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REUSABLE SUBSYSTEMS DESIGN/ANALYSIS STUDY

Vol III – Supplemental Data

L. L. Morgan

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AFRPL-TR-69-210
Vol III

(TITLE UNCLASSIFIED)
REUSABLE SUBSYSTEMS DESIGN/ANALYSIS STUDY

Vol III – Supplemental Data

L. L. Morgan
Lockheed Missiles & Space Company

TECHNICAL REPORT AFRPL-TR-69-210, Vol III
January 1970

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Air Force Rocket Propulsion Laboratory
Air Force Systems Command
Edwards Air Force Base, California

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AFRPL TR-69-210
Vol III

FOREWORD

The study summarized in this presentation was conducted by Lockheed Missiles & Space Company (LMSC) for the Air Force Rocket Propulsion Laboratory, Edwards, California, under contract F04611-69-C-0041. The study was under the technical direction of Mr. David T. Clift, Propulsion Subsystems Branch, Liquid Rocket Division, and Lt. George T. Reed, Analysis and Applications Branch, Liquid Rocket Division. The study technical effort has been conducted between the period from December 1968 to July 1969.

The study report is published in the following four volumes:

Volume I – Management Study Summary
Volume II – Technical Study Report
Volume III – Supplemental Data (Appendixes)
Volume IV – Special Supplemental Data

NOTE: Because of its size, Volume II is bound in two separate books: Part A contains Sections 1 through 5; Part B contains Sections 6 through 9. Both Part A and Part B contain a full table of contents, for the convenience of the reader.

Classified information has been extracted from those documents marked with an asterisk in Section 9, Volume II, Part B (References).

Major contributors of the study were as follows:

L. L. Morgan – Study Manager
R. L. Gorman – Component Engineering
H. L. Jensen – Subsystem Engineering
R. F. Hausman – Accessibility and Subsystem Tradeoff Studies
H. K. Burbridge – Reliability Studies
C. V. Hopkins – Advanced Technology Programs
K. Urbach – Subsystems Checkout
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This technical report has been reviewed and approved.

David T. Clift
AFRPL Project Engineer

CONTENTS

ILLUSTRATIONS

Appendix A
TECHNOLOGY SUMMARY (U)

(U) The purpose of this appendix is to provide background data to help assess the status of current technology in disciplines critical to reusable propulsion systems, that is, disciplines for which new exploratory development has been recommended in Task 7 of this study. The approach used in establishing this background of current technology was to identify and list the major exploratory development programs completed or in progress in each of the subject areas. Sources of data used include bibliographies supplied by the Defense Documentation Center and NASA, as well as tabulations compiled by Lockheed and Government agencies.

(U) The programs are summarized in tabular form in sections 1 through 9 of the appendix. The list is selective; it presents only the key exploratory programs in the disciplines of interest and closely-related technologies. No programs conducted prior to 1960 are listed.

Program	Contractor	Government Cognizance	Contract No.
A. Low Thrust Operating Modes (U)			
Advanced Maneuvering Propulsion System (Propellant Feed System Task)	Lockheed Missiles & Space Co. and General Dynamics/Convair (subcontract from North American Rockwell, Rocketdyne Div.)	USAF Rocket Propulsion Laboratory	F04611-67-C-0016
Maneuvering Satellite Propulsion System Optimization	North American Rockwell Corp., Rocketdyne Div.	USAF Rocket Propulsion Laboratory	AF 04(611)-10745
Analysis of an Optimum Thrust-Modulated Propulsion System for use in a Space Maneuvering Vehicle	Bell Aerosystems Co.	USAF Rocket Propulsion Laboratory	AF 04(611)-8183
B. Residual Fluid Behavior (U)			
Evaluation and Application of Data from Low Gravity Orbital Experiment	General Dynamics/Convair	NASA Marshall Space Flight Center	NAS8-21291
Orbital Refueling and Checkout Study	Lockheed Missiles & Space Co.	NASA Kennedy Space Center	NAS10-4606

Contract No.	Duration	Funding	Scope of Work
F04611-67-C-0016	Dec 1967- 1969		(C) Perform a detailed preliminary design study of an LF_2/LH_2 space maneuvering propulsion module based on the 30,000 lb thrust aerospike ADP engine concept. Define the integrated propellant feed system (tankage, insulation, supports, pressurization, venting, etc.). Assess the impact of low-thrust modes, rapid start and long-term launch readiness on the overall propulsion system.
AF 04(611)-10745	Mar 1965- Sep 1965	$400,000	(C) Conduct the conceptual design of an advanced LF_2/LH_2 propulsion system comprising a concentric aerospike/bell engine and a complete propellant feed system. Incorporate in the design a thrust variation of 30,000 to 370 lb (81.1) along with rapid start and maneuver capability.
AF 04(611)-8183	- Dec 1965		(C) Select the best propellant combination for a propulsive spacecraft to perform a military space inspection mission in which thrust-to-weight ratio varies from 0.1 to 1.5. Formulate spacecraft point designs using six different propellant combinations, four gross weights and three engine combinations; assume a space propellant-storage time of two weeks.
NAS8-21291	1969-		
NAS10-4606	Mar 1967- Feb 1968	$239,500	Analyze problems associated with propellant transfer in space. Generate reference tanker and receiver-vehicle designs and evaluate impact of these vehicles on KSC operations and facilities. Design ground and flight experiments to resolve developmental problem areas inorbital propellant transfer.

2

Section 1 (Cont.)

Program	Contractor	Government Cognizance	Contract No.
Earth Orbital Experiments for Low-Gravity Fluid Dynamics (Project THERMO)	McDonnell Douglas Astronautics Co.	NASA Marshall Space Flight Center	NAS8-18053 and NAS8-21129
Response of Liquid-Fueled Space Vehicles to Low G	General Dynamics/Convair	NASA Marshall Space Flight Center	NAS8-20356
Residual Cryogenic Propellant Behavior in Orbital Vehicles	General Dynamics/Convair	NASA Marshall Space Flight Center	NAS8-20165
Cryogenic Liquid Experiments in Orbit	Martin Marietta Corp., Denver Div.	NASA Marshall Space Flight Center	NAS8-11328
Terminal Draining for Liquid Oxygen and Liquid Hydrogen Propellants	Martin Marietta Corp., Denver Div.	NASA Marshall Space Flight Center	NAS8-5417
Geysering of Cryogenics	Martin Marietta Corp., Denver Div.	NASA Marshall Space Flight Center	NAS8-5418
C. <u>Leakage</u> (U)			
Improved Cryogenic Systems Valves	National Bureau of Standards	NASA Kennedy Space Center	CC51021

on 1 (Cont.)

Contract No.	Duration	Funding	Scope of Work
AS8-18053 and AS8-21129	Aug 1966-	$536,790	Define and perform preliminary design analysis of six low-g fluid mechanics experiments to be performed in the Apollo applications program, including propellant mass determination, liquid interface stability, boiling heat transfer, cryogenic propellant transfer, cryogenic propellant storage, and condensing heat transfer. Analyze carrier vehicle integration requirements.
AS8-20356	1966-	$ 28,600	Observe and report the fluid dynamics of space vehicle propellants in low-g fields.
AS8-20165	Jun 1965- Nov 1967	$140,220	Develop analytical methods for predicting the fluid mechanics of residual cryogenic propellants in orbiting space vehicles. Predict venting thrust of these residuals.
AS8-11328	Sep 1964-	$179,700	Conduct a program of analysis and design to define orbital experiments for cryogenic fluids, including (1) a liquid settling and interface dynamics experiment (2) a nuclear boiling experiment, (3) a liquid venting experiment, and (4) an experiment on the general behavior of bubbles in low-g fields. Conduct limited drop tower testing to support the design and analysis.
NAS8-5417	- Aug 1964		Determine the amount and behavior of cryogenic propellant residuals in typical space vehicles, and determine techniques to reduce residuals through the addition of sump bottoms and vortex inhibitors. Analyze fluid behavior during terminal draining, including the effects of vortexing, dropout (pullthrough), cavitation and slosh. Fabricate scaled plexiglass tanks to simulate the tank bottom geometry of the S-IVB LH_2 tank and a typical cryogenic torus tank. Conduct draining tests using water as the test fluid.
NAS8-5418	Jun 1963- Mar 1965	$114,900	Perform analytical and experimental studies to obtain data on the mechanics of geysering phenomena in cryogenic propellant feedlines.
CC51021	1966- 1967		Compile and analyze a history of deficiencies (e.g. leakage) encountered with cryogenic valves in space vehicle ground and airborne systems. Perform design analyses, prepare new specifications and test plans, and evaluate supplier capabilities to provide improved valves.

2

Section 1 (Cont.)

Program	Contractor	Government Cognizance	Contract No.
Leakage Testing Handbook Project	General Electric Co.	NASA	NAS7-396
Study of Propellant Valve Leakage in a Vacuum	Atlantic Research Corp.	NASA Manned Spacecraft Center	NAS9-4494
Space Effects on Propulsion Components	Aerospace Corp.	USAF Systems Command, Space and Missile Systems Organization	AF 04(695)-469
Analytical Techniques for the Design of Seals for use in Rocket Propulsion Systems	Illinois Institute of Technology	USAF Rocket Propulsion Laboratory	AF 04(611)-8020
Zero-Leakage Connectors for Launch Vehicles	General Electric Co., Missile & Space Div.	NASA Marshall Space Flight Center	NAS8-4012
D. Contamination (U)			
Development of Design Criteria for Valve Closures Operating in Rocket Propulsion System Contamination Environments	North American Rockwell Corp., Rocketdyne Div.	USAF Rocket Propulsion Laboratory	F04611-67-C0085
Research on New Techniques for Analysis of Contaminants in Liquid Propellants	Aerojet General Corp.	USAF Aero Propulsion Laboratory	AF 33(657)-7976
Prototype Propellant Testing System	Aerojet General Corp.	USAF Rocket Propulsion Laboratory	AF 04(611)-8196

1

on 1 (Cont.)

Contract No.	Duration	Funding	Scope of Work
AS7-396	- 1967		
AS9-4494	Jun 1965 Apr 1968		
F 04(695)-469	- Oct 1964		Conduct a survey of potential space environmental effects on propulsion system components (including leakage, freezing, etc.) and determine the experimental effort needed to confirm these effects.
F 04(611)-8020	Feb 1962- Nov 1963		Develop analytical design techniques for static, sliding, and rotating shaft seals as applied to rocket propulsion systems.
AS8-4012	Mar 1962-	$842,660	Conduct an analytical and experimental program to determine design criteria applicable to fluid connectors for launch-vehicle and space vehicle service. Study the fundamentals of connector design to obtain essentially zero leakage.
04611-67-C0085	Apr 1967-	$250,000	Conduct a survey of contamination in rocket propulsion fluid systems (propellant, pneumatic and hydraulic systems), using the techniques of literature search and industry survey. Identify the types and sources of contamination found in existing rocket fluid systems. Conduct an analytical and experimental program to define design criteria needed for metal-to-metal poppets and seats to attain reliable service in expendable rocket systems when subjected to the existing contamination environment. Demonstrate the adequacy of these criteria in a test program.
F 33(657)-7976	Mar 1962 Mar 1964		Improve the state of the art in propellant-contamination surveillance. Characterize detectable contaminants in 12 storable propellants and develop coherent gas chromatograph methods for their detection. Design and fabricate an automatic gas chromatograph for launch site use.
F 04(611)-8196	- 1963		Design and construct a contaminant-introduction system to be used in liquid rocket propellant testing.

2

Program	Contractor	Government Cognizance	Contract No.
Investigation of Main Tank Injection Pressurization System	McDonnell Douglas Astronautics Co.	NASA Lewis Research Center	NAS3-13306
Main Tank Injection Pressurization System	McDonnell Douglas Astronautics Co.	NASA Lewis Research Center	NAS3-7963
Liquid Surface Profile in a Cryogenic Tank During Gas Injection	Mississippi State University	NASA Marshall Space Flight Center	NAS8-11334
Advanced Pressurization System for Cryogenic Propellants	Martin Marietta Corp., Denver Div.	NASA Lewis Research Center	NAS3-2574
Investigation of Main Tank Injection Pressurization for High Energy Propellants	Martin Marietta Corp.,	USAF Rocket Propulsion Laboratory	AF 04(611)-9952
Liquid Hydrogen Pressurization Tests	Beech Aircraft Corp., Boulder Div.	NASA Marshall Space Flight Center	NAS8-5331
Thermodynamic Data for Tanks and Pressurization Systems	Lockheed Georgia Co.	USAF Rocket Propulsion Laboratory	AF 04(611)-10750

1

NIC PRESSURIZATION (U)

Contract No.	Duration	Funding	Scope of Work
NAS3-13306	Jun 1969-	\$269,600	Investigate the performance of main-tank-injection pressurization in large LH_2 tanks (200 cu ft or greater). Develop an analytical procedure for predicting the performance of this system over the entire range of LH_2-fueled vehicles.
NAS3-7963	Jun 1966- Jan 1968	\$197,950	Analytically and experimentally determine the feasibility, limitations, and operating characteristics of a propellant-tank pressurization system that utilizes injection of fluorine into a liquid hydrogen tank to generate pressurizing gas by vaporizing hydrogen. Conduct lab-scale tests to investigate reaction-product freezing and hypergolicity. Perform tests with a subscale LH_2 tank to investigate injection concepts and hardware (e.g., F_2 pressure regulator).
NAS8-11334	Jun 1964- 1966	\$117,400	Perform a research study to determine the effects of pressurant gas injection on the liquid surface profile in a cryogenic tank.
NAS3-2574	Nov 1963- Jun 1965	\$851,700	Analyze, design, develop, fabricate, and test propellant tank pressurization systems applicable to a manned spacecraft using liquid oxygen/liquid hydrogen propellants. Consider both stored-helium-gas and advanced pressurization techniques, and both pressure-fed and pump-fed propulsion-system requirements. Test active heat sources such as gas generators and main tank injection.
AF 04(611)-9952	- 1965		Conduct an analytical and experimental program to evaluate the use of main tank injection pressurization for ClF_5, ClF_3, N_2O_4, MHF-5, and N_2H_4 propellants.
NAS8-5331	May 1963- 1966	\$108,700	Conduct liquid hydrogen pressurization test program using scale-model tankage to determine reliable heat-transfer and stratification data, pressurization requirements, and insulation requirements.
AF 04(611)-10750	1962-		Perform analytical program to provide thermodynamic data for the design of liquid-hydrogen-propellant vehicle tankage and pressurization systems. Derive a generalized computer program that describes pressurization requirements for a wide range of cryogenic-propellant vehicle systems.

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Program	Contractor	Government Cognizance	Contract No.
Main Propellant Tank Pressurization System Study and Test Program	Lockheed Georgia Co.	USAF Rocket Propulsion Laboratory	AF 04(611)-6087

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Contract No.	Duration	Funding	Scope of Work
AF 04(611)-6087	Jul 1960- Dec 1961		Conduct a program of analysis and testing to study the pressurization of cryogenic and storable propellant tanks on launch vehicles and spacecraft, using the evaporated-propellant and main-tank-injection techniques. Conduct small-scale tests of main tank injection using storable propellants. Conduct small- and large-scale tests (up to 500-gal liquid hydrogen tank) of evaporated-propellant pressurization systems employing heat exchangers.

2

Program	Contractor	Government Cognizance	Contract No.
Demonstration of Advanced Attitude Control System	Bell Aerosystems Co.	USAF Rocket Propulsion Laboratory	
Fluorine/Hydrogen Gaseous Attitude Control Engine	TRW Systems Group	USAF Rocket Propulsion Laboratory	F04611-69-C0049
Investigation of Thrusters for Cryogenic Reaction Control System	TRW Systems Group	NASA Lewis Research Center	NAS3-11227
Development and Demonstration of Passively Cooled Thrust Chamber Assemblies for Fluorinated Propellants	Aerojet General Corp.	USAF Rocket Propulsion Laboratory	
Development and Demonstration of Passively Cooled Thrust Chamber Assemblies for Fluorinated Propellants	Marquardt Corp.	USAF Rocket Propulsion Laboratory	
Development and Demonstration of an Advanced Attitude Control System	Bell Aerosystems Co.	USAF Rocket Propulsion Laboratory	F04611-68-C0072
Radiosotope-Heated Reaction Control System	TRW Systems Group	USAF Rocket Propulsion Laboratory	AF 04(611)-11536
Pyrolytic Graphite Reaction Control Engines for use with Fluorine Oxidizers	Curtiss-Wright Corp., Wright Aeronautical Div.	NASA Manned Spacecraft Center	

CTION CONTROL SYSTEMS (U)

Contract No.	Duration	Funding	Scope of Work
	1969-		
F04611-69-C0049	Jan 1969-	$357,000	Develop and demonstrate 25-lb-thrust attitude control system thruster using gaseous hydrogen and fluorine propellants. Conduct analyses, and perform injector and thrust-chamber evaluation tests. Design and fabricate a flight-type thruster, and conduct test firings at simulated altitude conditions, in selected duty cycles.
AS3-11227	1968-	$362,200	Conduct an analytical and experimental program to determine the ignition and performance characteristics of gaseous hydrogen/oxygen reaction-control-system thrusters. Conduct laboratory tests of catalyst activity. Fabricate and test fire igniters and combined thruster/igniters at 10 psia and 100 psia in an altitude chamber.
	1967-	$141,000	
	1967-	$ 32,920	
04611-68-C0072	1968-	$671,875	Design an optimized integrated-attitude-control system using fluorine/hydrogen propellants extracted from the main propellant tanks. Conduct component evaluations. Fabricate a propellant feed system (pumps, heat exchangers, lines) and conduct a system verification test
F 04(611)-11536	Mar 1966-	$360,800	Perform an analytical and experimental investigation of using radioisotope-heated hydrogen for spacecraft attitude control.
	1966-	$305,000	Develop a 100 lb thrust reaction control engine for fluorine oxidizer systems using pyrolytic-graphite heat sink nozzles.

2

Program	Contractor	Government Cognizance	Contract No.
Evaluation and Demonstration of the use of Cryogenic Propellants for Reaction Control Systems	North American Rockwell Corp., Rocketdyne Div.	NASA Lewis Research Center	NAS3-7941
Feasibility Demonstration of Advanced Attitude Control Systems	Bell Aerosystems Co.	USAF Rocket Propulsion Laboratory	AF 04(611)-10818
Design, Fabrication, and Test of Pyrolytic-Graphite-Wedge Heat-Sink Nozzles	Curtiss-Wright Corp. Wright Aeronautical Div.	USAF Rocket Propulsion Laboratory	AF 04(611)-9365
Experimental Evaluation of Gaseous Hydrogen as a Monopropellant	Lockheed Missiles & Space Co.	NASA Marshall Space Flight Center	NAS8-9500 (Subtask 1.5)
Catalytically Ignited Oxygen/Hydrogen Attitude Control Systems	North American Rockwell Corp. Rocketdyne Div.	NASA Lewis Research Center	NAS3-4185
Catalytic Ignition of Hydrogen and Oxygen	North American Rockwell Corp., Rocketdyne Div.	NASA Lewis Research Center	NAS3-2565

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Section 3 (Cont.)

Contract No.	Duration	Funding	Scope of Work
NAS3-7941	Jun 1965-	$478,080	Perform an analytical and experimental program to define reaction control systems using hydrogen and oxygen propellants extracted from the main tanks of cryogenic space vehicles. Formulate preliminary designs of systems operating at 100 psia and 10 psia.
AF 04(611)-10818	1965-		Analyze the feasibility of an advanced attitude control system using gaseous hydrogen and fluorine propellants extracted from the main tank of a space propulsion vehicle. Fabricate a test apparatus and conduct preliminary feasibility demonstration tests.
AF 04(611)-9365	- Feb 1966		
NAS8-9500 (Subtask 1.5)	May 1964 Sep 1964	$ 44,230	Conduct an experimental evaluation to provide information on the propulsive performance of cryogenic gaseous parahydrogen when expanded through conical thrust nozzles.
NAS3-4185	Jun 1964-	$127,994	
NAS3-2565	Jun 1963-	$ 64,000	

Program	Contractor	Government Cognizance	Contract No.
A. Supersonic and Hypersonic Vehicles (U)			
Insulation System for Liquid Methane Fuel Tanks for Supersonic Cruise Aircraft	Martin Marietta Corp., Denver Div.	NASA Lewis Research Center	NAS3-12425
Thermal Protection System for Liquid Hydrogen Fuel Tanks in High-Speed, Long Range Aircraft	Rand Corp.	USAF	AF 49(638)-66-C0001
Hydrogen Tankage Application to Manned Aerospace Systems	General Dynamics/ Convair	USAF Systems Command, Research and Technology Div.	AF 33(615)-2048
Research on Hydrogen Fueled Hypersonic Vehicles	General Dynamics/ Convair	NASA Langley Research Center	NAS1-4017
B. Space Vehicles (U)			
Space Storable Propellant Module Environmental Control Technology	TRW Systems Group	NASA Pasadena Office	NAS7-750
Application of High Performance Insulation to Large Conical Support Structures	Goodyear Aerospace Corp.	NASA Marshall Space Flight Center	NAS8-24884

ERMAL PROTECTION SYSTEMS (U)

Contract No.	Duration	Funding	Scope of Work
NAS3-12425	Apr 1969 Feb 1971	$251,000	Design a lightweight insulation system for a temperature range capability of -285° to 700°F for use in liquid methane tanks of supersonic aircraft. Conduct laboratory tests of insulation materials and composites. Fabricate a large scale test rig and conduct flight environmental simulation testing to verify system performance.
AF 49(638)-66-C0001	- Oct 1965		
AF 33(615)-2048	Sep 1964- 1967	$473,500	Conduct an analysis of minimum-weight liquid hydrogen tankage for manned hypersonic aerospace vehicles. Design and fabricate a test specimen with segmented-tank construction (two 8-ft-diameter Inconel 718 cylinders cut off and joined along their 20-ft length). Insulate the tank with helium-purged quartz fiber batting. Test the insulated tank in an environmental chamber simulating Mach 6 flight and 100,000 ft.
NAS1-4017	May 1964- Dec 1964	$176,000	Develop a hypersonic-vehicle cryogenic tankage test specimen. Design and fabricate a conical 2219 aluminum liquid hydrogen tank, a conical outer shell of René 41, and an Inconel 718 bellows-type tank support. Insulate the tank using a carbon-dioxide-purged quartz batting as the insulation. Deliver the test apparatus to Langley Research Center for simulated hypersonic-flight testing.
NAS7-750	Sep 1969-	$ 94,940	Analyze, design and prepare a test plan for a thermal control system to regulate the temperature of oxygen difluoride/diborane propellants for a planetary orbiter spacecraft. Consider the thermal environments of ground hold, ascent, interplanetary cruise, and planetary orbit.
NAS8-24884	Jun 1969- Jan 1970	$ 48,530	Design and develop manufacturing techniques that will permit installation of a high-performance insulation on an MSFC-furnished 105 in. diameter cryogenic test tank.

2

Program	Contractor	Government Cognizance	Contract No.
Fiberglass Supports for Cryogenic Tanks	Lockheed Missiles & Space Co.	NASA Lewis Research Center	NAS3-12037
Lightweight Modular Multilayer Insulation	Line Div., Union Carbide Corp.	NASA Lewis Research Center	NAS3 12045
Analytical and Experimental Investigation into Problems Associated with Application of High Performance Insulation System Required for Modular Nuclear Vehicle	McDonnell Douglas Astronautics Co.	NASA Marshall Space Flight Center	NAS8-21400
Thermal Performance of Multilayer Insulation	Lockheed Missiles & Space Co.	NASA Lewis Research Center	NAS3-12025
Propulsion System Thermal Design Study	TRW Systems Group	NASA Pasadena Office	NAS7-711
Investigations Regarding Development of a High Performance Insulation System	Lockheed Missiles & Space Co.	NASA Marshall Space Flight Center	NAS8-20758

Contract No.	Duration	Funding	Scope of Work
AS3-12037	May 1969- Sep 1970	$ 99,950	Evaluate the structural potential of a filament-wound fiberglass strut for supporting cryogenic tankage on advanced space vehicles. Design a strut with the objective of providing a low-heat-leak support with a strength-to-weight ratio exceeding any metallic strut. Fabricate test articles and conduct compression, tension, and vibration tests at ambient and cryogenic temperatures.
AS3 12045	May 1969-	$ 93,600	
AS8-21400	Jan 1969- Oct 1970	$284,990	Design an insulation system for application to a full-size modular nuclear vehicle. Evaluate multilayer insulation density variations. Perform design verification testing. Design and fabricate and install a sealed insulation system on an MSFC 105 in. diameter LH_2 tank. Deliver the tank to MSFC for space environmental testing. Assist in test operations and data reduction.
AS3-12025	Jun 1968 Oct 1970	$151,000	Conduct an analytical and experimental study to accurately determine the heat flow through multilayer insulation systems. Perform laboratory testing with a flat-plate calorimeter and emittance measurement equipment. Install one insulation system on a 4-ft-diameter Government-furnished tank calorimeter for thermal-vacuum tests of insulation in the as-installed condition.
AS7-711	1968	$ 73,120	Formulate. analyze and evaluate alternative approaches to the environmental control of space storable propellants (particularly OF_2/B_2H_6) on planetary orbiter spacecraft. Design representative systems including encapsulated-propulsion-module concepts. Perform tradeoff analyses to identify the most favorable concepts.
AS8-20758	Jun 1967 Jul 1968	$226,300	Perform analytical and experimental program to define optimum multilayer-insulation and tank-support systems for a modular nuclear vehicle.

2

Program	Contractor	Government Cognizant	Contract No.
Cryogenic Tank Support Evaluation	Lockheed Missiles & Space Co.	NASA Lewis Research Center	NAS3-7979
Advanced Studies on Multilayer Insulation	Arthur D. Little Inc.	NASA Lewis Research Center	NAS3-7974
Tank Mounted Insulation Program	McDonnell Douglas Astronautics Co.	USAF Rocket Propulsion Laboratory	F04611-67-C0015
Nonmetallic Parts for Launch-Vehicle and Spacecraft Structures	Boeing Co., Aerospace Group	NASA Marshall Space Flight Center	NAS8-18037
Lightweight Multilayer Insulation System	Linde Div., Union Carbide Corp.	NASA Lewis Research Center	NAS3-7953
Cryogenic Insulation Development	General Dynamics/ Convair	NASA Marshall Space Flight Center	NAS8-18021
Study of High-Performance Insulation Thermal Design Criteria	Lockheed Missiles & S Space Co.	NASA Marshall Space Flight Center	NAS8-20353

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ection 4 (Cont.)

Contract No.	Duration	Funding	Scope of Work
NAS3-7979	Apr 1967- Jun 1969	\$ 96,340	Design, fabricate, and test advanced cryogenic tank support systems with very low heat-leakage rates suitable for long-term space missions.
NAS3-7974	Jan 1967- Jan 1968	\$ 64,735	Predict and measure the heat flow in a multilayer insulation system having a pipe-type penetration. Use a 4-ft-diameter calorimeter tank, insulated with multilayer blankets, as the test article; conduct tests in space environment simulator facilities using LN_2 as the test fluid. Test the thermal performance of a multilayer insulation after one-year storage, using the 4-ft calorimeter with LN_2 and LH_2 cryogens.
04611-67-C0015	Oct 1966- Apr 1967	\$ 61,000	Furnish a test device, comprising an 8-ft-diameter GFE stainless steel tank and a shroud, to be used in an experimental comparison of shroud-mounted vs tank-mounted multilayer insulation. Analyze and predict performance levels. Formulate a test plan and deliver the apparatus to AFRPL for space simulation tests with LH_2.
AS8-18037	Jun 1966- Mar 1968	\$116,510	Conduct a program of analysis, fabrication, and testing to determine the applicability of fiberglass reinforced plastics in spacecraft and launch vehicle structural components, with particular emphasis on cryogenic tank support structures.
AS3-7953	Jun 1966- Feb 1968	\$110,400	Continue work initiated under Contract NAS3-6289 by continuing tests on a 30-in.-diameter calorimeter. Formulate a preliminary design of the insulation system for an 82.6-in. LH_2 tank.
AS8-18021	Jun 1966- 1968		Conduct environmental tests on an LH_2 tank insulated with an MSFC-developed multilayer insulation. Subject the test tank to combinations of vibration, acceleration, and vacuum environments. Conduct experimental evaluations of the Convair-developed superfloc multilayer insulation concept.
AS8-20353	Mar 1966- Jun 1967	\$136,100	Correlate thermal protection system test data and insulation penetration test data with computer models. Perform tests to determine insulation off-gassing characteristics and diffusion coefficients. Produce insulation handbooks.

2

Program	Contractor	Government Cognizance	Contract No.
Partitioned Centaur Tank	General Dynamics/ Convair	USAF Rocket Propulsion Laboratory	F04611-67-C-C0004
System Effects on Cryogenic Propellant Storability and Vehicle Performance	McDonnell Douglas Astronautics Co.	USAF Rocket Propulsion Laboratory	AF 04(611)-10750
Lightweight Self-Evacuating Prefabricated Multilayer Insulation System for Cryogenic Space Propulsion Stages	Linde Div., Union Carbide Corp.	NASA Lewis Research Center	NAS3-6289
Thermal Protection System for a Cryogenic Spacecraft Propulsion Module	Lockheed Missiles & Space Co.	NASA Lewis Research Center	NAS3-4199
Cryogenic Insulation Research	Martin Marietta Corp., Baltimore Div.	NASA Marshall Space Flight Center	NAS8-11397
Design of High-Performance Insulation Systems	Lockheed Missiles & Space Co.	NASA Marshall Space Flight Center	NAS8-11347

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tion 4 (Cont.)

Contract No.	Duration	Funding	Scope of Work
4611-67-C-C0004	1966- 1967	$149,000	Design, fabricate and deliver to AFRPL a cryogenic space vehicle propellant-storage test specimen for testing in a space flight environment simulator. Fabricate test specimen from excess Centaur components by partitioning off separate LH_2 and LOX tanks and by applying multilayer insulation and other thermal protection systems to the exposed surfaces.
F 04(611)-10750	Mar 1965-	$516,000	Conduct a comprehensive analytical and experimental program to determine the insulation, tank-support, pressurization, venting, propellant management, feed system, and thermal control surface characteristics for an LF_2/LH_2 space vehicle. Fabricate and deliver to AFRPL a test apparatus incorporating the selected systems for testing in the AFRPL space flight simulator. Assist in conducting the space-simulation testing.
AS3-6289	Jun 1965- Jul 1966	$123,807	Develop a space vehicle insulation system based on the use of prefabricated panels of encapsulated multilayer insulation (the panels are filled with condensible gas and sealed; the gas condenses, evacuating the panel, when hydrogen is tanked). Fabricate test specimens and perform lab scale tests. Conduct thermal performance tests on a double guarded calorimeter tank at NASA Plum Brook Station.
AS3-4199	Jun 1964- Dec 1965	$577,500	Design and develop insulation and low-heat-leak tank support systems suitable for 8-day lunar missions. Fabricate half-scale vehicle mockup (built around 82.6-in. spherical tank) using candidate thermal-protection systems. Test in simulated flight environments.
AS8-11397	Jun 1964- Aug 1965	$277,200	Design, fabricate, and test experimental samples of multilayer insulation for cryogenic space vehicles. Apply two best systems to MSFC 105-in.-diameter LH_2 tank for further testing.
AS8-11347	Jun 1964- Aug 1965	$110,000	Develop digital computer models to describe heat flow in high-performance insulation systems. Derive insulation optimization techniques and produce insulation handbook.

Program	Contractor	Government Cognizance	Contract No.
Development of Materials and Materials Application Concepts for Joint use as Cryogenic Insulation and Micrometeoroid Bumpers	Goodyear Aerospace Corp.	NASA Marshall Space Flight Center	NAS8-11747
Development of a Lightweight Cryogenic Insulating System	Goodyear Aerospace Corp.	NASA Marshall Space Flight Center	NAS8-11761
Advanced Studies on Multilayer Insulation Systems	Arthur D. Little Inc.	NASA Lewis Research Center	NAS3-6283
Basic Investigations of Multilayer Insulation Systems	Arthur D. Little Inc.	NASA Lewis Research Center	NAS3-4181
Structure/Cryogenic-Insulation Integration	Martin Marietta Corp., Baltimore Div.	NASA Marshall Space Flight Center	NAS8-5300
Structure/Cryogenic-Insulation Integration	North American Rockwell Corp.	NASA Marshall Space Flight Center	NAS8-5268
Propellant Storability in Space	General Electric Co., Missile & Space Div.	USAF Rocket Propulsion Laboratory	AF 04(611)-9078
Liquid Propellant Losses During Space Flight	Arthur D. Little Inc.	NASA Headquarters	NASw-615
Liquid Propellant Losses During Space Flight	Arthur D. Little Inc.	NASA Headquarters	NAS5-664

Section 4 (Cont.)

Contract No.	Duration	Funding	Scope of Work
NAS8-11747	Jun 1964-	$1,079,640	Develop a concept for a composite material that will function as both insulation and micrometeoroid shielding for space vehicle LH_2 tanks on missions in excess of 30 days. Conduct analyses and laboratory-scale tests of insulation properties. Fabricate insulation specimens for MSFC 105-in.-tank. Conduct environmental tests with LH_2.
NAS8-11761	Jun 1964 May 1966	$ 324,350	
NAS3-6283	Mar 1964 Jun 1966	$ 214,840	Continue laboratory scale testing of multilayer insulation by performing emissometer, flat-plate calorimeter, and insulated calorimeter tests on improved radiation shields, spacer materials, and composites.
NAS3-4181	Dec 1963 Oct 1964	$ 340,110	Conduct a program of laboratory-scale testing on multilayer insulation systems for cryogenic space vehicle propellant tankage. Measure the thermal performance of promising insulation concepts. Design and build an emissometer to measure the total hemispheric emittance on candidate insulation materials.
NAS8-5300	Jun 1963 May 1964	$ 144,000	Conduct program of analysis and limited testing to establish system concepts for multilayer insulation on cryogenic space vehicles.
NAS8-5268	Jun 1963 Jun 1964	$ 118,400	Conduct program of analysis and limited testing to establish system concepts for multilayer insulation on cryogenic space vehicles.
AF 04(611)-9078	May 1963- Jun 1964	$ 730,000	Conduct an experimental investigation of the storability of liquid rocket propellants in space. Fabricate a test article comprising propellant tanks in an outer shell structure. Insulate the tanks with multilayer insulation blankets and conduct tests in vacuum, using liquid nitrogen as the test fluid.
NASw-615	Dec 1962- Sep 1963	$ 231,750	Continue the analytical and experimental evaluation of Multilayer insulation initiated under Contract NAS5-664.
NAS5-664	Sep 1960- Nov 1962		Conduct an analytical and experimental program to define techniques for the long-term storage of cryogenic propellants in space vehicles.

2

PROPELLANT FEED I

Program	Contractor	Government Cognizance	Contract No.
Aluminum Tube Joining for Apollo Systems	Boeing Co., Aerospace Group	NASA Marshall Space Flight Center	NAS8-24941
Dissimilar Metal Joining by Solid State Welding	Boeing Co., Aerospace Group	NASA Marshall Space Flight Center	NAS8-20156
Study of Cryogenic Container Thermodynamics During Propellant Transfer	Lockheed Missiles & Space Co.	NASA Marshall Space Flight Center	NAS8-20362
Separable Tube Connector Development	Battelle Memorial Institute	USAF Rocket Propulsion Laboratory	AF 04(611)-11204
Permanent Tube Joint Technology	North American Rockwell Corp., Los Angeles Div.	USAF Rocket Propulsion Laboratory	AF 04(611)-11203
Liquid Hydrogen Suction-Line Insulation	General Dynamics/ Convair	NASA Marshall Space Flight Center	NAS8-20167
Cooldown of Large-Diameter Liquid Hydrogen and Liquid Oxygen Lines	Aerojet General Corp.	NASA Lewis Research Center	NAS3-2555
Exploratory Development Work on Families of Welded Connections for Rocket Fluid Systems	North American Rockwell Corp., Los Angeles Div.	USAF Rocket Propulsion Laboratory	AF 04(611)-9892

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Contract No.	Duration	Funding	Scope of Work
NAS8-24941	1969-	$ 39,156	
NAS8-20156	1967-		
NAS8-20362	Jun 1966 Nov 1967	$186,700	Conduct an analytical and experimental program to define flow phenomena in the fill line and receiver tank of a cryogenic vehicle during propellant transfer. Develop techniques to eliminate flow oscillation in the fill line and implosion of the cryogenic tank.
AF 04(611)-11204	Jan 1966 Jan 1968		Continue the separable tube joint development program by improving aluminum-flanged connector design. Perform seal development and limited qualification testing to resolve problems of flange deformation in bobbin type aluminum seals. Use the results of this investigation to design an improved aluminum-flanged connector.
AF 04(611)-11203	Dec 1965 Nov 1968		Continue the permanent tube joint development program by exploring specialized technology areas in welded joint technology. Design machining and welding equipment concepts for installation of welded fittings in liquid rocket fluid systems from 1/4 to 16 inches diameter. Using the equipment developed, conduct machining and welding studies on 347 and 21 Cr-6Ni-9Mn stainless steel, 6061-T6 and 2219-T31 aluminum Inconel 718, and 6Al-4V and commercially-pure titanium.
NAS8-20167	Jun 1965 Aug 1966	$ 56,700	Conduct a program of analysis and testing to establish advanced insulation systems for liquid hydrogen feed lines on cryogenic space vehicles.
NAS3-2555	- Apr 1966		
AF 04(611)-9892	Apr 1964 Oct 1965		Develop a permanent tube joint connection system based on the automatic tungsten-inert-gas welding process. Develop prototype tooling, electrical equipment, and procedures for in-place parting, machining, and welding of tube segments. Verify the tooling, equipment, and procedures under simulated field use conditions.

Program	Contractor	Government Cognizance	Contract No.
Development of AFRPL Threaded Fittings for Rocket Fluid Systems	Battelle Memorial Institute	USAF Rocket Propulsion Laboratory	AF 04(611)-9578
Development of Mechanical Fittings	Battelle Memorial Institute	USAF Rocket Propulsion Laboratory	AF 04(611)-8176
Applied Research and Development Work on Families of Brazed and Welded Fittings for Rocket Propulsion Fluid Systems	North American Rockwell Corp. Los Angeles Div.	USAF Rocket Propulsion Laboratory	AF 04(611)-8177

Section 5 (Cont.)

Contract No.	Duration	Funding	Scope of Work
AF 04(611)-9578	Dec 1963 Nov 1965		Continue the separable connector development program by designing families of threaded-type tube connectors based on the so-called AFRPL concept evolved by Battelle on contract AF 04(611) 8176. Design elbows, tees, crosses, and unions of 347 stainless steel, 6061-T6 aluminum, and René 41. Conduct limited qualification tests.
AF 04(611)-8176	Apr 1962 Dec 1963		Study the problem of evolving reliable separable connectors for liquid rocket propulsion systems. Design, develop, and evaluate lightweight mechanical connectors that can effectively seal helium in missile system environments.
AF 04(611)-8177	Apr 1962 Feb 1964		Analyze the feasibility of using brazed or welded permanent fittings to attain reliable low-leakage connections in liquid rocket fluid systems. Fabricate test specimens in a range of materials and perform qualification testing in flight environments.

