GenCorp
Aerojet

Propulsion Division

S27-12
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P-15

Space Defense Initiative Technologies and Hardware Can Help Resolve Certain Space Exploration Initiative Weight and Performance Issues

Many Aerojet Programs Have Contributed to Advanced Technologies and Hardware

Program and POP	Objective
Advanced Liquid Axial Stage (89-92)	Space Based Interceptor - Advanced Liquid Propulsion and Structures Technologies
Missile Integrated Stage (90-94)	Low Cost Booster/Interceptor
Liquid Propellant Sustainer (90-94)	Gelled Technology for Interceptor
High Endoatmospheric Def. Int. (87-93)	Ground Based Interceptor
SCIT-DACS (87-92)	Kill Vehicle Propulsion
THAADS (92-)	Theatre Missile Defense Propulsion
GBI (90-)	Ground Based Interceptor
Brilliant Pebbles (90-95)	Advanced Booster and Kill Vehicle Propulsion Systems and Structures
Endo LEAP (90-)	Endoatmospheric Interceptor Controls & Cooling

SDI Programs' Technical Focus

Lightweight –
- High Mass Fraction Stages
- Heavy Use of Composites
- Advanced Propellants

Low Cost –
- Highly Producible Designs
- Integrated Propulsion Modules

High Performance –
- Ultrafast Engine Responses
- Front-End Cooling for In Atmospheric Flight
- Advanced Propellants

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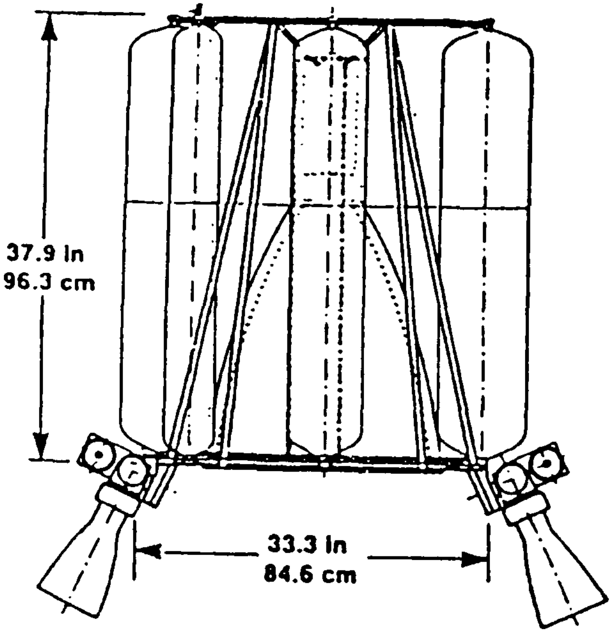
SDI Technology Provides Order of Magnitude Savings on Weight

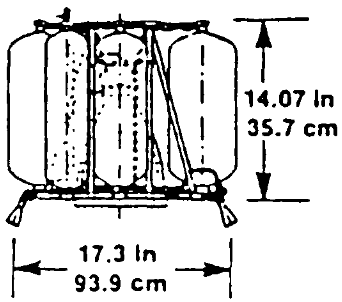
Propulsion Division

Current State of the Art



Wt = 290 lbm (132 kg)

ALAS



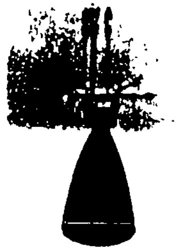
SIGNIFICANT STAGE DESIGN DRIVERS	Current S.O.A.	ALAS	Weight Impact
Material	All Metal	Carbon Composites	High strength to weight composites are more weight efficient than best metals
Propellants	N_2O_4/ N_2H_4	ClF_5/N_2H_4	High density oxidizers result in denser, smaller packages
Isp, sec $\left(\frac{N\text{-}sec}{kg}\right)$	310 – 320 (3040-3140)	340 – 360 (3330-3530)	Higher ISP results in less required propellant for same mission
F/Wt	50	500 – 1000	Decreases engine weight an order of magnitude
Response Time, sec	0.010 – 0.030	0.001	Improves control of stage — saves using another set of smaller control engines
$\frac{\text{Press Vol}}{\text{weight}}$ in (cm)	6×10^5 (15.2×10^5)	1-2 $\times 10^6$ (2.5 - 5 $\times 10^6$)	Halves the tank weight

