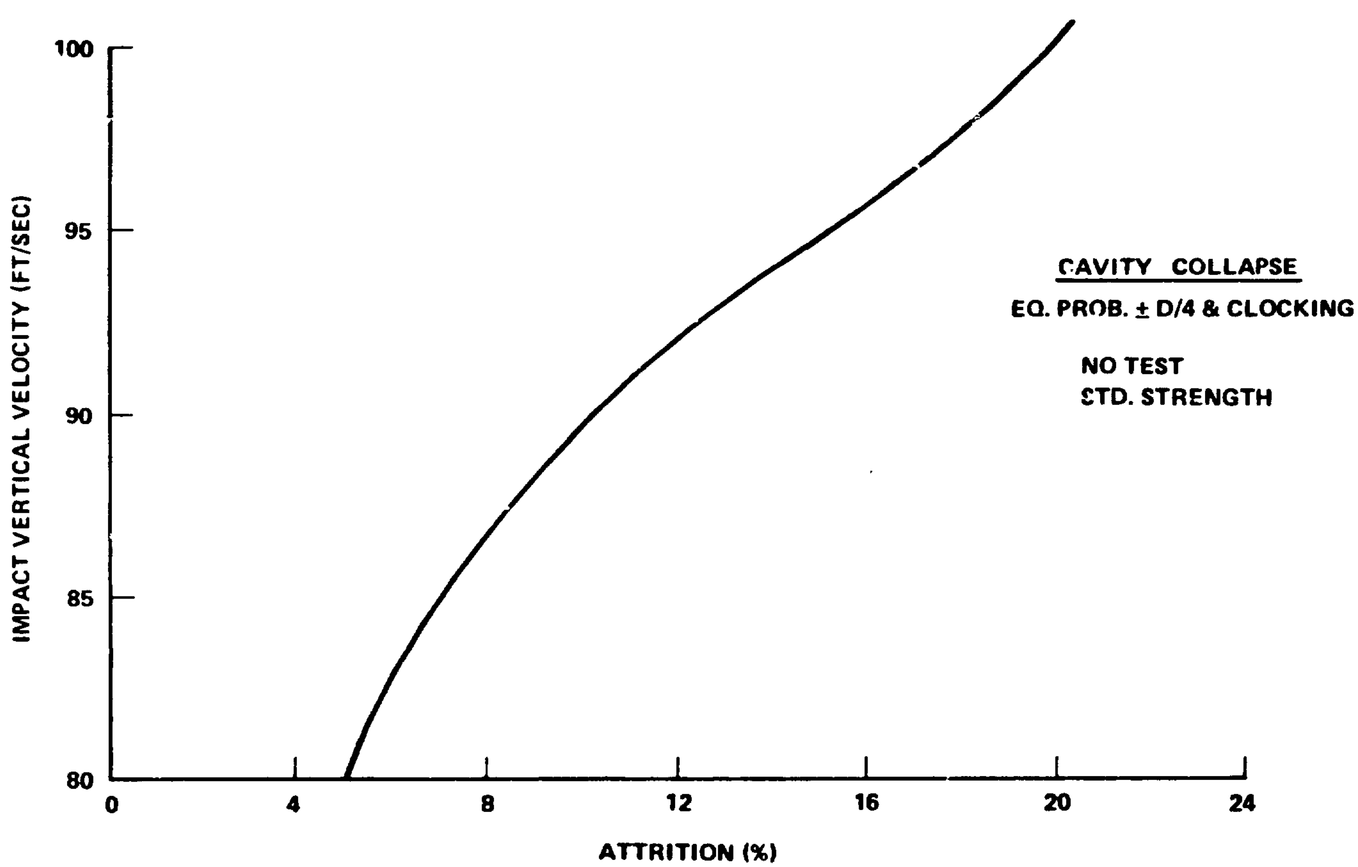


FIGURE 20. SRB AFT SKIRT ATTRITION VERSUS VERTICAL IMPACT VELOCITY (V_V)