2

Program	Contractor	Government Cognizance	Contract No.
A. **Tankage Material Properties** (U)			
Evaluation of Stress Corrosion Cracking Susceptibility Using Fracture Mechanics Techniques	Aluminum Co. of America	NASA Marshall Space Flight Center	NAS8-21487
Correlation of Stress Wave Emission Characteristics with Fracture in Aluminum	Aerojet General Corp., Sacramento	NASA Marshall Space Flight Center	NAS8-21405
Investigation of Subcritical Flaw Growth Characteristics in Metal Tanks	Boeing Co., Aerospace Group	NASA Lewis Research Center	NAS3-12044
Experimental Study of Pop-In Behavior of Surface Flaw Type Cracks	Martin Marietta Corp., Denver Div.	NASA Manned Spacecraft Center	NAS9-9579
Investigation of Cyclic and Constant-Stress Flaw Growth Characteristics of 6Al-4V Titanium	Boeing Co., Aerospace Group	NASA Manned Spacecraft Center	NAS9-7637
Investigation of Deep Flaws in Thin Wall Tanks	Boeing Co., Aerospace Group	NASA Lewis Research Center	NAS3-10290
Cryogenic Alloy Screening	Martin Marietta Corp., Denver Div.	NASA Lewis Research Center	NAS3-11203
Weldment Flaw Enlargement Characteristics	General Dynamics/ Convair	NASA Lewis Research Center	NAS3-7951

PROPELLANT TANKAGE (U)

Contract No.	Duration	Funding	Scope of Work
NAS8-21487	1969-		
NAS8-21405	1969-		
NAS3-12044	Jun 1969-	$128,935	Conduct an analytical and experimental study to evaluate the mechanisms of subcritical flaw growth under conditions of sustained load, cyclic load, and conditions of sustained and cyclic loading.
NAS9-9579	Jun 1969-	$ 59,610	
NAS9-7637	May 1968	$ 69,940	
NAS3-10290	Jun 1967 Mar 1969	$267,500	Investigate the conditions controlling fracture instability and subcritical flaw growth in thin sections containing deep part-through flaws. Test 2219-T87 aluminum and 5Al-2.5 Sn Titanium specimens at room temperature, -320°F, and -423°F.
NAS3-11203	Aug 1967		Determine the fracture toughness and the mechanical properties of cryoformed 301 stainless steel, and 2021-T8E31 and 7007-T6E136 aluminum alloys and weldments. Determine the susceptibility of these materials to general corrosion and stress corrosion.
NAS3-7951	Jun 1966 Nov 1967	$ 85,000	Conduct a program of analysis and testing to establish the flaw enlargement characteristics of weldments in cryogenic space vehicle tankage.

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Program	Contractor	Government Cognizance	Contract No.
Investigation of Allowable Stresses for Thick-Walled Tanks	Boeing Co., Aerospace Group	NASA Lewis Research Center	NAS3-7993
Toughness Data on Materials at Cryogenic Temperatures	General Dynamics/ Convair	USAF Systems Command, Research & Technology Div.	AF 33(615)-3779
Extended Loading of Cryogenic Tanks	Boeing Co., Aerospace Group	NASA Lewis Research Center	NAS3-6290
Plane-Strain Flaw Growth in Thick Walled Tanks	Boeing Co., Aerospace Group	NASA Lewis Research Center	NAS3-4194
Growth of Plane-Stress Flaws in Thin-Walled Cryogenic Tank Materials	McDonnell Douglas Astronautics Co.	NASA Lewis Research Center	NAS3-4192
Low Temperature Fatigue Properties of Aluminum and Titanium Alloys	Martin Marietta Corp., Denver Div.	NASA Marshall Space Flight Center	NAS8-2631 and NAS8-11300
Physical and Mechanical Properties of Pressure Vessel Materials for Application in a Cryogenic Environment	General Dynamics/ Convair	USAF Systems Command, Aeronautical Systems Div.	AF 33(616)-7719
B. <u>Structural Analysis of Irregular Tank Shapes</u> (U)			
Study of Juncture Stress Fields Peculiar to Multicellular Propellant Containers	Lockheed Missiles & Space Co.	NASA Marshall Space Flight Center	NAS8-11480
Investigation of Juncture Stress Fields Peculiar to Multicellular Shell Structures	Lockheed Missiles & Space Co.	NASA Marshall Space Flight Center	NAS8-11079

Section 6 (Cont.)

Contract No.	Duration	Funding	Scope of Work
NAS3-7993	Mar 1966 Oct 1967	$163,000	Continue work initiated under NAS3-4194, by establishing the enlargement characteristics of small-flaw enlargement under cyclic loading conditions.
AF 33(615)-3779	Mar 1966-	$ 38,600	Perform mechanical properties testing on space vehicle propellant tankage alloys at cryogenic temperatures.
NAS3-6290	Jun 1965 Dec 1966	$161,010	Conduct analytical and experimental program to establish the propagation characteristics of surface flaws in 2219-T87 aluminum and 5Al-2.5 Sn titanium under conditions of sustained loading at cryogenic temperatures.
NAS3-4194	Jun 1964 Sep 1965	$206,030	Conduct program of analysis and testing to establish the enlargement characteristics of plane-strain flaws in thick-walled pressure vessels of 2219-T87 aluminum and 5Al-2.5 Sn titanium at 70°F, and -423°F.
NAS3-4192	Jun 1964 May 1966	$233,300	Conduct program of analysis and testing to establish the plane-stress flaw-propagation characteristics of thin-wall cryogenic tanks.
NAS8-2631 and NAS8-11300	Apr 1962- Jun 1965	$157,000	Conduct test program to determine properties of aluminum, titanium, and stainless-steel sheet alloys at cryogenic temperatures.
AF 33(616)-7719	Dec 1960- Jan 1962		Evaluate the toughness of stainless steel, aluminum alloys, and titanium alloy in sheet form and in complex welded joints at cryogenic temperatures. Test stainless steel alloys 301, 304, and AM-355; aluminum alloys 2014-T6, 5052-H38, and 5456-H343; and titanium alloy 5Al-2.5 Sn.
NAS8-11480	Nov 1964 Dec 1965	$ 97,900	
NAS8-11079	Jun 1963 Feb 1964		

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PROPELLANT ORIENTATION AND ACQ

Program	Contractor	Government Cognizance	Contract No.
A. Surface Tension Devices (U)			
Investigation of Space Storable Propellant Acquisition Devices	Martin Marietta Corp., Denver Div.	NASA Pasadena Office	NAS7-754
Low-Gravity Propellant Control Using Capillary Devices in Large Scale Cryogenic Tanks	General Dynamics/ Convair	NASA Marshall Space Flight Center	NAS8-21465
Experimental Investigation of Capillary Propellant Control Devices for Low-Gravity Environments	Martin Marietta Corp., Denver Div.	NASA Marshall Space Flight Center	NAS8-21259
Design of Advanced Propellant Management System	Martin Marietta Corp., Denver Div.	NASA Manned Spacecraft Center	
Study of Long Term Effects of High Energy Propellants on Fine Micronic Stainless Steel Used in Surface Tension Devices	Western Filter Co.	USAF Rocket Propulsion Laboratory	F 04611-68-C0064
Design, Fabrication, and Testing of Subscale Propellant Tanks with Capillary Tank Traps	Martin Marietta Corp., Denver Div.	NASA Marshall Space Flight Center	NAS8-20837
In-Space Propellant Orientation and Venting Experiments	Lockheed Missiles & Space Co.	USAF Rocket Propulsion Laboratory	AF 04(611)-11403

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NTATION AND ACQUISITION (U)

Contract No.	Duration	Funding	Scope of Work
NAS7-754	Jul 1969 Oct 1970	$150,000	Investigate the utility of current propellant acquisition devices (surface tension devices, bladders, diaphragms, settling rockets, start tanks) for application in a planetary spacecraft using OF_2/B_2H_6 propellants. Recommend combinations of acquisition devices, pressurization systems, and propellant tankage for this application. Complete detailed designs of the selected devices.
NAS8-21465	1968- 1969	$130,000	
NAS8-21259	1968- 1969		
	1968-	$ 85,000	Compile and evaluate data on potential propellant orientation and expulsion techniques including surface-tension, dielectrophoretic, bladder, bellows, and diaphragm devices. Compare performance data against requirements for an N_2O_4/50-50 propellant management system and select candidate systems for testing. Conduct subscale tests (including drop tower testing, as required) to evaluate the performance of these systems.
F 04611-68-C0064	- Jul 1968		
NAS8-20837	Jun 1967-	$ 39,850	
AF 04(611)-11403	Mar 1966- Apr 1968	$468,000	Design two propellant behavior experiments for flight use: (1) a 16-in. sphere with liquid nitrogen to study dielectrophoretic propellant orientation, and (2) a 12-in sphere with allyl alcohol to study surface-tension orientation techniques. Fabricate and check out the surface-tension experiment.

2

Program	Contractor	Government Cognizance	Contract No.
Propellant Orientation and Venting System for Zero-G Applications	Bell Aerosystems Co.	USAF Rocket Propulsion Laboratory	AF 04(611)-9901
Propellant Expulsion and Orientation Systems for Advanced Liquid-Rocket Propulsion Systems	Bell Aerosystems Co.	USAF Rocket Propulsion Laboratory	AF 04(611)-8200
B. <u>Positive Expulsion Bellows</u> (U)			
Cycle Testing of Cryogenic Expulsion Bellows to Evaluate Cycling Performance in Liquid Fluorine	Martin Marietta Corp., Denver Div.	NASA Lewis Research Center	NAS3-12053
Propellant Expulsion System for Missiles	Solar Div., International Harvester Co.	US Army Picatinny Arsenal	DAA 21-68-C0809
Cryogenic Metallic Positive Expulsion Bellows Evaluation	Martin Marietta Corp., Denver Div.	NASA Lewis Research Center	NAS3-12017
Metallic Expulsion Bellows Design	Bell Aerosystems Co.	NASA Pasadena Office	NAS7-385
Liquid Hydrogen Expulsion Bellows	Solar Div., International Harvester Co.	NASA Lewis Research Center	NAS3-11755

Section 7 (Cont.)

Contract No.	Duration	Funding	Scope of Work
AF 04(611)-9901	Jun 1964-	\$128,000	Develop a propellant orientation system based on the surface-tension principle. Analyze systems using concentric conical baffles and capillary tubes.
AF 04(611)-8200	Jun 1962- Jul 1963		Analyze and evaluate advanced propellant orientation and positive expulsion systems, including surface-tension, acoustic-force, foaming-plastic, dielectrophoretic, electrophoretic, electromagnetic, and magnetostatic orientation techniques.
NAS3-12053	Jun 1969-	\$ 79,126	Conduct a program of liquid fluorine expulsion cycle testing to evaluate the feasibility of such a device, using a 12-in.-diameter Minuteman III metallic expulsion bellows as the test article.
DAA 21-68-C0809	1968- 1969		Develop a 321 stainless steel positive expulsion system for use with missile liquid propulsion systems. Design the unit with an inner fuel bellows of 945 cu. in. volume and a 1563 cu. in. oxidizer volume between inner and outer bellows. Design for more than 500 cycles of operational lifetime with an expulsion efficiency of 98% for fuel and 90 % for oxidizer. Fabricate a prototype 14-in.-diameter by 35 in. and conduct pressure-cycle feasibility testing.
NAS3-12017	Jun 1968 Mar 1969		Conduct a test program to evaluate the performance of the 321 stainless steel LH_2 expulsion bellows fabricated by Solar Div., International Harvester Co., under Contract NAS3-11755. Perform expulsion-efficiency tests using water, and cycle and leak tests using liquid hydrogen.
NAS7-385		\$ 76,400	Perform an analytical program to design and develop improved metallic bellows for positive expulsion.
NAS3-11755	1968-		Develop a metallic positive-expulsion bellows for LH_2 service. Design the bellows for more than 500 cycles of operational lifetime with a capacity of 3.1 gallons (1.9 lb LH_2) and an expulsion efficiency of 98%. Fabricate a prototype, using 321 stainless steel construction, that is 15 inches in diameter by 15 inches long (including pressurization gas container).

Program	Contractor	Government Cognizance	Contract No.
Improved Welded Bellows Design	Battelle Memorial Institute	USAF Rocket Propulsion Laboratory	F 04611-68-C0031
Propellant Expulsion System for Spacecraft	Solar Div., International Harvester Co.	NASA Pasadena Office	NAS7-100
Subcritical Cryogenic Positive Expulsion System	Arde Inc.	USAF Aero Propulsion Laboratory	AF 33(615)-2827
Development of Analytical Techniques for Bellows and Diaphragm Design	Battelle Memorial Institute	USAF Rocket Propulsion Laboratory	AF 04(611)-10532
Low Pressure Cryogenic Storage and Expulsion System	Arde Inc.	USAF Aero Propulsion Laboratory	AF 33(657)-11314

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Contract No.	Duration	Funding	Scope of Work
F 04611-68-C0031		$165,000	
NAS7-100	1967- 1968		Develop a 321 stainless steel positive-expulsion bellows for use with hydrazine propellant. Design the bellows for more than 500 cycles of operational lifetime with a capacity of 2.5 gal and an expulsion efficiency of 98%. Fabricate a prototype 15 inches in diameter by 10 inches long (including pressurization gas container).
AF 33(615)-2827	Jun 1965 Mar 1968		Design, construct, and test a prototype liquid hydrogen tankage system capable of subcritical storage and positive expulsion of 500 lb of LH_2, using a collapsing metal bladder for expulsion. Deliver six test articles to AFAPL.
AF 04(611)-10532	Mar 1965 Mar 1968		Conduct an analytical and experimental program to define the characteristics of metallic bellows and diaphragms for use in aerospace plumbing systems (but not positive-expulsion applications). Conduct a literature search and an industry survey to establish the current state of the art. Establish analytical design procedures. Develop improved stress analysis procedures. Conduct laboratory verification of spring rates, effective areas, vibration response, and fatigue life for representative formed and welded bellows and diaphragms.
AF 33(657)-11314	Jun 1963- Sep 1967		Design, fabricate, test, and evaluate 23-in.-diameter multicycling metallic bladders for the storage and positive expulsion of 20 lb of LH_2 from a spherical tank. Fabricate test specimens and run expulsion tests in water, LN_2, and LH_2. Deliver test specimens to AFAPL.

2

Program	Contractor	Government Cognizance	Contract No.
Liquid Propellant Thermal Conditioning System, Testing	Lockheed Missiles & Space Co.	NASA Lewis Research Center	NAS3-12033
Liquid Hydrogen Mixer Unit	Garrett Corp., AiResearch Mfg. Co.	NASA Lewis Research Center	NAS3-11208
Vent-Free Fluorine Feed System	Martin Marietta Corp., Denver Div.	USAF Rocket Propulsion Laboratory	F 04611-67-C0044
Liquid Propellant Thermal Conditioning System	Lockheed Missiles & Space Co.	NASA Lewis Research Center	NAS3-7942
Zero-Gravity Liquid/Vapor Separators	General Dynamics/ Convair	NASA Marshall Space Flight Center	NAS8-20146
Advanced Valve Technology	TRW Systems Group	NASA Pasadena Office	NAS7-107

ROPELLANT CONDITIONING (U)

Contract No.	Duration	Funding	Scope of Work
NAS3-12033	Jan 1969- Jul 1970	$320, 700	Perform additional analysis and testing on the liquid propellant thermal conditioning unit developed on Contract NAS3-7942. Conduct tests with unit installed in 110- and 41.5-in.-diameter LH_2 tanks to observe scaling effects and unit operating characteristics in LH_2, GH_2, and GHe. Analyze the role of a thermal conditioning unit aboard a cryogenic spacecraft on an unmanned Mars mission.
NAS3-11208	1968-	$118, 400	Develop a mixer unit for submerged operation in LH_2. Design mixer to use a DC brushless motor. Fabricate a prototype and test in a liquid hydrogen dewar.
F 04611-67-C0044	Mar 1967- Mar 1968	$257, 000	Analyze, design, fabricate, and test a fluorine tank thermal control system for F_2/H_2 space vehicles that uses the heat capacity of vented hydrogen to maintain the fluorine tank in a nonvented condition during flight. Apply chosen system to two existing stainless steel tanks for testing with LN_2 and LH_2 in an AFRPL space flight simulator. Assist in test operations and data reduction.
NAS3-7942	Jan 1966- Nov 1968	$208, 100	Define, develop, produce, and test a liquid hydrogen thermal conditioning system capable of serving as a combined zero-g vent system and open-loop refrigeration system for future cryogenic space vehicles with long flight durations.
NAS8-20146	June 1965-	$235, 630	Analyze techniques for hydrogen liquid/vapor separation in zero g. Design, develop, and demonstrate a system based on liquid withdrawal, vaporization, and venting.
NAS7-107	Feb 1962-		Conduct a broad-based development program to advance the state-of-the-art of valves and associated systems used in spacecraft liquid propulsion systems (cryogenic and storable), including the feasibility testing of a liquid hydrogen zero-g vent system.

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Program	Contractor	Government Cognizance	Contract No.
Pressure Sensing Control	McDonnell Douglas Astronautics Co.	NASA Lewis Research Center	NAS3-13310
Space Storable Oxidizer Valve	Aerojet General Corp.	NASA Lewis Research Center	NAS3-12035
Space Storable Oxidizer Valve	McDonnell Douglas Astronautics Co.	NASA Lewis Research Center	NAS3-12029
Liquid Fluorine Feed System	McDonnell Douglas Astronautics Co.	NASA Lewis Research Center	NAS3-11195
Liquid Fluorine Shutoff Valve Development Program	McDonnell Douglas Astronautics Co.	USAF Rocket Propulsion Laboratory	F 04611-67-C-0072
Liquid Fluorine Shutoff Valve Development Testing	McDonnell Douglas Astronautics Co.	USAF Rocket Propulsion Laboratory	F 04611-67-C0064
Development and Demonstration of Criteria for Liquid Fluorine Feed System Components	McDonnell Douglas Astronautics Co.	NASA Headquarters and Lewis Research Center	NASw-1351
Liquid Fluorine Pre-Valve	J. C. Carter Co.	USAF Rocket Propulsion Laboratory	AF 04(611)-10925

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E FLUORINE SYSTEMS (C)

ontract No.	Duration	Funding	Scope of Work
3-13310	Jul 1969- Sep 1970	$173, 500	Develop a cryogenic pressure sensing control device for use on a spacecraft propulsion module using either LF_2/LH_2 or flox/methane propellants. Fabricate two test articles and perform functional, environmental, and fluorine-compatibility tests.
3-12035	Mar 1969-	$124, 745	Develop a flight-type fill-and-drain valve for service with liquid fluorine and other space-storable oxidizers. Design the valve using a sphere/cone poppet concept. Fabricate a prototype, and conduct fluorine compatibility testing.
3-12029	1969-		Develop a flight type fill-and-drain valve for service with liquid fluorine and other space-storable oxidizers. Design the valve using a flat-on-flat poppet concept. Fabricate a prototype, and conduct fluorine compatibility testing.
3-11195	Jun 1967-		Continue liquid fluorine feed system component development initiated on Contract NASw-1351. Test flow loops containing filters and explosively-actuated valves.
4611-67-C-0072	Apr 1967- Apr 1969	$232, 300	Design, fabricate, and test a 3-in.-diameter pneumatically-actuated, in-line main engine shutoff valve for liquid fluorine service in a space propulsion system. Fabricate three valves, and test first in LN_2 and then in LF_2.
4611-67-C0064	Jan 1967-	$ 49, 275	Conduct liquid fluorine compatibility, leakage, and cycle testing of a tank-mounted LF_2 prevalve developed for AFRPL by the J. C. Carter Company on Contract AF 04(611)-10925.
w-1351	Dec 1965 Oct 1967	$604, 498	Conduct a program of research and testing to establish and demonstrate design criteria applicable to feed system components for space propulsion systems using liquid fluorine oxidizer. Conduct liquid fluorine cold flow tests on flightweight components (vent/relief and fill/drain valves) modified from LOX to LF_2 service. Publish a fluorine systems handbook.
04(611)-10925	Aug 1965- Oct 1967		Develop a tank-mounted prevalve for liquid fluorine service in a space vehicle. Design the valve for pneumatic actuation using a coaxial poppet. Fabricate a 2-in.-diameter prototype.

CONFIDENTIAL

Program	Contractor	Government Cognizance	Contract No.
Remotely-Actuated Quick Disconnect for Liquid Fluorine Service	McDonnell Douglas Astronautics Co.	USAF Rocket Propulsion Laboratory	AF 04(611)-10798
FLOX Atlas Program	General Dynamics/ Convair	NASA Lewis Research Center	NAS3-3228 and NAS3-3245 (Subtasks)

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Section 9 (Cont.)

Contract No.	Duration	Funding	Scope of Work
AF 04(611)-10798	Jun 1965-1967	$ 258,000	Design, fabricate, and test a 2 in.-diameter remotely-actuated quick-disconnect coupling suitable for launch service with space vehicles using fluorine-containing oxidizers.
NAS3-3228 and NAS3-3245 (Subtasks)	Sep 1963-Sep 1965	$1,100,000	Conduct a program of analysis and testing to determine the feasibility of substituting liquid oxygen/liquid fluorine mixtures for liquid oxygen on the Atlas launch vehicle. Test the compatibility of existing Atlas components (e.g., tankage, boiloff valve) with Flox. Establish the atmospheric diffusion characteristics of Flox.

2

Appendix B

PROPOSED SPECIFICATIONS FOR REUSABLE PROPULSION COMPONENTS AND FEED SYSTEM

To achieve reusability without excessive redundancy of parts means that each component must be highly reliable in itself. A necessary step in achieving high reliability components is a careful review of current spacecraft component specifications and their updating to reflect the much more stringent requirements imposed by reusability. As an indication of the kind of changes necessary, two particular military specifications have been revised to incorporate such requirements. The selected specifications are

MIL-C-27410	Components, Rocket Propulsion Fluid System, General Specification for
MIL-P-27409	Propellant Feed System, Rocket Propulsion General Specification for

The modified specifications are presented herein. The requirements presented in these modifications are based on current experience and modified with calculated data where necessary. As such, numerical values quoted should be considered preliminary.

NOTE TO READER

No classified material is contained in this appendix.

PROPOSED GENERAL SPECIFICATION FOR ROCKET PROPULSION FLUID SYSTEM COMPONENTS

1. SCOPE

1.1 Scope. This specification covers the requirements and instructions for preparation of the manufacturer's specification for all components of a rocket propulsion system which control the pressure or flow of ullage, gas, pressurizing gas, propellants, combustion products, or hydraulic fluid. Specifically excluded from this specification are tankage, turbo machinery, injectors, thrust chambers, nozzles, and gas generators. New or modified paragraphs of MIL-C-27410 dated 15 November 1966 have been marked by enclosing the paragraph number within a box, and an asterisk in front.

2. APPLICABLE DOCUMENTS.

2.1 The following documents of the issue in effect on date of invitation for bids or request for proposal, form a part of this specification to the extent specified herein.

SPECIFICATIONS

Military

MIL-P-116	Preservation, Methods of
MIL-D-1000	Drawings, Engineering and Associated Lists
MIL-D-4040	Solenoid, Electrical, General Specification For
MIL-E-5272	Environmental Testing, Aeronautical and Associated Equipment, General Specification For
MIL-C-6021	Castings, Classification and Inspection of
MIL-I-6181	Interference Control Requirements, Aircraft Equipment
MIL-P-6906	Plates, Identification
MIL-S-7742	Screw Threads, Standard, Optimum Selected Series; General Specification For
MIL-W-8160	Wiring, Guided Missile, Installation of General Specification For
MIL-E-8189	Electronic Equipment, Guided Missiles, General Specification For

MIL-W-8160	Wiring, Guided Missile, Installation of, General Specification For
MIL-E-8189	Electronic Equipment, Guided Missiles, General Specification For
MIL-S-8879	Screw Threads, Controlled Radius Root with Increased Minor Diameter: General Specification For
MIL-M-9950	Missile Component, Liquid Oxygen Nitrogen Gaseous Oxygen, Instrument Air, Helium and Fuel Handling Systems, Cleaning and Packaging for Delivery
MIL-N-25027	Nut, Self-Locking, 250 Deg. F, 450 Deg. F, and 800 Deg. F, 125 KSI FTU, 60 KSI FTU, and 30 KSI FTU
MIL-E-25366	Electric and Electronic Equipment and Systems, Guided Missiles, Installation of, General Specification For
MIL-H-25475	Hydraulic Systems, Missile, Design, Installation Tests, and Data Requirements, General Requirements For
MIL-P-27407	Propellant, Pressurizing Agent, Helium
*	Propellant Feed System, Rocket Propulsion, Proposed Specification For

STANDARDS

Military

MIL-STD-129	Marking for Shipment and Storage
MIL-STD-130	Identification Marking of U. S. Military Property
MIL-STD-143	Specifications and Standards Order of Precedence for the Selection of
MIL-STD-446	Environment for Electronic Parts, Tubes and Solid State Devices
MIL-STD-454	Standard General Requirements for Electronic Equipment
MIL-STD-785	Reliability Program for Systems, Subsystems, and Equipment
MIL-STD-810	Environmental Test Methods for Aerospace and Ground Equipment
MS 33540	Safety Wiring, General Practices For
MS 33588	Nuts and Plate Nuts, Self-Locking, Aircraft Design and Usage Limitations of

PUBLICATIONS

Air Force – Navy Aeronautical Bulletins

No. 343	Specifications and Standards Applicable to Aircraft Engines and Propellers, Use of
No. 438	Age Controls of Age-Sensitive Elastomeric Items
No. 445	Engineering Changes to Weapons, Systems, Equipment, and Facilities

3. REQUIREMENTS

3.1 General.

* 3.1.1 General specification. A general specification conforming to the requirements specified herein shall be prepared by the contractor or manufacturer for approval by the procuring activity (6.3.8).

3.1.2 Pre-production. Prior to initiating production of the component for use in flight systems, components shall have successfully completed the Qualification tests (4.2.2).

3.1.3 Changes. The contractor shall notify the procuring activity of any proposed design changes to the component as defined in the general specification. Following successful completion of the Qualification tests, no change shall be made except when such changes are made in accordance with ANA Bulletin No. 445 or procurement activity requirements, as applicable. Approval of changes does not relieve the contractor from full responsibility for the effects of the changes on the component performance.

3.1.4 Selection of specifications and standards. Specifications and standards for necessary commodities and services not specified herein shall be selected in accordance with MIL-STD-143.

3.2 Materials and processes. The materials and processes used in the manufacture of components shall conform to the applicable specifications, in accordance with paragraph entitled "Material Specifications" of ANA Bulletin No. 343 and shall be selected from the list of materials and processes approved by the procuring activity for the specific application.

3.2.1 Metals. Metals shall be compatible with fluids (3.4.8), fluid vapors, fluid decomposition products, products of combustion, where applicable, and with environments to which subjected. In addition they shall not deteriorate in normal usage and storage. The use of dissimilar metals, especially brass, copper, or steel in contact with aluminum alloy, shall be avoided where practicable. Protection of dissimilar metal combinations shall be in accordance with MIL-STD-454, Requirement 16.

3.2.2 Rubbers, plastics, and elastomers. Rubbers, plastics, and elastomers shall be compatible with fluids (3.4.8), fluid vapors, fluid decomposition products, products of combustion where applicable, and with environments to which subjected. Age control of synthetic rubber parts shall be in accordance with ANA Bulletin No. 438.

* 3.2.3 Lubricants. All components near surfaces in contact with system fluids shall not require additional lubrication other than the system fluid itself. Lubricants used during periodic maintenance and service shall be compatible with fluids, fluid vapors, fluid decomposition products, products of combustion where applicable, and with environments to which subjected.

* 3.2.4 Finishes. All finishes, surface treatments, platings, coatings, or paints shall be compatible with fluids (3.4.8), fluid vapors, decomposition products, and products of combustion where applicable, and with the environments to which they are subjected.

* 3.3 Performance Characteristics. The performance characteristics, including the intended application of the component, and the fluid interactions are specified in Table 3-1. The following characteristics are included as a minimum.

3.3.1 Operating attitude. Components shall be capable of meeting the performance characteristics specified when operated in any attitude the component may be exposed to during the operating life (6.3.6).

* 3.3.2 Life characteristics. The component operating and storage life (6.3.12) are shown in Table 3-1.

* TABLE 3.1

PERFORMANCE CHARACTERIS

Component	Application (3.3)	Attitude (3.3.1)	Life (3.3.2)		Leakage (3.3.3)		Fluid Spillage (Disconnect) (3.3.9.1)	Fluid Flow		Act	
			Operating (3.3.2.2)	Storage (3.3.2.1)	External	Internal		Rate (3.3.4)	Press. Drop (3.3.4)	Mode	R

1

TABLE 3.1

NCE CHARACTERISTICS

uid Flow		Actuation (3.3.5)			Power (3.3.6)		Stability (3.3.7)				Pressure (3.4.4)		
te .4)	Press. Drop (3.3.4)	Mode	Response	Repeatability	Type	Range	Over Shoot	Under Shoot	Damping	Dead Band	Working	Proof	Burst

2

* 3.3.2.1 Storage life. All rocket fluid components shall have a minimum required storage life (non-operating) of 5 years, with the exception of those items identified in Section 3.2.2. The internal and external environmental extremes to be encountered during storage are as specified in 3.4.6.1.1. When the component is in contact with propellants or actuating fluids during storage, it shall not degrade these fluids.

* 3.3.2.2 Operating life. The operating life of the component is as specified in Table 3.1, and includes anticipated time for acceptance testing, system checkout tests, and propulsion system operation.

* 3.3.3 Leakage. The maximum component leakage, both external and internal, with the fluid medium at the operating pressure shall not exceed those specified in Table 3.1. In those applications where fuel and oxidizer are controlled in a single component, seal leakage shall be ducted such that mixing of fuel and oxidizer within the component is precluded.

* 3.3.4 Flow characteristics. The component flow characteristics are as specified in Table 3.1 The flow rate versus pressure drop at the normal operating temperature and pressure of the component shall be as specified in Table 3.1 for the various percentages of maximum flow or flow rate versus percentage maximum flow position of the control element at given temperature and pressure drop.

* 3.3.5 Activation. The component shall be activated as specified in Table 3.1 and response characteristics specified from application of activation signal to fully open and closed conditions. The repeatability of the response characteristic, the time from first valve movement to fully open or closed position shall be as specified.

* 3.3.6 Power. The power range of the component for which the component must meet the activation requirements over the operating temperature range are shown in Table 3.1. The tolerance and characteristics of the power available to the component and the maximum power to which the component may be subjected shall be specified in the general specification.

* 3.3.7 Stability characteristics. Stability characteristics shall be as specified in Table 3.1 for overshoot, undershoot, damping, and dead band conditions.

* 3.3.8 Filtration. The specified fluid shall be filtered through a 10-micron nominal and 40 micron absolute filter prior to service use or test of the component. The fluid medium shall conform to the specified fluid specification.

* 3.3.9 Draining. Draining provision shall be incorporated into the component so that propellants cannot be trapped during unloading operations in ground procedures. If the component is specified for cryogenic service, design provisions are to be included for relieving pressure from any trapped compartments.

* 3.3.9.1 Disconnect spillage. The maximum spillage which may occur for a disconnect component during connect or disconnect operations is as shown in Table 3.1.

* 3.4 Design. Components shall be designed to provide high inherent reliability (6.3.10), permit use of proven manufacturing processes and positive inspection at each level of manufacture, have low susceptibility to assembly errors, minimize variation of performance caused by manufacturing tolerances, and minimize weight while achieving the performance characteristics (3.3) specified, when subjected to the expected operating environment.

* 3.4.1 Misalignment. Maximum allowable interface loads on the component caused by axial lateral and angular misalignments in the tubing or the support structure under the most severe environmental condition including any influences from deflection or misalignment accommodation features are as specified.

3.4.2 Standards. MS or AN standard parts shall be used wherever they are suitable for the purpose, and shall be identified by their standard part numbers. The use of nonstandard parts will be acceptable only when standard parts have been determined to be unsuitable. MS and AN design standards shall conform to applicable standards in accordance with paragraph entitled "Utility Parts Standards" in ANA Bulletin No. 343.

3.4.3 Special tools. The design of system components shall be such that disassembly and replacement of parts required in operational maintenance shall be accomplished without the use of special tools which are unique to the component.

* 3.4.4 Pressure. The working (6.3.13) proof (6.3.9) and burst pressure (6.3.2) are as specified in Table 3.1. The proof and burst pressures shall be at least 1.5 and 2 times the working pressure, respectively, and they shall be adjusted for the differences in test temperature and maximum working temperature to account for the changes in properties.

* 3.4.5 Installation characteristics. Mounting details: overall dimensions; location, size and type of plumbing and electrical connections; servicing clearances, weight, center of gravity and flow directions are specified on envelope dwg. Fig. 3.1. All dimensions not specifically marked are the responsibility of the component manufacturer.

* 3.4.6 Environment. The ranges of environmental conditions the component is required to endure are defined herein. Although each condition is defined separately, some will be imposed simultaneously upon equipment in actual operation, as stated herein.

* 3.4.6.1 Temperature. The equipment shall be able to withstand the following temperature conditions.

* 3.4.6.1.1 Transportation and storage temperature. Equipment ready for shipment may encounter temperatures in the range of minus 65 degrees Fahrenheit to plus 160 degrees Fahrenheit during transportation and storage. Equipment performance shall not deviate beyond those specified in 3.3 after equipment exposure to these conditions.

* 3.4.6.1.2 Ground conditions. Equipment may encounter the extreme temperature conditions specified below prior to countdown. Equipment performance shall not deviate beyond the specified limits during or after equipment exposure to these conditions.

a. Equipment not operating: this range is not applicable when adequate shelter or environmental control is provided.
   (1) A minimum temperature of minus 65 degrees Fahrenheit for six hours.
   (2) Plus 125 degrees F ambient still air with a direct solar irradiation flux of 360 British thermal units (BTU) per hour per ft^2 for 6 hours.
   (3) Plus 160 degrees F without solar irradiation for 6 hours.
b. Equipment operating under conditions other than countdown:
   (1) Ambient still air from plus 20 to plus 120 degrees F.
   (2) Atmospheric pressures from 710 to 810 millimeters (mm) mercury Hg.
   (3) Relative humidities of up to 99 percent.

* **Fig. 3.1 Envelope Dwg. (3.4.8)**

This drawing should present the following data, in graphic or tabulated form:

- Physical envelope dimensions
  Clearance requirements
  Allowable weight
- Center-of-mass
- Flow direction, if appropriate
- Electrical interface
- Mechanical interface

* 3.4.6.1.3 Countdown conditions. The components will not be temperature controlled during countdown, and internal component temperatures will equal or approach the temperature of the operating fluid. Temperature of components mounted on or near external structure may vary between -5°F minimum to +160°F maximum.

* 3.4.6.1.4 Ascent, orbital, and entry conditions. The effective temperature range of the component environment will be dependent on proximity to the vehicle external surfaces. The following temperatures (°F) will be expected:

	Ascent	Orbit		Entry
	Max	Min	Max	Max
Heat Shield Temp (°F)	+1500°	-100°	+200°	+2200°
Structure Temp (°F)	+250°	-100°	+200°	+250°

* 3.4.6.1.5 Operating fluid effects. Component performance will not deviate beyond the specified limits during and after component internal exposure to cryogenic temperatures equal or approaching the temperature of the operating fluid.

* 3.4.6.2 Pressure. The component will experience the following pressure conditions.

* 3.4.6.2.1 Transportation and storage pressures. The component performance shall not deviate beyond the specified limits after equipment exposure to atmospheric pressures in the range of 87 to 810 mm Hg during transportation and storage.

* 3.4.6.2.2 Pressure in flight. The equipment shall operate within its specified limits at any pressure above 10^{-13} mm of Hg during flight. Equipment performance shall not deviate beyond the specified limits as a result of pressure gradients during altitude changes. The following atmospheric pressures correspond approximately to the flight phases and are given for design reference.

Phase	Estimated Pressure Range (mm Hg)
Boost	810 to 10^{-6}
Orbit	10^{-6} to 10^{-10}
Entry	10^{-6} to 810

* 3.4.6.3 Explosive atmosphere. Components intended to operate in areas where a possibility of an ambient explosive atmosphere exists shall operate in such an atmosphere without causing explosion.

* 3.4.6.4 Fungus. Component performance shall not deviate beyond the specified limits after equipment exposure to high humidity which is conductive to rapid fungus growth. Equipment whenever practical, shall be fabricated from materials that will not support the growth of fungus.

* 3.4.6.5 Sand and dust. Component performance shall not deviate beyond the specified limits after component exposure to sand and dust concentrations encountered during transportation and at desert or seashore locations.

* 3.4.6.6 Salt fog. Component performance shall not deviate beyond the specified limits after equipment exposure to the salt atmosphere conditions encountered during transportation and at launch base seashore locations.

* 3.4.6.7 Rain. Component performance shall not deviate beyond the specified limits after component exposure to rainfall in the amount of 4 inches per hour as measured by a U. S. Weather Bureau Gauge.

* 3.4.6.8 Corrosive atmosphere. Component performance shall not deviate beyond the specified limits during and after component exposure to corrosive atmospheres containing propellant fumes and those gases or vapors (e.g., ozone) that may be present during operation of the component at test bases or launch sites.

* 3.4.6.9 Shock. Components will be subject to the following shock environments.

* 3.4.6.9.1 Transportation and handling. Components may experience the following shock conditions during ground handling. Performance shall not deviate beyond the specified limits after equipment exposure to this shock form on each of the three axes. The shock form shall be a sawtooth pulse with a 30 g peak, having a 10 ±1 millisecond rise time and a 1 ±0.1 millisecond decay time.

* 3.4.6.9.2 Flight. Components may experience the following shock conditions during flight. Performance shall not deviate beyond the specified limits during and after equipment exposure to these shock forces.

Ascent shock (truncated sawtooth curve)

Rise to peak – 200 ±20 milliseconds
Dwell at peak – 20 ±2 milliseconds at 14 g's
Decay to zero – 40 ±4 milliseconds

The peak value of 14 g's may occur on all three axes.

* 3.4.6.9.3 Pyrotechnic shock. Components may also be subjected to shocks induced by pyrotechnic devices during events such as booster separation or fairing separations. Only susceptible components shall be qualified. Components considered susceptible to the pyrotechnic shock environment includes the following: electrical equipment, electro-mechanical equipment, mechanical equipment containing delicate sub-assemblies, and mechanical components containing non-metallic elements such as ceramics, epoxies, phenolics, glass, and silicates. The performance of components subjected to this environment shall not deviate beyond the specified limits during or following exposure to the pyrotechnic shock responses listed.

* 3.4.6.10 Acceleration. Components operating or non-operating as applicable may encounter the acceleration forces shown below during ascent and reentry. Component performance shall not deviate beyond the specified limits during and after component exposure to the ultimate acceleration values shown below. Components intended to operate during the coast and orbit phases shall also operate with the specified performance limits at zero gravity.

	Longitudinal Axis	Normal Axis	Lateral Axis
Boost Phase	4.0 g	±0.25 g	±0.25 g
Orbit Phase	2.2 g	±0.25 g	±0.25 g
Reentry Phase	0.25 g	2.5 g	±0.25 g
Landing Phase	<1.0 g	±0.25 g	±0.25 g

* 3.4.6.11 Vibration during engine burn. Component performance shall not deviate beyond the specified limits during and after component exposure to the vibration levels encountered during the conditions of ground operation, boost phase, and reusable vehicle phase of engine operation. During the non-powered portion of the orbital phase, the vibration level for most equipment will be near zero.