Wt = 38.3 lbm (17.4 kg)

Benefits are Realized in Several Areas

- New Engines
- Structures
- Tanks
- Advanced Propellant

Emerging Composites Technologies Result in Numerous Propulsion Benefits

Subsystem	Conventional Technology	ALAS Technology	Benefit
 ALAS Axial Engine	• Refractory Nozzle • Low Density Graphite Chambers • Metal Structural Shell	• Braided Carbon Axial Nozzle • Carbon Structural Shell	• Nozzle Weight Reduced 90%
 Propellant Tanks	• All Metal Designs Usually Titanium • Glass – Overwrapped Thick-Wall Metal Liners (Pressure Load Is Shared Between Liner and Overwrap	• Carbon Fiber Overwrapped with Very Thin Wall Liners (Pressure Load Is Not Shared Between Liner and Overwrap)	• ~60% Weight Savings from 1 lbm to 45 lbm Order of Magnitude Savings in Cost $10,000 vs ≤$1000
 ACS Engine	• Refractory Nozzle	• Free Standing Graphite Nozzle	• Nozzle/Chamber Weight Reduced from 2 lbm to <.2 lbm
 Composite Structure	• All Aluminum Bolted/Welded Configuration	• Injection Molded Carbon Rings • Braided Rings • Stamped Struts • Plastic Welding	• Weight Savings – from 2 lbm to .5 lbm

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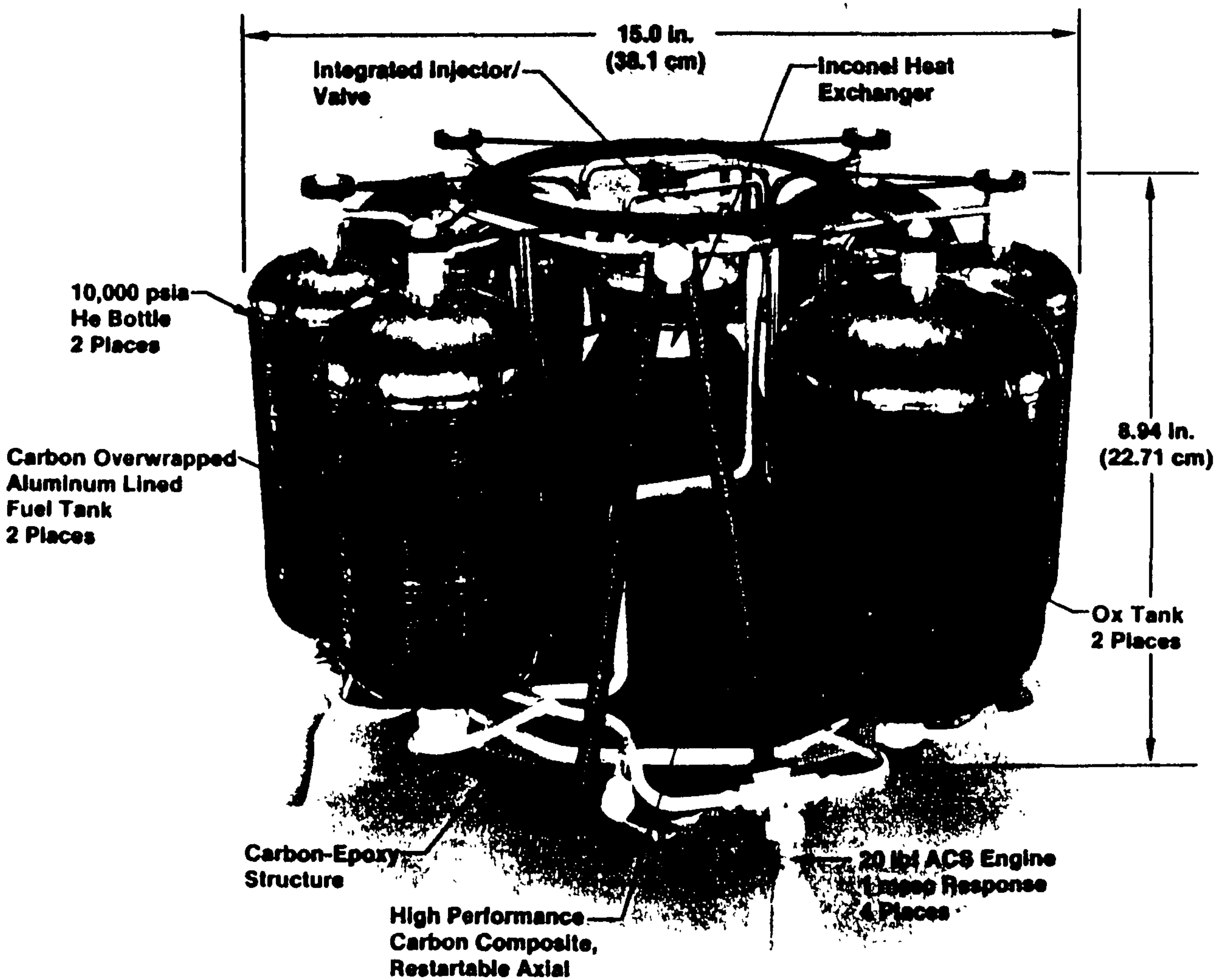
Advanced Liquid Axial Stage