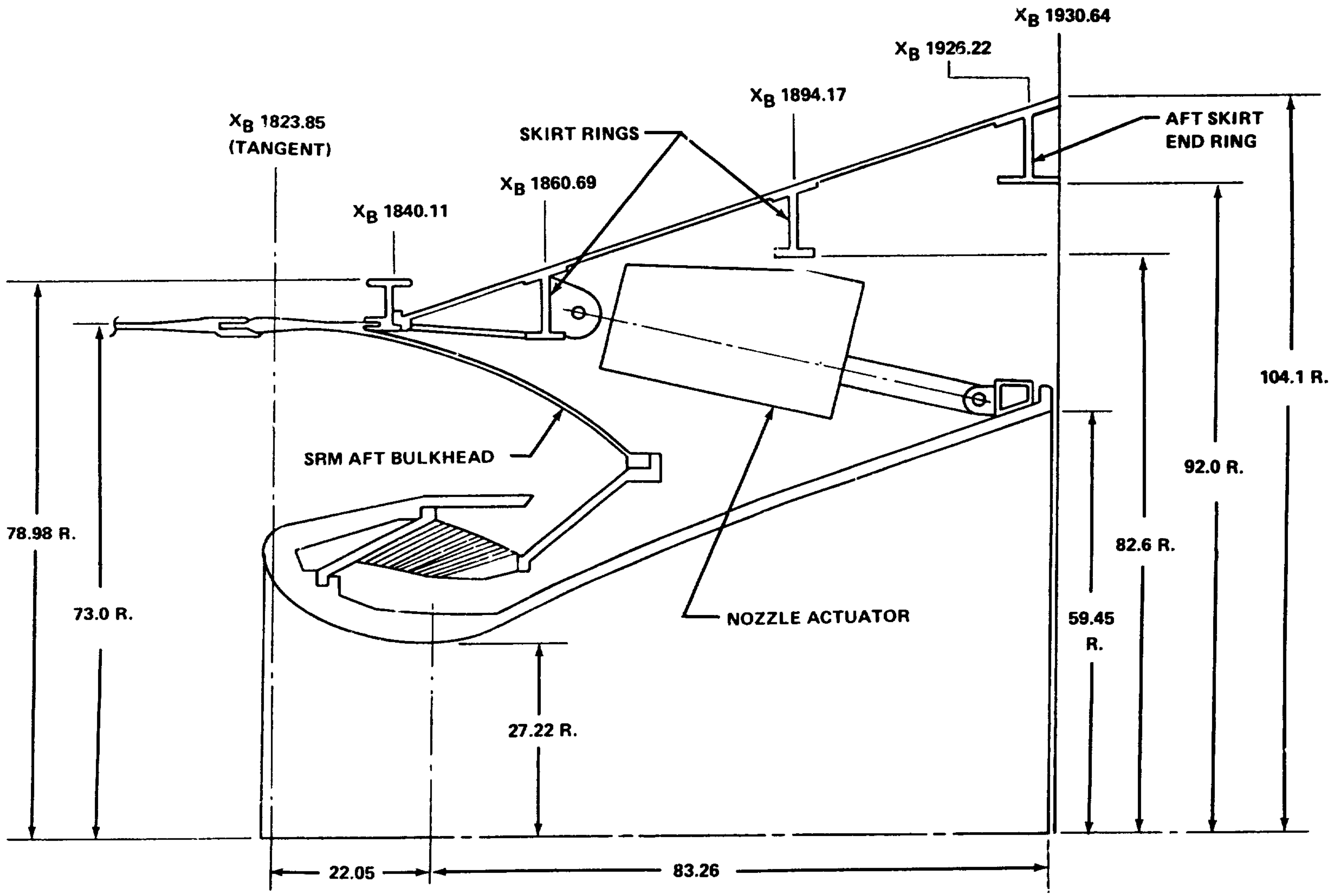


FIGURE 21. CONFIGURATION 5/1/75 BASELINE SRB AT AFT END WATER IMPACT