Sinusoidal Vibration Frequency Range	Acceleration (g's zero to peak)
2 - 6.2 cps	1.1 - 10 g
6.2 - 198 cps	10 g
198 - 370 cps	10 to 32 g
370 - 2000 cps	32 g

Random Vibration Frequency Range	Power Spectral Density
5 - 20 cps	+9 dB
20 - 2000 cps	0.25 g^2/cps

* 3.4.6.12 Acoustic excitation. Component performance shall not deviate beyond the specified limits during and after equipment exposure to the acoustic excitation levels during ground firing, ascent, and entry as specified. Peak intensity occurs during liftoff and in the period of maximum aerodynamic forces on the vehicle.

* 3.4.6.13 Space radiation. The component may be subjected to the following types of radiation environments. Estimates of the most severe radiation doses are given below. Data on the new artificial radiation belt, have been included in these estimates. The half life of this new belt is not known but estimates indicate that this belt will persist for many years at altitudes of 2000 nm or more. All reusable vehicle missions will be subjected to much lower fluxes. Hence, dosages must be evaluated on the basis of individual mission objectives and launch dates.

a. Internal for an equivalent skin thickness of 0.1 inch aluminum

(1)	Integrated ionizing dose	3×10^8 roentgens/year
(2)	Maximum ionizing dose rate	10^5 roentgens/hr
(3)	Integrated proton flux	2×10^{12} protons/cm^2
(4)	Maximum proton flux (E >20 mev)	7×10^4 protons/cm^2/sec
(5)	Integrated electron flux	3×10^{16} electrons/cm^2/year
(6)	Maximum electron flux (E >1.6 mev)	10^9 electrons/cm^2/sec

b. Surface, for unshielded exposure:

(1)	Integrated ionizing dose	10^9 roentgens/year
(2)	Maximum ionizing dose rate	10^7 roentgens/hr
(3)	Integrated proton flux	3×10^{12} protons/cm^2/year
(4)	Maximum proton flux (E >1 mev)	10^5 protons/cm^2/sec
(5)	Maximum electron flux (E >1 kev	3×10^9 electrons/cm^2/sec

* 3.4.7 Contamination. Contamination levels that the component shall operate in shall be commensurate with the operating fluid medium. Maximum particle count shall not exceed 10 microns nominal and 40 microns absolute rating.

* 3.4.8 Fluids. The operating fluid shall be in accordance with the specified MIL-specification. The pressure and temperature range and flow rates are as specified in Table 3.1.

3.5 Construction.

3.5.1 Threaded connections and attachments.

3.5.1.1 Locking provisions. All threaded members such as nuts, screws, and bolts shall be provided with safety wiring or other acceptable means of locking. Any adjustments which may be provided shall be capable of being locked securely enough to prevent disturbance of setting under all service and test conditions. Self-locking nuts shall conform to MIL-N-25027 and shall be used in accordance with MS 33588. Safety wiring shall comply with the requirements of MS 33540. The use of staking and lock washers shall be avoided unless they can be shown to have superior characteristics to the more conventional methods and approval is obtained from the procuring activity.

3.5.1.2 Pipe threads. Pipe threads shall not be used on components.

3.5.1.3 Threads. Conventional straight screw threads shall conform to MIL-S-7742 or MIL-S-8879. Duplicate parts, differing only in thread form, shall not be permitted. Unless otherwise specified, threaded parts smaller than 0.164 inch diameter shall have threads in accordance with MIL-S-7742. When an allowance is required for application in elevated temperature, corrosive atmosphere, or other conditions which may cause thread seizure, this allowance shall be obtained by increasing the diameter of the internal threads.

3.5.2 Electrical devices. Components incorporating electrical devices shall conform to MIL-S-4040, MIL-W-8160, MIL-E-8189, MIL-E-25366, MIL-STD-446, and each electrical connector used on a component shall incorporate a ground return terminal.

3.5.3 Hydraulic devices. Hydraulic actuation devices shall conform to the applicable requirements of Table I and paragraph 3.y of MIL-H-25475. Hydraulic activation devices, which operate using the rocket engine's propellant as the working fluid, are excluded from the requirements of MIL-H-25475.

3.6 Reliability. The contractor shall include in the general specification the requirements for performing a detailed failure mode analysis. The failure mode analysis shall be used in designing the development and qualification tests and in reporting the test results. The general specification shall also include the manufacturing control and standards of MIL-STD-785. The contractor shall be responsible for establishing the reliability design reviews, reliability reporting procedures and reliability demonstration as specified in MIL-STD-785.

3.7 Interchangeability. All parts having the same manufacturer's part numbers shall be directly and completely interchangeable with each other with respect to installation and performance. Changes in manufacturer's part numbers shall be governed by the drawing number listed in MIL-D-1000. The use of non-interchangeable assemblies, i.e., lapped piston cylinder assemblies, shall be approved by the procuring activity and the assembly shall be given one part number.

3.8 Accessibility. Where practicable, component parts requiring routine service checking, adjustment, or replacement shall be made readily accessible for servicing without tear-down of the units, removal of any major part, component, or accessory. Where periodic or field adjustment is required, positive locking of the adjustment shall be included to effectively prevent unauthorized adjustment.

3.9 Identifying products. Components shall be marked for identification in accordance with MIL-STD-130.

3.10 Nameplate. Nameplate conforming to MIL-P-6906 shall be securely attached to the component, or the information may be electrochemically etched, in a suitable location on the component. In addition to marking required by MIL-STD-130, the following shall be included.

a. Manufacturers part number.
b. Serial number
c. Rating (i.e., working pressure, set point, etc.)
d. Date of acceptance.

3.11 Drawings and diagrams. Manufacturer's assembly and detail drawings shall conform to MIL-D-1000. A complete set of full size drawings and diagrams, together with the general specification, shall incorporate reduced size copies of the same drawings and diagrams in the body of the general specification and shall be prepared for the contractor by the manufacturer with the preproduction components.

3.12 Parts list. A manufacturer's parts list (6.3.7) shall be prepared for each unit and shall list, but not be limited to, such information as the unit nomenclature, manufacturer's part numbers, detail nomenclature, and numerical identification of each part.

3.13 Contamination control. Methods for cleaning and handling of each component and component element to assure that minimum cleanliness levels are compatible with propulsion system use shall be established. Minimum requirements for oxygen, nitrogen, air helium, and fuel systems shall be as specified in MIL-M-9950.

4. QUALITY ASSURANCE PROVISIONS

4.1 Responsibility for inspection. Unless otherwise specified in the contract or purchase order, the supplier is responsible for the performance of all inspection requirements as specified herein. Except as otherwise specified, the supplier may utilize his own facilities or any commercial laboratory acceptable to the Government. The Government reserves the right to perform any of the inspections set forth in the specification where such inspections are deemed necessary to assure supplies and services conform to prescribed requirements.

4.2 Classification of tests. The tests to be performed shall be classified as follows:

a. Development tests (4.2.1)
b. Qualification tests (4.2.2)
c. Quality Conformance tests (4.2.3)

4.2.1 Development tests. Development tests consist of all tests performed prior to qualification testing on the preproduction components.

4.2.2 Qualification tests.

4.2.2.1 Sampling instructions. Unless otherwise specified, each qualification test sample shall consist of a set of components of each manufacturer's part number upon which approval is desired. The number of components in each set shall be those deemed necessary by the procuring activity to perform the applicable tests as indicated.

One set of components shall have been tested by the manufacturer in accordance with this specification prior to being forwarded to the testing facility (each component shall be tested separately). The components shall be accompanied by one complete set of manufacturer's drawings, the component specification, the failure mode analysis, a parts list, and a complete test report showing the results of the contractor's tests. Samples shall be identified as required and forwarded to the testing facility designated in the contract.

4.2.2.2 Tests. The qualification of components shall consist of tests in Section 4.5 which are applicable to the particular type component. Any additional tests or more severe requirements may be specified. All qualification tests shall be specified in detail in the model specification.

4.2.3 Quality conformance tests. Quality Conformance testing of propulsion fluid system components shall consist of inspection and performance tests required to assure components meet the standards of the model specification. Quality Conformance test procedure shall be reviewed following successful completion of qualification to determine its adequacy. The Quality Conformance test procedures shall be specified in detail in the model specification.

4.3 Failures and retest of test samples.

4.3.1 Development tests. Failures encountered during the development testing shall be reported on tests of the preproduction versions of the complete component. The design changes shall also be documented and the failure and change referenced to the failure mode analysis.

4.3.2 Qualification tests. Failures encountered during the Qualification testing shall be reported and the failure referenced against the failure mode analysis. If a component failure is encountered, a detailed failure analysis shall be performed to determine the cause of failure and necessary corrective action. Components may be reworked to comply with the corrective action. Following the corrective action the series of tests for the components shall be started again from the beginning. If a design change is required in the component or one of its elements, the design change shall be reported with the effects of the change on the failure mode analysis. A design change shall require restarting qualification for the component with components incorporating the design change unless waiver of retest is granted by the procuring activity.

4.3.3 Quality conformance test. Failure of any component to pass the Quality Conformance test shall be cause for rejection of all components in the lot presented. An immediate investigation shall be made to determine the cause of performance degradation below the qualification standards. If a design change is required in the component or one of its elements, the modified design shall be requalified. If a variation in a manufacturing process caused the failure and closer control of the process or a different process is required to produce the required quality, all components of the lot will be reinspected to assure they are of acceptable quality. Inability to adequately, inspect the parts to determine if they are of an acceptable quality shall cause their rejection and replacement.

4.4 Test conditions. Unless otherwise specified, the following test conditions shall apply during the tests performed in accordance with this specification.

4.4.1 Cleaning. Unless otherwise specified, the test system shall be cleaned and passivated to the approved standards established for the propulsion system. All test fluids shall be filtered to assure that the contamination level at the component does not exceed the propulsion system cleanliness specification.

* 4.4.2 Temperature pressure and relative humidity. Unless otherwise specified, all tests shall be conducted at a temperature of 60° to 90°F (15.6° to 32.2°C), at an atmospheric pressure of 710 to 810 mm Hg and relative humidity not more than 90 percent.

4.4.3 Attitude. Unless otherwise specified, all tests shall be conducted with the component installed in the normal operating attitude.

4.4.4 Test fluid. The test fluid for each test shall be specified in the general specification.

* 4.4.5 Tolerances. Unless otherwise specified herein, the maximum allowable tolerances on test conditions during environmental testing shall be as follows:

a.	Temperature (°F)	±5° or 3 percent, whichever is greater;
b.	Barometric Pressure (mm Hg)	900 mm to 1 mm, ±10 percent 1 mm to 10^{-4} mm, ± factor of 2 10^{-4} mm to 10^{-7} mm, ± factor of 5 below 10^{-7} mm, ± an order of magnitude

c.	Relative humidity (RH)	±5 percent of RH,
d.	Vibration amplitude (g or inches)	±10 percent,
e.	Vibration frequency (cps)	±2 percent or one cps, whichever is greater;
f.	Standard Shock (g and sec)	±10 percent
g.	Acceleration (g)	±5 percent (at reference point)
h.	Random Vibration Spectral density (*) (g^2/cps)	±10 percent in any one-third octave band (lowest one-third octave band center frequency is 25 cps); however, ±20 percent for any 50 cps band from 20 to 225 cps is acceptable
i.	Random Vibration rms acceleration (*)	±10 percent
j.	Random Vibration instantaneous peaks (*)	Limited to three times the rms acceleration,
k.	Sound pressure level overall (dB)	±2 dB,
l.	Sound pressure level in any one octave (dB)	±3 dB,
m.	Pyrotechnic Shock (g x cps)	±10 percent

(*) The tolerances for h, i, and j, refer only to the accuracy of the test setup, and represent the minimum standard. Tighter tolerances may be specified in the individual equipment specification, as required.

4.5 Tests and test methods. The contractor shall list and describe in detail the tests, test procedure, and test system design for the Qualification and Quality Conformance tests. In addition, required instrumentation and allowable tolerances shall be specified in the general specification. All instrumentation upon which the accuracy of the test results depends shall be calibrated frequently enough to ensure the accuracy required by the general specification. Calibration records shall be maintained and shall be made available to the procuring activity upon request. The instrumentation accuracy shall be subtracted from the allowable performance tolerance of the measurement to determine the as measured tolerance.

4.5.1 Examination. The units shall be examined to assure compliance with the requirements of this specification. Such inspection shall include but shall not be limited to the requirements of identification marking, physical measurement, weight, continuity of required wiring, proper wiring, finish, freedom from damage, and maintenance of the required standard of workmanship. Radiographic plates for all castings, in accordance with MIL-C-6021, shall be presented with the unit at the time of acceptance inspection. These plates shall be identifiable to the particular unit.

4.5.2 Strength.

4.5.2.1 Proof pressure. The proof pressure shall be specified in Section 3.4.4 and shall be applied for not less than three (3) minutes. Where multizone components are being pressurized, the proof pressure sequency shall simulate system operation. Where the pressure ratio between zones will vary during operation, two or more tests may be required to simulate maximum pressure differentials across various sections. Evidence of permanent deformation shall be cause for rejection.

4.5.2.2 Burst pressure. The component shall have the burst pressure as specified in Section 3.4.4 applied and maintained for a period of not less than three (3) minutes. The pressure shall be applied at all pressure ports (where the burst pressure varies between parts on a component the appropriate burst pressure will be applied to each part simultaneously). The units shall not burst. The method of applying the pressure shall be specified. Permanent set may occur but subsequent functioning of the units is not required. If practicable, pressure shall then be increased above the specified burst pressure until failure occurs. Failure pressure shall be recorded.

* 4.5.2.3 Surge pressure. The component shall have the working pressure specified in Table 3.1. Applied and repeated for ten (10) cycles. Each cycle shall be counted as from the zero pressure to the working pressure, momentarily held and then reduced to zero pressure. After operation of this test, the component shall not show any evidence of permanent deformation or any deviation in performance.

4.5.2.4 Mechanical load. With the component mounted in the normal manner and operating at maximum working pressure, it shall be subjected to the most severe tension, compression bending, and torsional loads that would be expected to occur in service. There shall be no evidence of failure, malfunction, permanent distortion or unsatisfactory leakage as a result of this test.

4.5.3 Leakage. Tests shall be conducted at pressures up to the working pressure to determine both internal and external leakage using the Helium, MIL-P-27407 or other fluid approved by the procuring activity (3.3.3).

4.5.3.1 Internal. The leakage shall be measured at five equal pressure increments from ambient to working pressure using an instrument with an accuracy and precision at least one order of magnitude lower than the allowable leakage for the component. For components with more than one outlet port, the total internal leakage will be measured. For components with more than one outlet port, the total internal leakage will be measured. For components that must seal against flow in either direction, a reverse flow leakage test will also be performed.

* $\boxed{4.5.3.2}$ External. The external leakage shall be measured at five equal pressure increments from ambient to working pressure using an instrument with an accuracy and precision at least one order of magnitude lower than the allowable leakage for the component. Components within hermetically sealed containers which are to be operated in the space environment shall be leakage tested as follows:

a. The container shall be purged with helium and then charged to the required pressure before being sealed.

b. The sealed container shall then be placed in a suitable high-vacuum test chamber and elevated to its maximum operating temperature.

c. The chamber shall then be evacuated to 10^{-3} mm Hg as quickly as possible.

d. A suitable helium leakage detector shall be used for measurements.

e. For containers with equipment that must be operational for more than a one-day period in orbit, the test chamber shall be maintained below 10^{-3} mm Hg for a minimum of 4 hours.

f. The test item shall be maintained at its maximum specified operating temperature during this 4-hour period.

g. The leakage rate shall not exceed that amount specified in each respective detailed equipment specification.

4.5.4 Functional.

4.5.4.1 Pressure drop. This test shall be applicable to all components whose function in the propulsion system is such as to affect the total pressure drop of the propulsion system. The pressure drop test shall be conducted over a range of temperature and flow rates that completely covers the design capacity of the unit, and sufficient data shall be recorded to permit the plotting of curves. The pressure drop graph shall show the pressure drop of the component using the test fluid, ΔP observed, and where a substitute fluid is used, the pressure drop of the component corrected to the propulsion system fluid.

4.5.4.2 Pressure control. Pressure control tests shall measure the stability characteristics for pressure control components. The start transients, steady state, lock up (6.3.4) and droop (6.3.3) characteristics or the crack, reseat, and flow stability shall be determined over a range of pressures and flow rates that completely covers the design capacity of the unit. The test system used for this test shall dynamically simulate the propulsion system installation. The instrumentation used for this test shall have a frequency response at least two times the minimum frequency response specified for the component in the model specification. The test procedure for this test and test configuration shall be specified in detail in the general specification.

4.5.4.3 Flow control. Flow control and stability characteristics of a component shall be measured by this test. The throttling characteristics, control input to flow characteristics, repeatibility of the control input to achieve a particular flow and stability of the component shall be determined for the complete range of pressures, flow rates and response rates within the design capacity of the component. The test system used for this test shall be dynamically equivalent to the propulsion system installation. This test shall be specified in detail in the general specification.

4.5.4.4 Response. In performing its design function, the response of the component shall be measured using instrumentation with a frequency response at least two times greater than the required response of the component. This test shall be conducted over the range of conditions which cover the design capacity of the unit. This test shall be specified in detail in the general specification.

4.5.4.5 Power requirements. The power requirements test shall be applicable to all components requiring an external source of power for their operation, whether this source be electrical, mechanical, manual, pneumatic, hydraulic, or other. This test shall be conducted over the complete range of operating flows, pressures, ambient and fluid temperatures, and other parameters affecting power as are specified. The minimum power required for satisfactory operation and the operating characteristics with maximum allowable power shall be measured.

* 4.5.4.6 High vacuum orbital test. Components that are subject to these low pressure effects in space shall be tested under high-vacuum conditions in accordance with the following requirements. A performance record shall be made prior to placing

the equipment in the test chamber. Chamber pressure shall be reduced from atmospheric conditions to 10^{-5} mm Hg or less. During chamber evacuation, equipment shall be operating beginning at 10^{-3} mm Hg. Equipment operation shall be terminated when a pressure of 10^{-5} mm Hg has been reached. Equipment shall be soaked at this pressure for a period associated with the expected life on orbit as called out in the detailed equipment specification, and shall then be operated for 2 hours if operated continuously on orbit or for 1.25 times the maximum orbit duty cycle if operated intermittently. The test chamber conditions shall then be returned to the atmospheric conditions specified in 4.4.2. The equipment performance shall be compared with the performance data obtained prior to this test.

* 4.5.5 Endurance. The endurance test shall be specified in the general specification. This test, as a minimum, shall equal the operating life requirement in 3.3.2.2, plus a margin of safety necessary to demonstrate the required reliability. The test shall require a series of component performances which simulate operating conditions of a start-stop-start-stop nature for a sufficient number of cycles to assure the total operating life required of the component.

4.5.6 Electrical system.

4.5.6.1 Explosion-proof. The explosion-proof test shall be conducted in accordance with Procedure IV, MIL-E-5272.

4.5.6.2 High ambient air temperature. This test shall be conducted on all components which incorporate any electrical subcomponents and which are rated as "continuous duty" with the exception of pumps. This will include items which are solenoid operated. The test shall be conducted as follows:

The entire unit, dry, shall be placed into a chamber with the ambient air controlled within the limits of 160°F (71.1°C) and 170°F (76.7°C). It shall then be energized with the maximum allowable voltage; e.g., 30 volts DC, etc., applied to the power unit terminals, for a period of three hours. At approximately 10 minute intervals, the current flow, terminal voltage, ambient temperature, and power unit housing temperatures shall be recorded. The unit shall then be removed from the chamber and the functional test shall be conducted at room temperature with the minimum allowable voltage; e.g., 18 volts DC, etc., applied to the power unit terminals.

The unit shall meet the performance requirements (3.5) for 50 cycles. Using data taken during the high temperature test, a curve shall be plotted showing the variation of coil temperature as determined by the resistance method with time.

4.5.6.3 Dielectric strength. This test shall be applicable to all components which include any electrical circuits. The applicable test voltage as specified in Table 4.1 shall be applied between circuits and between each circuit and the body of the component. Current flow in excess of 2 milli-amperes or breakdown of insulation shall constitute failure.

TABLE 4.1
Test voltage

Nominal voltage	Component	Test voltage	Time
28V dc	Motor	600V or 500V	1 second 1 minute
28V dc	Other than motors	1,000V	1 minute
115/200V 400 cps ac	All	1,500V	1 minute

4.5.6.4 Radio interference. Unless otherwise specified, all propulsion system components employing any electrical circuits shall conform to MIL-I-6181. The detailed test procedure for each particular component shall be specified in the general specification.

4.5.7 Fluid compatibility.

4.5.7.1 Internal. The compatibility of the component with the actuating and working fluids (3.4.8) shall be demonstrated at the maximum fluid pressure and at the maximum and minimum fluid temperature. The minimum test period at each condition shall be 60 days. The component shall be operated once every six hours. Degradation of the fluid or reduction of the component performance characteristics below those specified (3.3) shall disqualify the component.

* 4.5.7.2 External. With the component mounted in its normal attitude, it shall be subjected to a spray of the propellant until all exposed surfaces are wetted. Then air dry the component for one day and inspect for detrimental corrosion or other evidence of incompatibility. Performance of this test is required for the fuels and oxidizers only. This test shall be demonstrated at the maximum and minimum fluid temperature.

4.5.8 Environment.

4.5.8.1 Ground handling and storage.

* 4.5.8.1.1 Mechanical shock. The shock test shall be conducted in accordance with MIL-STD-810. The equipment shall be operated prior and subsequent to the following shock test, and a performance record made. The shock test shall be conducted with the equipment operative, unless otherwise specified. Shocks shall be applied through the normal mounting points of the equipment three times in each direction along each of the three mutually perpendicular axes at the values given in 3.4.6.9.1. The magnitude of the wave-form shall be measured at the interface of the equipment being tested and the test fixture. Induced secondary accelerations shall be measured along the two transverse axes. The deceleration rate shall be no greater than one-half the initial input acceleration when the velocity is maximum at the end of the input shock.

4.5.8.1.2 High temperature. High temperature test shall be in accordance with MIL-STD-810.

4.5.8.1.3 Low temperature. Low temperature test shall be in accordance with MIL-E-5272.

4.5.8.1.4 Temperature shock. Temperature shock test shall be in accordance with MIL-STD-810.

4.5.8.1.5 Humidity. With all ports suitably connected as in use, including electrical receptacle, test the unit in accordance with the humidity test in MIL-STD-810.

4.5.8.1.6 Salt fog. With all ports suitably connected as in use, the units shall be subjected to the salt spray test as outlined in MIL-E-5272.

4.5.8.1.7 Sand and dust. With all ports suitably connected as in use, the units shall be subjected to the sand and dust test in MIL-E-5272.

* 4.5.8.1.8 Fungus resistance test. The component shall be subjected to the fungus resistance test in accordance with Procedure I of Specification MIL-E-5272. This test shall be required only for a component constructed of materials which may act as nutrients to fungus.

* 4.5.8.1.9 Rain test. Unsheltered components shall be subjected to the rain test specified in Procedure II of MIL-E-5272C (ASG), except that the equipment shall be dried out before operation and the examination of the product and operating test shall be made in accordance with the detail equipment specification. This test shall be required only for a component which is not protected by the vehicle skin when ready for launch.

* 4.5.8.10 Corrosive atmosphere. The component, where applicable, shall be subjected to a test to determine that it is resistant to the corrosive effects of an atmosphere containing propellant fumes and those gases or vapors that may be present during operation of the component.

4.5.8.2 Flight environment. Two types of flight environment tests shall be performed. The first type simulates flight environments encountered when the component is not operating. This condition is typical of upper stage components during boost. The second type simulates environments which are encountered when the component is operating.

4.5.8.2.1 Vibration. Vibration tests for both the operating and nonoperating portions of the components flight shall be specified in the general specification, MIL-STD-810 shall take precedence if the specified test is more severe than the expected flight conditions.

* 4.5.8.2.1.1 Random vibration test. The random vibration test shall be conducted in the frequency range of 20 to 2000 cps at the levels given in 3.4.6.11. The equipment shall be vibrated for 5 minutes in each of three mutually perpendicular axes at the maximum level specified. Tolerances for the test set-up are given in 4.4.5.

* 4.5.8.2.1.2 Sinusoidal vibration test. Vibration shall be applied along each of three mutually perpendicular axes at the amplitude values specified in 3.4.6.11. The test along each axis shall consist of a single sinusoidal sweep starting at the lowest frequency limit and proceding at a constant-octave sweep rate to the highest frequency limit in not less than 25 minutes. A sweep rate of 3 minutes per octave shall be employed. All resonant frequencies shall be noted and recorded. Specific dwell at resonance is not required.

* 4.5.8.2.2 Acceleration. The component shall be secured to the test fixture by its mounting points. For equipment whose orientation in the vehicle is specified, the longitudinal acceleration shall be applied only in the thrust direction. The equipment shall then be subjected to the ultimate values of acceleration specified in 3.4.6.10 in each direction along each of the indicated axes for a period of 5 minutes. The equipment shall be operated during acceleration if it is to be operated during any acceleration phase of the flight. A record shall be made of all data necessary for comparison with a pre-test performance record. The specified accelerations apply to the geometric center of the test item. The centrifuge arm (measured to the geometric center of the test item) shall be at least five times the dimension of the test item measured along the arm. This test shall be repeated for the component in the operating and non operating portions of flight simulation.

4.5.8.2.3 Temperature.

* 4.5.8.2.3.1 Low temperature – low pressure test. The low temperature-low pressure test shall simulate the ascent and orbital temperature-pressure conditions as closely as possible.

a. Chamber conditions shall be at atmospheric conditions (4.4.2) at the start of this test.

b. The chamber pressure shall be reduced to simulate ascent from sea level to 25 mm Hg in approximately 90 seconds. During this period, the maximum pressure reduction rate shall be 15 mm Hg per second for a maximum duration of 30 seconds. Pressure reduction shall continue until a pressure of 10^{-3} mm Hg or less is achieved.

c. Temperature reduction shall be started at approximately the same time as evacuation. The temperature reduction rate of both the fixture and the chamber walls shall not exceed 3 degrees F per minute, or as otherwise specified. Temperature reduction shall be continued until an equilibrium temperature of minus 65 degrees F is attained.

d. All equipment shall be operating during chamber evacuation and temperature reduction. Orbital equipment shall be turned off when the 10^{-3} mm Hg pressure level is achieved. Ascent equipment operation shall be discontinued after operating for 1.25 times its maximum duty period, or as otherwise specified. An equipment performance record shall be made.

e. The equipment shall be soaked at these conditions for 4 hours and then operated (cold started) for 2 hours if operated continuously on orbit or at 1.25 times the maximum orbit duty cycle (6.6.9) if operated intermittently. A performance record shall be made.

f. The test chamber internal conditions shall then be returned to the atmospheric conditions specified in 4.4.2. The chamber rate of pressure increase shall not exceed 30 mm Hg per second, and the rate of temperature increase shall not exceed 3 degrees F per minute.

g. The equipment performance shall be determined after allowing sufficient time for the equipment to reach equilibrium temperature.

* 4.5.8.2.3.2 High temperature – low pressure test. The high temperature-low pressure test shall simulate the ascent and orbital temperature-pressure conditions as closely as possible.

a. Chamber conditions shall be at atmospheric conditions (4.4.2) at the start of the test.

b. The chamber pressure shall be reduced to simulate ascent from sea level to 25 mm Hg in approximately 90 seconds. During this period, the maximum pressure reduction rate shall be 15 mm Hg per second for a maximum duration of 30 seconds. Pressure reduction shall continue until a pressure of 10^{-3} mm Hg or less is achieved.

c. Temperature elevation shall be started at approximately the same time as evacuation. The temperature elevation rate of both the fixture and the chamber walls shall not exceed 3 degrees F per minute, or as otherwise specified. The final chamber wall and fixture temperatures shall be plus 150 degrees F. Temperature elevation shall be continued until an equilibrium temperature is attained.

d. All equipment shall be operating during chamber evacuation and temperature elevation. Orbital equipment shall be turned off when the 10^{-3} mm Hg pressure level is achieved. Ascent equipment operation shall be discontinued after operating for 1.25 times its maximum duty period, or as otherwise specified. An equipment performance record shall be made during this test.

e. The equipment shall be soaked at these conditions for 4 hours and then operated (hot started) for 2 hours if operated continuously on orbit or for 1.25 times the maximum orbit duty cycle if operated intermittently. A performance record shall be made.

f. The test chamber internal conditions shall then be returned to the atmospheric conditions specified in 4.4.2. The chamber rate of pressure increase shall not exceed 30 mm Hg per second, and the rate of temperature decrease shall not exceed 3 degrees per minute.

4.5.8.2.4 Altitude. An altitude test for the operating portions of the flight only shall be specified in the general specification. For components operating in the boost phase or in air vehicle propulsion systems, a rapid ascent test shall be performed in addition to determining performance at extreme altitude, including space.

4.5.8.3 Combined environmental tests. Combined environmental tests shall be specified in the general specification for those component operating environments that will be encountered during operation and whose interactions represent the most severe operating conditions.

4.5.8.4 Limit tests. Limit tests shall be specified in the general specification for the most severe stress producing environments to determine operating margins of safety. Limit tests shall be performed for each stress environment which affects the failure modes, as determined from the failure mode analysis.

4.5.9 Disassembly and inspection. After completion of all qualification tests scheduled for a test article, it shall be disassembled for examination of parts to disclose excessively worn, distorted, or weakened parts or deterioration of functional capability.

5. PREPARATION FOR DELIVERY

5.1 Preservation and packaging. Propulsion system components shall be preserved and packaged in accordance with the applicable method or submethod of MIL-P-116.

5.2 Marking. Interior packages and exterior shipping containers shall be marked in accordance with MIL-STD-129. The nomenclature shall be as follows:

Part name
Name of manufacturer
Manufacturer's part number
Manufacturer's serial number
Contractor
Contractor's part number
Contractor's order number
Date of acceptance

6. NOTES

6.1 Intended use. The component system covered by this specification is intended for use in either manned or unmanned remote launched, air launched, and space craft vehicle systems. Propulsion feed system requirements are contained in MIL-P-27409.

6.2 Symbols. The symbols used herein and in the general specification will be those in American Association Standard ASA Y10.14-1959. Symbols not included in the preceeding standard that may be required shall be defined and included in the general specification.

6.3 Definitions.

6.3.1 Absolute filtration rating. The absolute filtration rating is a value where all particles greater than the rated size (based on a standard contaminate) will be removed by the filter.

6.3.2 Burst pressure. Burst pressure is the highest pressure to which a component may be subjected without catastrophic failure. Subsequent operation is not required.

6.3.3 Droop. Droop is the decrease in regulated pressure caused by a decrease in the reference force as the metering element opens from the closed to full open position.

6.3.4 Lockup. Lockup is the condition reached in pressure control components when the downstream pressure reaches a value where the component shuts off flow.

6.3.5 Nominal filtration rating. The nominal filtration rating is a value where 98 percent or more of the particles larger than a given size (based upon a standard contaminate) will be removed by the filter.

6.3.6 Operating life. Operating life is the total number of duty cycles including Quality Conformance tests, but prior to overhaul or replacement of worn parts (except for specified limited life parts).

6.3.7 Parts list. A complete listing of the parts required to assemble a complete component of a specific configuration.

6.3.8 Procuring activity. Procuring activity is the activity which negotiates the contract.

6.3.9 Proof pressure. Proof pressure is the highest test pressure to which an item is subjected without leakage, deformation adversely affecting normal operation, or permanent set.

6.3.10 Reliability. Reliability is the probability that a component will perform a required function under specified conditions, without failure, for a specified period of time.

6.3.11 Service life. Service life is the sum of the storage life and operating lives.

6.3.12 Storage life. Storage life is the time that the component can be stored after Quality Conformance tests without replacement of parts and subsequently operate within specified limits. This includes both shelf type storage and storage after assembly in operating system.

6.3.13 Working pressure. Working pressure is the maximum expected operating pressure to which the component will be exposed, considering surge pressures and operating temperatures.

6.4 Applicability to NASA. This specification has been coordinated with the National Aeronautics and Space Administration, Washington, D.C., and approved for use by their activities when specifically invoked in a contract or order.

Custodians:	Preparing activity:
Air Force – 12	Air Force – 12
Review Activities:	Civilian Agencies Interest:
Air Force – 12, 14, 19, 70	NASA

Reviewer/user information is current as of the date of this document. For further coordination of changes to this document, draft circulation should be based on the information in the current DOD Index of Specifications and Standards.

PROPOSED GENERAL SPECIFICATION FOR ROCKET PROPULSION PROPELLANT FEED SYSTEM

1. SCOPE

1.1 Scope. This specification covers the propellant feed system consisting of the vehicle portion of the propulsion system and includes the propellant and pressurant tankage, all components such as the valves, regulators and switches, the lines and fittings, the propellant gaging and utilization system, the propellant orientation device or system, the vent and relief system, the servicing system, and other items needed to supply propellants to the rocket engine at the proper pressure, temperature, flow rate and mixture ratio. The propellant feed system interface with the rocket engine is usually the inlet to the engine pump in a pump-fed system and the inlet to the engine shut off valves in a pressure-fed system. New paragraphs and paragraphs modified from MIL-P-27409 dated 20 March 1967 are indicated with an asterisk and are also boxed.

1.2 Classification. This specification shall be applicable to the propulsion systems of the following classes of vehicles:

Class I – Ground Launched Systems
Class II – Air Launched Systems
Class III – Spacecraft Systems

2. APPLICABLE DOCUMENTS

2.1 The following documents of the issue in effect on date of invitation for bids or request for proposal, form a part of this specification to the extent specified herein.

SPECIFICATIONS

Military

MIL-P-116	Preservation, Methods of
MIL-D-1000	Drawings, Engineering and Associated Lists
MIL-R-5149	Rocket Engine, Liquid Propellant, General Specification For

MIL-T-5208	Tanks, Removable, Liquid Propellant Rocket Engine, General Specification For
MIL-E-5272	Environmental Testing, Aeronautical and Associated Equipment, General Specification For
MIL-C-5501	Caps and Plugs, Protective, Dust and Moisture Seal
MIL-P-5518	Pneumatic Systems, Aircraft, Design, Installation, and Data Requirements For
MIL-I-6866	Inspection, Penetrant Method of
MIL-S-7742	Screw Threads, Standard, Optimum Selected Series, General Specification For
MIL-M-7911	Marking, Identification of Aeronautical Equipment Assemblies and Parts
MIL-I-8500	Interchangeability and Replaceability of Component Parts for Aircraft and Missiles.
MIL-S-8879	Screw Threads, Controlled Radius Root with Increased Minor Diameter, General Specification For
MIL-H-25475	Hydraulic Systems, Missile, Design Installation Tests, and Data Requirements, General Specification For
MIL-E-26144	Electric Power, Missile, Characteristics and Utilization, General Specification For
* Proposed	Component, Rocket Propulsion Fluid, General Specification For

STANDARDS

Military

MIL-STD-129	Marking for Shipment and Storage
MIL-STD-130	Identification Marking of United States Military Property
MIL-STD-143	Specifications and Standards Order of Precedence for Selection of
MIL-STD-453	Inspection, Radiographic
* MIL-STD-454	Standard General Requirements for Electronic Equipment
MIL-STD-704	Electric Power, Aircraft Characteristics and Utilization of

MIL-STD-785	Requirements for Reliability Program
MIL-STD-810	Environmental Test Methods For Aerospace and Ground Equipment
MS33586	Metals, Definition of Dissimilar

PUBLICATIONS

Air Force - Navy Aeronautical Bulletins

No. 343	Specifications and Standards Applicable to Aircraft Engines and Propellers, Use of
No. 428	Engines, Rocket, Liquid Propellant, Design and Installation Criteria For
No. 445	Engineering Changes to Weapons, Systems, Equipment, and Facilities

(Copies of specifications, standards, drawings, and publications required by suppliers in connection with specific procurement functions should be obtained from the procuring activity or as directed by the contracting officer.)

3. REQUIREMENTS

* 3.1 Pre-production. The rocket propulsion feed system furnished under this specification shall be a product which meets the requirements specified herein. Flight systems shall employ only components which have successfully completed their Qualification tests.

3.2 General specification. A rocket propulsion feed system general specification conforming to the requirements specified herein shall be submitted by the contractor and shall have been approved by the procuring activity (6.3.3) prior to design and development of the system.

3.3 Selection of specifications and standards. Specifications and standards for necessary commodities and services not specified herein shall be selected in accordance with MIL-STD-143.

3.4 Changes. The contractor shall notify the procuring activity of any proposed design changes to the component as defined in the general specification. Following successful completion of the Qualification tests, no change shall be made except when such changes are made in accordance with ANA Bulletin No. 445 or procurement activity requirements as applicable. Approval of changes does not relieve the contractor from full responsibility for the effects of the changes on the component performance.

3.5 Flow test model. A full scale flow test model shall be constructed by the contractor for the purpose of performing system flow testing. The model configuration shall be similar to the flight system except that heavy tanks and nonflight weight components may be used for testing until flight components are available.

3.6 Performance characteristics. The performance characteristics shall be specified in the general specification.

3.7 Ratings.

* 3.7.1 Flow characteristics. The system flow characteristics are as specified in Table 3.1. The flow rate versus pressure drop at the normal operating temperature and pressure of the system shall be as specified in Table 3.1 for the various percentages of maximum flow or flow rate versus percentage maximum flow position of the control element at given temperature and pressure drop.

* 3.7.1.1 Pressure. The working proof and burst pressure are as specified in Table 3.1. The proof and burst pressure shall be at least 1.5 and 2 times the working pressure respectively and they shall be adjusted for the differences in test temperature and maximum working temperature to account for the reduced properties. The system shall incorporate relief and burst diaphram devices to insure protection and integrity of all tankage and components from overpressure from any cause whatsoever.

* 3.7.1.2 Operating temperatures. Nominal fluid operating temperatures and limits are as specified in Table 3.1.

* 3.7.1.3 System pressure loss. System pressure loss is as specified in Table 3.1. to operating temperatures and limits specified in 3.7.1.2. The manufacturer shall include in his specification the pressure loss for each subsystem and component for conditions specified in 3.7.1.2.

* 3.7.1.4 Engine propellant interface pressure. The propellant pressure and flow rate delivered to the engine/vehicle interface (6.3.2) shall be as specified in Table 3.1. The operating temperatures and limits specified in 3.7.1.2 shall be as specified in Table 3.1.

TABLE 3.1

PROPELLANT FEED SYSTEM CHA

Propellant or Fluid	Fluid Parameters							
	Temp. (3.7.1.2)			Flow Characteristics				
	Min.	Nom	Max.	Flow Rate (3.7.1.4)	Interface Pressure (3.7.1.4)	Pressure Drop (3.7.1.3)	Flow Rate Change Rate (3.7.1.5)	Respons Time (3.7.1.5

1

TABLE 3.1

EED SYSTEM CHARACTERISTICS

		System Parameters						
		Pressure (3.7.1.1)			Life (3.7.1.8)		Leakage (3.7.1.9)	
Rate Rate 1.5)	Response Time (3.7.1.5)	Working	Proof	Burst	Operating	Storage	External	Internal

2

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* 3.7.1.5 Thrust variation. The propellant feed system shall be capable of delivering propellant to the engine at the required pressure, flow rate and mixture ratio during engine thrust variation. The required response of the feed system to changing flow rates is shown in Table 3.1.

3.7.1.6 Restart. The method of providing positive propellant feed for restart shall be specified. Such items as propellant orientation and sequence of operation shall be described.