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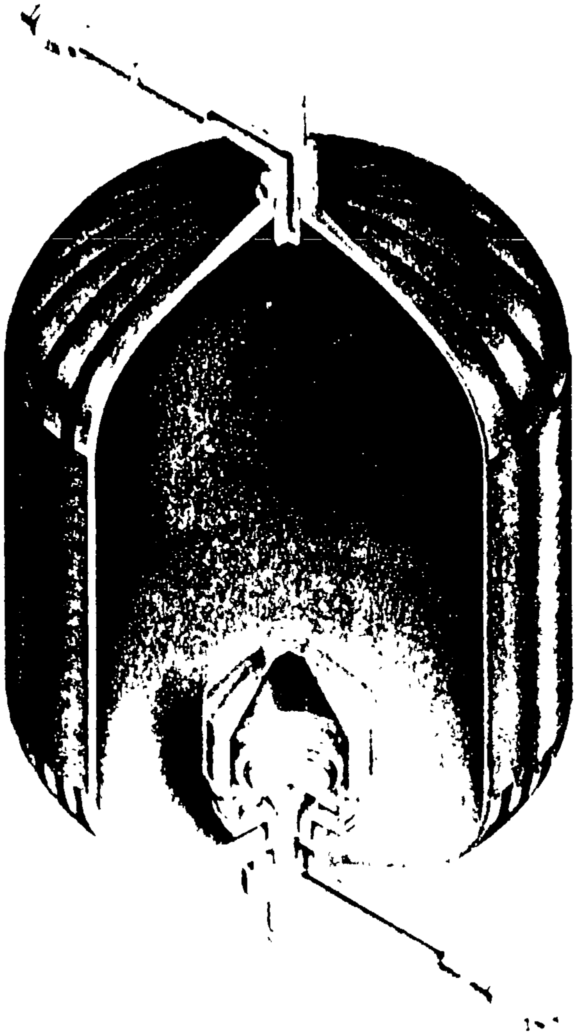
Propellant and Pressurant Tank Accomplishments

Features

- 10^6 psi (7000 MPA) Carbon Fiber
- Yielding .006 in (.015 cm) Al Liner
- No Liner Welds
- Passive Propellant Management Device