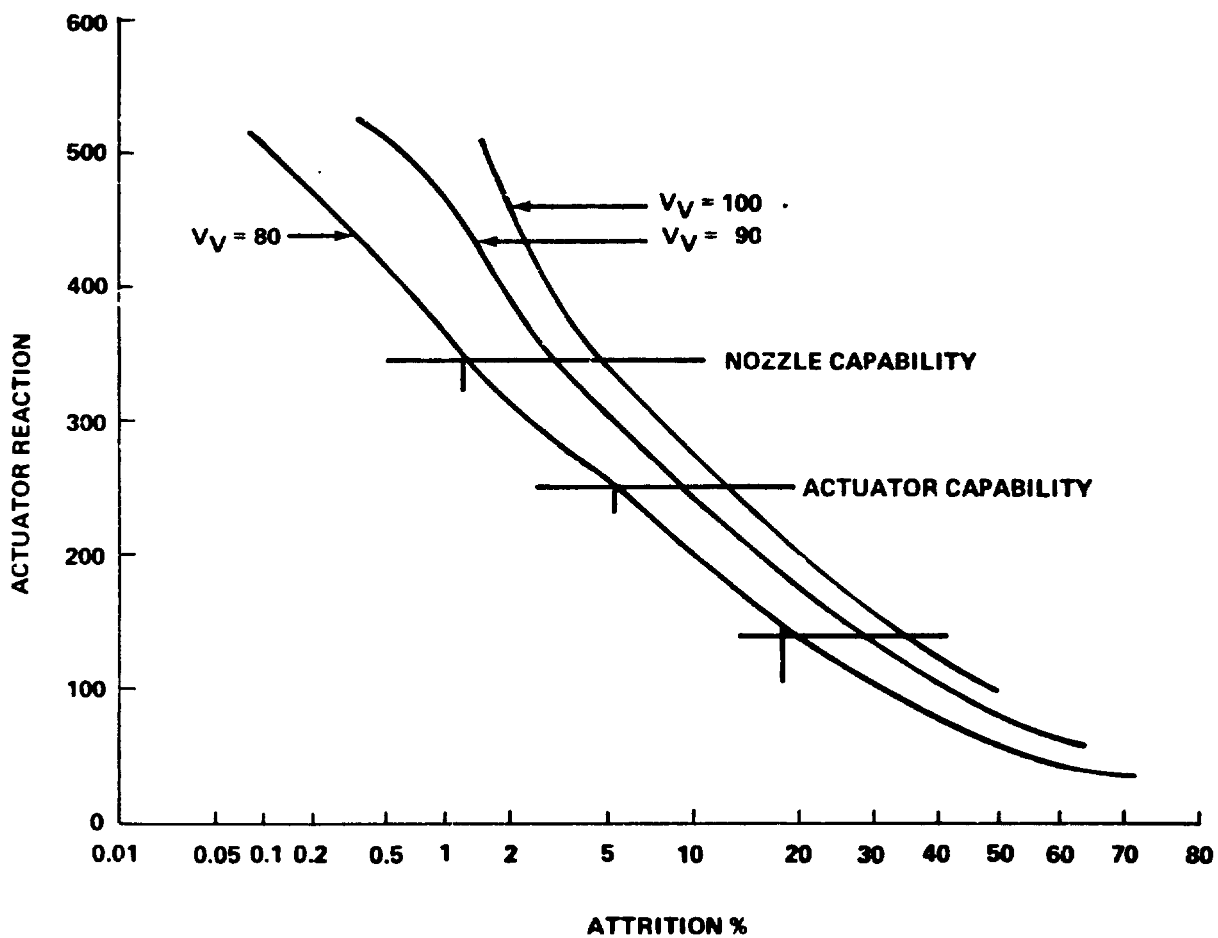


FIGURE 22. ACTUATOR REACTION CAPABILITY VERSUS ATTRITION VERSUS VERTICAL VELOCITY (V_V)