3.7.1.7 Weight. A weight tabulation for the system shall be listed in the general specification and should include inert or dry weight (6.3.1) of hardware, flight weight and lubricants.

* 3.7.1.8 Operating life. The operating life of the system is as specified in Table 3.1 and includes anticipated time for acceptance testing, system checkout tests and propulsion system operation, for ground and normal flight operations.

* 3.7.1.9 Leakage. The maximum system leakage, both external and internal, with the fluid medium at the operating pressure, shall not exceed those specified in the Table 3.1. In those applications where fuel and oxidizer are controlled in a single component, seal leakage shall be ducted such that mixing of fuel and oxidizer within the component is precluded.

3.7.1.10 Contamination. The specified fluid shall be filtered through a 10 micron nominal and 40 micron absolute filter prior to service use or test of the system. The fluid medium shall conform to the specified fluid specification.

3.7.1.11 Safety factors. Safety factors for all pressurized containers and lines shall be specified in the general specification. Values for burst pressure less than 2.00 times maximum expected operating pressure shall be justified to the procuring activity.

3.7.1.12 Over pressure protection. All pressurized containers shall be protected with pressure relief devices which function independently from the pressure source and its control.

3.7.1.13 Ullage volume. Ullage volume limits for all liquid containers shall be specified in the general specification. The method of determining the ullage volume during ground servicing or flight operation shall be described.

3.7.1.14 Propellant slosh. The resonant liquid slosh frequency shall be specified in the general specification for all liquid containers. Methods of suppressing the slosh mode shall be described.

3.7.1.15 Expulsion efficiency. The percentage of loaded propellant available to the rocket engines shall be specified in the general specification.

3.7.1.16 Propellant orientation. Propellant orientation shall be provided for systems requiring restart when subjected to adverse acceleration conditions. The methods employed shall be described in the general specification.

3.7.1.17 Attitude. Propulsion feed system attitude limits shall be specified in the general specification for flight operation and ground handling.

* $\boxed{3.7.1.18}$ Storage life. All rocket fluid systems shall have a minimum required storage life (non-operating) of 5 years with the exception of those items identified in section 3.12.2.3. The internal and external environmental extremes that may be encountered during storage are as specified in 4.2.3.1.2.1. When the system is in contact with propellants or actuating fluids during storage, it shall not degrade these fluids.

3.7.1.19 Purging. Purging requirements for the feed system shall be specified in the general specification.

3.7.1.20 Thermal control. Requirements for propulsion feed system thermal control on the ground and during flight shall be specified in the general specification. The method of providing this control shall be described.

3.7.2 Start and shutdown characteristics.

3.7.2.1 Start. Feed system start capabilities and allowable limits on pressure and temperature transients shall be specified in the general specification.

3.7.2.2 Shutdown. Feed system shutdown capabilities and allowable limits on pressure and temperature transients shall be specified in the general specification. In addition, emergency shutdown capabilities shall be specified, if applicable.

3.7.3 Reliability. The contractor shall establish feed system reliability objectives and minimum acceptable requirements in the general specification as referenced in MIL-STD-785. The provisions of MIL-STD-785 will apply in demonstrating the ability of the system to meet these requirements and objectives. The increase in reliability obtained through the use of a malfunction detection system and pilot control in manned vehicles shall be specified in the general specification.

3.7.4 Propellants and fluids.

3.7.4.1 Propellants. The propellants which may be used in the feed system shall be specified in the general specification. The propellants shall conform to the requirements of the applicable military propellant specifications.

3.7.4.2 Pressurizing gas. The pressurizing gas which may be used in the feed system and the quantity shall be specified in the general specification. The gases shall conform to the requirements of the applicable military specifications.

3.7.4.2.1 Solid gas generator. The use of solid propellant gas generators for pressurization, the composition of the gas produced and the amount and composition of solid contaminant in the gas shall be specified in the general specification.

* $\boxed{3.7.4.3}$ Lubricants. All components near surfaces in contact with system fluids shall not require additional lubrication other than the system fluid itself. Lubricants used during periodic maintenance and service shall be compatible with fluids, fluid vapors, fluid decomposition products, products of combustion where applicable, and with environments to which subjected.

3.7.4.4 Other fluids. Other fluids required for operation test or storage of the feed system shall be specified in the general specification.

3.7.5 Propellant.

* $\boxed{3.7.5.1}$ Quantities. A propellant weight statement shall be included in the general specification and shall provide an accounting of the following propellant quantities as applicable.

a. Usable propellant (6.3.9).
b. Trapped propellant (6.3.8).

c. Purge, bleed, and pressurization gas.
d. Loaded propellant at lift-off.
e. Propellant boil-off losses, if any.

3.7.5.2 Utilization. The accuracy of the propellant utilization system shall be specified in the general specification and shall consist of the percentage of loaded propellant remaining at the completion of the required duty cycle. Allowable variation in mixture ratio limits of propellants supplied to the rocket engines shall be specified in the general specification.

3.7.5.2.1 Change rate. The change rate of propellant utilization system employing variable flow control devices for mixture ratio control shall be sufficient to maintain the mixture ratio within the limits of 3.7.5.2, when subjected to variations in tank pressure, propellant temperature, vehicle acceleration, and engine mixture ratio.

3.7.5.3 Propellant loading.

3.7.5.3.1 Limits. Propellant loading tolerances for each propellant shall be specified in the general specification. The limit established shall consider: loading control system accuracy, propellant temperature, tank manufacturing tolerances, tank thermal shrinkages and expansions, and other factors which might affect the quantity of loaded propellant.

3.7.5.3.2 Rates. Propellant loading rates commensurate with plumbing design limits and boiloff rates shall be established and specified in the general specification.

3.7.5.3.3 Temperature control. Temperature limits of the propellants during loading shall be specified in the general specification.

3.7.5.4 Defueling. Provisions for safe removal of all fluids and gases from the feed system shall be made. The defueling method and rate shall be specified in the general specification.

3.8 Environmental and load factors.

3.8.1 Environmental conditions. The feed system, and where applicable, its major subassemblies shall be capable of accomplishing intended functions under the environmental conditions imposed during its service life (6.3.5).

3.8.1.1 Transportation and storage. The feed system shall not be adversely affected by transportation and storage environments specified below. The requirement to transport the feed system in a loaded or empty condition shall be specified in the general specification.

* 3.8.1.1.1 Temperature limits. Equipment ready for shipment may encounter temperatures in the range of minus 65 degrees Fahrenheit to plus 160 degrees Fahrenheit during transportation and storage. System performance shall not deviate beyond that specified in 3.7.1 after equipment exposure to these conditions.

* 3.8.1.1.2 Pressure limits. Atmospheric pressure may vary from 87 millimeters to 810 millimeters of mercury during transportation and handling.

3.8.1.2 Checkout and prelaunch. The feed system shall not be adversely affected by the prelaunch environment specified below.

* 3.8.1.2.1 Prelaunch conditions. Equipment may encounter the extreme conditions specified below prior to countdown. Equipment performance shall not deviate beyond the specified limits during or after equipment exposure to these conditions.

a. Equipment not operating: This range is not applicable when adequate shelter or environmental control is provided.
   (1) A minimum temperature of minus 65 degrees Fahrenheit for six hours.
   (2) Plus 125 degrees Fahrenheit ambient still air with a direct solar irradiation flux of 360 British thermal units (BTU) per hour per ft^2 for 6 hours.
   (3) Plus 160 degrees Fahrenheit without solar irradiation for 6 hours.
   (4) Atmospheric pressures from 710 to 810 millimeters (mm) mercury mercury (hg).
   (5) Relative humidities of up to 90 percent.

b. Equipment operating under conditions other than countdown:
   (1) Ambient still air from plus 20 to plus 120 degrees Fahrenheit.
   (2) Pressures from 710 to 810 millimeters (mm) mercury.
   (3) Relative humidities of up to 90 percent.

* 3.8.1.2.2 Countdown conditions. The component will not be temperature controlled during countdown and internal component temperatures will equal or approach the temperature of the operating fluid. External component temperatures may vary

between minus 5 degrees Fahrenheit minimum to plus 160 degrees Fahrenheit maximum. Atmospheric pressure may vary from 710 millimeters to 810 millimeters mercury. Relative humidity may be up to 90 percent.

3.8.1.3 Mission and trajectory. The feed system shall operate satisfactorily in the launch and flight environment specified below.

* 3.8.1.3.1 Environmental temperature ranges. The effective temperature range of the system environment will be dependent on the proximity to the vehicle external surface. The following temperatures will be expected:

	Ascent	Orbit		Entry
	Max.	Min.	Max.	Max.
Heat Shield Temperature (°F)	+1500°	-100°	+200°	+2200°
Substructure Temperature (°F)	+250°	-100°	+200°	+250°

* 3.8.1.3.2 Environmental pressure range. The feed system shall operate satisfactorily at any pressure above 10^{-13} mm Hg during flight. The following atmospheric pressures correspond to the flight phases and are given for design reference only.

Flight Phase	Estimated Pressure Range (mm Hg)
Ascent	810 to 10^{-6}
Orbit	10^{-6} to 10^{-10}
Entry	10^{-6} to 810

* 3.8.2 Explosive atmosphere. Components intended to operate in areas where a possibility of an ambient explosive atmosphere exists shall operate in such an atmosphere without causing explosion.

* 3.8.3 Fungus. Component performance shall not deviate beyond the specified limits after equipment exposure to high humidity which is conducive to rapid fungus growth. Equipment,whenever practical, shall be fabricated from materials that will not support the growth of fungus.

* 3.9 System components. General requirements for propulsion subsystem components shall be as specified in Proposed General Specification for Rocket Propulsion Fluid System Components.

3.9.1 Lines and fittings. Propulsion feed system lines and fittings shall conform to the requirements in 3.7.1.11. Provisions for flexibility shall be provided to prevent line failure due to vehicle flexure or thermal extremes.

* $\boxed{3.9.2}$ Drains. Drains for reactive fluids should be separate with suitable provisions made to drain all hazardous fluids from the feed system. Drain fittings shall be located so that complete draining can be effected with the feed system installed in its normal launch attitude so that the fluid will drain by the force of gravity. If the system is specified for cryogenic service, design provisions are to be included for relieving pressure from any trapped compartments.

3.9.3 Tankage. Propulsion feed system tankage shall conform to the requirments in MIL-T-5208.

* $\boxed{3.9.4}$ Filters. Filters shall be incorporated in the feed system when contamination impairs subsystem or engine operation. Filter requirements shall be capable of maintaining system contamination levels to a maximum of that specified in 3.7.1.10.

* $\boxed{3.9.5}$ Service connections. Service connections such as propellant fill and drain, pressurization, pneumatic, and hydraulic line connections shall conform to Proposed General Specification for Rocket Propulsion Fluid System Components.

3.10 Auxiliary power requirements. Propulsion feed system requirements for electrical, pneumatic, and hydraulic support shall be specified in the general specification as applicable. These requirements shall include electrical power, fluid type, operating pressures, temperatures, flow rates, response, and duty cycle. The requirements shall be established in accordance with MIL-P-5518, MIL-H-25475, MIL-E-26144, and MIL-STD-704.

3.11 Installation and maintainability.

3.11.1 Mounting. All components, lines, and fittings shall be supported from vehicle structure by suitable mounting bracketry, clamps, and other associated hardware. These mounting provisions shall provide for thermal expansions and contractions, facilitate component inspection and replacement, and provide sufficient access for component and subsystem servicing in accordance with ANA Bulletin 428. When required, the mounting hardware shall provide shock mounting for the components. The location of components, lines, and fittings shall be described in schematics and drawings as specified in MIL-D-1000.

3.11.2 Protective shielding. Thermal, electric, magnetic, and nuclear shielding shall be applied to all components of the feed system as required to assure safe, compatible operation. Protective coverings may be used for component protection during extended inert ground storage.

3.12 Design and fabrication.

3.12.1 Design. The detailed design of the propulsion feed system shall be accomplished by the contractor subject to the requirements of this specification and any associated specifications. The relative importance of cost, weight, schedule, envelope, and reliability as design considerations shall be specified in the general specification.

3.12.1.1 Design standards. MS and AND design standards shall be used wherever applicable.

3.12.1.2 Standards. MS or AN standard parts shall be used wherever they are suitable for the purpose, and shall be identified by their standard part numbers. The use of nonstandard parts will be acceptable only when standard parts have been determined to be unsuitable. MS and AND design standards shall be used wherever applicable. MS or AN utility standard parts shall conform to applicable standards in accordance with paragraph entitled "Utility Parts Standards" in ANA Bulletin 343.

3.12.1.3 Threads. Conventional straight screw threads shall conform to the requirements in MIL-S-7742 or MIL-S-8879. Duplicate parts, differing only in thread form, shall not be permitted. Unless otherwise specified, threaded parts smaller than 0.164 inch diameter shall have threads in accordance with MIL-S-7742. When an allowance is required for application in elevated temperature, corrosive atmosphere, or other conditions which may cause thread seizure, this allowance shall be obtained by increasing the diameters of the internal threads. Pipe threads may be used only with specific approval of the procuring activity.

3.12.2 Materials and processes.

3.12.2.1 Quality. Materials and processes used in the manufacture of the feed system shall conform to applicable specifications in accordance with paragraph entitled "Material Specifications" in ANA Bulletin 343. When feed system manufacturer's specifications are used for materials and processes that may affect performance or durability of the feed system, such specifications shall be made available to the

Government for review prior to the applicable PFRT or qualification tests. These specifications, unless specifically disapproved, shall be considered released for use in manufacture of the feed system upon completion of the qualification test program. The use of non-Government specifications shall not constitute a waiver of Government inspection.

* 3.12.2.2 Dissimilar metals. Dissimilar metals are defined by MS33586 and shall not be used in intimate contact with each other unless suitably protected. Protection of dissimilar metal combinations shall be in accordance with MIL-STD-454.

* 3.12.2.3 Rubbers, plastics, and elastomers. Rubbers, plastics and elastomers shall be compatible with fluids, fluid vapors, fluid decomposition products, products of combustion where applicable, and with environments to which subjected. Age control of synthetic rubber parts shall be in accordance with ANA Bulletin No. 438.

* 3.12.2.4 Compatibility. All materials and finishes not included in 3.12.2.3 shall be compatible with the fluid used in the operational environment. The materials shall also be compatible with the environments expected during long term, inert storage unless suitable coatings or similar protection is provided. Nameplates need only be splash resistant to the fluids used in the system.

3.12.2.5 Protective treatment. All protective coatings and treatments shall be applied in accordance with applicable military and Federal standards and specifications.

3.12.2.6 Interchangeability. All parts and components having the same manufacturer's part number shall be functionally and dimensionally interchangeable. Changes in manufacturer's part numbers shall be governed by the drawing number requirements specified in MIL-D-1000. Interchangeability requirements shall be in accordance with MIL-I-8500.

* 3.12.2.7 Special tools. The design of system components shall be such that disassembly and replacement of parts required in operational maintenance shall be accomplished without the use of special tools which are unique to the component.

3.12.3 Parts list. A manufacturer's parts list shall be included in the general specification. Changes to the parts list shall be in accordance with the requirements in 3.12.4.1.

3.12.4 Changes.

3.12.4.1 Design. Feed system design changes shall be made in accordance with requirements in ANA Bulletin 445. Two classes of changes shall be defined.

3.12.4.2 Approval. Approval of changes does not relieve the contractor of full responsibility for the results of such changes to the propulsion feed system.

3.12.5 Product identification. Equipment, assemblies, and parts shall be marked for identification in accordance with MIL-M-7911 (for the Bureau of Aeronautics only) and MIL-STD-130.

3.12.6 Drawings and diagrams. Drawings and diagrams shall include and identify all applicable components required for the feed system in accordance with MIL-D-1000. The following data shall be provided:

a. Feed system assembly drawings complete with component assembly drawings and identifying part numbers.
b. Final installation drawing.
c. Fluid flow diagrams.
d. Electrical system diagram.
e. Control system diagram.

The following preliminary data shall be provided with the preliminary general specification:

a. General layout drawing.
b. Fluid flow diagram.

3.12.7 System weight. System weight shall be included on the drawings and in the general specification.

4. QUALITY ASSURANCE PROVISIONS

4.1 Classification of tests. Propulsion feed system testing shall be classified as follows:

4.1.1 Development tests. Development tests shall be conducted to verify and refine propulsion feed system operating characteristics during the development cycle.

4.1.2 Qualification tests. Qualification tests shall be conducted to demonstrate the suitability of the propulsion feed system for flight and production.

4.1.3 Acceptance tests. Acceptance tests shall be conducted to demonstrate the suitability of the production feed system for operational use.

4.2 Tests and test methods.

4.2.1 Development tests. Development tests shall be conducted on a full-scale propulsion feed test system. Heavy weight tankage may be used in the interest of safety. This test system will be used as a development tool to determine the interaction between components and subsystems, to explore thermal effects, and to determine system operating and response characteristics. System operating and response tests may be repeated in flight systems when structural stiffness has a significant effect upon system pressure or dynamic response characteristics. The system shall be capable of operating with the actual propellants and gases; however, an engine firing capability is not required.

4.2.2 Qualification tests. Qualification tests shall be conducted with full-scale flight weight feed systems capable of supporting engine firings. The feed system, its components, and the test apparatus shall be subject to inspection by authorized Government inspectors. Two copies of the complete parts list, drawings, and specifications for all components of the qualification test feed system shall be provided to the procuring activity prior to beginning the qualification tests.

4.2.2.1 Test apparatus and procedures. Schematic drawings and descriptions of all test apparatus including points of measurement shall be provided prior to initiation of the qualification test. Test procedures and methods to be used shall be provided the procuring activity.

4.2.2.2 Instrumentation calibration. Each instrument and other measuring apparatus upon which the accuracy of test results depends shall be calibrated frequently enough to insure attainment of steady state accuracy of ±1 percent of the specified value of the measurement. Calibration records shall be maintained and made available for inspection by the procuring activity upon request.

4.2.2.2.1 Automatic recording equipment. Automatic recording equipment of adequate response shall be used to obtain data during transient conditions of feed system and component operation requiring an evaluation of time critical variables.

4.2.3 Test conditions. Unless otherwise specified, all inspections and tests shall be conducted in an external environment at ambient temperatures (4.2.3.1.2) and at ambient pressure.

4.2.3.1 Temperatures.

* 4.2.3.1.1 Low temperature. Low temperature tests shall be conducted with the temperature of ambient air, test system, and fluids at the minimum expected operating temperature as specified in 3.8.1 for the appropriate operational phase.

* 4.2.3.1.2 Ambient temperature. Ambient temperature tests shall be conducted with the temperature of ambient air, test system, and fluids at the normally expected ambient temperature ranges as specified in 3.8.1 for the appropriate operational phase.

* 4.2.3.1.3 High temperature. High temperature tests shall be conducted with the temperature of ambient air, test system, and fluids at the maximum expected operating temperature as specified in 3.8.1 for the appropriate operational phase.

* 4.2.3.2 Atmospheric pressure and humidity.

* 4.2.3.2.1 Atmospheric pressure. Unless otherwise specified, tests shall be conducted at atmospheric pressures of 710 mm to 810 mm Hg.

* 4.2.3.2.2 Humidity Unless otherwise specified, tests shall be conducted with relative humidity of not more than 90 percent.

4.2.4 Parts failure and replacement. Maintenance, adjustment, or replacement of parts other than normal expendables such as squibs, burst diaphragms or single cycles positive expulsion devices shall not be permitted during qualification and acceptance testing. The qualification test on the feed system shall be considered complete when every part of the system has been subjected to and has satisfactorily completed the entire test. At the discretion of the procuring activity, redesign and retesting may be conducted on any part which fails or indicates a weakness after completing the qualification test but is retained in the system to complete the testing on other parts.

4.3 Propulsion feed system qualification tests. The feed system(s) submitted for qualification testing shall have passed the acceptance tests (4.4) and then shall be subjected to the following tests. Each series of tests shall be performed on the feed system in the sequence listed unless impractical due to feed system size, lack of facilities, or cost. Tests may be conducted on part of the feed system when such a procedure is more practical. Elimination or substitution of any test shall be the prerogative of the procuring activity. Two feed systems may be used for these tests (one for series A and one for series B).

SERIES A

a. Fluid resistance and extreme temperature
b. Vibration
c. Shock
d. Thermal altitude
e. Attitude
f. Humidity
g. Salt spray
h. Sand and dust

SERIES B

a. Acceleration
b. Slosh
c. Response
d. Propellant utilization
e. Ignition
f. Acoustic noise
g. Electrical interference
h. Endurance
i. Proof pressure

4.3.1 Fluid resistance and extreme temperature. The feed system fluid resistance and extreme temperature tests shall be conducted in accordance with Table 4-1. The system shall be tested in an environmental chamber, if practical. The test may be conducted in two parts with the fuel and oxidizer tested separately for reasons of safety. Phase I of the test may be eliminated for low boiling point propellants and Phase III eliminated for high freezing point propellants at the option of the procuring activity.

TABLE 4-1

FLUID RESISTANCE AND EXTREME TEMPERATURE

Conditions	Phase I	Phase II	Phase III
System configuration	Flight	Flight	Flight
Test fluid	Fuel or oxidizer, and pressurizing gas loaded at normal operating temperature	Fuel or oxidizer, and pressurizing gas	Fuel or oxidizer, and pressurizing gas
Duration	96 hours	48 hours	48 hours
Ambient temperature	$160^0 \pm 5^0$F ($71.1^0 \pm 5^0$C) or the operating temperature of the system whichever is higher	$60^0 \pm 5^0$F ($15.6^0 \pm 5^0$C)	$-65^0 \pm 5^0$F ($-53.9^0 \pm 5^0$C) or the operating temperature of the system whichever is lower
Test operations	Cycle all intermittent duty components once every 6 hours. Run all continuous duty components 10 minutes every 6 hours, normal system operating pressure shall be maintained.	Cycle all intermittent duty components once every 6 hours. Run all continuous duty components 10 minutes every 6 hours, normal system operating pressure shall be maintained.	Cycle all intermittent duty components once every 6 hours. Run all continuous duty components 10 minutes every 6 hours, normal system operating pressure shall be maintained.

Notes:

1. Phases I, II and III shall be run consecutively.
2. Propellant or gaseous flow is not required during this test.
3. Feed systems having self generating pressurization systems may use helium or nitrogen for this test.

Propellant or gaseous leakage in excess of the amount specified in the general specification (3.7.1.9) which occurs at any time during the test shall be considered disqualifying.

* 4.3.2 Vibration. Vibration tests shall be conducted in accordance with MIL-E-5272 or MIL-STD-810. The following levels of vibrational excitation shall be imposed on the system to simulate actual environment, however, in no case shall this requirement be less than that imposed by MIL-E-5272 or MIL-STD-810. This test may be waived at the option of the procuring activity when it becomes impractical due to feed system size. The calibration (4.4.3) and static leakage (4.4.2) tests shall be performed at the completion of this test. Substitute fluids may be used in lieu of propellants with prior approval of the procuring activity.

* 4.3.2.1 Vibration during engine burn. System performance shall not deviate beyond the specified limits during and after component exposure to the vibration levels encountered during the conditions of ground operation, boost phase, and reusable vehicle phase of engine operation. During the non-powered portion of the orbital phase, the vibration level for most equipment will be near zero.

Sinusoidal Vibration

Frequency Range	Acceleration (g zero to peak)
2 – 6.2 cps	1.1 – 10g
6.2 – 198 cps	10 g
198 – 370 cps	10 – 32 g
370 – 2000 cps	32 g

Random Vibration

Frequency Range	Power Spectral Density
5 – 20 cps	+9 db
20 – 2000 cps	0.25 g^2/cps

4.3.3 Shock. The feed system mounted in a normal shipping configuration shall be subjected to a shock test in the applicable direction to an acceleration level and duration as specified in the general specification. The static leakage test (4.4.2) shall be performed at the completion of this test.

* 4.3.4 Thermal altitude. The feed system shall be tested at maximum expected altitude and temperature extremes as specified for proper operation. The feed system shall be pressurized to normal operating pressure and maintained at the altitude condition at each temperature extreme for 6 hours. A calibration sequence (4.4.3) shall be performed on the system at each temperature. Malfunction of any component or electrical shorts as noted by increased power consumption shall be cause for rejection.

* 4.3.4.1 Pressure in flight. The equipment shall operate within its specified limits at any pressure above 10^{-13} mm of Hg during flight. Equipment performance shall not deviate beyond the specified limits and result of pressure gradients during altitude changes. The following atmospheric pressures correspond approximately to the flight phases and are given for design reference.

Phase	Estimated Pressure Range (mm Hg)
Boost	810 to 10^{-6}
Orbit	10^{-6} to 10^{-10}
Entry	10^{-6} to 810

4.3.5 Attitude. Satisfactory operation of the feed system pressurized to operating pressure shall be demonstrated in all attitudes expected during flight. This test may be combined with the thermal altitude test (4.3.4).

4.3.6 Humidity. Humidity tests shall be conducted in accordance with MIL-E-5272 or MIL-STD-810. A calibration test (4.4.3) shall be performed at the completion of this test.

4.3.7 Salt spray. Salt spray tests shall be conducted in accordance with MIL-E-5272 or MIL-STD-810. A calibration test (4.4.3) shall be performed at the completion of this test.

4.3.8 Sand and dust. Sand and dust tests shall be conducted in accordance with MIL-E-5272 or MIL-STD-810. A calibration test (4.4.3) shall be performed at the completion of this test.

* 4.3.9 Acceleration. The acceleration tests in MIL-E-5272 or MIL-STD-810 shall be performed on the feed system where possible up to the acceleration levels specified as follows. The feed system shall be loaded with propellant or substitute

fluids having a specific gravity within ± 5 percent of the propellants, and the acceleration test conducted with propellant quantities from empty to full in 10 percent increments at the appropriate mission acceleration levels. A calibration test (4.4.3) shall be conducted at the completion of this test.

	Longitudinal Axis max g's	Normal Axis max g's	Lateral Axis max g's
Boost	4.0	0.25	0.25
Orbit	2.2	0.25	0.25
Entry	0.25	2.5	0.25
Landing	1.0	0.25	0.25

4.3.10 Slosh. The resonant slosh frequencies of the feed system shall be determined experimentally for each 10 ±2 percent increment of propellant quantity from 10 to 100 percent. Substituted fluids and subscale tankage may be used if the final results are corrected for fluid density, viscosity, size, and acceleration in accordance with the relationship shown below.

$$dr = \left(\frac{\mu r}{\rho r}\right)^{2/3} (ar)^{-1/3}$$

d = tank diameter

μ = fluid viscosity

ρ = fluid density

a = acceleration

r = ratio of subscale to full-scale feed system or substitute fluid to actual propellants

4.3.11 System response. The response of the feed system to start and throttling, if applicable, and the fluid surge that occurs at shutdown shall be determined. In the event the propellant system supplies more than one engine, the appropriate operation of these engines shall be performed or simulated as is applicable. This test may be conducted in accordance with the rocket engine firing tests in MIL-R-5149 or may be conducted with feed system shut-off valves capable of equalling or exceeding the response of the rocket engine. Pressurization and propellant system pressures shall be recorded with instrumentation of 500 cycles per second (cps) response or better. System response and surge characteristics shall be determined at each 10 ±2 percent increment of propellant and pressurant quantity from 10 to 100 percent at rated flow or at each 10 ±2 percent increment of rated flow if the system is throttleable.

4.3.12 Propellant utilization. The propellant utilization accuracy of the feed system shall be determined. This test may be conducted in conjunction with the rocket engine firing tests in MIL-R-5149. The system shall be fully loaded with propellants and pressurization gas and a full duration run conducted simulating the mission profile. Propellant quantities in the tanks shall be determined at the beginning and at the completion of the run and the propellant utilization accuracy shall be the percent of total fuel or oxidizer, whichever is larger, remaining in the tanks at the end of the run.

4.3.13 Ignition. The feed system shall be installed in a test chamber containing a combustible mixture capable of being ignited by an electrical spark. Maximum input voltage shall be applied to the electrical system and the system actuated through 11 complete cycles. Each cycle will be conducted at 10,000-foot increments starting at sea level and progressing to 100,000 feet. Any reaction or explosion occurring during the test shall be cause for rejection. At the completion of the test, a sample of the mixture shall be ignited by an electrical spark. Small tankage may be used to replace the full-scale tankage. Gases and propellants are not required during this test.

4.3.14 Acoustic. The feed system shall be subjected to the maximum expected acoustic noise level as specified in the general specification for 10 minutes. The system shall be pressurized to normal operating pressure during this test. Small tankage may be used to replace the full-scale tankage.

4.3.15 Electrical interference. The feed system shall conform to the electrical interference requirements of MIL-R-5149. The tests entitled "Electrical and electronic interference and susceptibility check" in MIL-R-5149 shall be conducted on the feed system and its components to demonstrate compliance with these requirements.

4.3.16 Endurance. A single duty cycle feed system shall be required to accumulate, through qualification testing and additional calibration tests, a total running time equal to 25 rated duration runs. A multiple duty cycle feed system shall be required to accumulate, through qualification testing and additional calibration tests, a total running time equal to 100 rated duration runs. Failure of the system to meet any of its performance requirements during these tests shall be cause for rejection. These tests may be combined with rocket engine testing in MIL-R-5149.

4.3.17 Proof pressure. Proof pressure (6.3.4) tests shall be conducted on the propulsion feed system by pressurizing both the pressurization and propellant systems. The pressure shall be imposed and held for at least 2 minutes. Evidence of deformation or permanent set shall be cause for rejection.

4.4 Acceptance test. The acceptance tests specified in 4.4.1 through 4.4.6.4 shall be conducted on each propulsion feed system. Each feed system or its components shall be visually examined to determine conformance with its applicable drawings.

4.4.1 Weight. The dry weight (6.3.1) of the feed system shall be determined by either weighing the assembled system or adding the weights of the component parts. This weight shall not exceed that specified in the specification.

4.4.2 Static leakage. The feed system shall be tested for leakage by pressurizing the propellant and pressurization system with helium to normal operating pressures. The loading system shall be isolated from the feed system and feed system pressures and temperatures monitored for a period of one hour. Leakage shall not exceed the amount specified in the general specification.

4.4.3 Calibration. The feed system shall be operated through one complete cycle to demonstrate compliance with the performance characteristics of the general specification. System pressures, flow rates, temperatures, and pressure drops will be recorded. The amount of propellant required to fill the system and the propellant residuals remaining at the completion of the operating cycle shall also be determined. The test shall be performed at ambient temperature and pressure. Propellants shall be used for the calibration tests unless substitute fluids are approved by the procuring activity.

4.4.4 Additional tests. For the purpose of testing special features of the feed system, additional tests may be required. The following tests shall be included as a minimum.

* 4.4.4.1 Space Radiation. The system may be subjected to the following types of radiation environments. Estimates of the most severe radiation doses are given

below. Data on the new artificial radiation belt have been included in these estimates. The halflife of this new belt is not known, but estimates indicate that this belt will persist for many years at altitudes of 2000 nm or more. All reusable vehicle missions will be subjected to much lower fluxes. Hence, dosages must be evaluated on the basis of individual mission objectives and launch dates.

a. Internal, for an equivalent skin thickness of 0.1 inch aluminum

(1) Integrated ionizing dose	3×10^{8} roentgens/yr
(2) Maximum ionizing dose rate	10^{5} roentgens/hr
(3) Integrated proton flux	2×10^{12} protons/cm^{2}
(4) Maximum proton flux (E>20 Mev)	7×10^{4} protons/cm^{2}/sec
(5) Integrated electron flux	3×10^{16} electroncs/cm^{2}/yr
(6) Maximum electron flux (E > 1.6 Mev)	10^{9} electrons/cm^{2}/sec

b. Surface, for unshielded exposure:

(1) Integrated ionizing dose	10^{9} roentgens/yr
(2) Maximum ionizing dose rate	10^{7} roentgens/hr
(3) Integrated proton flux	3×10^{12} protons/cm^{2}/yr
(4) Maximum proton flux (E > 1 Mev)	10^{5} protons/cm^{2}/sec
(5) Maximum electron flux (E > 200 Kev)	3×10^{9} electrons/cm^{2}/sec

* 4.4.4.2 Corrosive Atmosphere. System or component performance shall not deviate beyond the specified limits during and after component exposure to corrosive atmospheres containing propellant fumes and those gases or vapors (e.g., ozone) that may be present during operation of the component at test bases or launch sites.

4.4.5 Rejection. Malfunction of the system during calibration and leakage testing in excess of allowable limits specified in the model specification shall be cause for rejection. Rejected systems may have their faulty components repaired or replaced and be subjected to those tests necessary to confirm acceptance.

4.4.6 Quality evidence tests. Evidence of suitable quality of material, parts, and components shall be based on physical inspection and process control data and may be supplemented by physical and chemical tests to determine the extent of conformance of the quality characteristics to the manufacturer's specifications and drawings.

4.4.6.1 Magnetic inspection. All stressed parts made of magnetic materials shall be subjected to magnetic particle inspection in accordance with MIL-I-6866.

4.4.6.2 Fluorescent penetrant inspection. All stressed parts made of non-magnetic materials shall be subjected to fluorescent penetrant inspection in accordance with MIL-I-6866.

4.4.6.3 Antifriction bearings. Assembled ball or roller bearings shall not be inspected magnetically or with a penetrant.

4.4.6.4 Radiographic inspection. All magnesium and aluminum castings shall be subjected to radiographic inspection in accordance with MIL-STD-453.

5. PREPARATION FOR DELIVERY

5.1 Storage and shipment requirements. The propulsion feed systems and accessories shall be prepared for storage and shipment in accordance with the requirements set forth in subsequent paragraphs.

5.1.1 Draining and purging. Prior to packaging for shipment, all working fluids shall be drained from the propulsion feed systems. The feed systems shall be purged with an inert gas having characteristics and purity that are compatible with the contamination limitations of the feed systems.

5.1.2 Cleaning, preservation, and packaging. Cleaning, preserving, and packaging of the propulsion feed systems and associated equipment shall be accomplished in accordance with MIL-P-116. All caps, plugs, and covers used for closures of open ports shall be in accordance with MIL-C-5501.

5.1.3 Hazardous conditions. Hazardous conditions during shipment of the feed system shall be minimized. Explosive ordnance equipment such as squibs or igniters shall not be transported while installed in the feed system. Desiccant type breathers shall be employed on all feed systems during storage and transportation except where internal pressurization is required for structural purposes. For systems requiring pressurization, provisions shall be made for maintaining pressure within required limits. For air transport, maximum rate of altitude change shall be specified in the model specification.

5.1.4 Marking of shipments. Shipping containers shall be marked in accordance with MIL-STD-129.

6. NOTES

6.1 Intended use. The propulsion feed system specification is intended for use in either manned or unmanned remote-launched, air-launched, and spacecraft systems.

6.2 Symbols. The symbols used herein and in the model specification will be those in American Association Standard ASA Y10.14 – 1959. Symbols not included, that may be required, shall be defined in the model specification.

6.3 Definitions.

6.3.1 Dry weight. Dry weight is the weight of the assembled propellant feed system when completely dry of all propellants, lubricant, hydraulic fluids, etc.

6.3.2 Interfaces. Interfaces are those requirements or physical features of the propellant feed system which attach to or otherwise affect the characteristics of the engine or vehicle or the characteristics of aerospace ground equipment which is not furnished by the engine manufacturer.

6.3.3 Procuring activity. Procuring activity is the activity which negotiates the contract.

6.3.4 Proof pressure. Proof pressure is the test pressure to which an item is subjected without leakage, deformation or detrimental permanent set adversely affecting engine operation.

6.3.5 Service life. Service life is the sum of storage and operating lifes.

6.3.6 Standard Condition. Standard conditions are the values of air temperature and pressure given in the U. S. Standard Atmosphere 1962. The standard humidity, for the purpose of this specification, is zero vapor pressure for all altitudes.

6.3.7 Storage life. Storage life is the time that the propellant feed system can be stored, after quality conformance tests, without replacement of parts and subsequently operate within specification limits.

6.3.8 Trapped propellant. Trapped propellant is the residual propellant remaining in the propellant feed system which is unavailable to the rocket engine.

6.3.9 Usable propellant. Usable propellant is that propellant consumed in the production of useful impulse. It does not include that consumed during vehicle holddown during launch.

Custodian:	Preparing activity:
Air Force – 12	Air Force – 12
Review activities:	Civilian agency interest:
Air Force – 14, 19, 70	NAS

Reviewer/user information is current as of the date of this document. For further coordination of changes to this document, draft circulation should be based on the information in the current DoD Index of Specifications and Standards.

Appendix C
STRESS ANALYSIS OF REUSABLE PROPELLANT TANKS

Section 1
INTRODUCTION

In the course of evaluating the reusability of any launch vehicle or spacecraft, the stress histories imposed on the propellant tankage must be considered. Although a comprehensive structural analysis of all the parameters involved in such a study was beyond the scope of this program, analyses were performed in sufficient depth to furnish the information necessary to support the program requirements.

Results are presented for three cryogenic propellant configurations that were analyzed. Both stresses and displacement were calculated for the two tank configurations that were bodies of revolution, using versions of the SADISTIC (Stress and Displacements In Shell with Thermally Induced Conditions) computer program. For the unsymmetric tank which had no axis of revolution, a general shell analysis program was employed to determine stress levels only.

All tanks were considered to be fabricated from 2219-T87 aluminum alloy. Material properties at expected operating temperature were used. In selecting the appropriate operating temperature, an estimate of the effect of heated pressurant gas injection was made and tank wall temperatures were increased appropriately. Specific results for each configuration are presented in the following pages.

NOTE TO READER

No classified material is contained in this appendix.

Section 2
REUSABLE LAUNCH VEHICLE PROPELLANT TANKS

2.1 GEOMETRY

The fuel and oxidizer tanks for the Reusable Launch Vehicle (Space Shuttle) are shown in Figure 3-1 of Volume II. The tanks are shells of revolution subjected to a uniform internal pressure loading in one condition, and in another to a uniform internal pressure superposed on a hydrostatic pressure due to axial acceleration of the filled tank. The geometry and directions of positive displacement components and stresses are shown in Figure C2-1 for both the oxidizer and the fuel tank. Actually, the axis of the vehicle does not exactly coincide with those of the tanks. However, in order to render the loading completely axisymmetric, it was assumed that the axes did exactly coincide. The mid-section of each tank was composed of one or two conical segments; the end caps were composed of spherical and toroidal segments. The oxidizer tank is supported by a heavy ring at the small end of the conical segment and receives additional radial restraint from a heavy stabilizing ring at the large end of the conical segment. The fuel tank is supported by a heavy ring at the juncture between the two conical segments and receives additional radial restraint from a heavy stabilizing ring at the large end of the larger conical segment. It was assumed that each ring could not deform in the radial direction or rotate out of its plane.