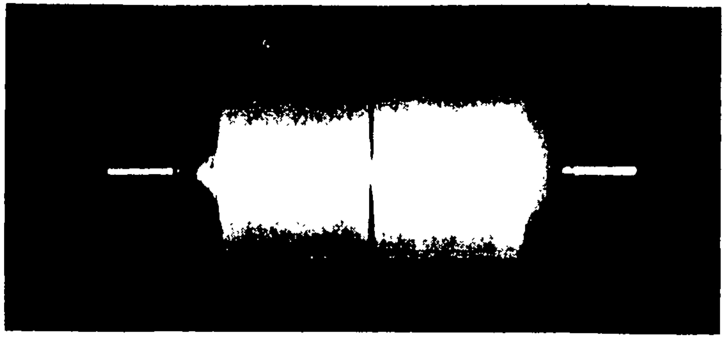
Status

- Fiber/Resin System Demonstrated
- .006 in (.015 cm) Liners Made
- Long Term CIF Material Storage Demonstrated
- He Containment Demonstrated With 0.010 in (.025 cm) Liner/@ 10,000 psi
- Prototype PMD Made
- First Burst Tests at 14,100 and 16,860 psia

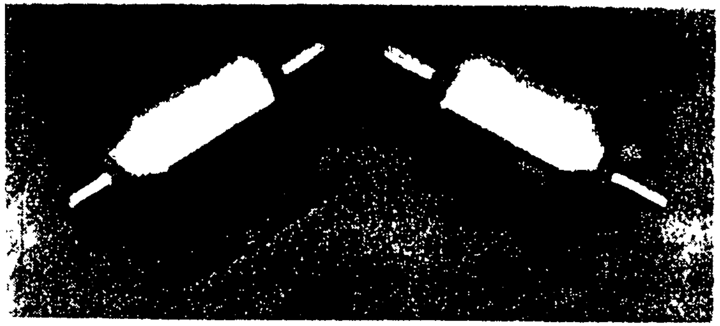
New Family of Lightweight Engines Has Been Developed

Program	Engine Type	Pc	Tests
ALAS	Axial	775	150 Tests 1989-91
ALAS	ACS	500	110 Tests 1989-91
SCIT	Divert	500	20 Tests 1989-92
LDI	Axial/Divert	300-600	23 Tests 1992 (On-going)
GBI	ACS	500	To Be Tested July 1992
BP	Divert	500	To Be Tested Early 1993
BP	ACS	300	To Be Tested Mid 1993

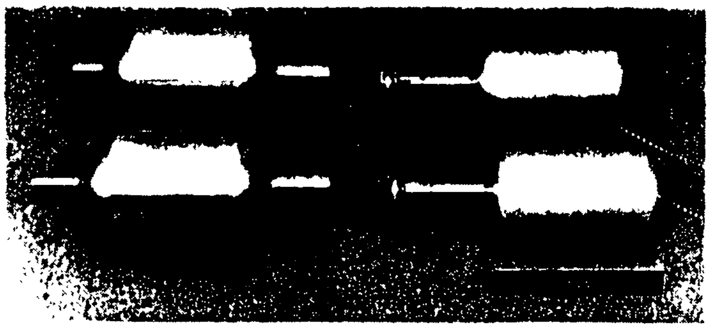
ALAS Has Demonstrated High Performing Helium Tanks