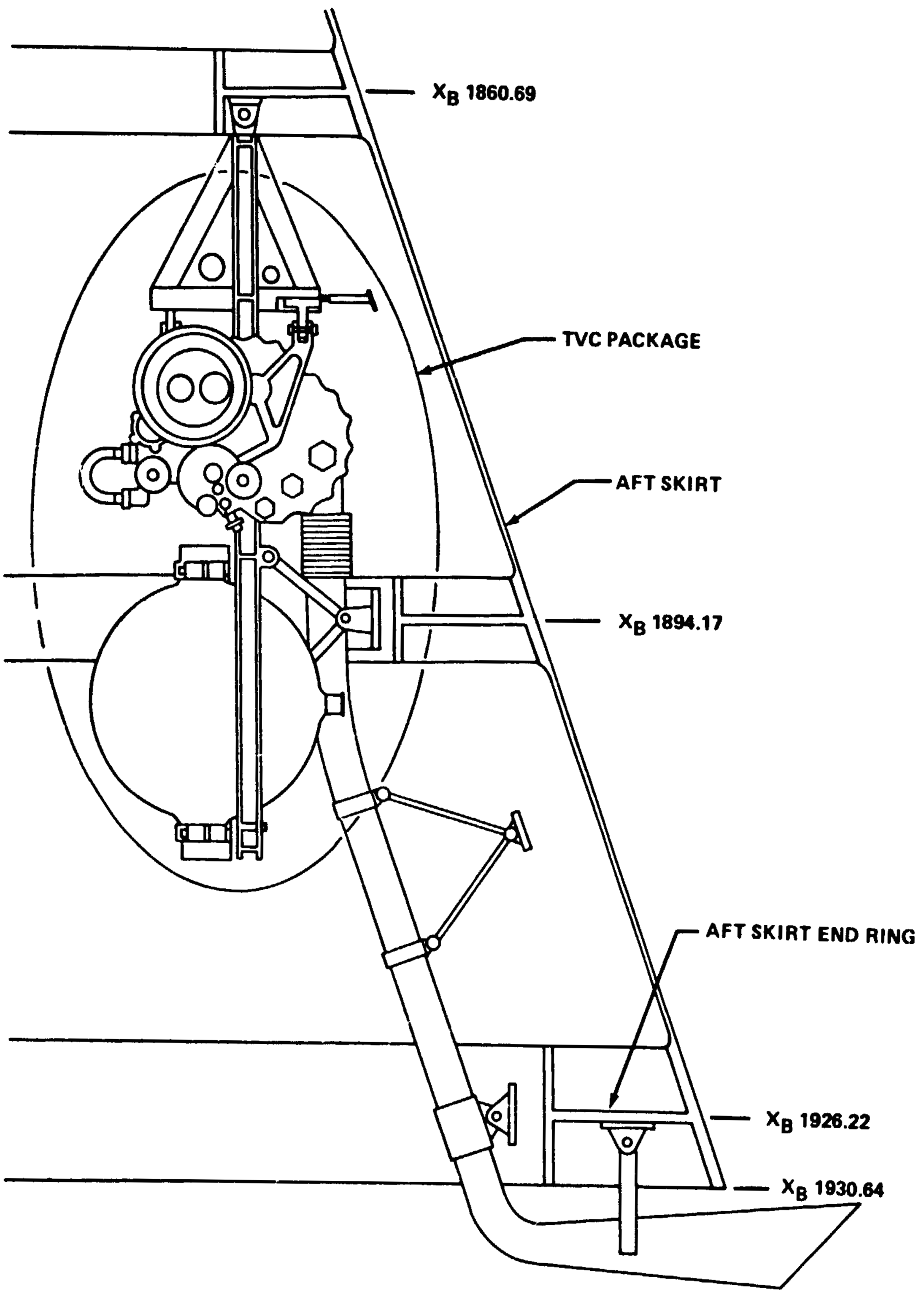


FIGURE 23. BASELINE 11/1/74 