2.2 LOAD CASES

Five different cases were run. These are as follows:

Case	Tank	Temp (^oF)	Wall Thickness (in.)	Loading (psi)
1	Oxidizer	-160	0.04	32 internal
2	Oxidizer	-160	0.04	21 internal +61 hydrostatic
3	Oxidizer	-160	0.10	21 internal +61 hydrostatic
4	Fuel	-160	0.10	42 internal
5	Fuel	-160	0.10	24 internal +3.7 hydrostatic

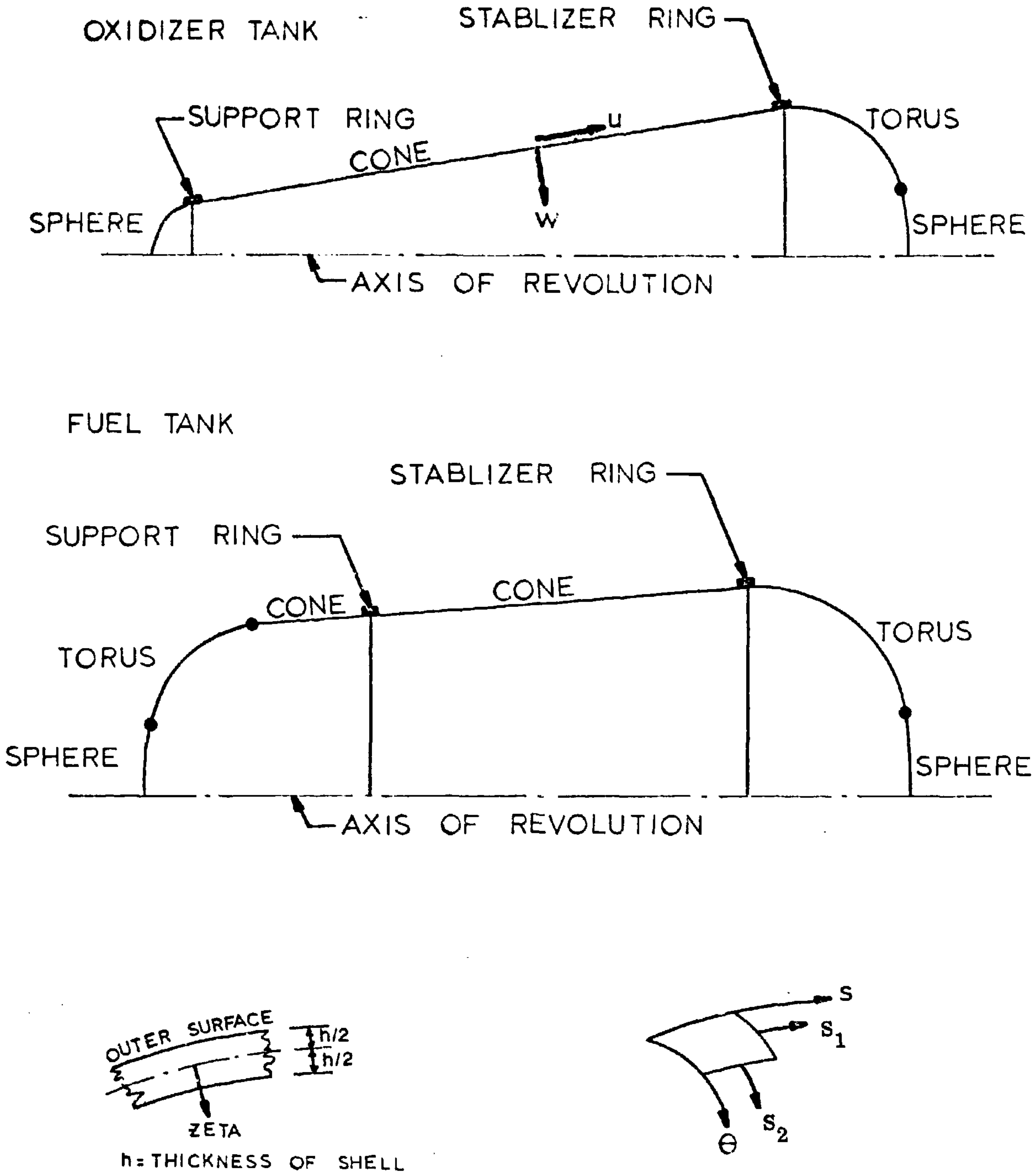

Figure C2-1 Tank Geometry and Definition of Positive Displacement and Stress Components

Acceleration loads were assumed to act along the axis of revolution with the small end of the tank being forward in the vehicle. Thus the hydrostatic pressures quoted are those at the "bottom", i.e., at the apex of the big end of the tank. The hydrostatic component of the total pressure varies linearly from this maximum value at the "bottom" to zero at the "top".

2.3 RESULTS

Results are presented in the form of stress plotted as a function of a nondimensional arc length S/S_L where S_L is the total length of the element under consideration. For the oxidizer tank (Cases 1, 2, and 3) the four elements considered are the sphere, cone, torus, and sphere indicated in Figure C2-1 which also shows the six elements used in the fuel tank analysis (Cases 4 and 5). Meridional stress (S_1) and circumferential stress (S_2) are presented. Calculations were made at inner, outer, and mid-point of the material thickness. In general, the results indicated little or no variation from the inner to outer surface. Therefore, results are presented for only one surface for each case.

Figure C2-2 presents the four elements of the oxidizer tank inner surface for Case 1, Figure C2-3 for Case 2, and Figure C2-4 for Case 3.

The stress distributions along the outer surface of the six elements of the fuel tank are presented in Figure C2-5 for Case 4 and Figure C2-6 for Case 5.