Welded 2219/1100 Liner

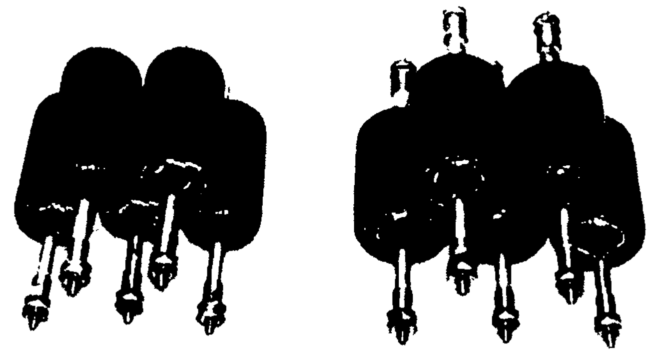


Spun 2219 Liner



Spun 6061 Liner

- 32 Helium Tanks Fabricated
- 0.010 in. Liner Wall Thickness Demonstrated
- PV/W = 1.2×10^{6} Achieved
- Helium Permeability 1.0×10^{-9} sccs at 10,000 psi after 20 Cycles Demonstrated



Specification

	Phase I	Phase II
Volume, in^3	40	335
Diameter, in	3.2	6.3
Operating Pressure, psi	10,000	10,000

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Propellant Hoop And Helical Fibers Have Been Selected

Fiber	Tank Application	Modulus (MSI)	Tank Weight Comparison, % Fu	Ox	Delivered Fiber Stress (KSI)	Avg
T-400 (3K Tow)	Helical	36.4	+8	+4	367 368 370	368
T-650[1] (3K Tow)	Helical	35.0	—	—	591 605 591	596
T-650 (6K Tow)	Helical	42.0	+10	+5	596 609 603	603
Apollo 53-750 (12K Tow)	Helical	53.0	+3	-1	615 666 660	647
T-1000H	Hoop	42.0	+6	+5	919 901 791*	910
T-1000GB[3]	Hoop	42.0	—	—	909 901 961	(2) 924