SRB CONFIGURATION FOR TVC POWER SUPPLY SYSTEM LOCATION

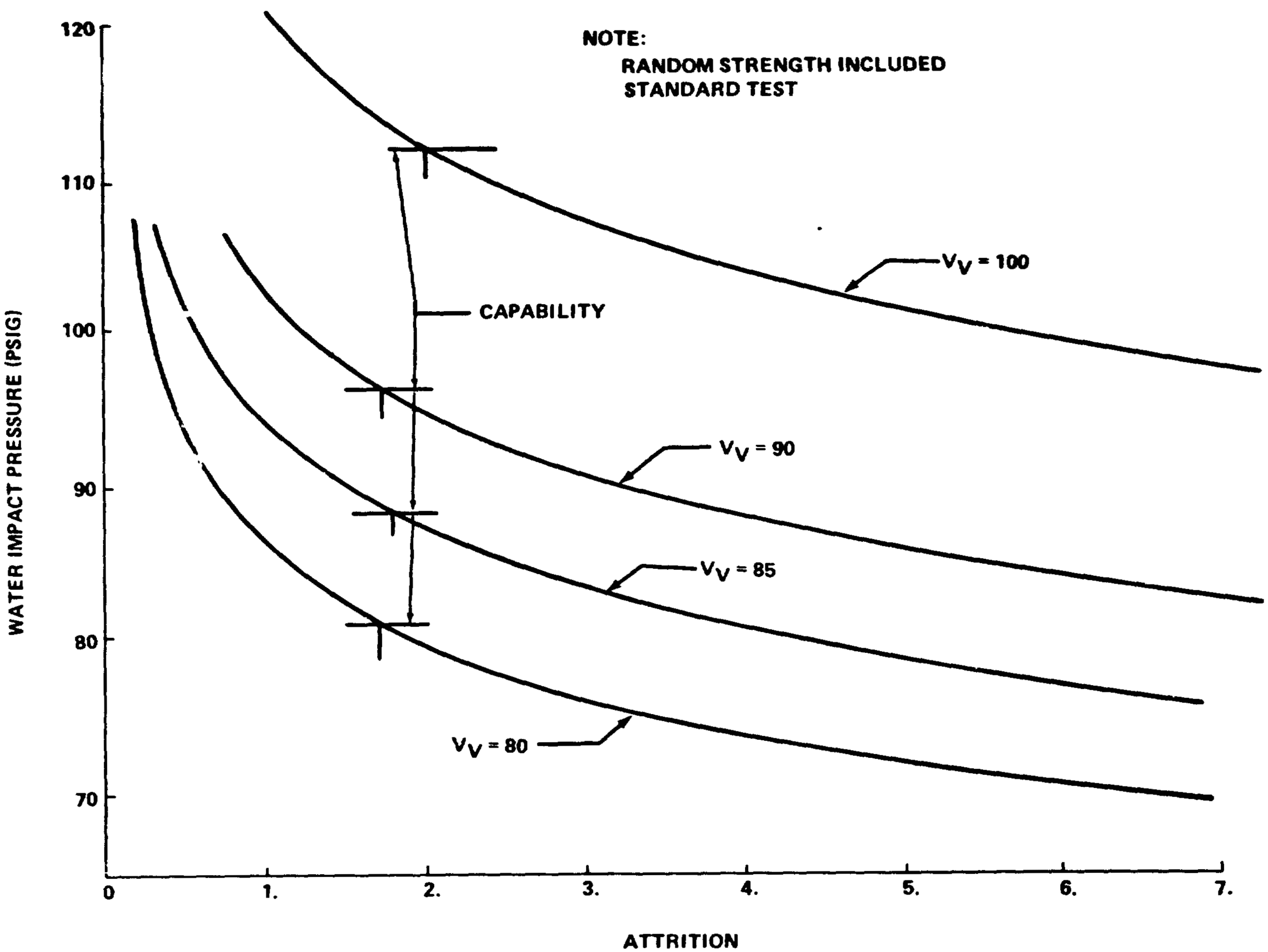
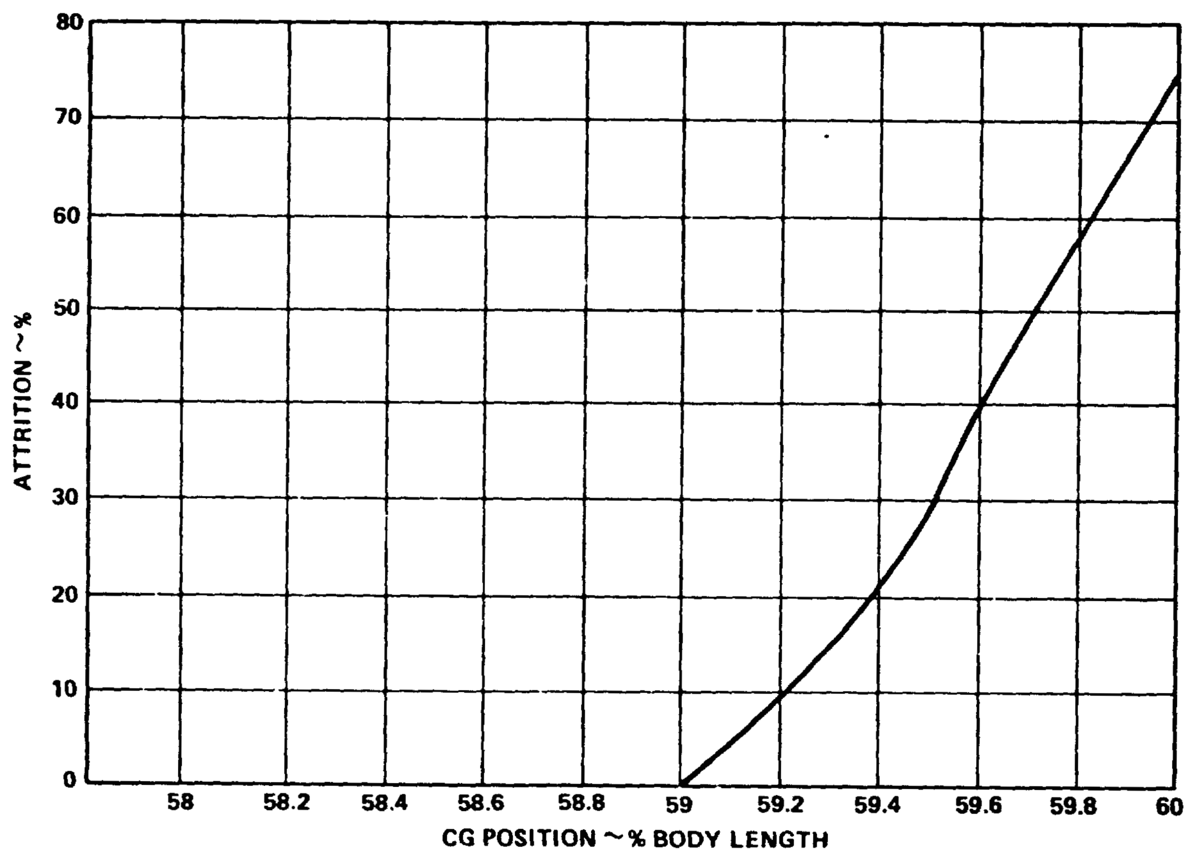