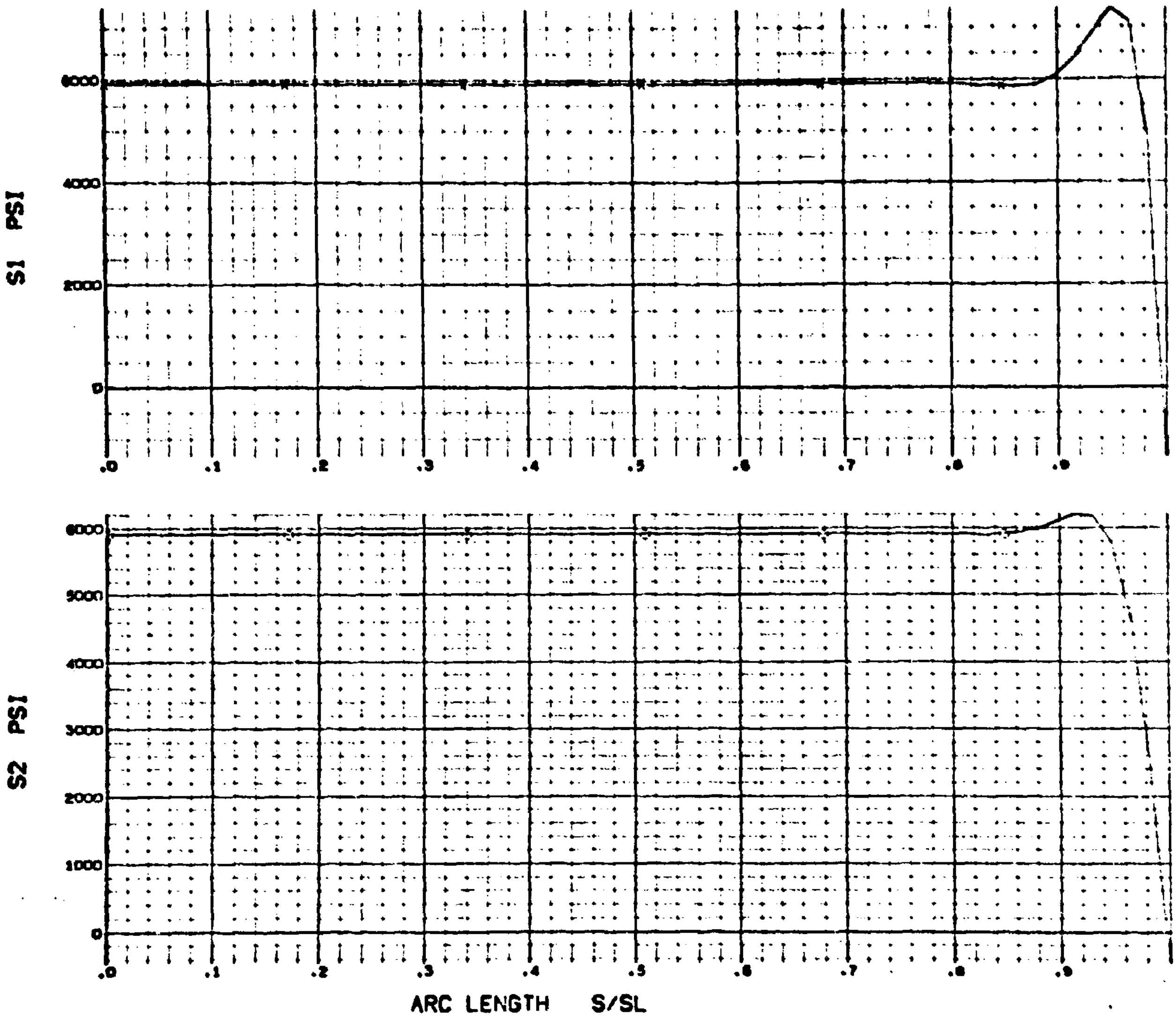

Figure C2-2a Oxidizer Tank Stress vs S/S_L – Sphere, Element 1

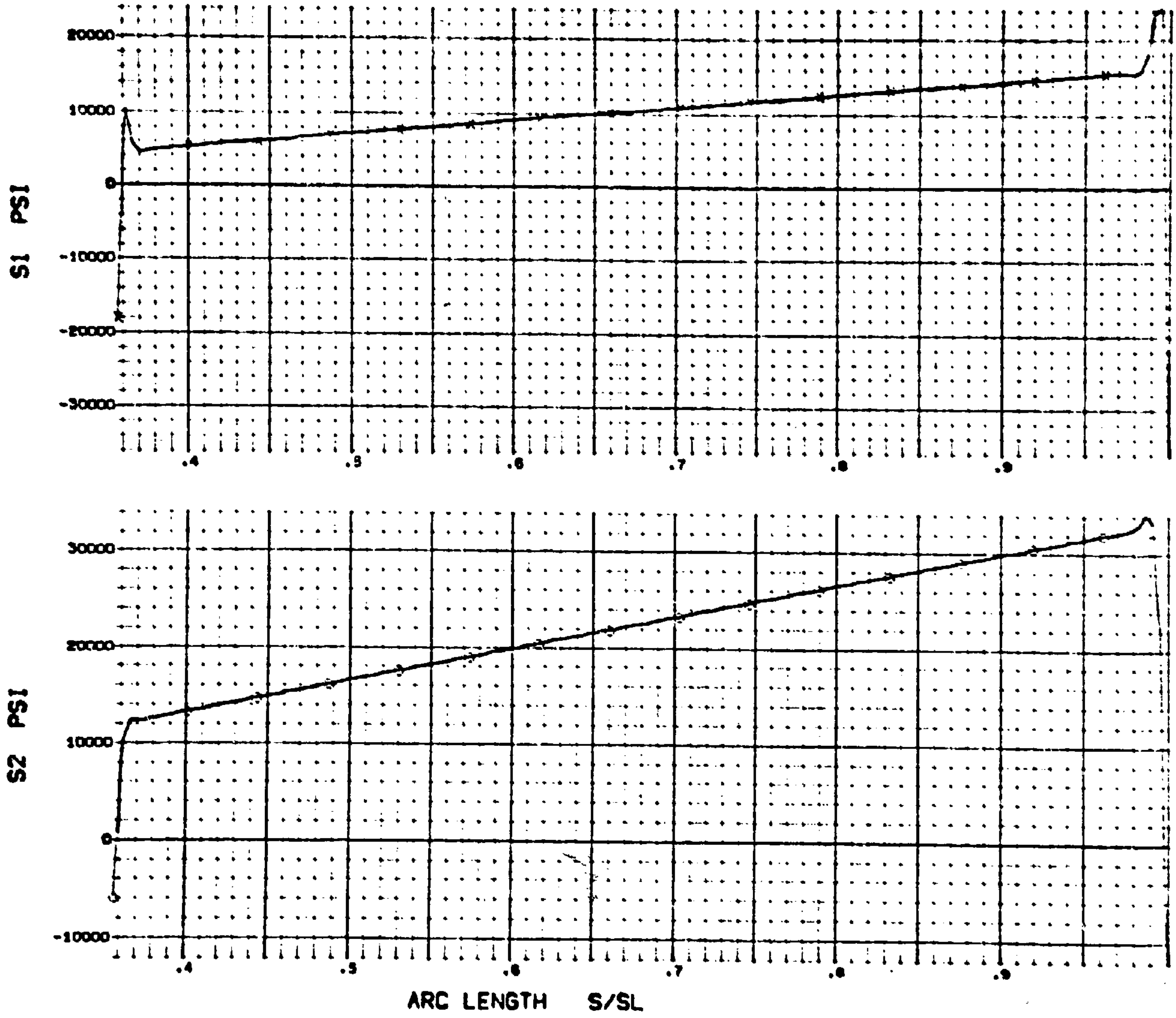

Figure C2-2b Oxidizer Tank Stress vs S/S_L – Cone, Element 2

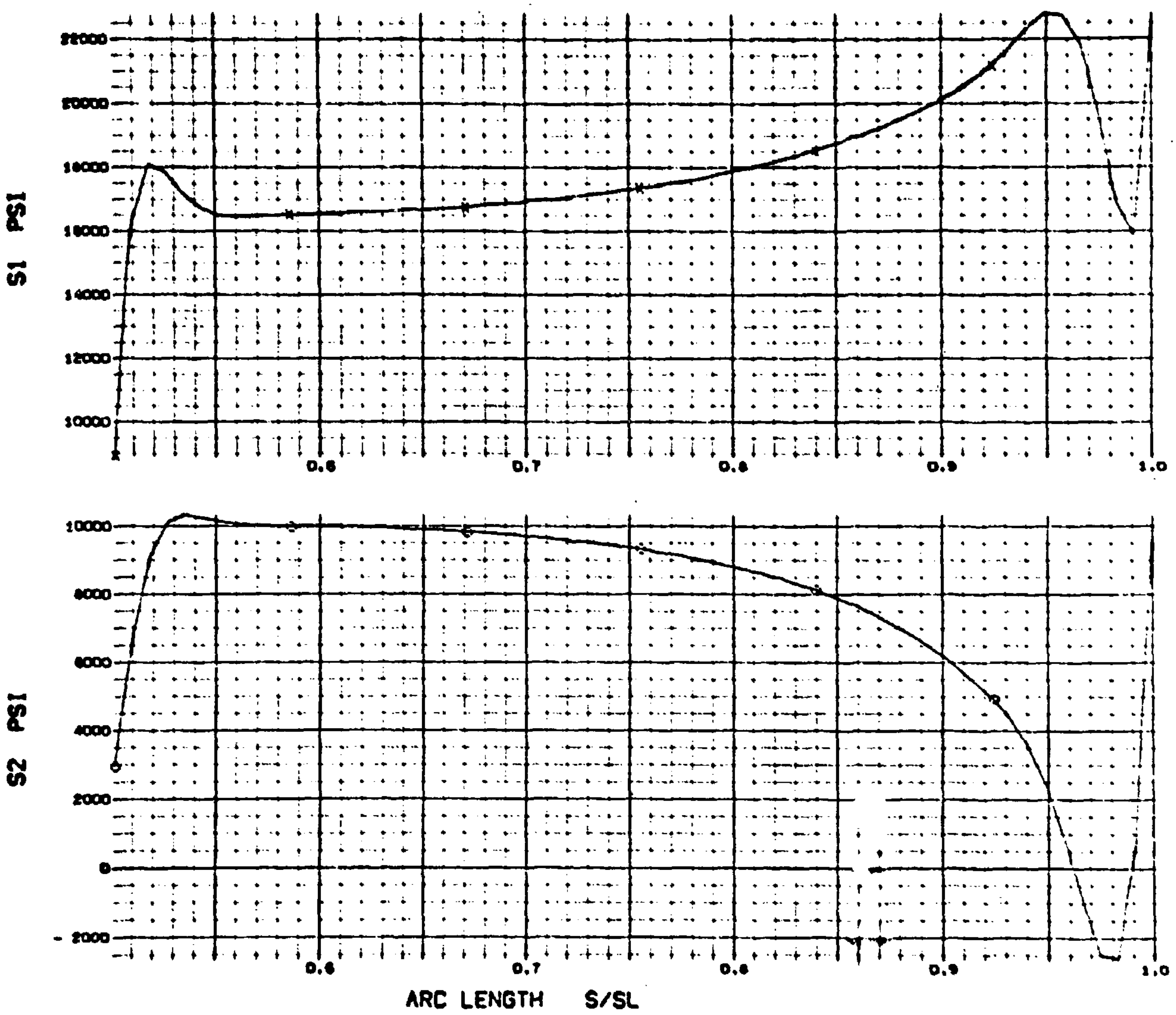

Figure C2-2c Oxidizer Tank Stress vs S/S_L – Torus, Element 3

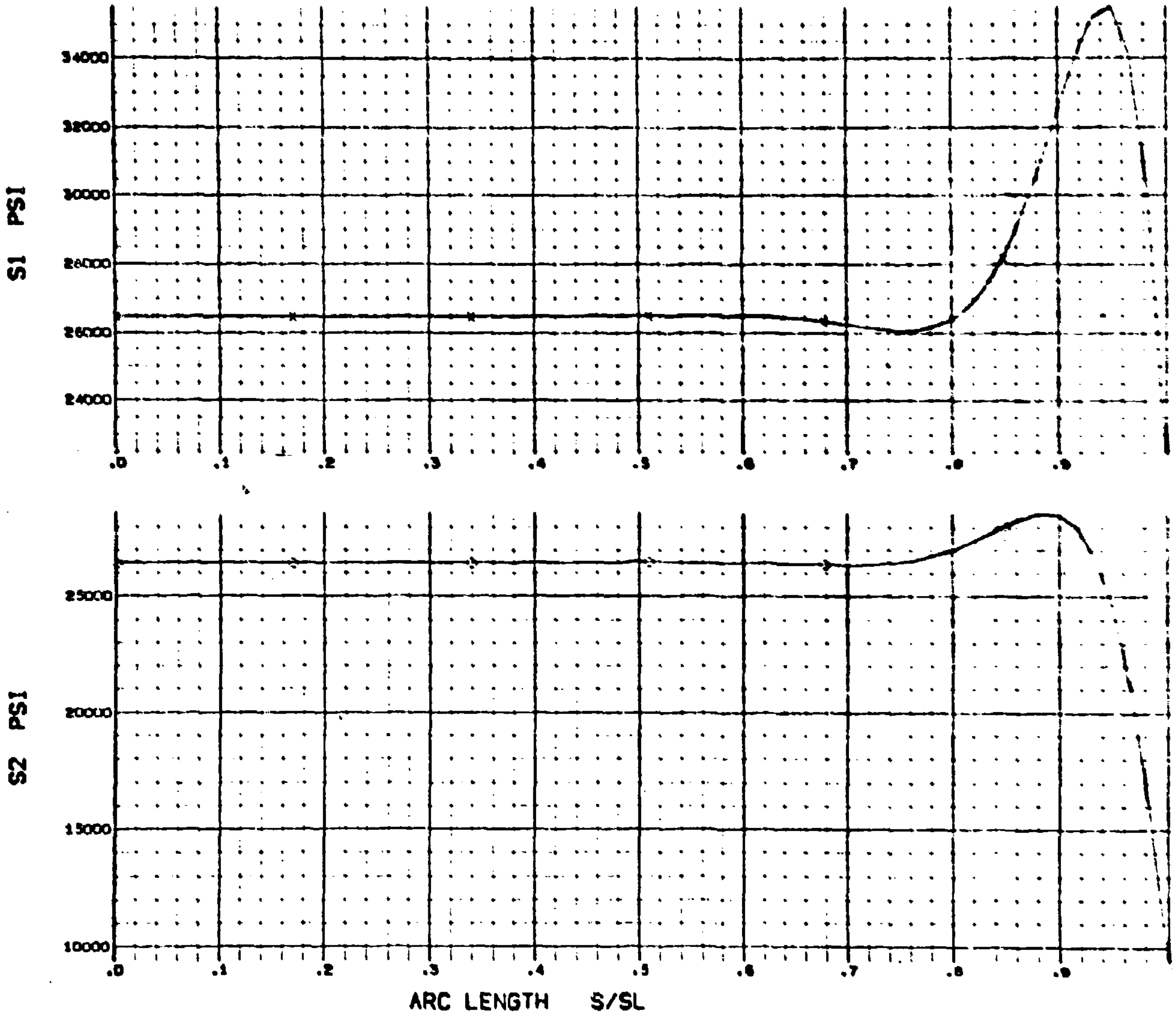

Figure C2-2d Oxidizer Tank Stress vs S/S_L – Sphere, Element 4

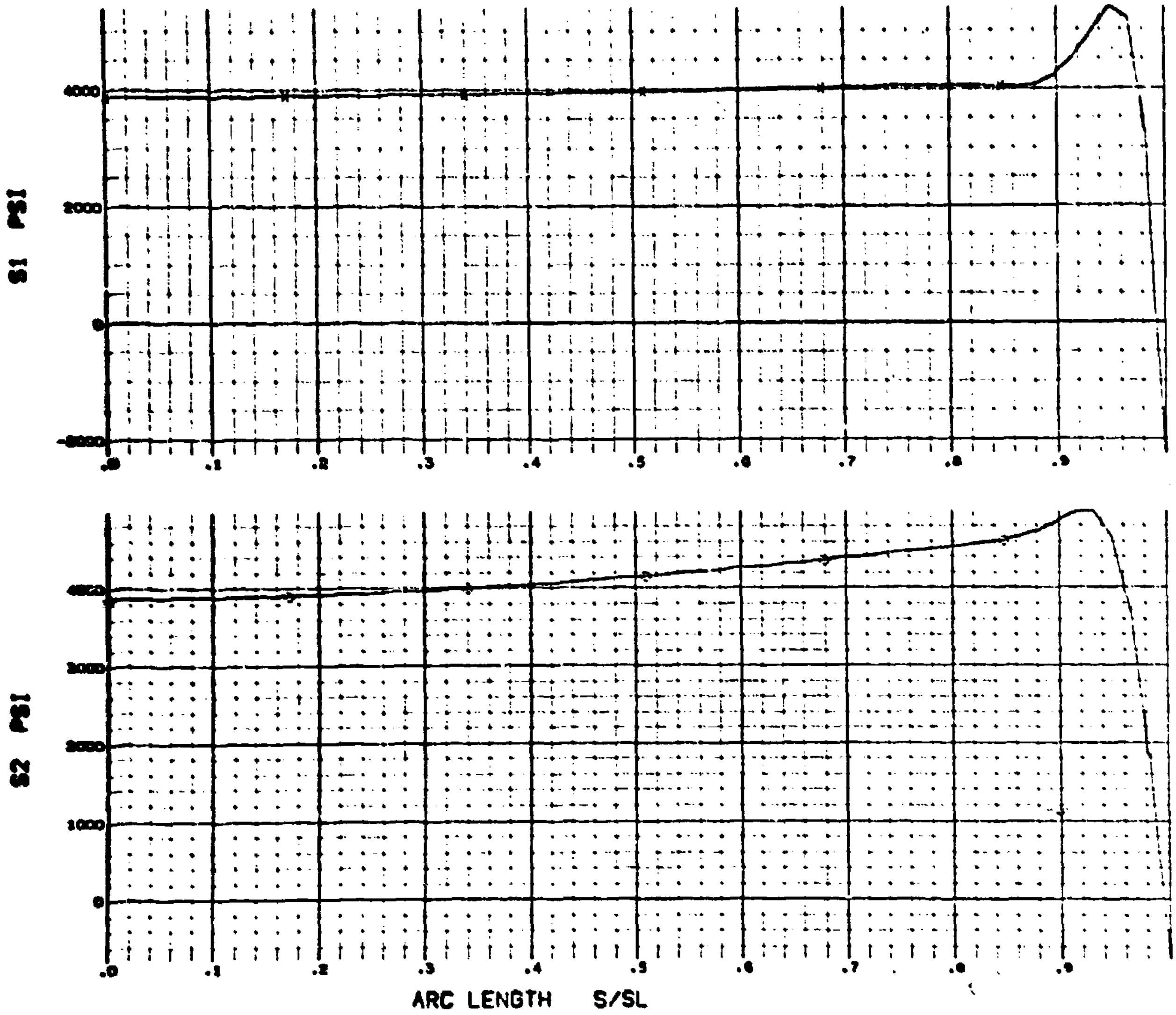

Figure C2-3a Oxidizer Tank Stress vs S/S_L – Sphere, Element 1

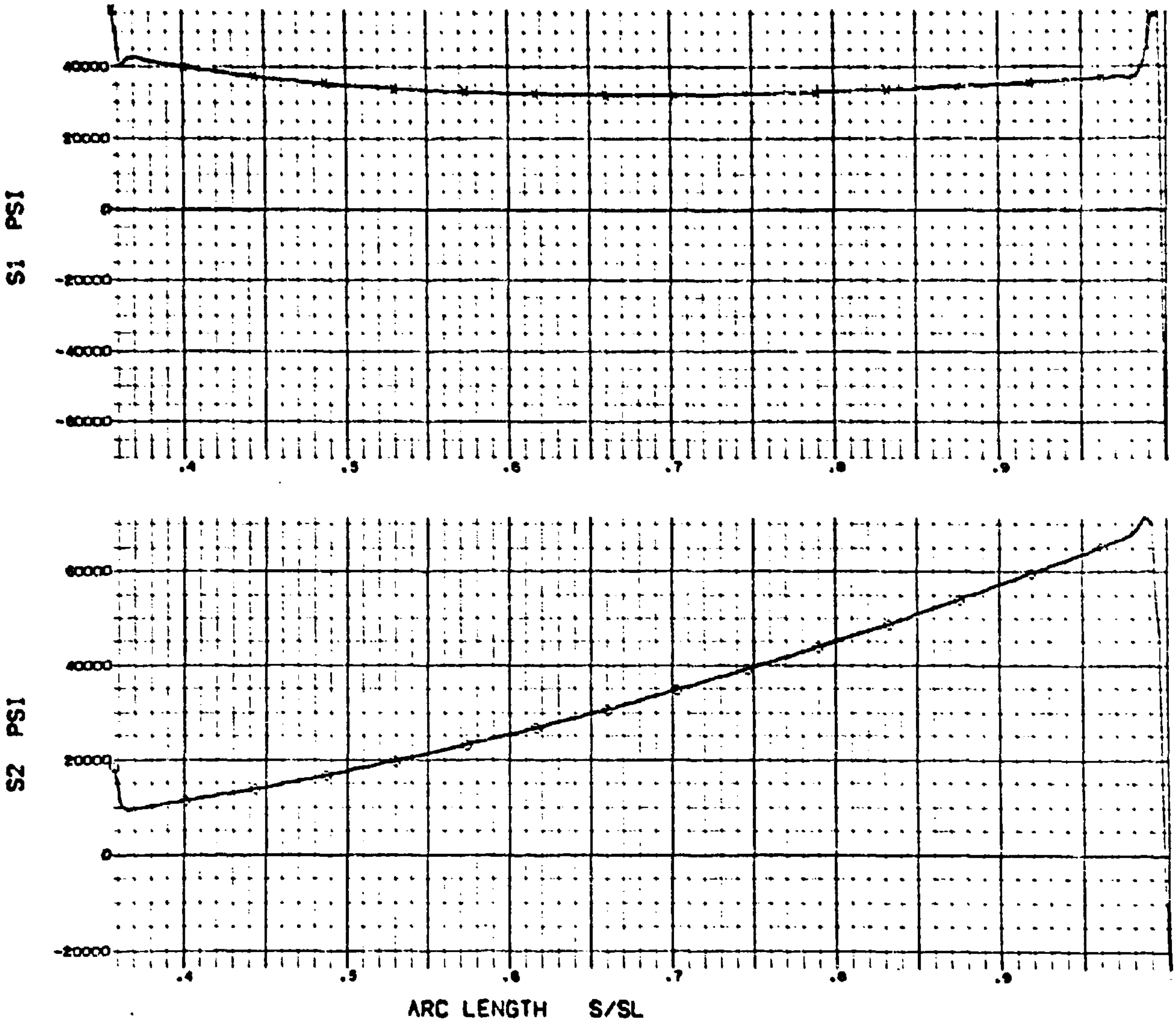

Figure C2-3b Oxidizer Tank Stress vs S/S_L – Cone, Element 2

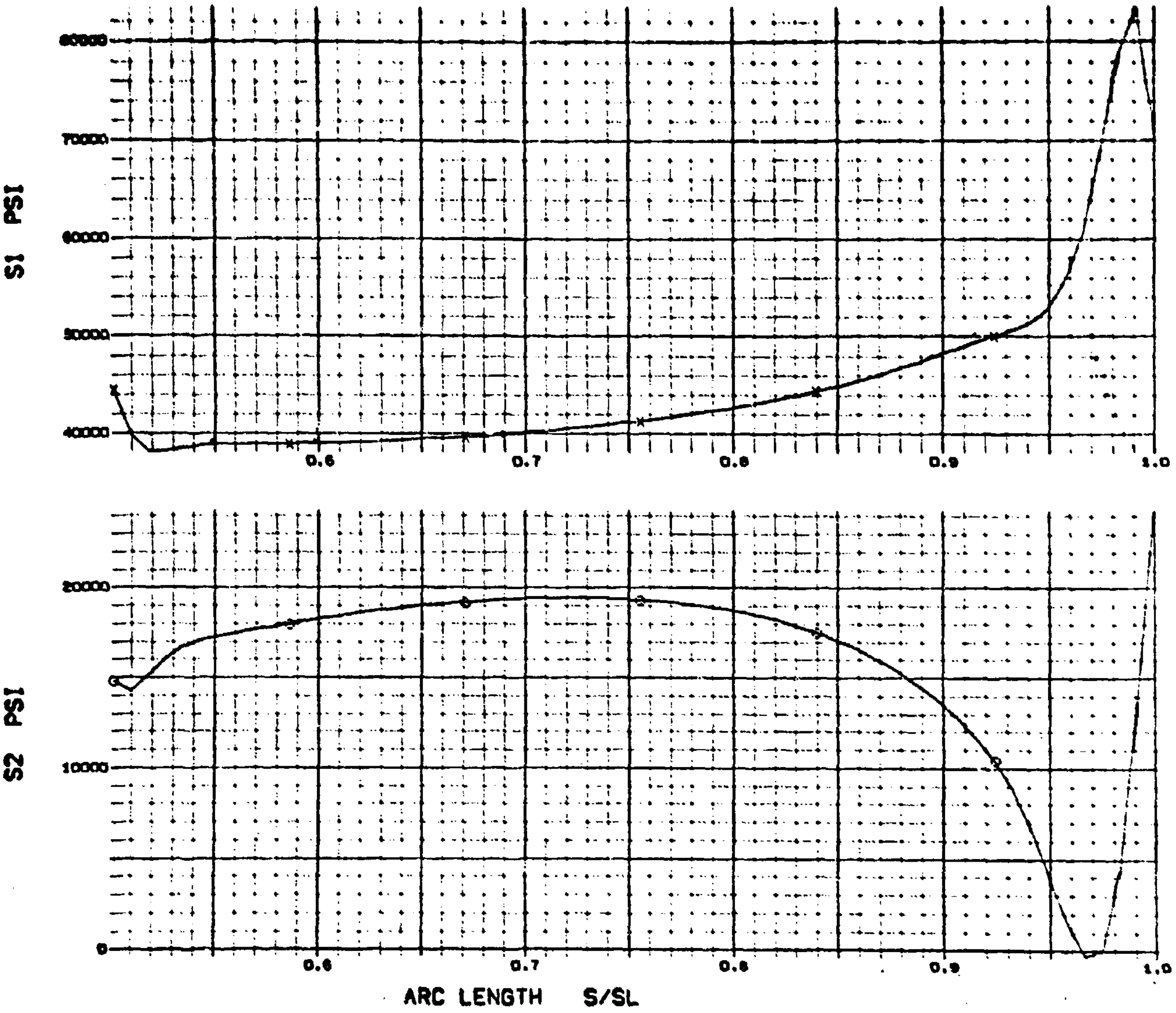

Figure C2-3c Oxidizer Tank Stress vs S/S_L – Torus, Element 3

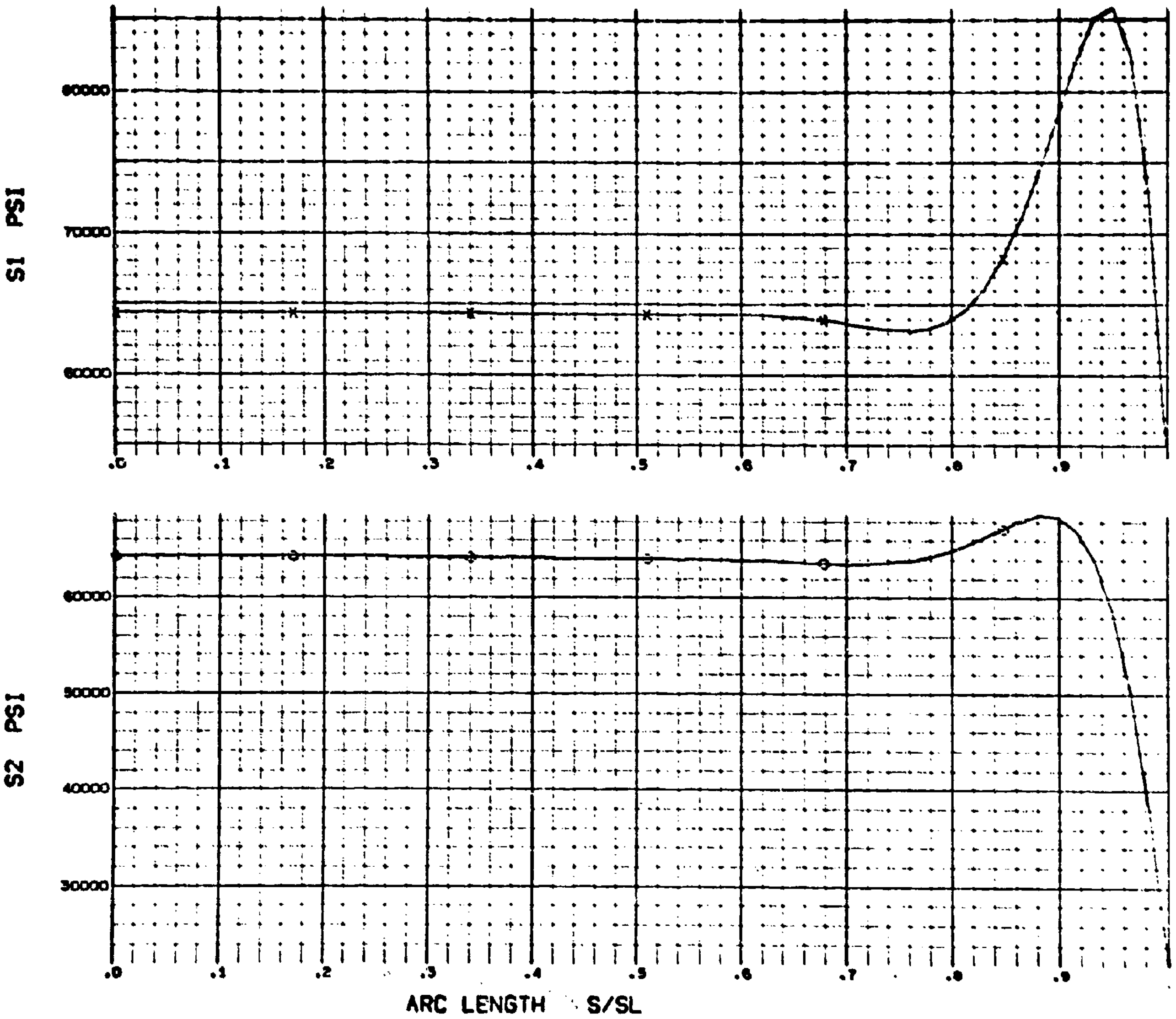

Figure C2-3d Oxidizer Tank Stress vs S/S_L – Sphere, Element 4

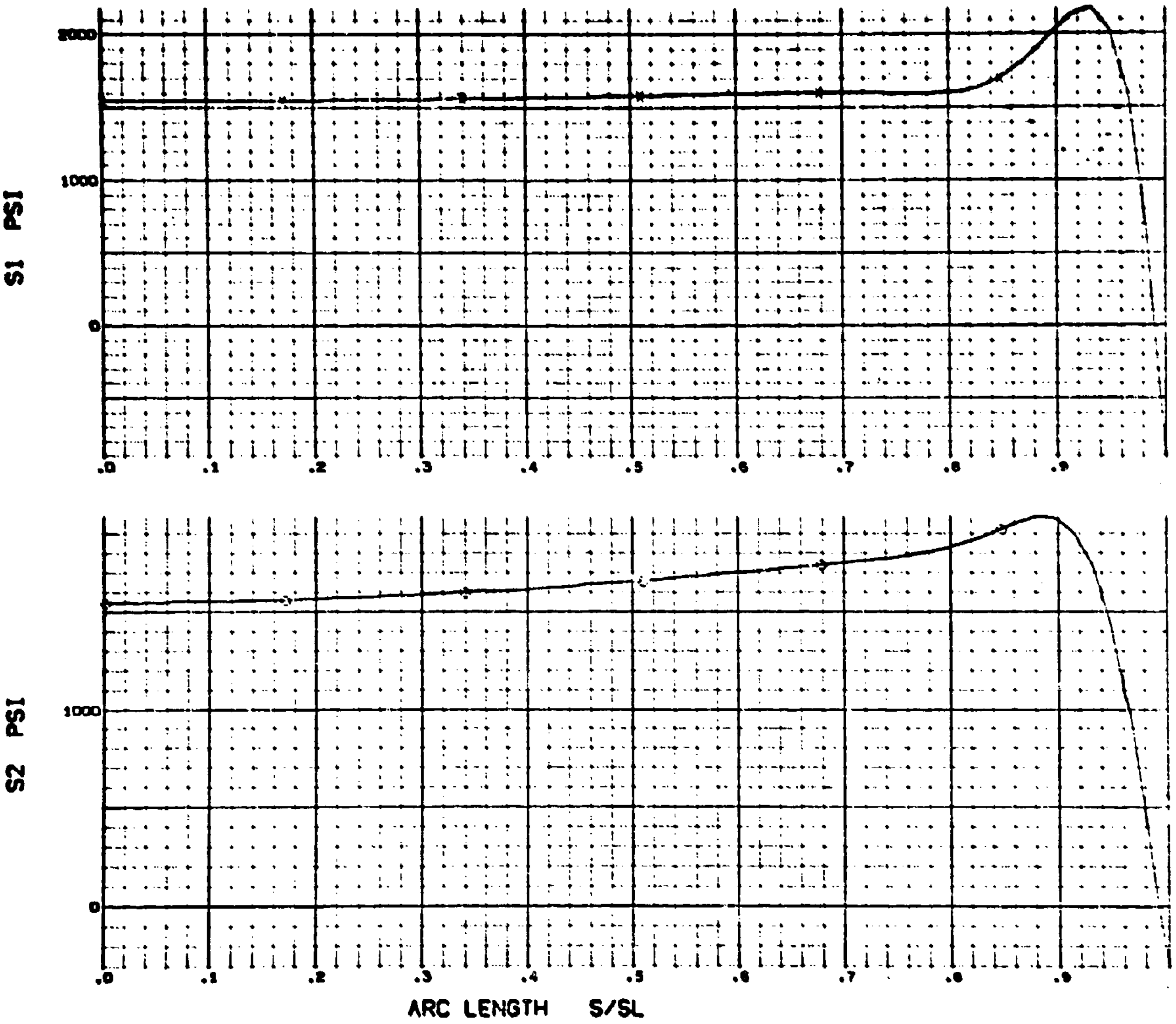

Figure C2-4a Oxidizer Tank Stress vs S/S_L – Sphere, Element 1

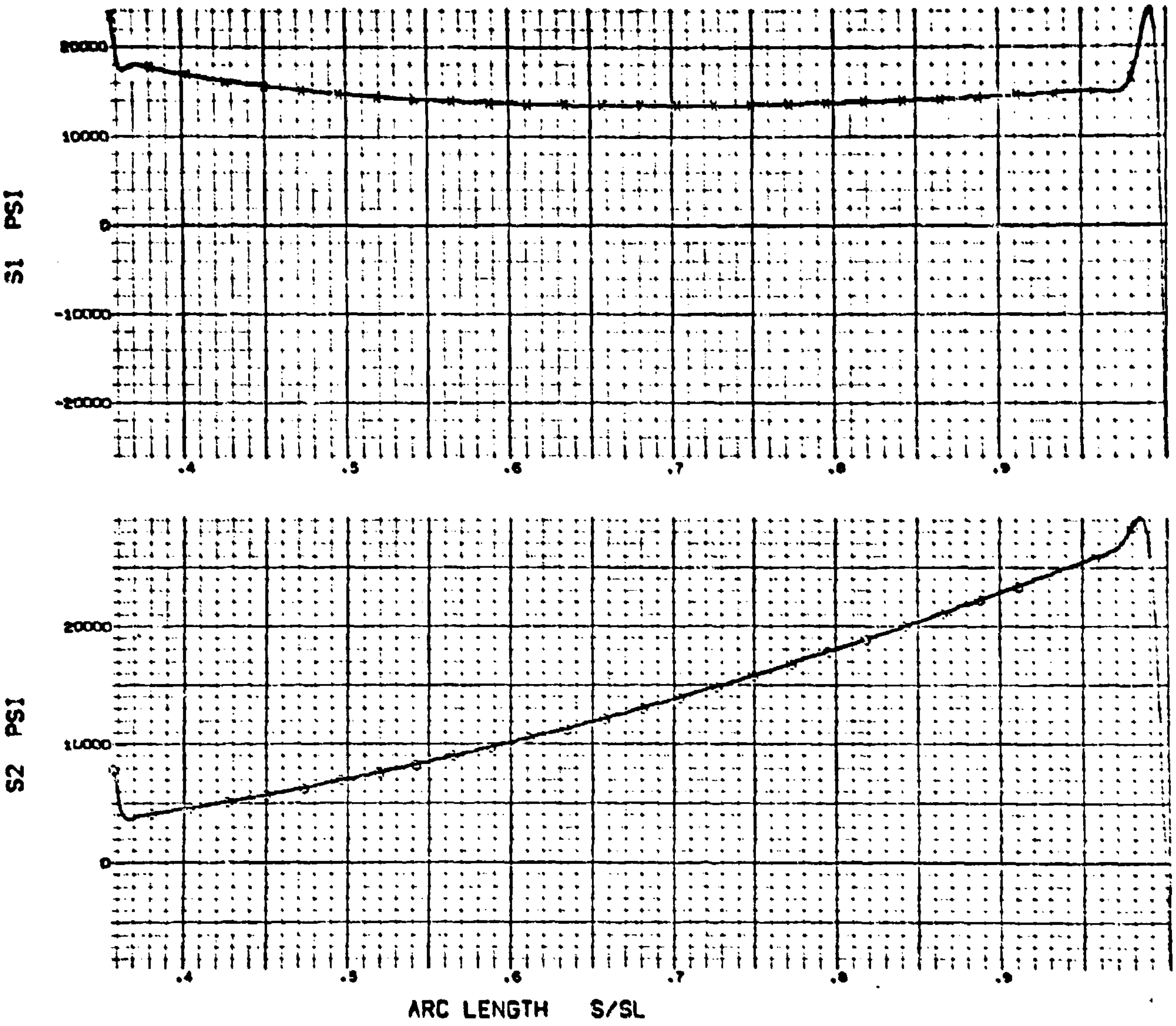

Figure C2-4b Oxidizer Tank Stress vs S/S_L – Cone, Element 2

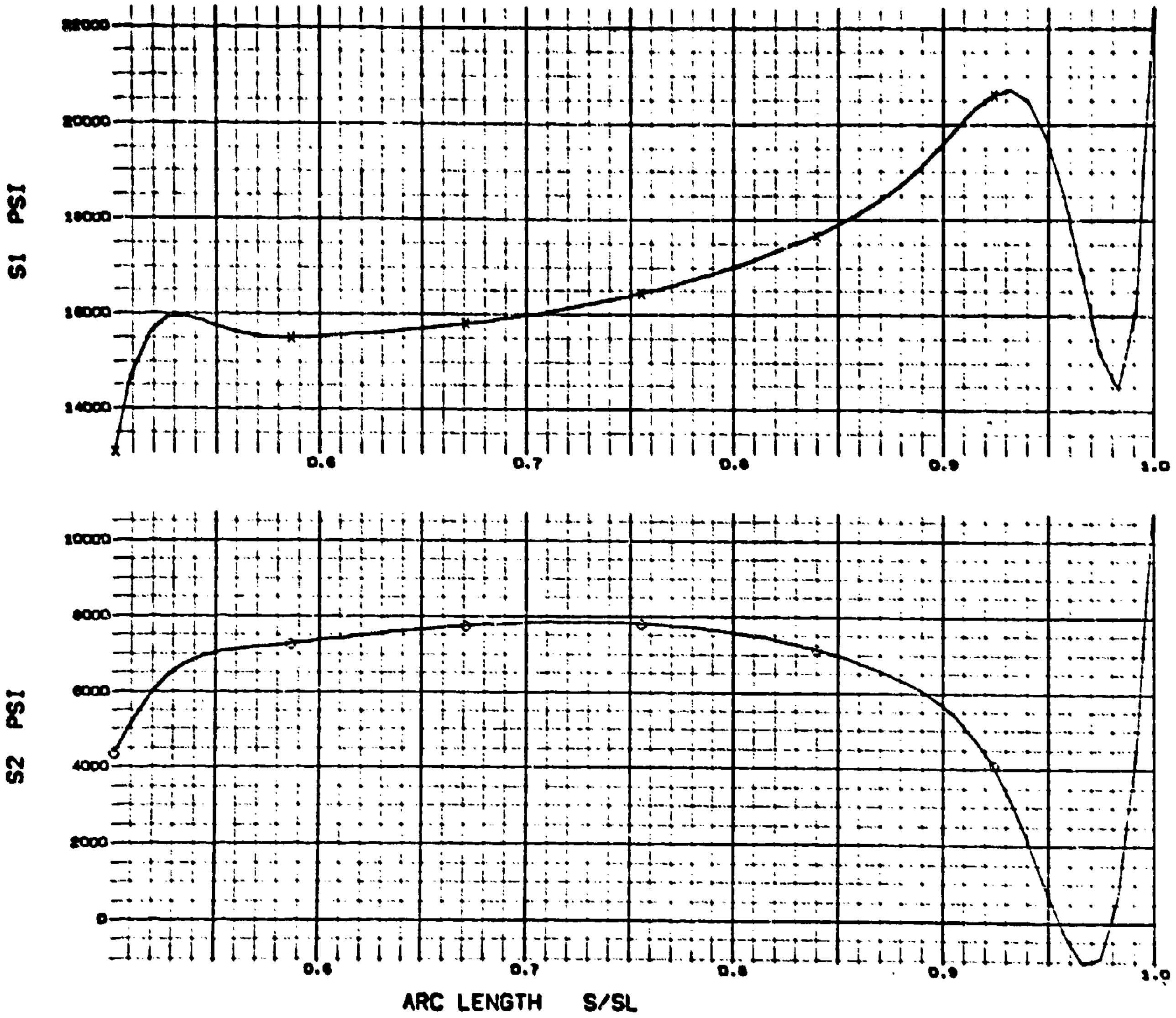

Figure C2-4c Oxidizer Tank Stress vs S/S_L – Torus, Element 3

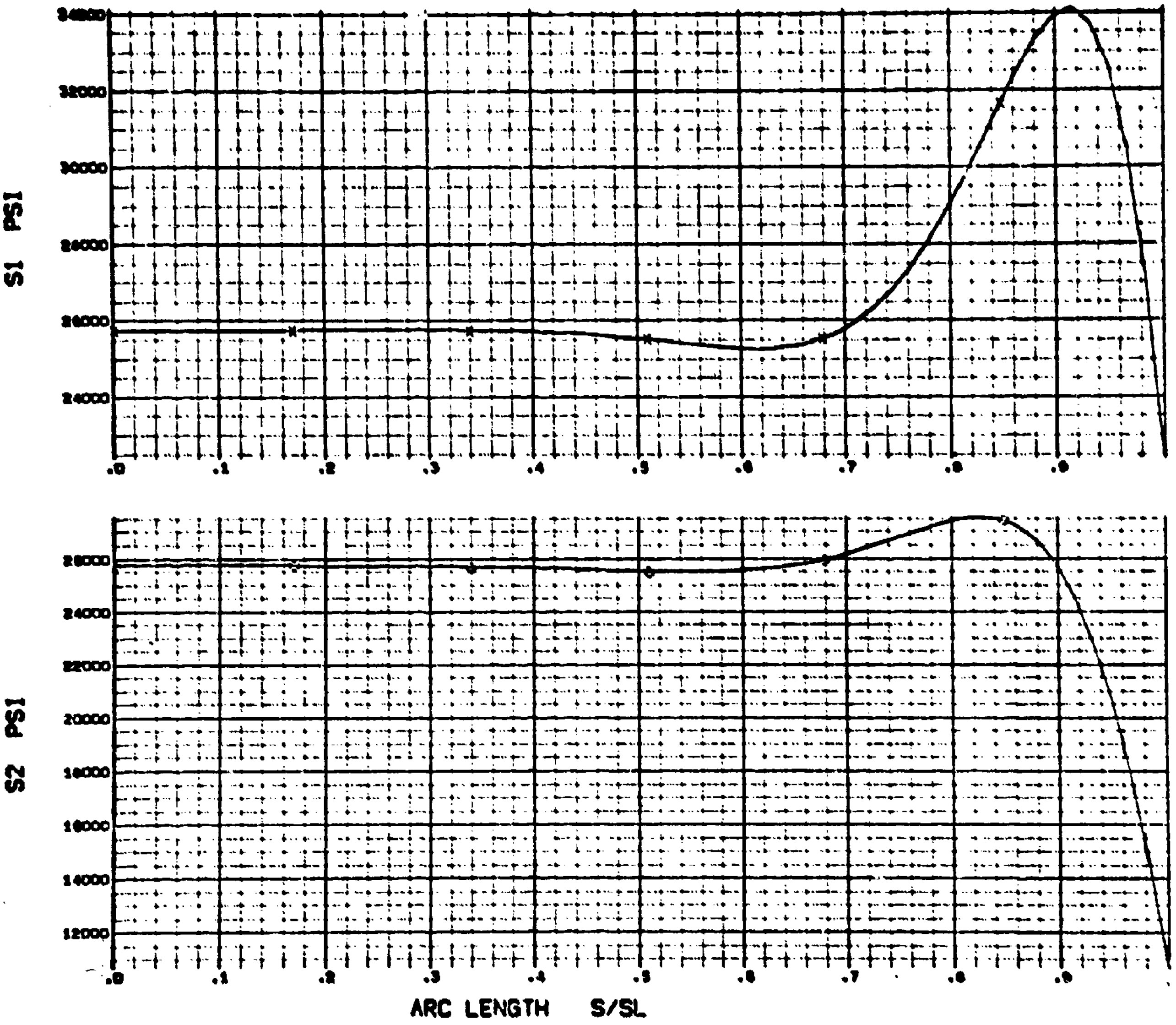

Figure C2-4d Oxidizer Tank Stress vs S/S_L – Sphere, Element 4

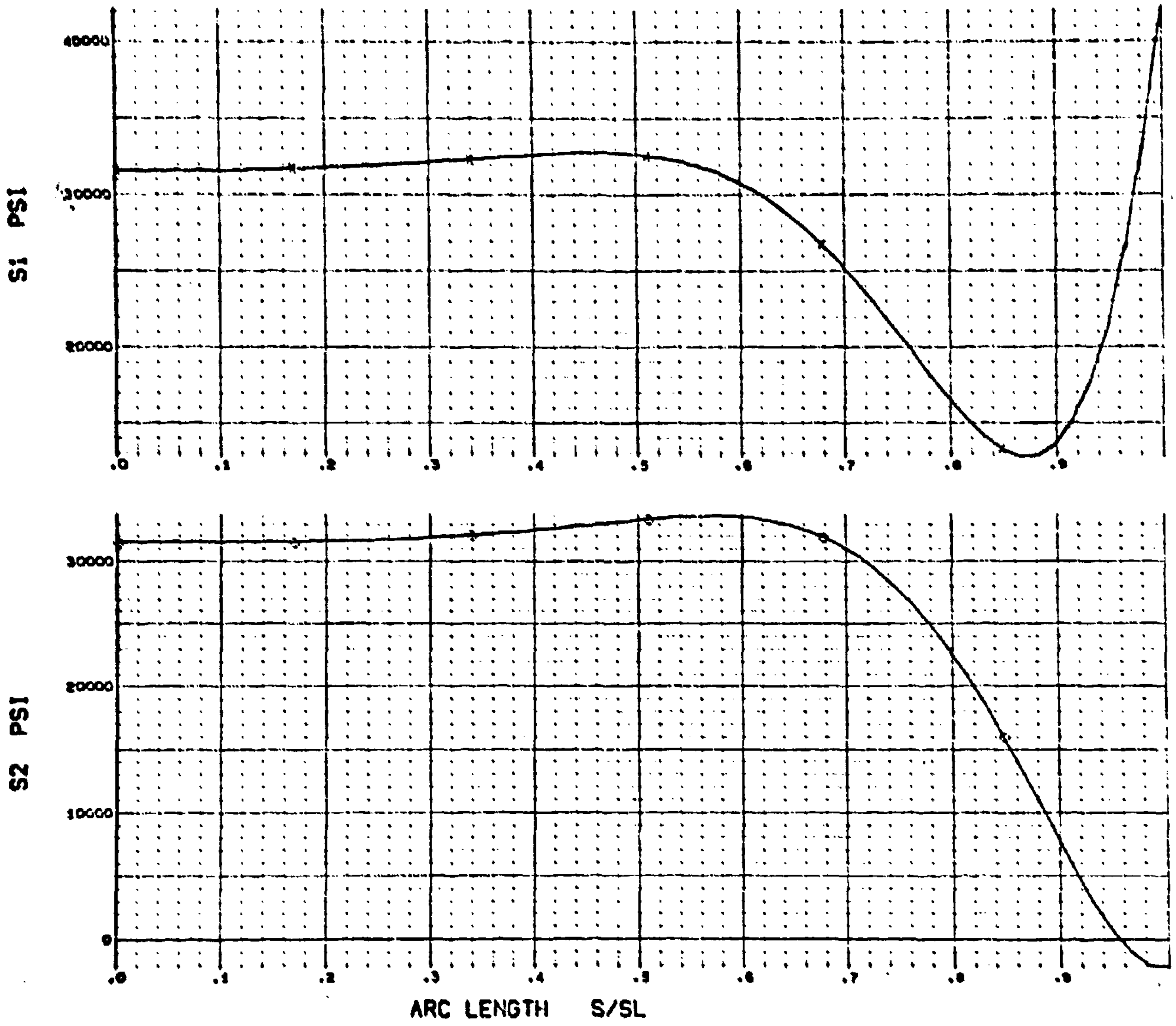

Figure C2-5a Fuel Tank Stress vs S/S_L – Sphere, Element 1

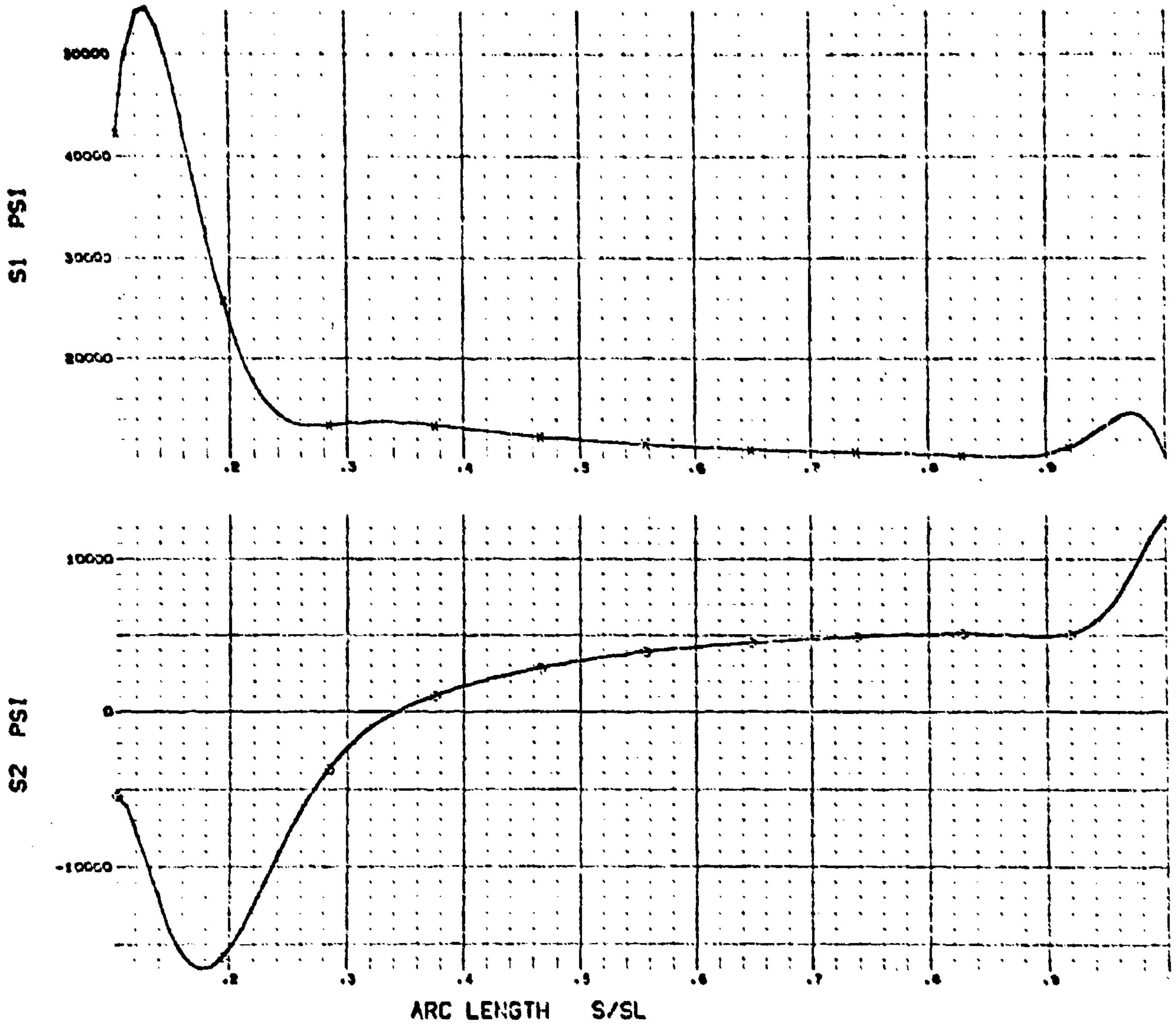

Figure C2-5b Fuel Tank Stress vs S/S_L – Torus, Element 2

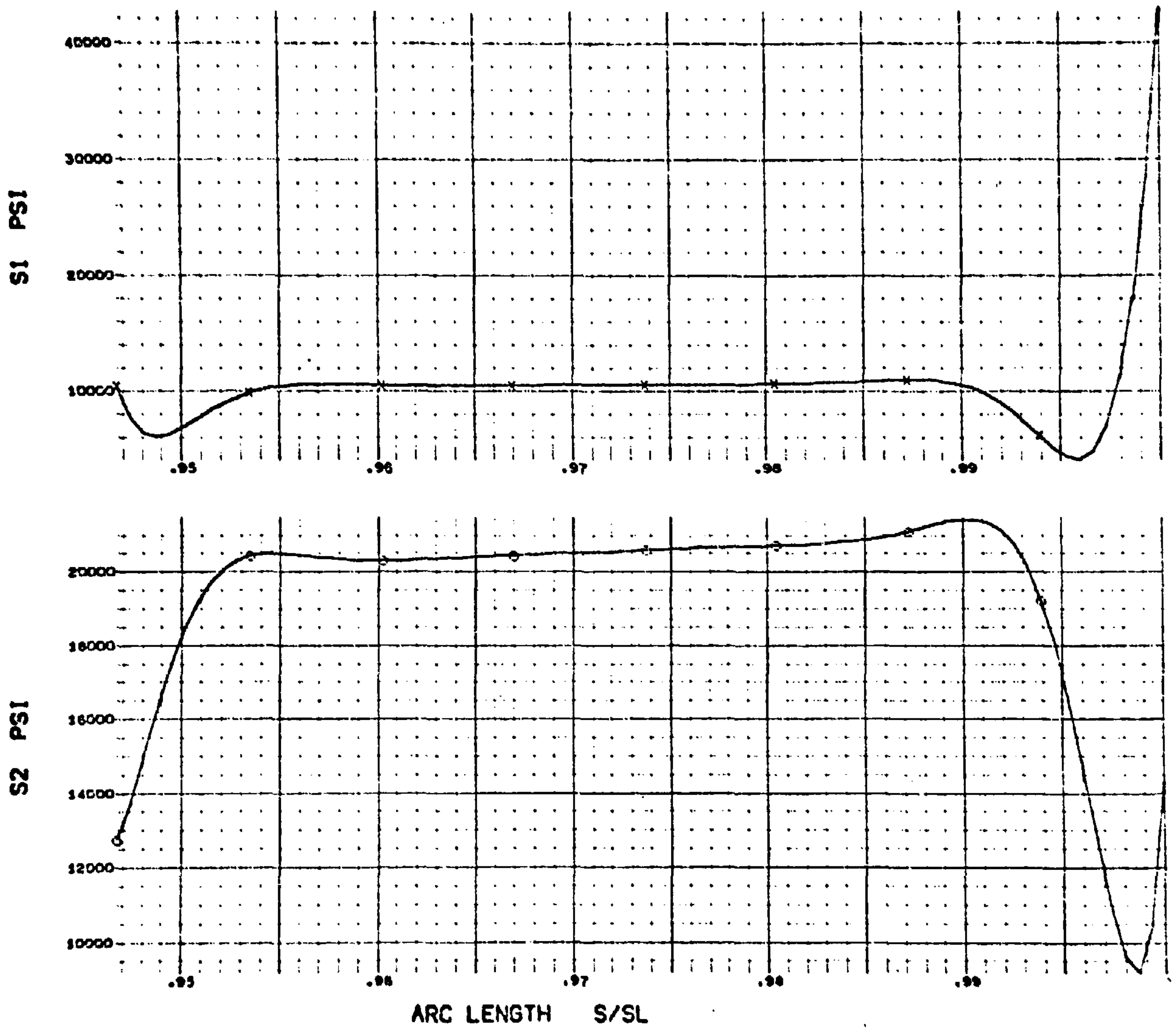

Figure C2-5c Fuel Tank Stress vs S/S_L -- Cone, Element 3

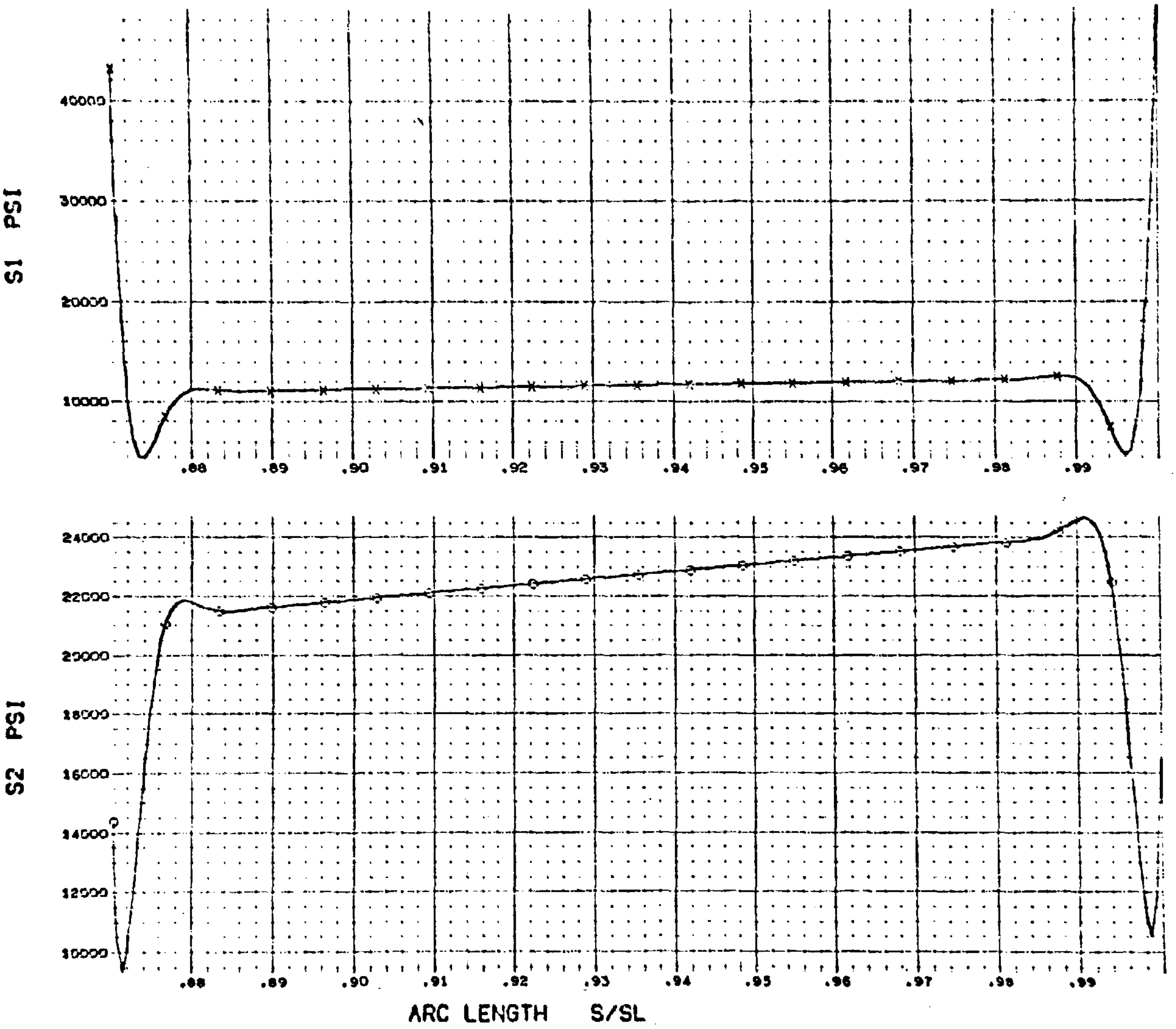

Figure C2-5d Fuel Tank Stress vs S/S_L – Cone, Element 4

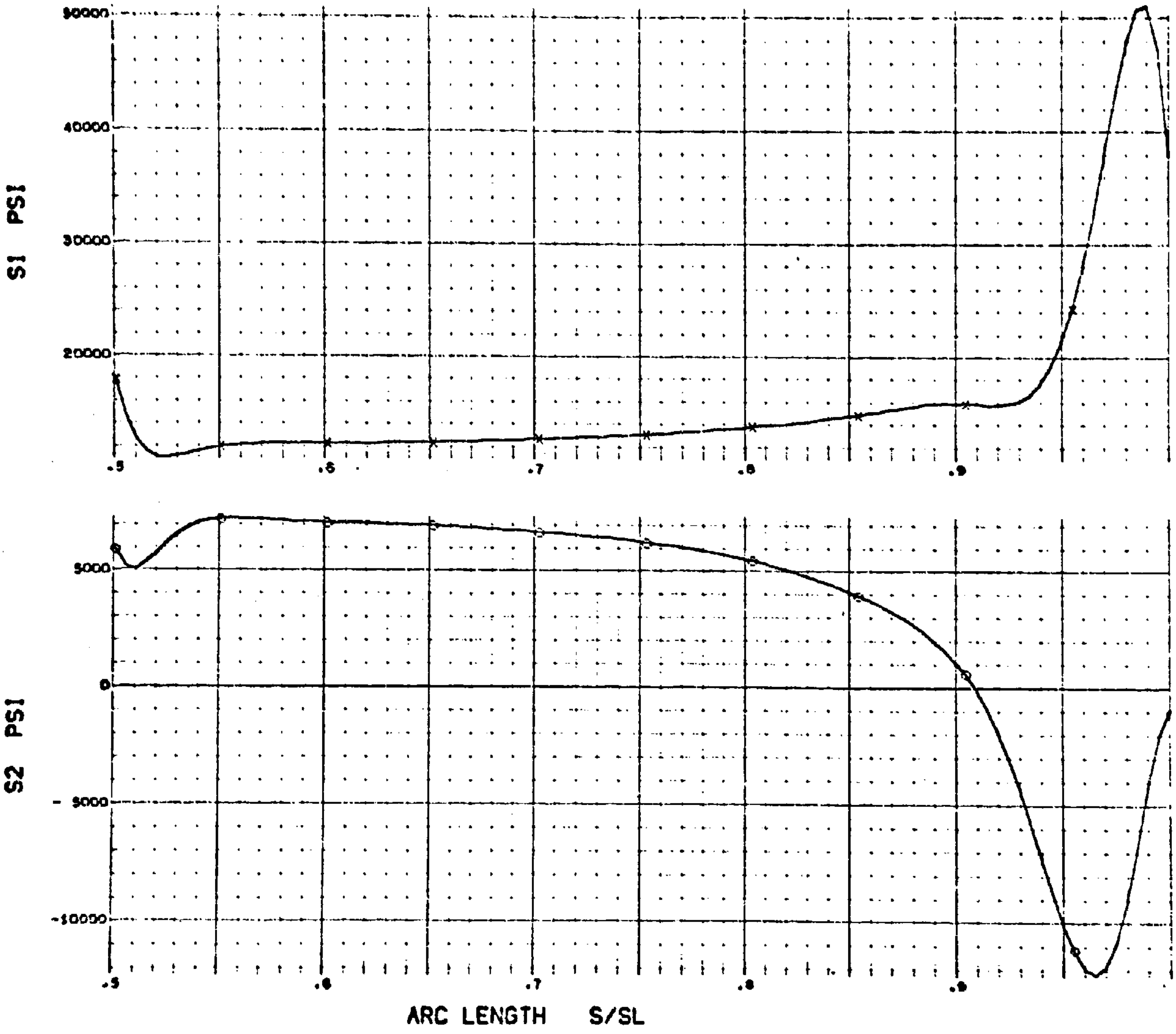

Figure C2-5e Fuel Tank Stress vs S/S_L – Torus, Element 5

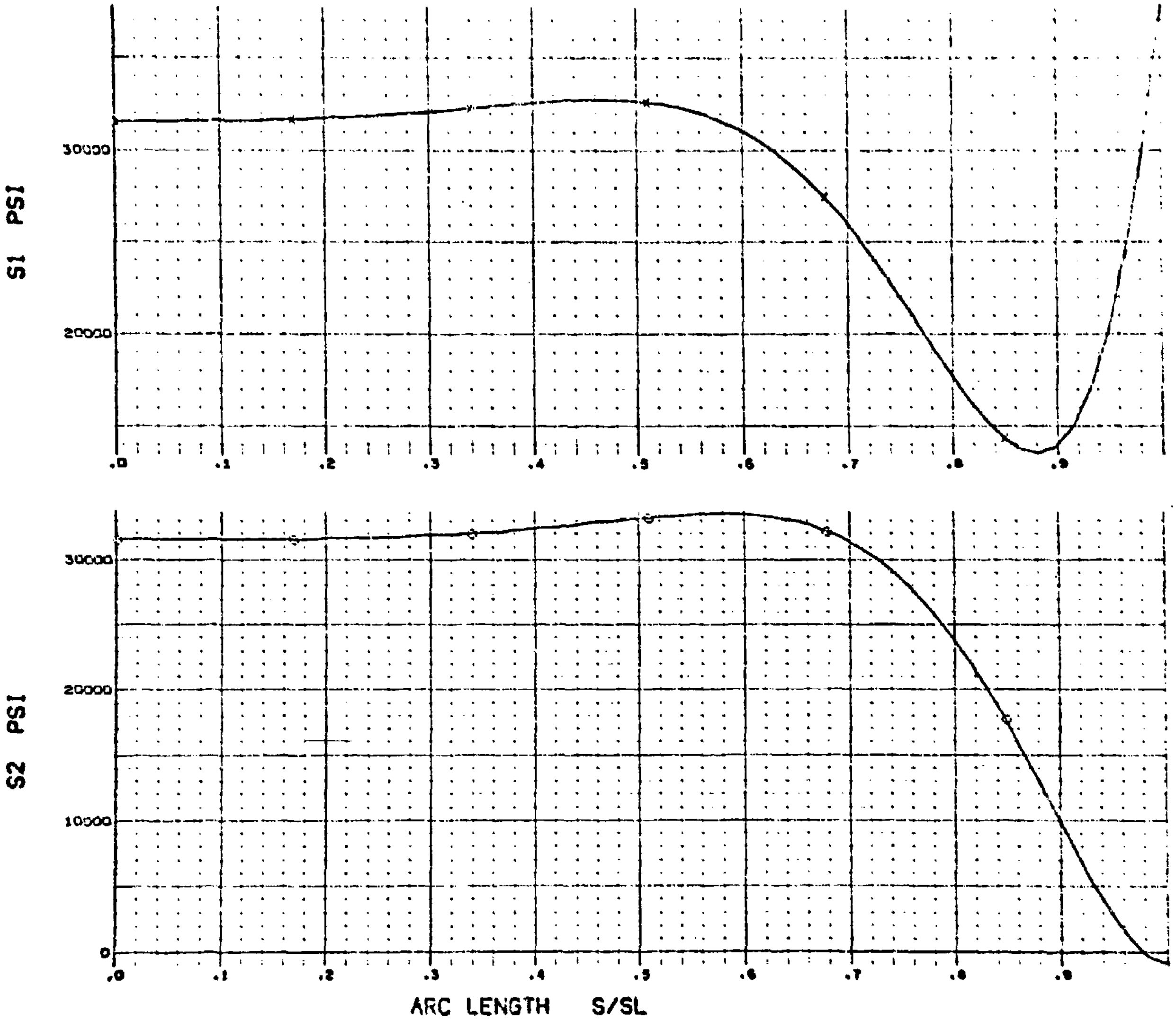

Figure C2-5f Fuel Tank Stress vs S/S_L – Sphere, Element 6

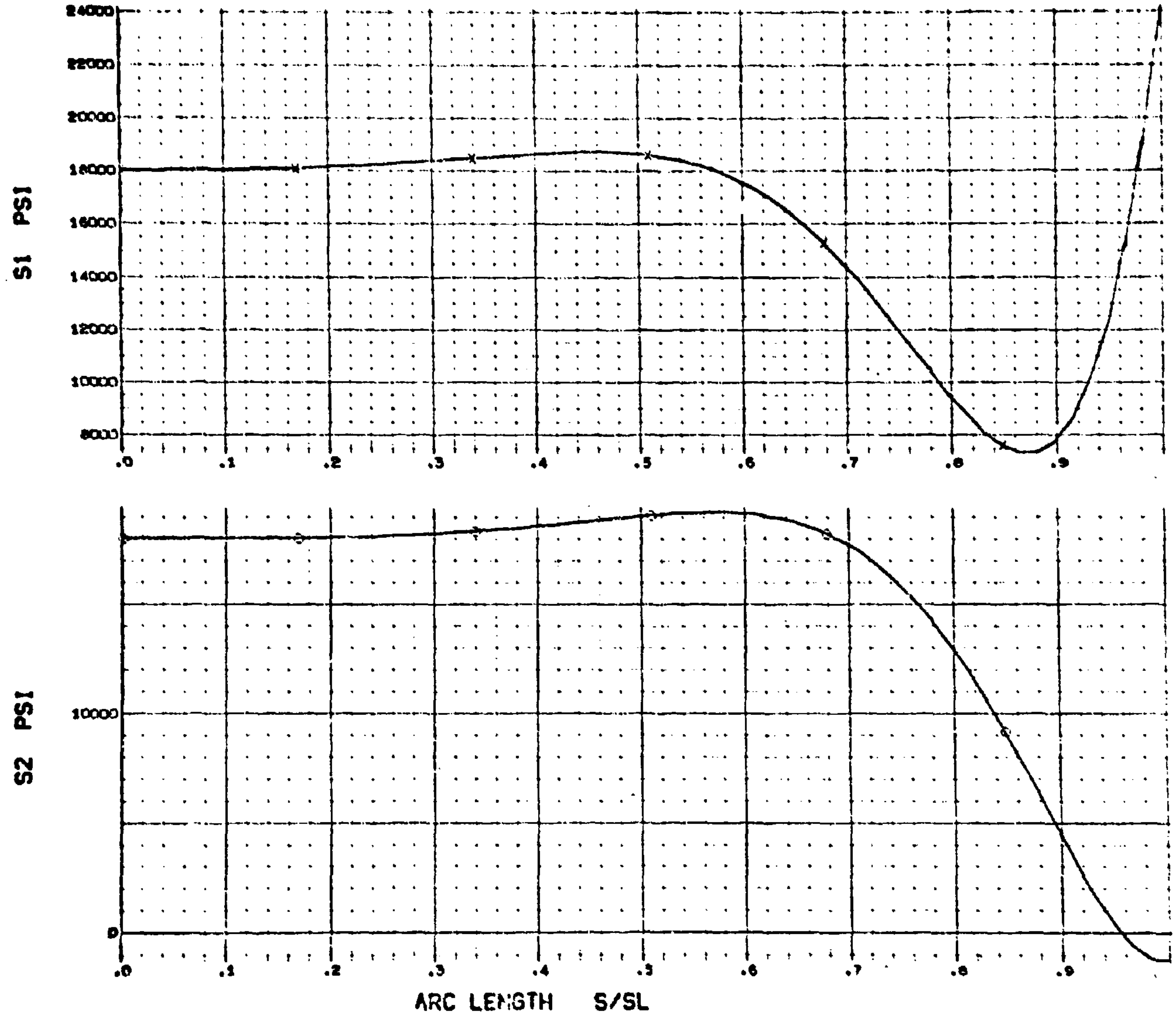

Figure C2-6a Fuel Tank Stress vs S/S_L – Sphere, Element 1

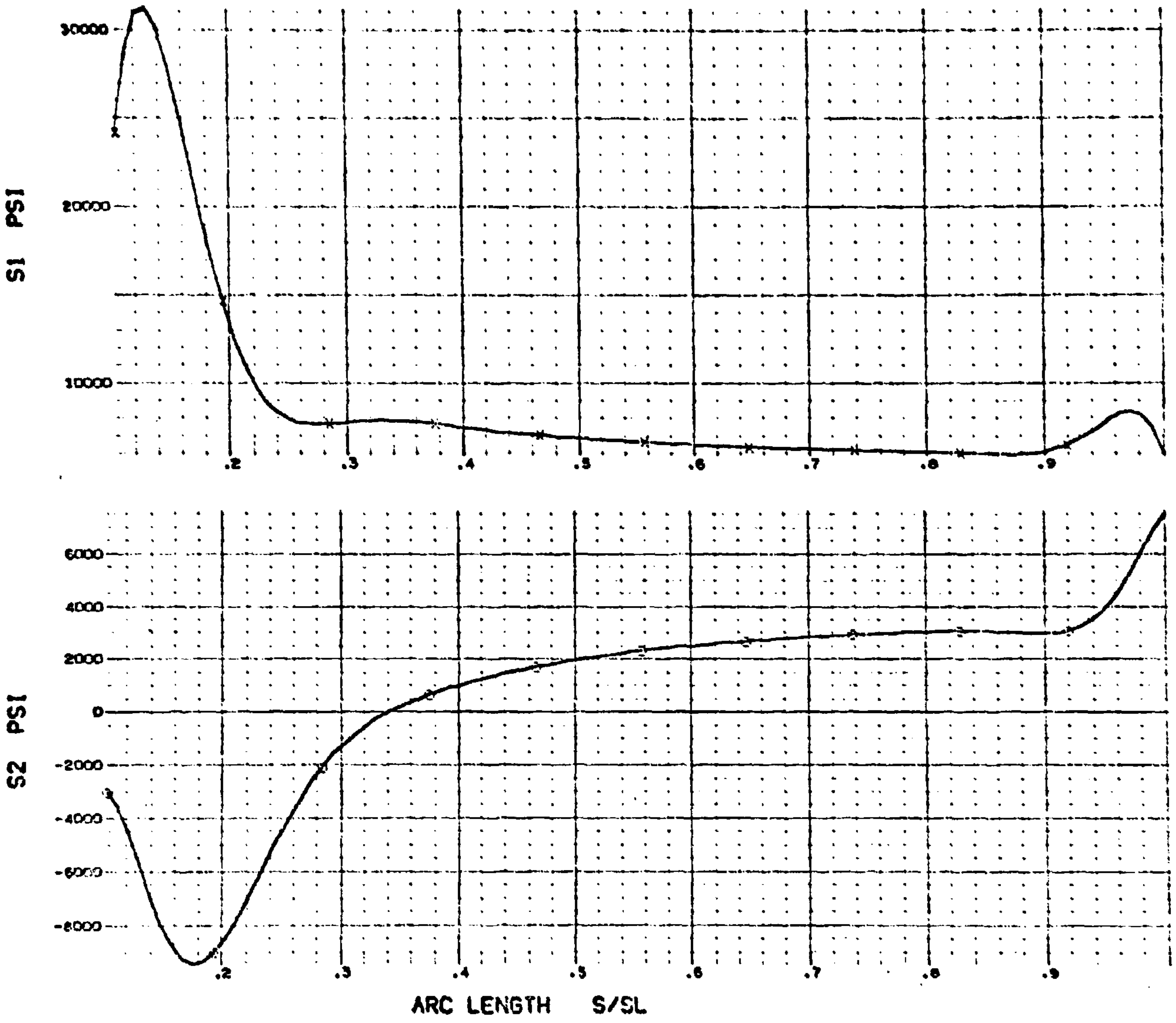

Figure C2-6b Fuel Tank Stress vs S/S_L – Torus, Element 2

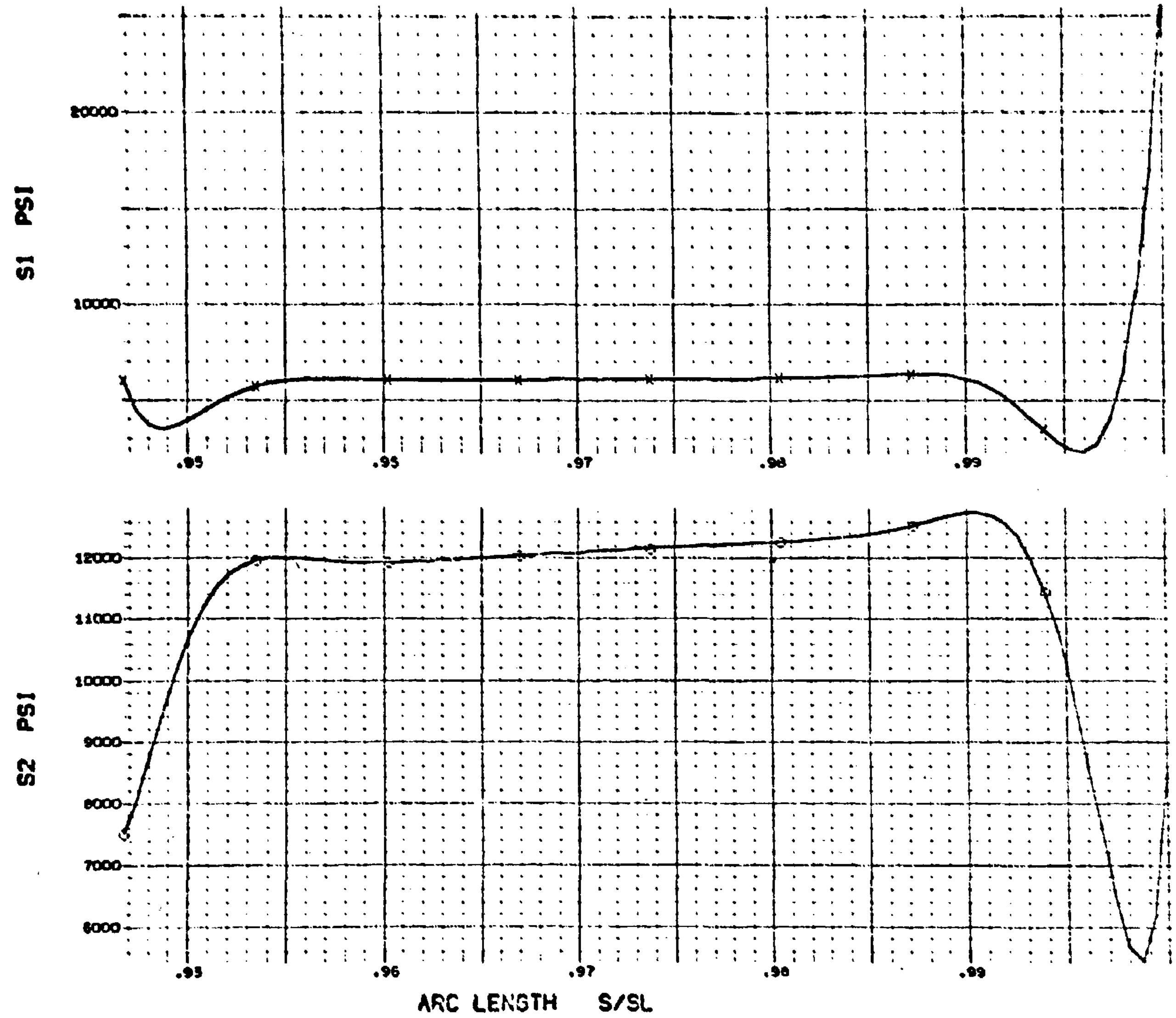

Figure C2-6c Fuel Tank Stress vs S/S_L – Cone, Element 3

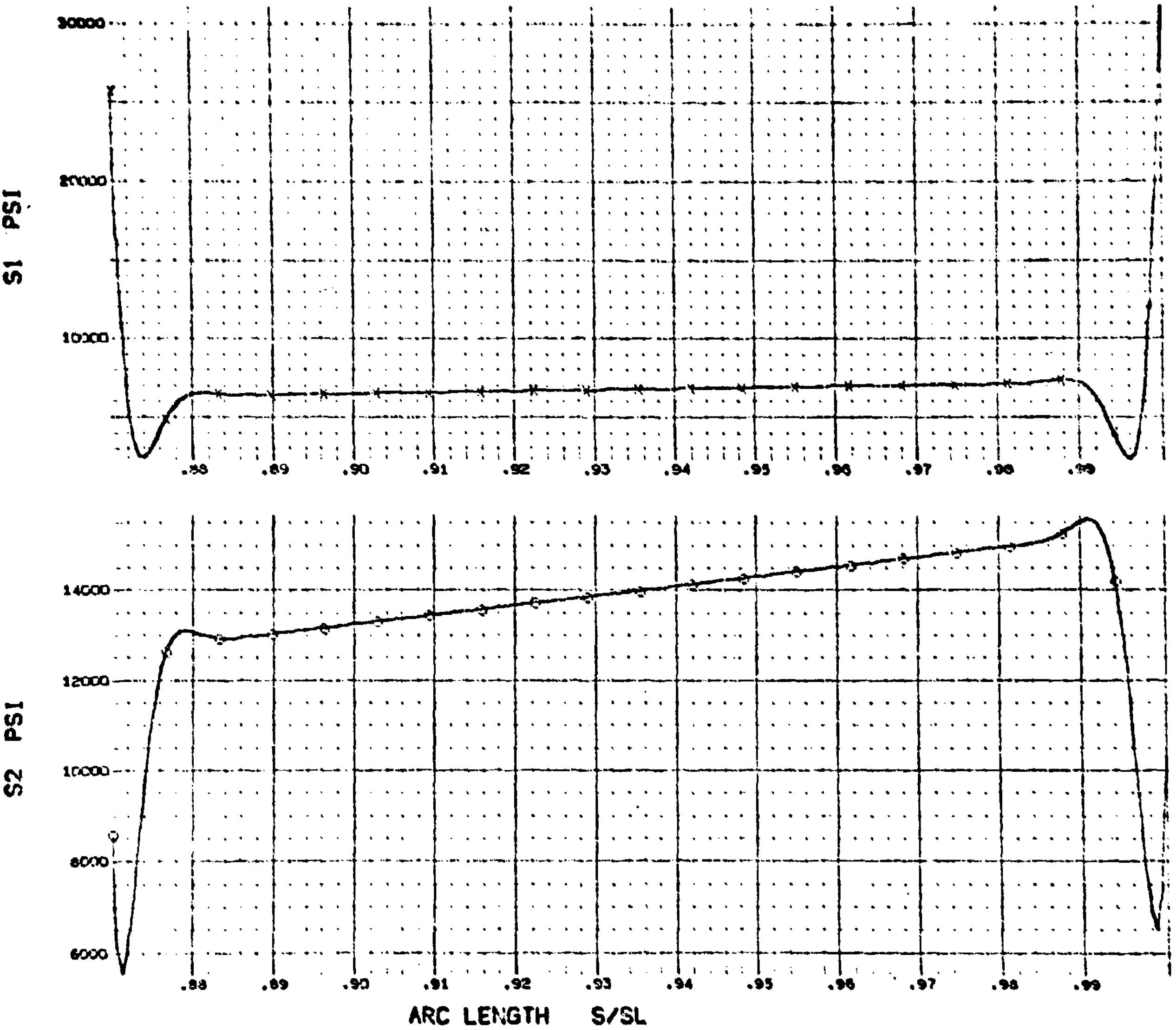

Figure C2-6d Fuel Tank Stress vs S/S_L – Cone, Element 4

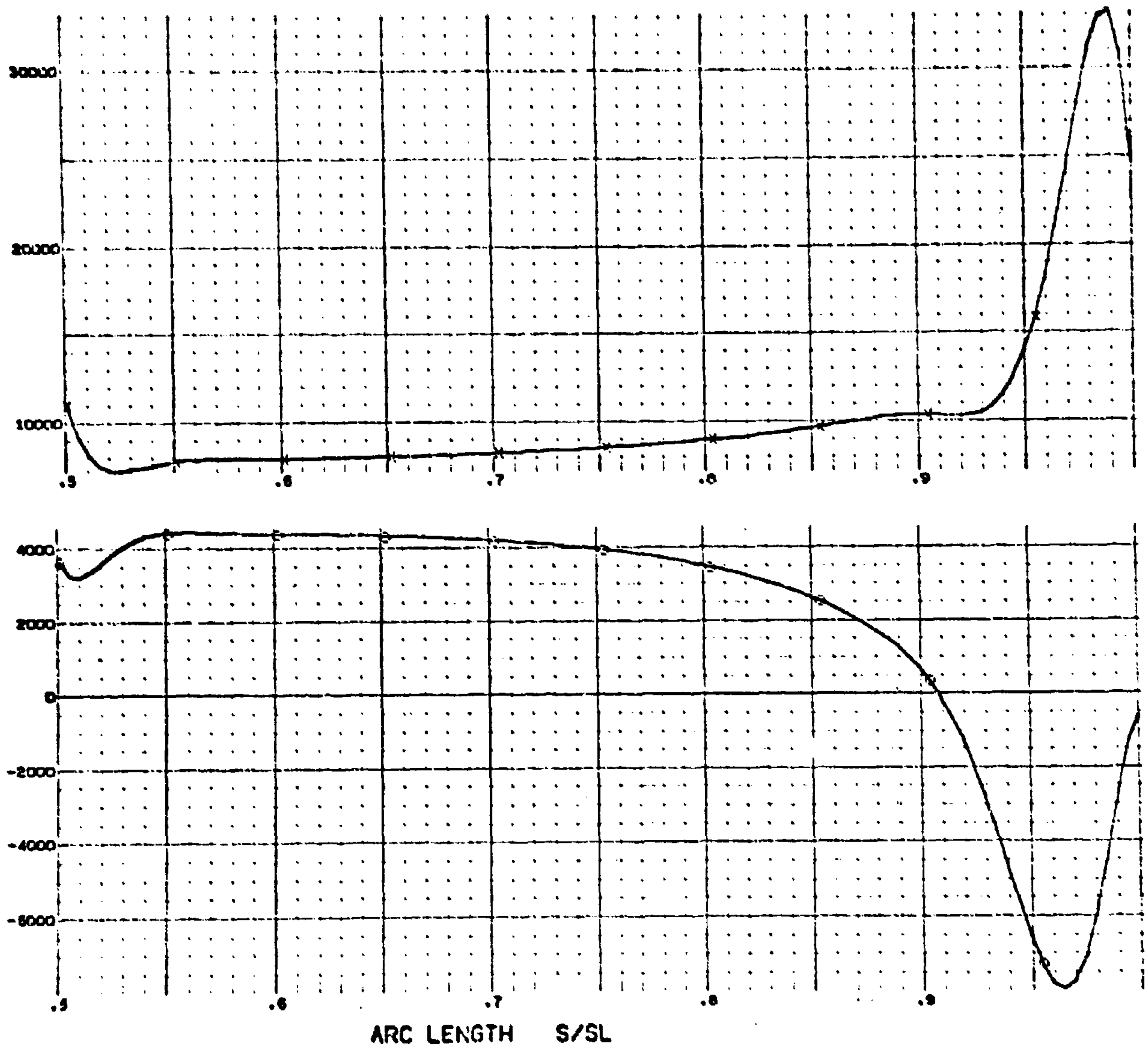

Figure C2-6e Fuel Tank Stress vs S/S_L – Torus, Element 5

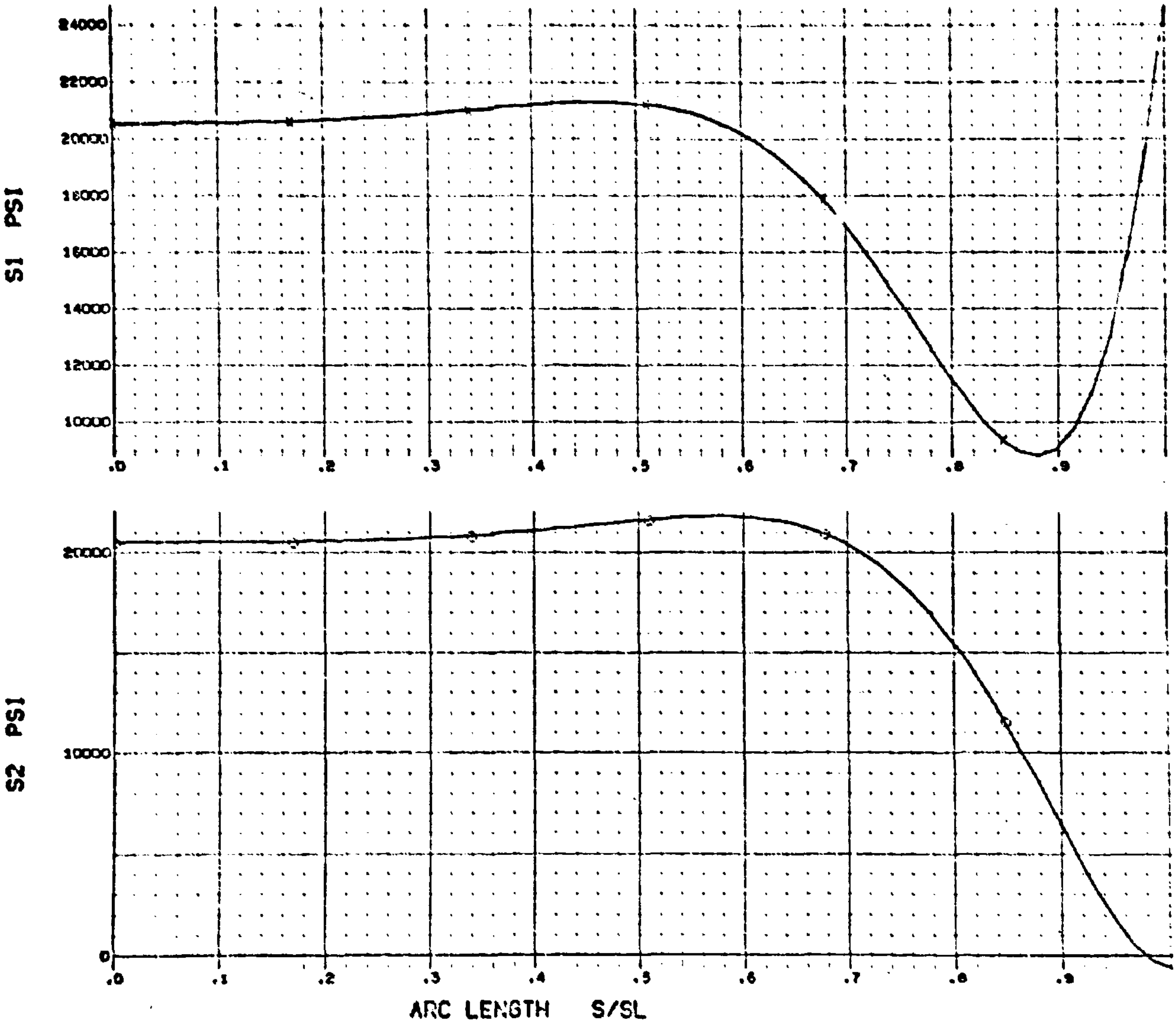

Figure C2-6f Fuel Tank Stress vs S/S_L – Sphere, Element 6

Section 3

STRUCTURAL ANALYSIS OF UNSYMMETRIC FUEL TANK

3.1 GEOMETRY

This analysis considered the unsymmetric fuel tank presented in Figure 3-2 of Volume II. The geometry of the fuel tank is shown in Figure C3-1. The tank consists of three cylindrical shells of equal radius joined along generators so that the three parallel axes of the cylinders lie in the same plane and so that each of the two outer axes is equidistant from the central one. Each pair of generators common to two intersecting cylinders is joined by a plane diaphragm. Each end of each of the cylinders is closed by a segment of a spheroidal cap. These caps meet at, and are joined to, prolongations of the planar diaphragms. Since the tank possesses no axis of revolution, it could not be analysed with one of the shell-of-revolution programs, and an appropriate finite element model was devised. The structure has three planes of symmetry; therefore it was necessary to consider only one octant of the entire structure. This model consists mostly of rectangular and other quadrilateral elements, although triangular elements are also used where needed for convenience in modeling or to keep certain program parameters within required limits. The model has 293 elements and 320 node points. In the regions of high curvature, in the cap, the discretization is considerably coarser than is desirable. However, it could not have been made much finer without exceeding program limitations.

The wall thickness was assumed to be 0.1 inch.

3.2 LOAD CASES