*Not Included in Average

ALAS0228

Selected

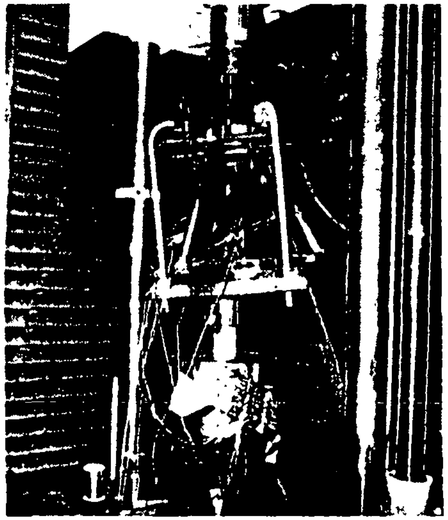
Selection Criteria

(1) Minimum Weight Design

(2) Higher Strength

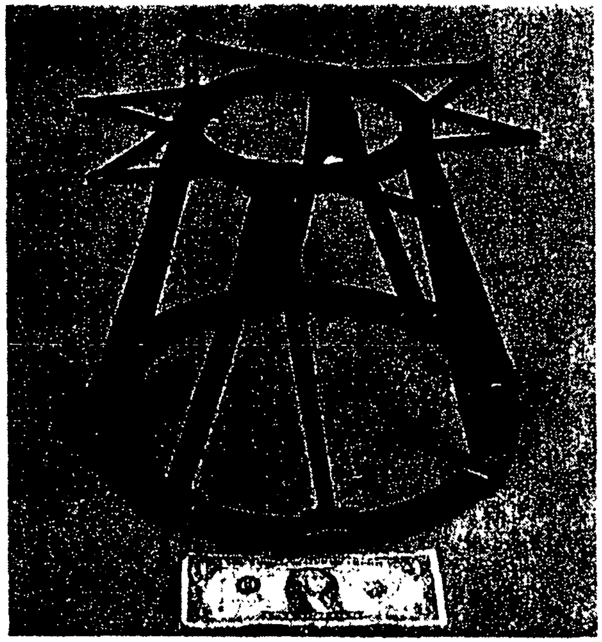
(3) Cheaper and Available

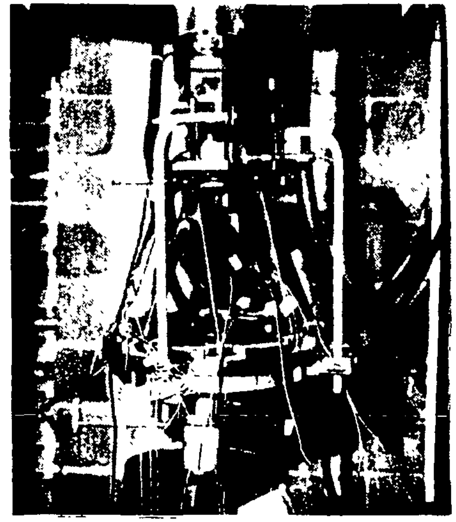
ALAS Developed An Advanced Carbon Composite Structure



KKV Deflection Test
0.018 in. Deflection at Flight Load

5 Structures Fabricated

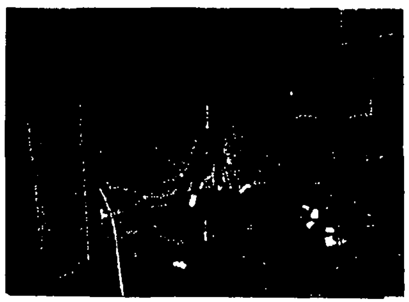




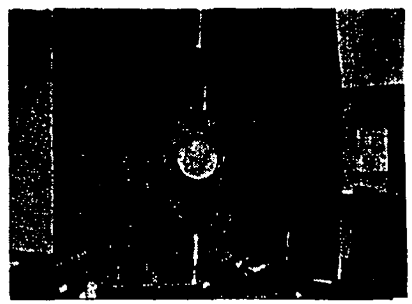
Compression Test
- Ultimate Failure at 5000 lbf

SLOSH Tensile Test
- Strut Demonstrated at 2X Load

Component Tests



Main Strut Component Test Set-Up



Forward Ring Component Test Set-Up

ALAS Aft Ring Component Test Set-Up

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ALAS Structure
Estimated Weight Summary

• Forward Ring, lbs	.147
• Aft Ring, lbs	.230
ACS Supports, lbs	.0178
Tank Support Inserts, lbs	.0086
• Struts, Structure, lbs	.328
• Struts, Engine, lbs	.041
• Tank Retaining Pins, lbs	.011
Total, lbs	.757

Note: Change in Tank Mounting Method Provides .0195 lbs Total Tank Weight Saving

Integrated Concept Employs Optimum Material for Each Component

Component	Material	Rationale
Helium Tank Mount	High Strength Graphite Fiber/High Elongation Resin [±45°] Layup	Best Balance of Stiffness/Strength
Longeron	High Modulus Graphite Fiber/BMI Resin [±45°/0°/±45°] Layup	Stiffness Driven Producible BMI for Thermal Capability
Aft Ring*	High Strength Graphite Fiber/High Elongation Resin	Best Strength/Weight Ratio for Launch Looks
Forward Flange*	Beryllium	Stiff Isotropic Machined Part Ribs/Bosses

*Detailed Structural Analysis and Dynamics Must Be Done

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Propulsion Division

CLF_5 Offers Improved Performance Without Undue Safety/Toxicity Issues

- Performance
  - High specific impulse - 340-360 sec delivered
  - High specific gravity - 1.8 vs. N_2H_4 = 1.04
- Safety
  - No untoward incidents in 5 years of recent testing
    - Over 300 rocket engine tests
    - Over 25 different engines
    - Stage test (loading and firing)
  - Handles like N2O4 - and tested with same precautions (Amines are more trouble)
  - Strong reaction with hydrocarbons - must be clean
    - Lox cleanliness level is appropriate
- Toxicity
  - Only about two-four times as toxic as N_2H_4
  - About 4-8 times safer than Titan III launch
    - Titan III fuel load = 105,000 lb of N_2H_4/UDMH
    - CLF_5 on Atlas ~ 6,500 lb
    - Equivalent N_2H_4 = 13,000-26,000 lb