FIGURE 24. TVC POWER SUPPLY PRESSURE CAPABILITY VERSUS ATTRITION AS A FUNCTION OF VERTICAL VELOCITY (V_V)

FIGURE 25 ATTRITION VS C. G. LOCATION (95% CONFIDENCE)



(1% = 18 INCHES)

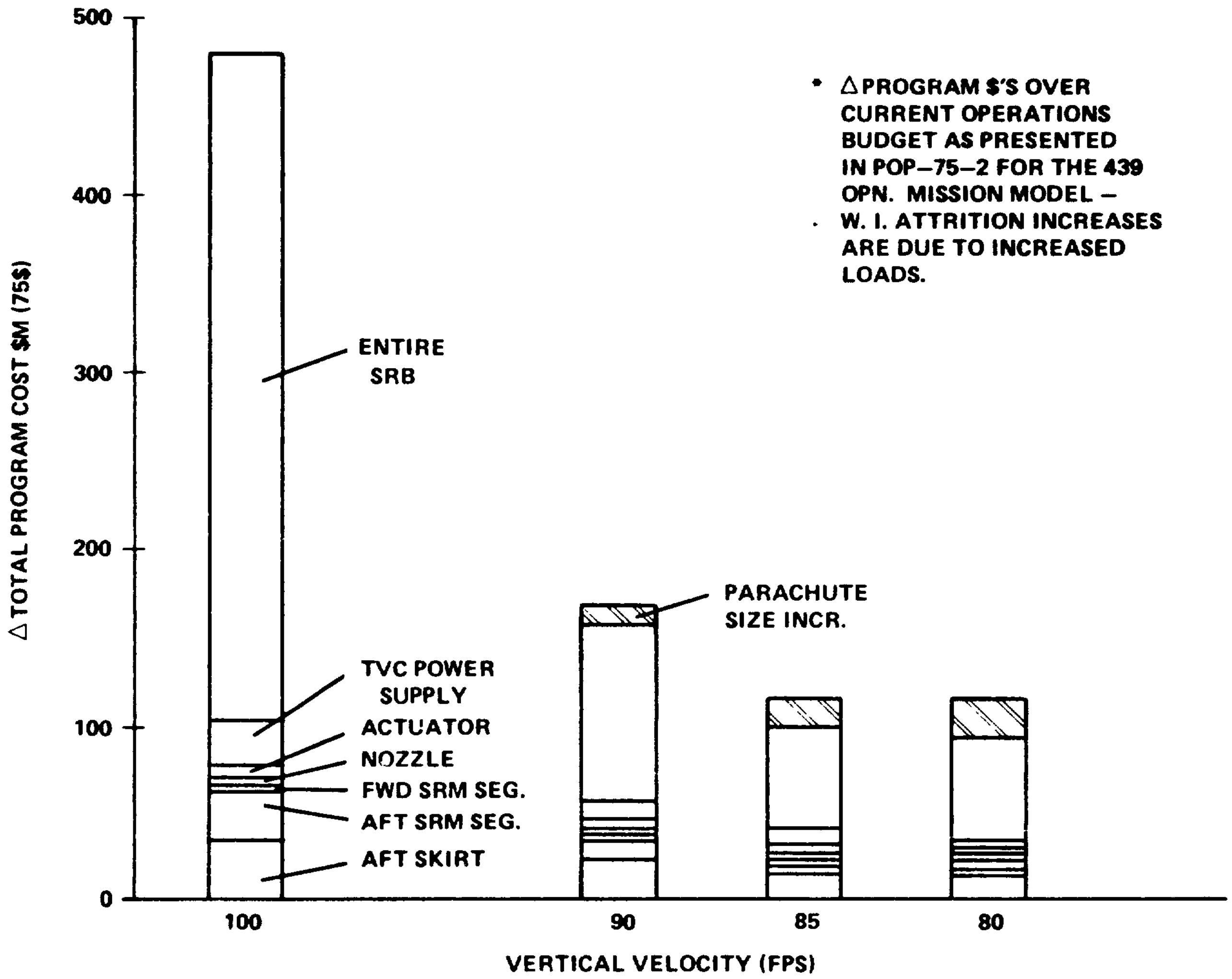


FIGURE 26 TOTAL PROGRAM COST DUE TO WATER IMPACT ATTRITION INCREASES*

APPROVAL

SRB WATER IMPACT VELOCITY TRADE STUDY

By

Duane N. Counter and Charles D. Crockett

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

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