The complete tank was analyzed for the loading due to an internal pressurization of 75 psi. Small circular holes were omitted from the model of the cap; along these circular arcs, boundary conditions corresponded to assumed membrane conditions in these regions of the shell. At the junction of the cylindrical portions of the tank with the end cap, it was assumed that a mounting ring was placed. This ring was assumed

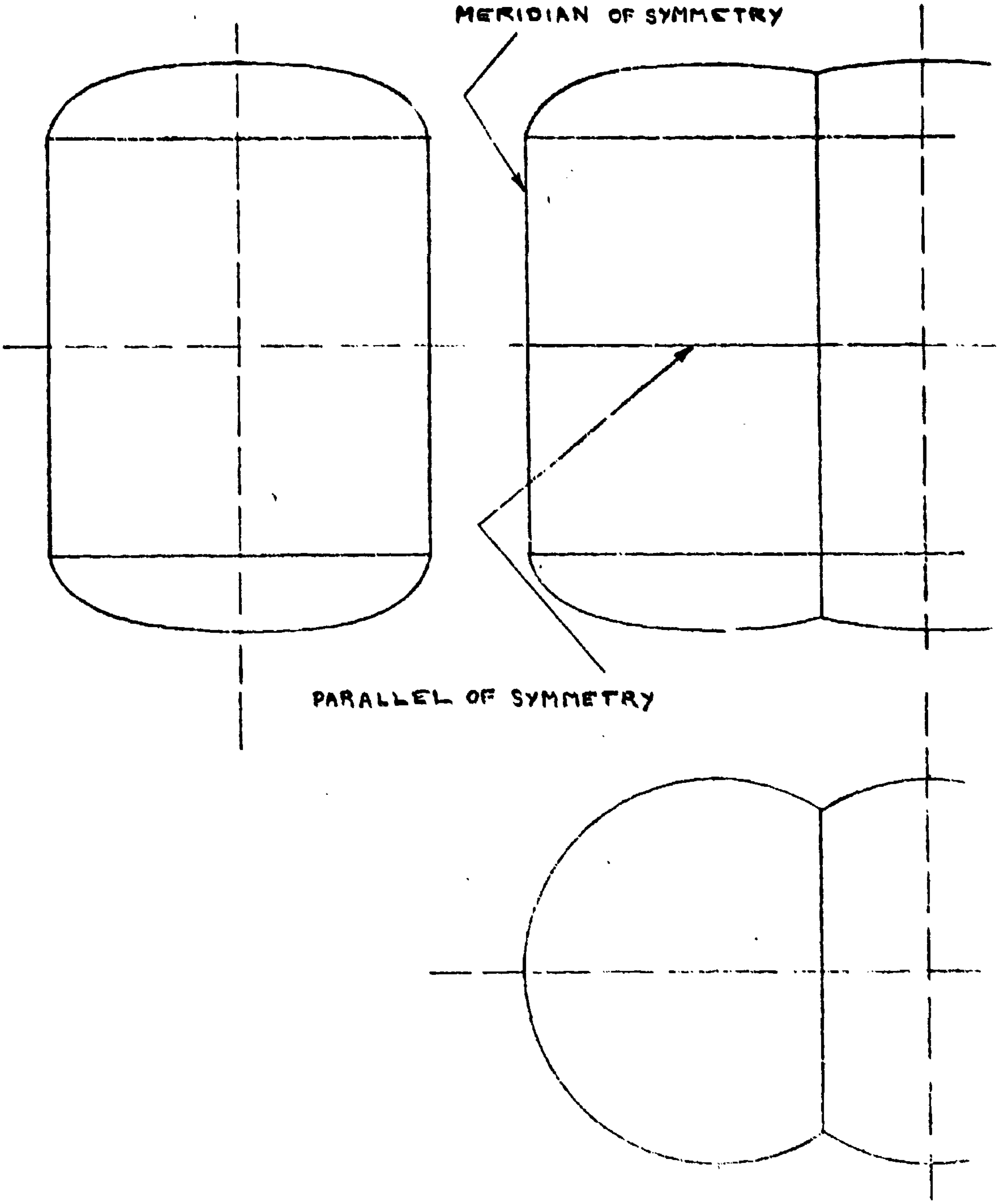

Figure C3-1 General Arrangement of Unsymmetric Fuel Tank to be stiff against all deflections in its own plane, but to be completely flexible with respect to deformations out of its plane. Thus at the ring, radial and circumferential deflections are suppressed, but meridional deflections are unrestrained.

3.3 RESULTS

The general conclusion to be drawn from the results of these analyses can be stated quite simply: for a tank with the shape, wall thickness, and loading described above, stresses appear never to exceed 50,000 psi, a value less than the yield strength; hence, the proposed tank appears to be feasible.

Figure C3-2 presents the total hoop stress along the parallel of symmetry. This stress consists of contributions from both stress resultants and stress couples, and is evaluated at both the inner and the outer surface of the shell. The discontinuity in the stresses occurs at the seam, and the stress pattern is perturbed in the vicinity of the seam. However, these stresses are everywhere less than 26,000 psi.

Figure C3-3, presents a similar plot of the hoop stresses along a parallel in the end cap. The same general characteristics along this double arc section are evident, as in Figure C3-2, but the stresses are higher because of the rapid variation of shell geometry in this region.

Figure C3-4 presents the stress in the meridional direction (coinciding with the y-direction in the cylindrical portion) along the meridian of symmetry. As can be seen, the stresses behave quite erratically near the end of the cap. This result may be partly fictitious, due to an overly coarse discretization of the cap and an inadequate representation of the boundary conditions on the circular arc boundaries of the end cap.

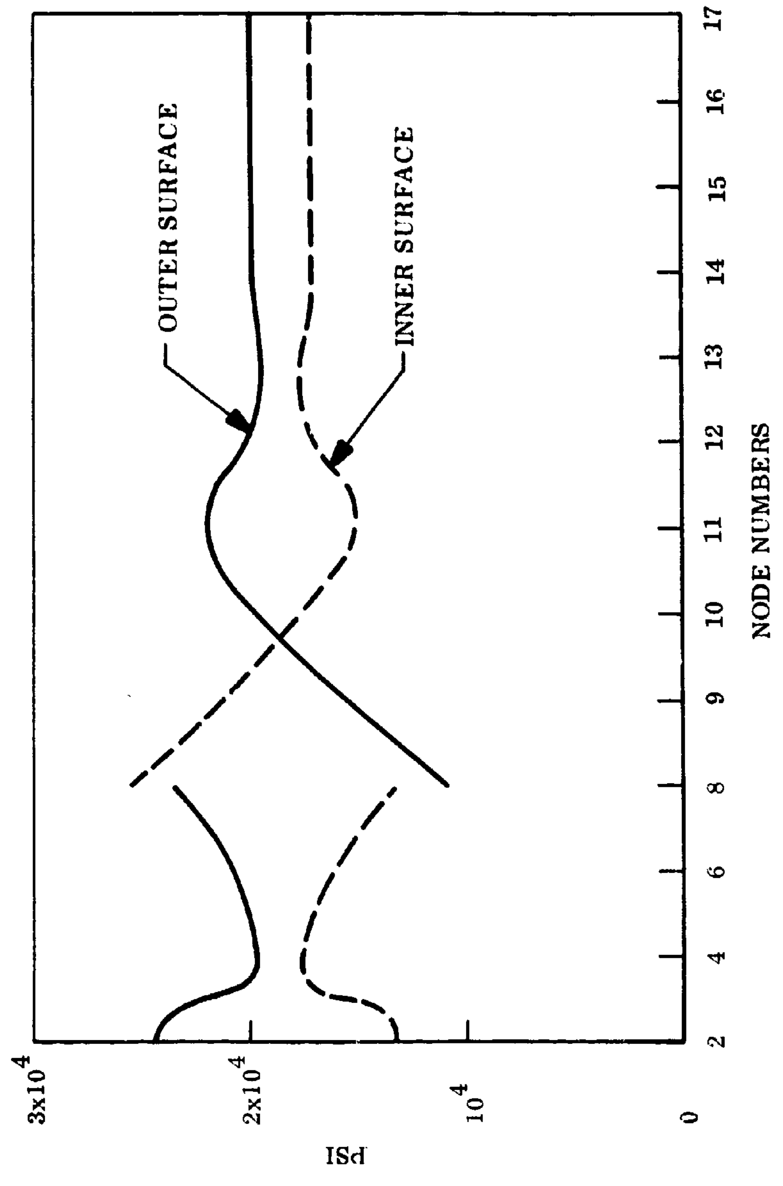

Figure C3-2 Hoop Stresses Along Parallel of Symmetry

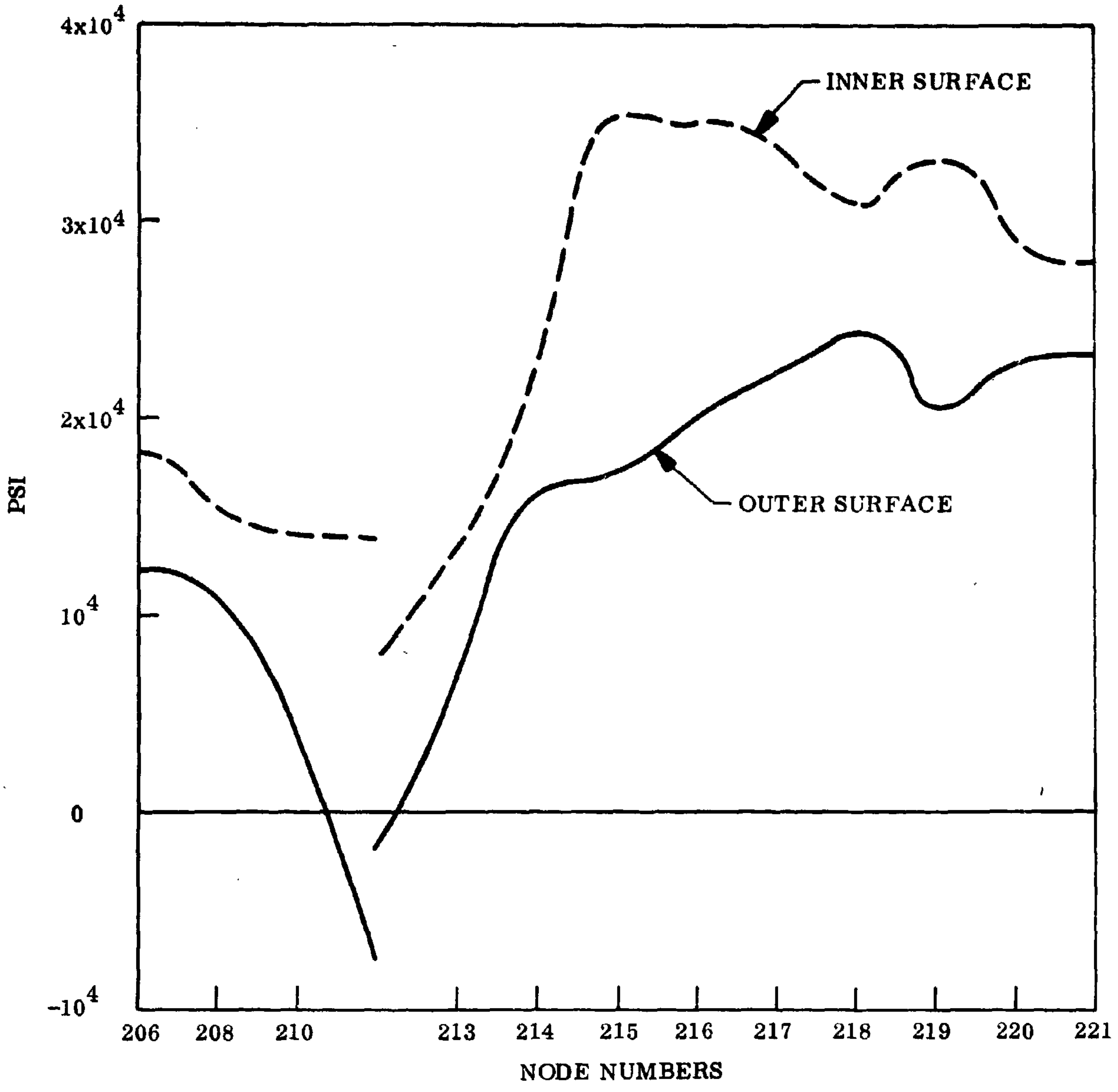

Figure C3-3 Hoop Stresses Along a Parallel in the End Cap

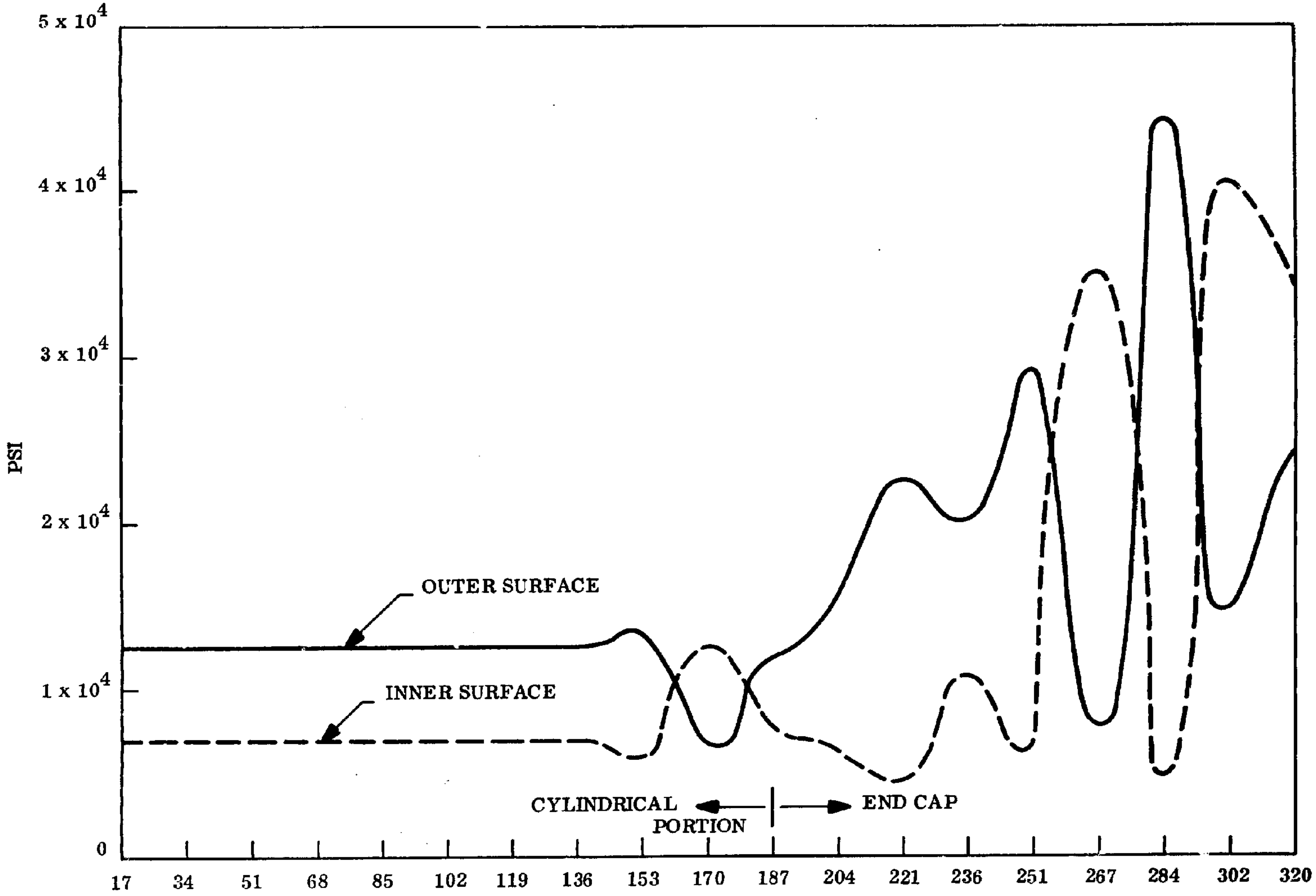

Figure C3-4 Meridional Stresses Along the Meridian of Symmetry

Section 4

STRUCTURAL ANALYSIS OF CRYOGENIC SPACECRAFT SYMMETRIC PROPELLANT TANKS

4.1 GEOMETRY

This analysis considered the cryogenic spacecraft propellant tanks shown in Figure 3-3 of Volume II. The geometry and positive displacement and stress components of the oxidizer and fuel tank are shown in Figure C4-1. Both the spherical and cylindrical elements were assumed to be 0.1-inch thick 2219-T87 Aluminum. The tanks were supported at the juncture of the spherical and cylindrical elements by a ring that would not deform in the radial direction and would not rotate out of its plane. Symmetry conditions were imposed at the middle plane of the cylindrical element.

4.2 LOAD CASES

Three load cases were run. The conditions are given in the table below.

Case	Tank	Temp. (°F)	Internal Pressure (psi)	Accel (g)	Propellant Density (lb/cu. in.)
1	Oxidizer	-265	75	0	–
2	Oxidizer	-265	21	4.6	0.0588
3	Fuel	-230	51	4.6	0.00234

Acceleration was considered positive along the positive Z axis (Figure C4-1).

The normal pressure (p) for internal pressure (p_i) and acceleration of the fluid for the spherical and cylindrical element is given by:

$$p = p_i + \rho g R (1 - \sin \phi \cos \theta) \quad \text{sphere}$$

$$p = p_i + \rho g R (1 - \cos \theta) \quad \text{cylinder}$$

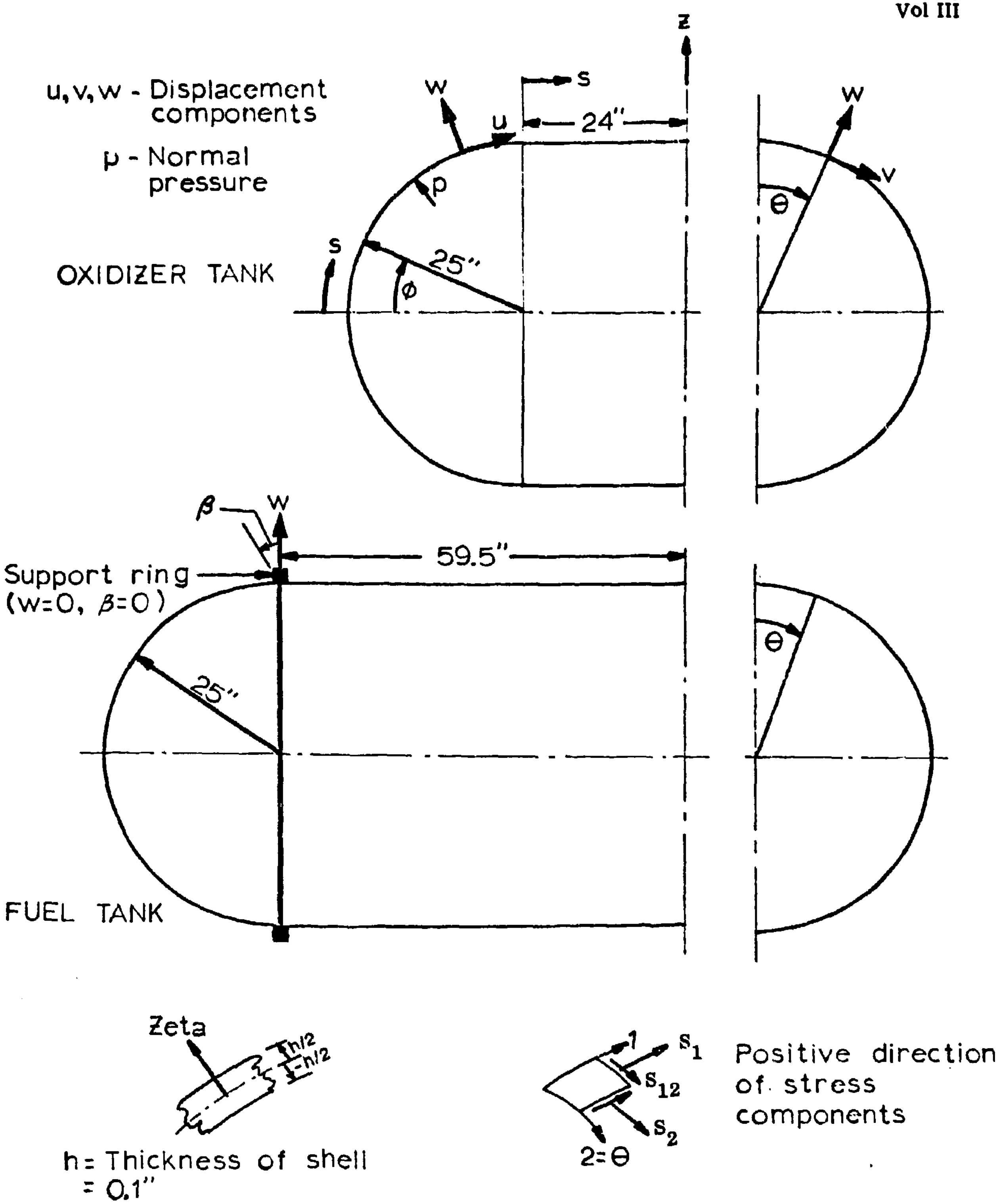

Figure C4-1 Cryogenic Spacecraft Symmetric Propellant Tanks in which the propellant density, ρ, is 0.0588 lb/cu. in. and 0.00234 lb/cu. in. for the oxidizer and fuel respectively, and R = 25 in. with ϕ and θ shown in Figure C4-1.

Thus for the three cases considered, these equations reduce to the following:

Case 1	$p = p_i = 75$	
Case 2	$p = 27.75 - 6.75 \sin\phi \cos\theta$	sphere
	$p = 27.75 - 6.75 \cos\theta$	cylinder
Case 3	$p = 51.2675 - 0.2675 \sin\phi \cos\theta$	sphere
	$p = 51.2675 - 0.2675 \cos\theta$	cylinder

The pressure loading for Cases 2 and 3 is composed of two cos $(n\theta)$ harmonics of a Fourier Series in the circumferential direction (i.e. $n = 0$ and 1). For each of these cases two runs were made, one for $n = 0$ and one for $n = 1$. In order to compute stresses (S_1, S_2, S_{12}) for the total pressure, it is necessary to add the two solutions as follows:

$$S_1 = S_1^{n=0} + S_1^{n=1} \cos\theta$$

$$S_2 = S_2^{n=0} + S_2^{n=1} \cos\theta$$

$$S_{12} = S_{12}^{n=0} + S_{12}^{n=1} \sin\theta$$

in which positive stresses S_1, S_2, S_{12} are defined in Figure C4-1.

4.3 RESULTS

Results are presented as plots of the stress levels S_1, S_2, and S_{12} as a function of the nondimensional arc length S/S_L, where S_L corresponds to the total length of the sphere or cylinder as appropriate. Calculations were made at the inner, mid-plane, and outer surface of the shell thickness. Stresses were virtually identical at these thickness locations for most of the arc length. For simplicity, results are presented herein for the inner surface only.

For Case 1, results for the sphere and cylinder are presented in Figure C4-2. Since no acceleration forces were considered, the value of S_{12} is identically zero, and S_1 and S_2 are given directly. Additionally, since there is no acceleration force, the propellant weight does not enter into the solution. Thus, the stresses can also be used for the fuel tank under an internal pressure of 75 psi. The stresses are linear with pressure in both tanks.

For Cases 2 and 3, results are presented for each of the two terms given in the equations above. For the sphere (Case 2), the stresses for the n = 0 term is given in Figure C4-3a and for the n = 1 term in Figure C4-3b. The maximum stress is given by the sum of these two solutions. (Note that S_{12} is identically equal to zero for the n = 0 solution.) Similar Case 2 results are presented for the cylinder section in Figure C4-4a for the n = 0 term and Figure C4-4b for the n = 1 term. Results for Case 3 are presented subsequently in Figure C4-5a for the n = 0 term and Figure C4-5b for the n = 1 term for the sphere, and Figure C4-6a for the n = 0 term and Figure C4-6b for the n = 1 term for the cylinder.

All stress levels are low, generally being below 15,000 psi for Cases 2 and 3.

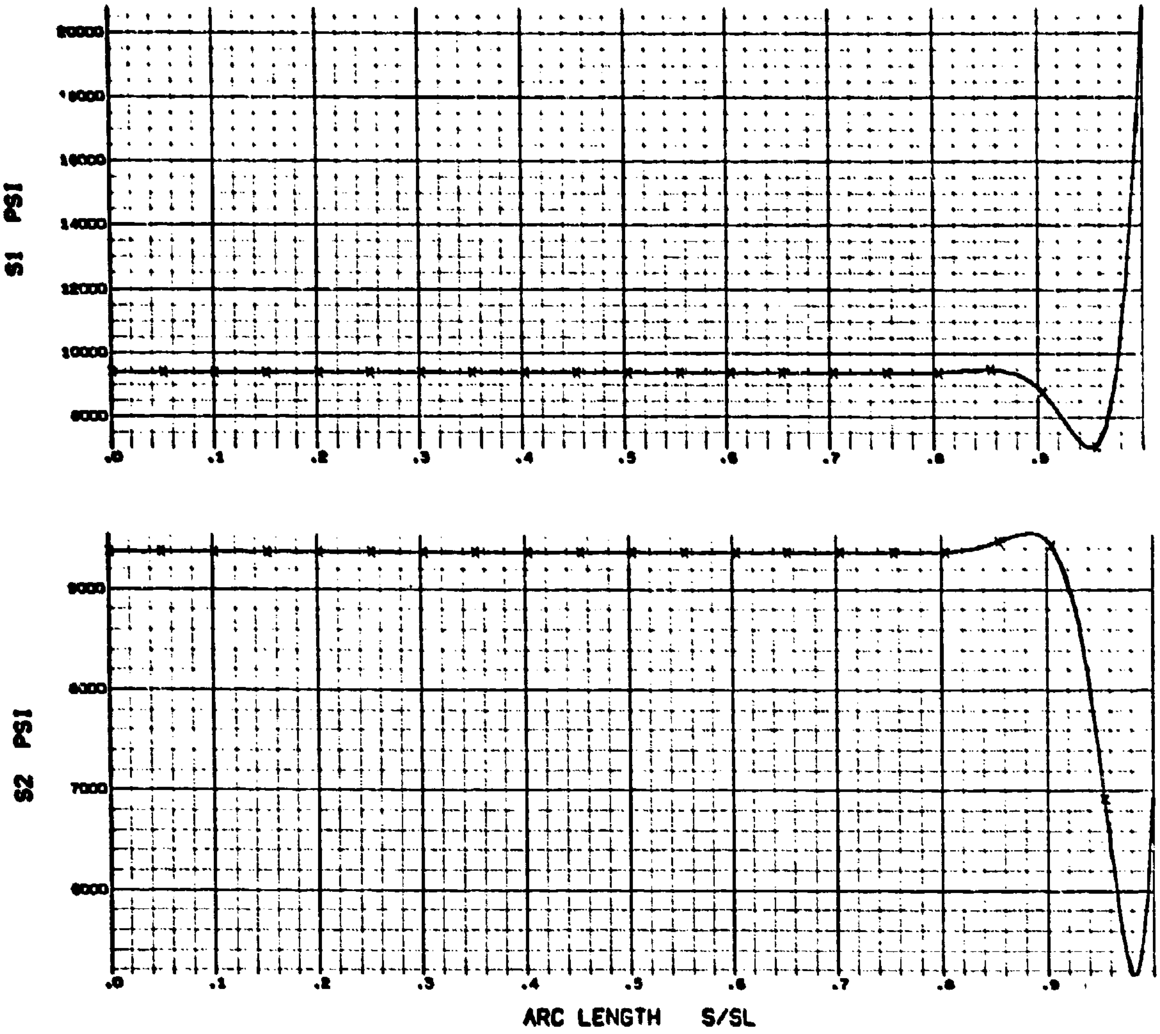

Figure C4-2a Oxidizer Tank Stress vs S/S_L – Sphere Element

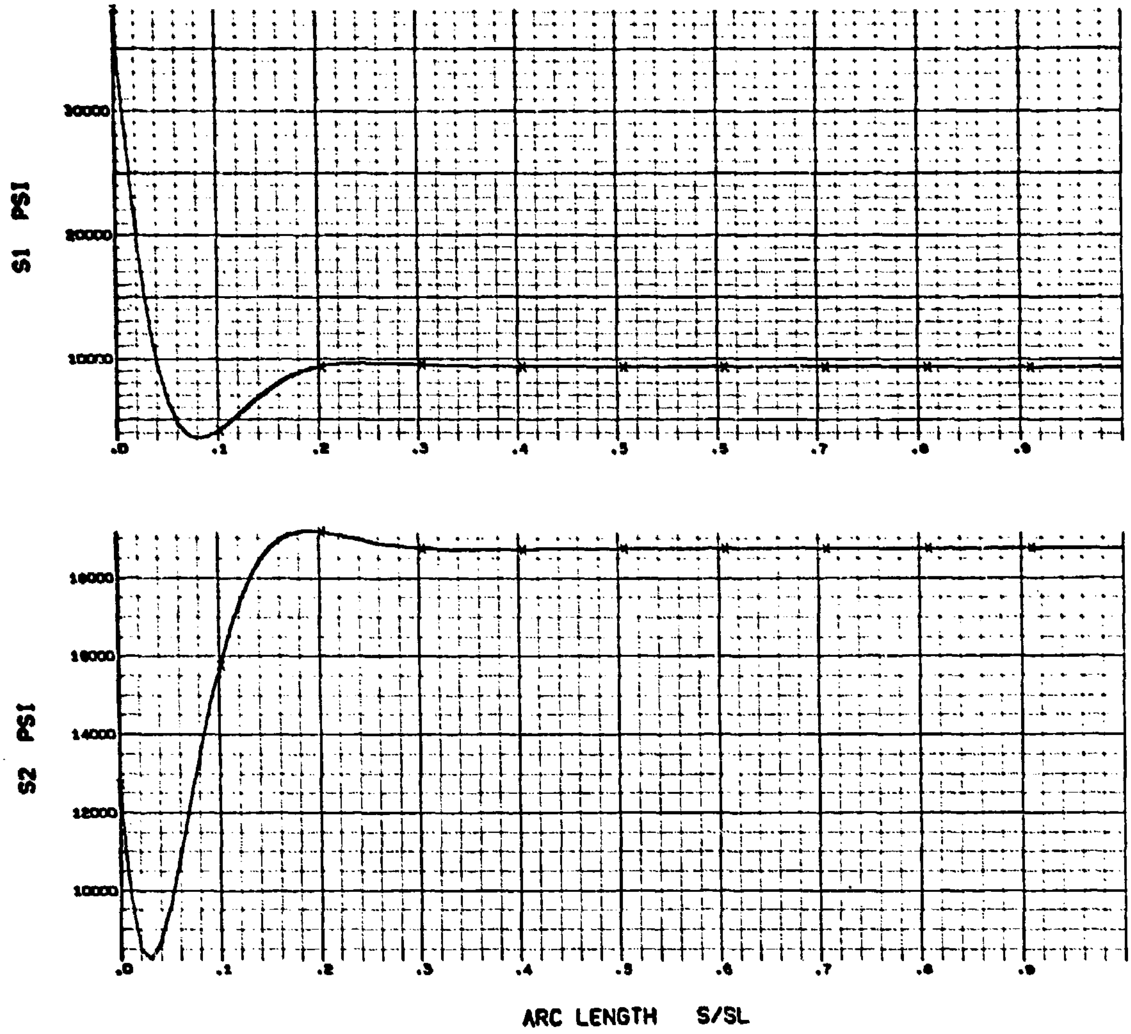

Figure C4-2b Oxidizer Tank Stress vs S/S_L – Cylinder Element

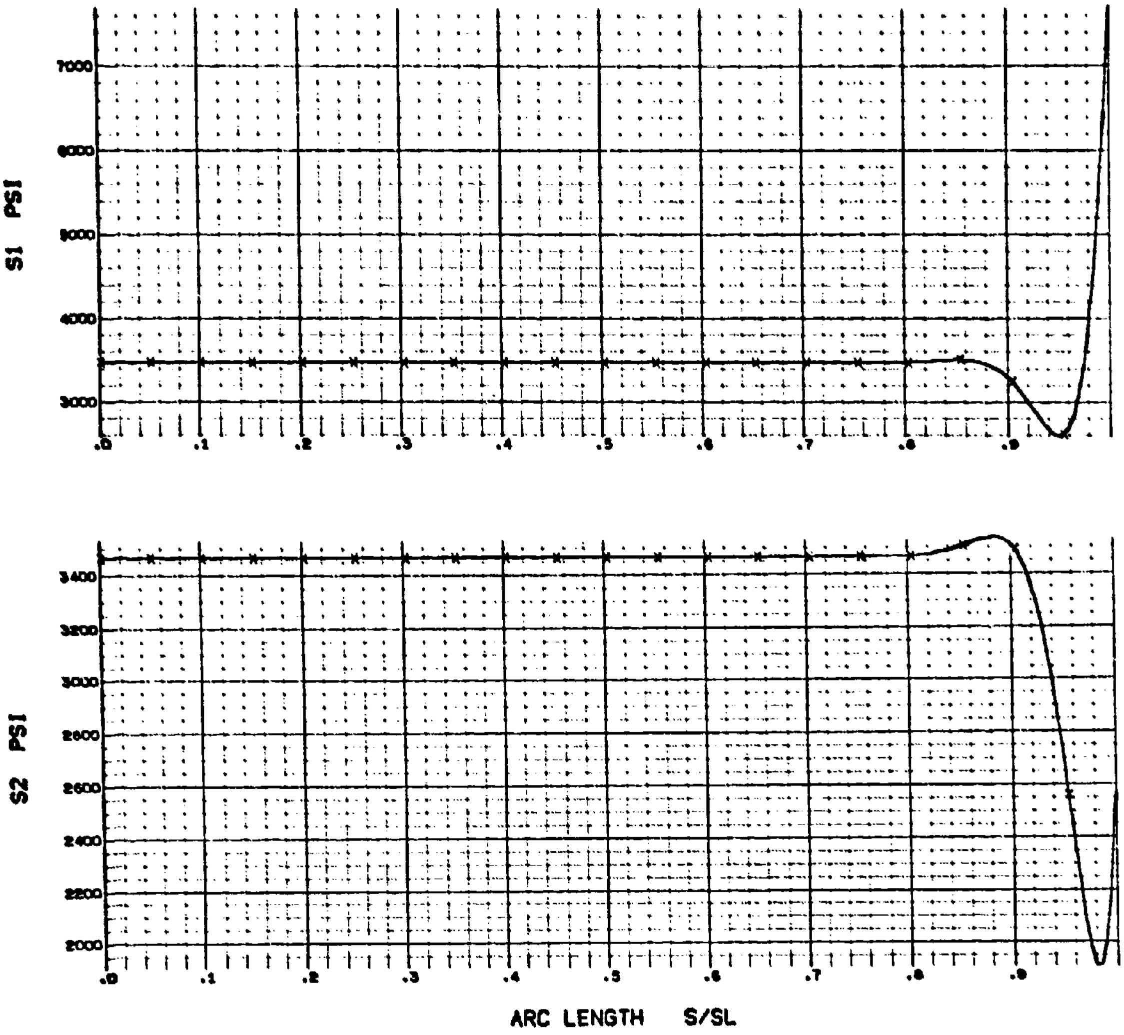

Figure C4-3a Oxidizer Tank Stress vs S/S_L – Sphere Element (27.75 psi, n=0)

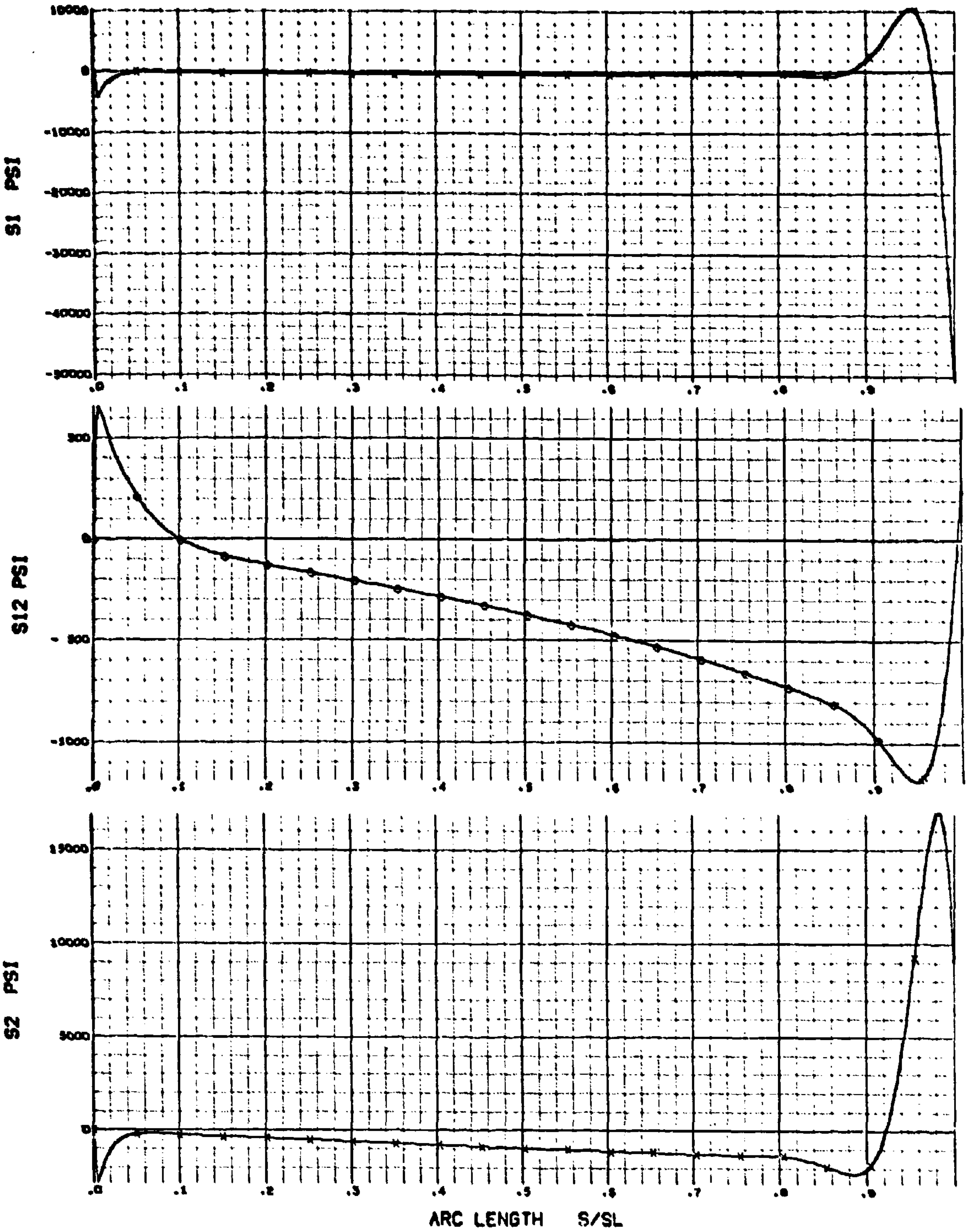

Figure C4-3b Oxidizer Tank Stress vs S/S_L – Sphere Element (-6.75 psi, n=1)

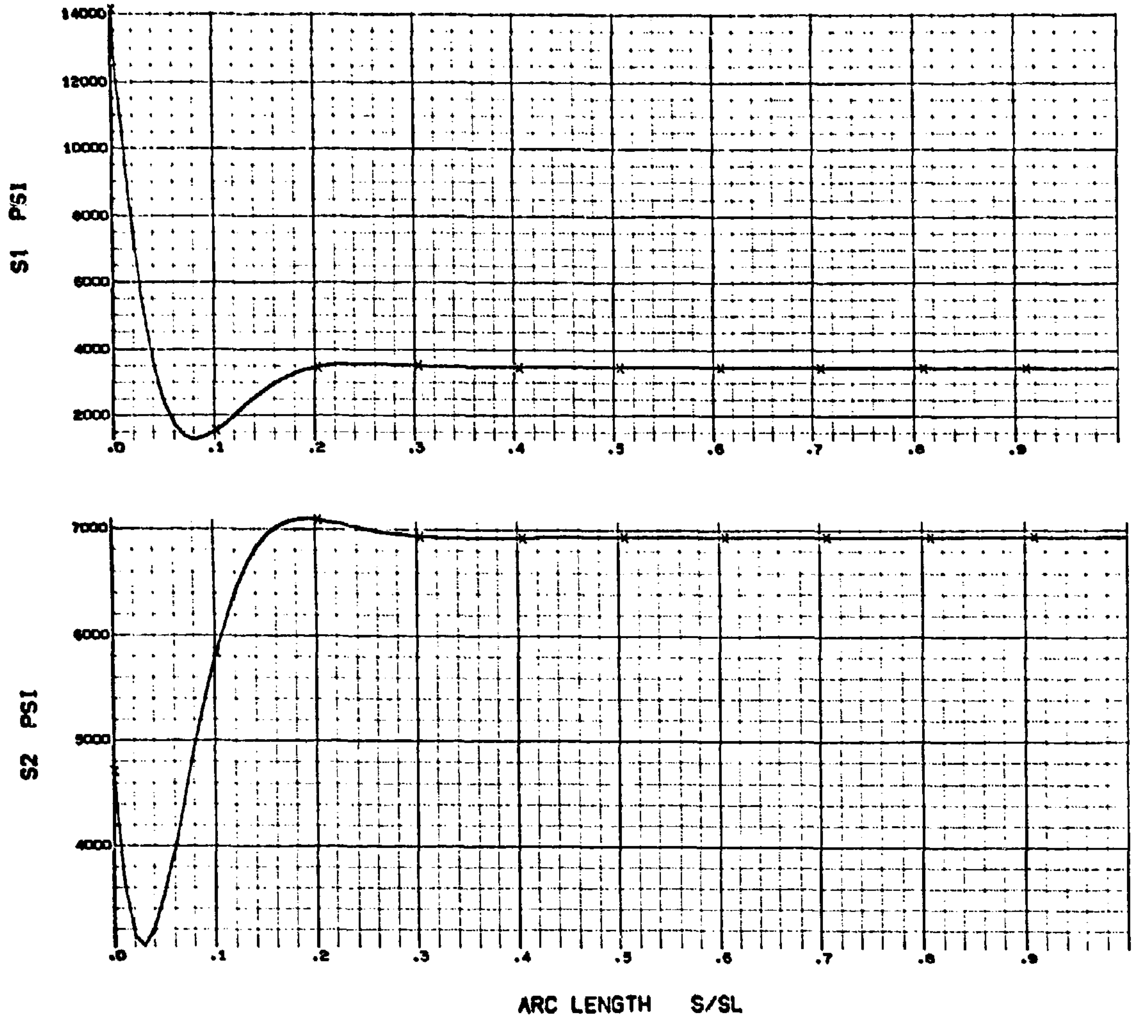

Figure C4-4a Oxidizer Tank Stress vs S/S_L – Cylinder Element (27.75 psi, n=0)

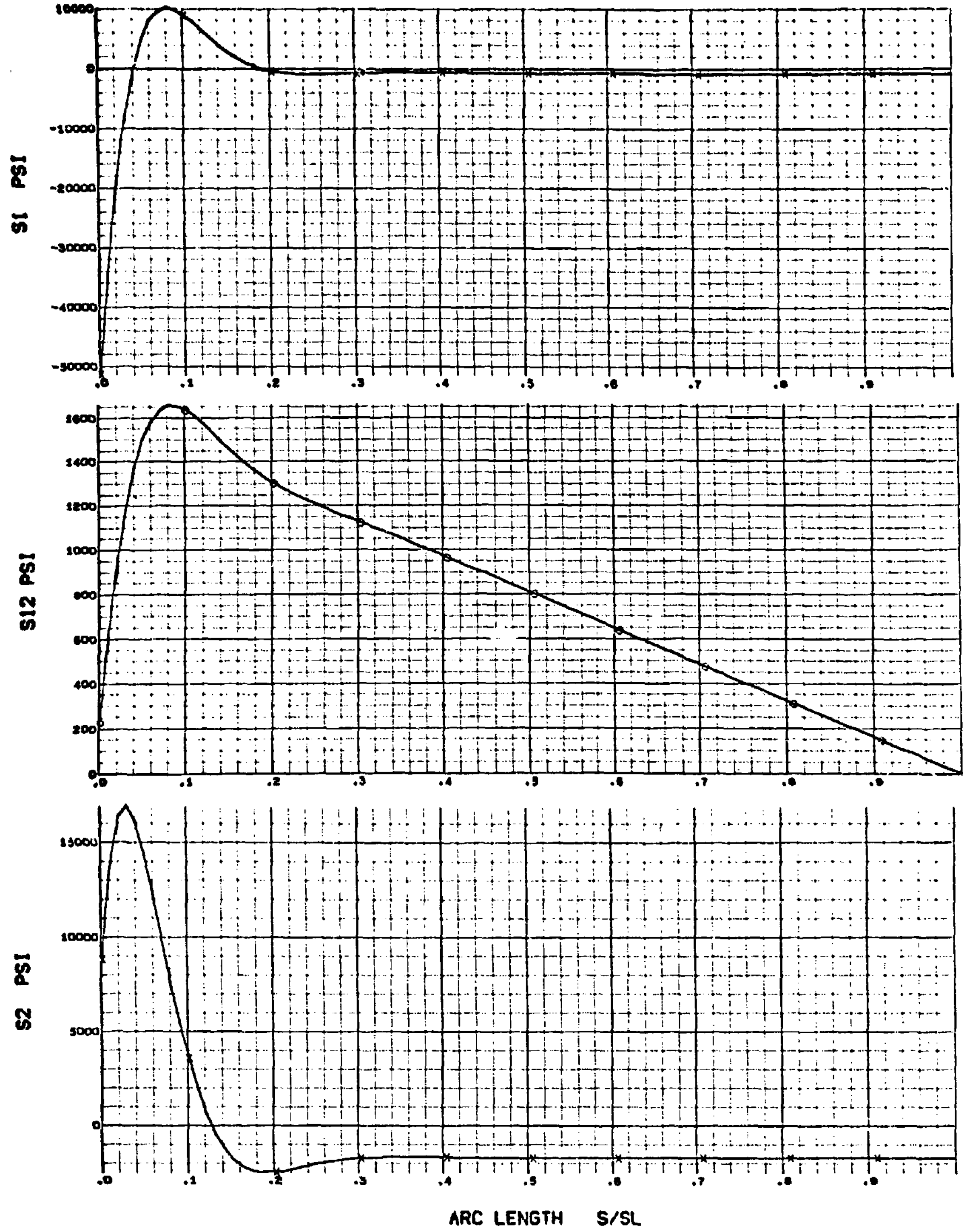

Figure C4-4b Oxidizer Tank Stress vs S/S_L – Cylinder Element (-6.75 psi, n=1)

Figure C4-5a Fuel Tank Stress vs S/S_L – Sphere Element (51.2675 psi, n=0)

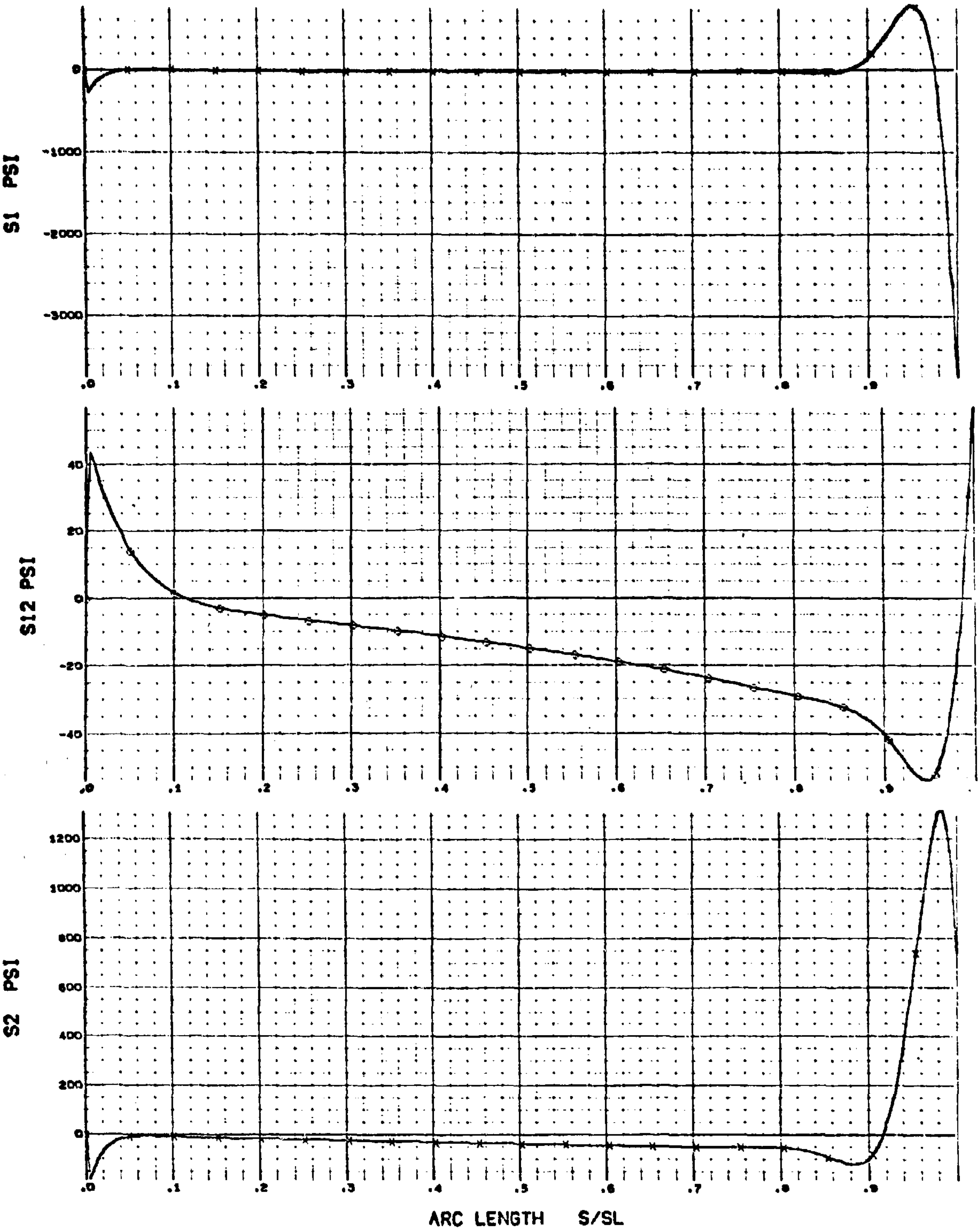

Figure C4-5b Fuel Tank Stress vs S/S_L – Sphere Element (-.2675 psi, n=1)

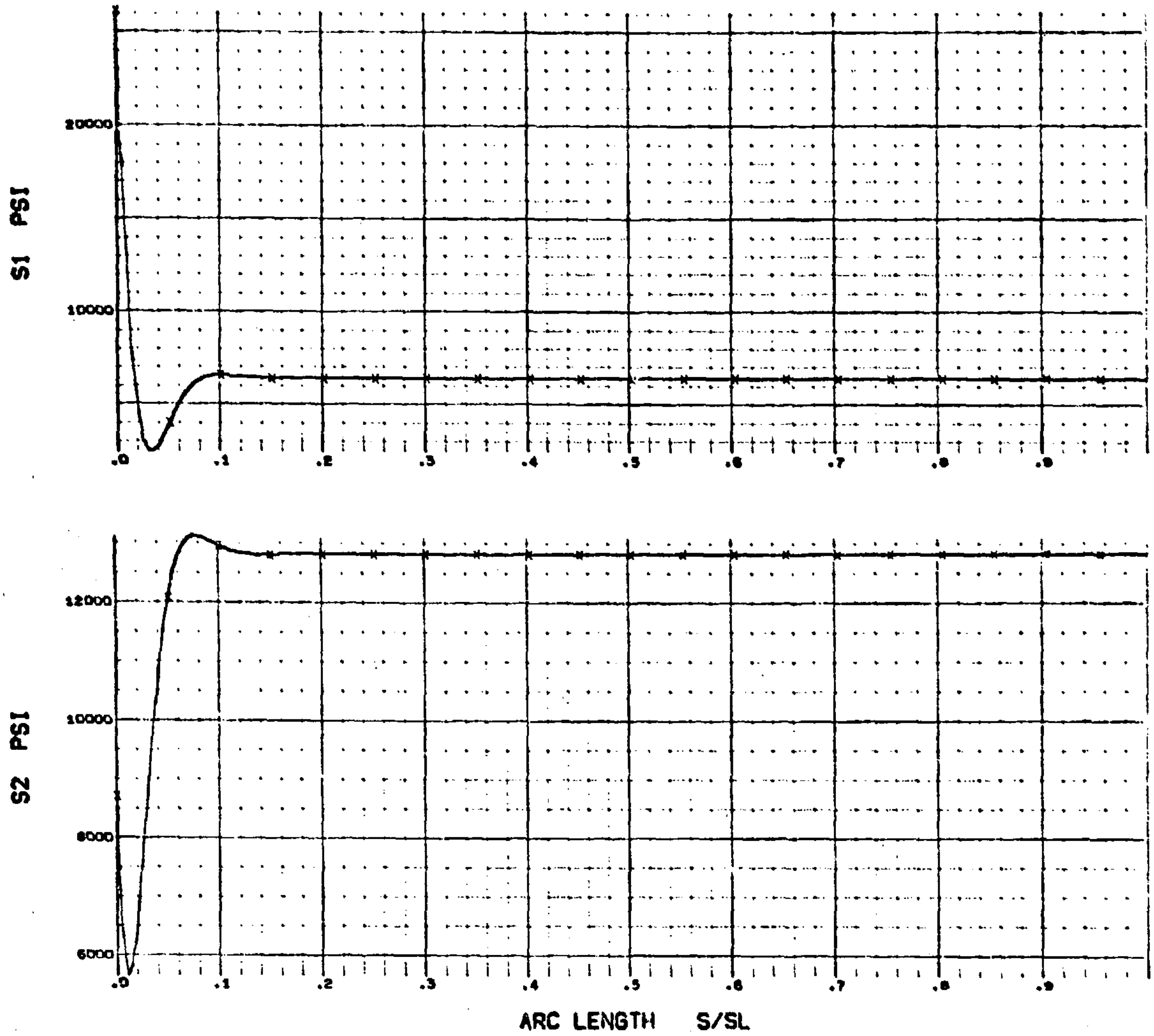

Figure C4-6a Fuel Tank Stress vs S/S_L – Cylinder Element (51.2675 psi, n=0)

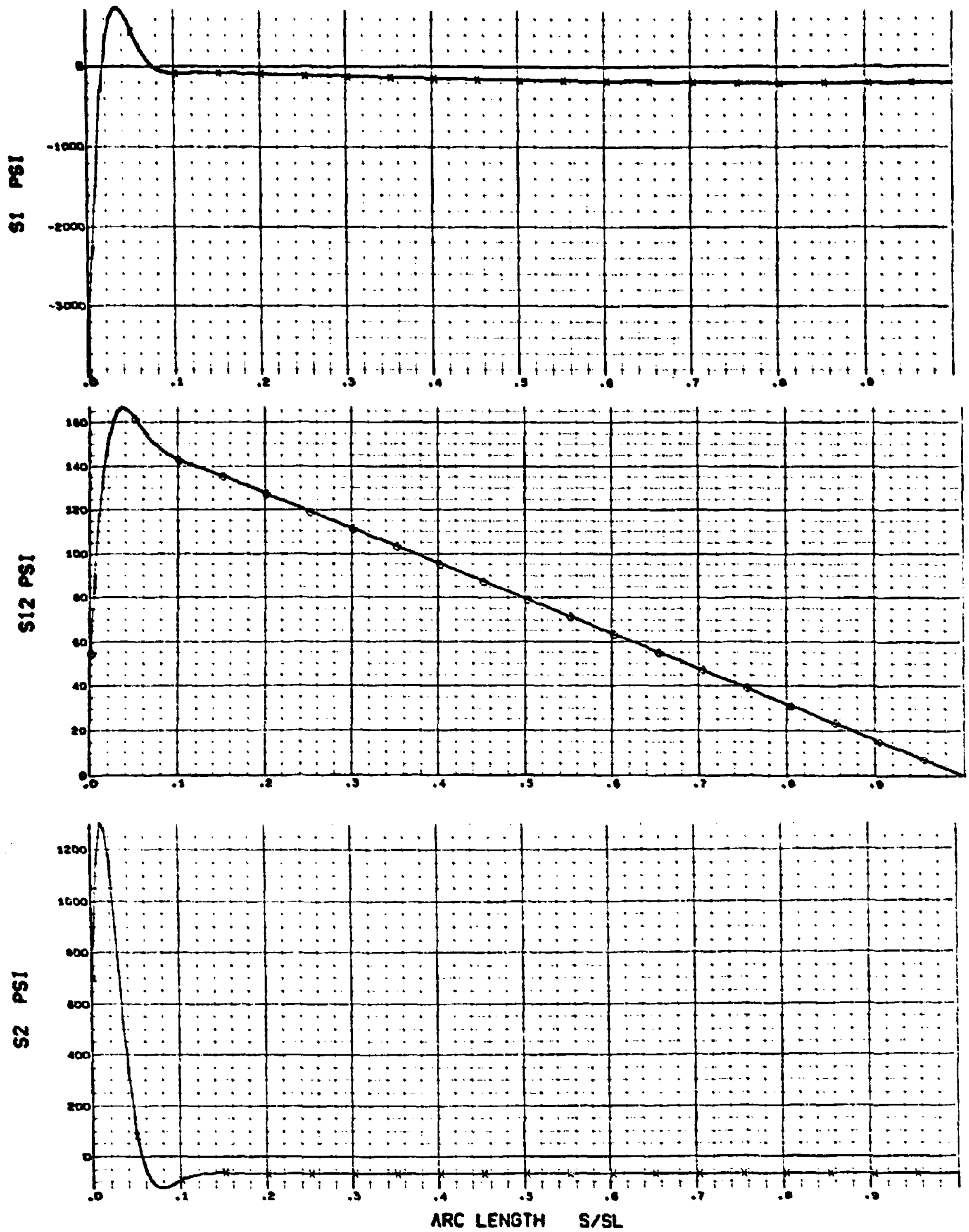

Figure C4-6b Fuel Tank Stress vs S/S_L – Cylinder Element (-.2675 psi, n=1)

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13. ABSTRACT

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(U) Volume III provides supplemental data by way of appendixes to the task presented in Volume II. These appendixes include a Technology Summary, a Proposed Specification for Reusable Propulsion Components and Feed System, and Stress Analysis of Reusable Propellant Tanks. The Technology Summary presents a listing and information regarding previous technology programs in the areas of: integrated propulsion systems, cryogenic pressurization, cryogenic reaction control systems, propellant feed lines, liquid propellant tankage, propellant orientation and acquisition, inflight propellant conditioning, and space vehicle fluorine systems. The proposed specifications include a Proposed General Specification for Rocket Propulsion Fluid System Components and a Proposed General Specification for Rocket Propulsion Propellant Feed System, each obtained by modification of existing specifications. The stress analyses are presented for Reusable Launch Vehicle Propellant Tanks, Structural Analysis of Unsymmetric Fuel Tanks, and Symmetric Propellant Tanks.

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