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Thermal Protection Systems for Space Transportation Vehicles

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HISTORY OF REUSABLE EXTERNAL INSULATION (RSI)

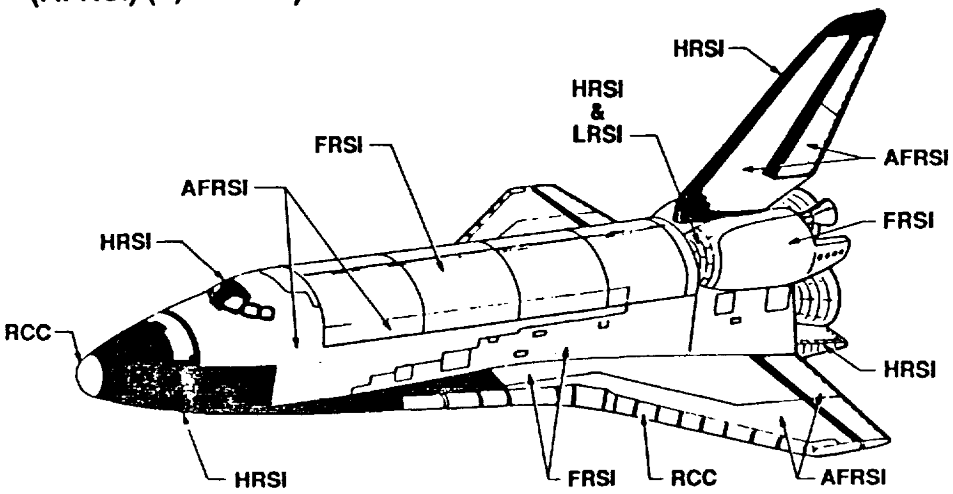
- EARLY 1960'S
  - TILE CONCEPT INVENTED BY LMSC
- LATE 1960'S AND EARLY 1970'S
  - SMALL R&D CONTRACTS TO LMSC 1968-69
  - COMPETITIVE R&D CONTRACTS TO LMSC, GE, McDAC, MARTIN 1969-72 BY NASA
  - R&D AT NASA CENTERS ON SHUTTLE TPS
- RSI CHOSEN AS PRIMARY TPS FOR SHUTTLE 1972
- ROCKWELL AWARDED CONTRACT TO LMSC TO MANUFACTURE RSI 1973
- 1973-1978: PILOT PLANT, MANUFACTURING SETUP, DDT&E PERFORMED, ORBITER TPS DESIGNED BY RI
- 1972-1981: IMPROVED RSI MATERIALS DEVELOPED AND ADOPTED LI-900 (1972) , RCG COATING (1975), FRSI (1975), LI-220 (1976) AFRSI (1978), FRCI-12 (1981)....
- 1978-1989: FIVE ORBITERS WERE BUILT WITH 24000+RSI TILES, 3000+FT^2 OF FRSI, UP TO 3000 FT^2 OF AFRSI BLANKETS
- 1981-1991: SECOND AND THIRD GENERATION TILES HTP, AETB, TUFI AND BLANKETS TABI + CFBI WERE DEVELOPED

EXAMPLES OF SHUTTLE RSI DEVELOPMENT CHALLENGES

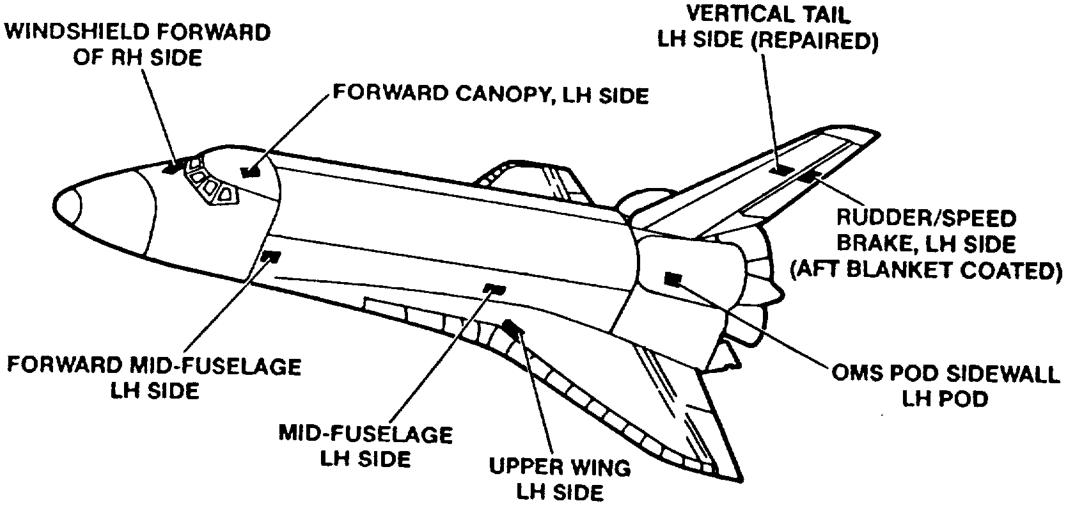
- MANUFACTURING
  - RAW MATERIALS: FIBERS, COATING COMPONENTS
  - PROCESSES: SLURRY BLENDING, PRODUCTION UNIT MOLDING, SINTERING, TILE MACHINING, GLAZING
- DESIGN
  - TILE PLANFORM SIZE
  - STRAIN ISOLATION
  - GAP HEATING
- INSTALLATION
  - BONDING, BOND VERIFICATION
  - TOLERANCES
  - QUALITY CONTROL
- OPERATION
  - DURABILITY
  - WATERPROOFING

SHUTTLE ORBITERS
TPS LOCATIONS

TOTAL RSI CERAMIC TILES - 24,300
REINFORCED CARBON/CARBON (RCC) (44 PANELS/NOSE CAP)
FELT REUSABLE SURFACE INSULATION (FRSI) (3,581 FT^2)
ADVANCED FLEXIBLE REUSABLE SURFACE INSULATION (AFRSI) (4,100 FT^2)



OEX-AMES ADVANCED CERAMIC TPS EXPERIMENT LOCATIONS OF UNCOATED AFRSI BLANKETS ON OV-099



REPLACEMENT/REPAIR OF UNCOATED AFRSI BLANKET

Blanket Location / No.	POST FLIGHT						
	STS-8	41B	41C	41G	51B	51F	61A
Forward Windshield, RH							
#391142-012	NO	NO	NO	NO	NO	C-9 Repairs	C-9 Repairs
Forward Canopy, LH							
#391142-013	NO	NO	NO	NO	NO	NO	NO
#391142-014	NO	NO	NO	NO	NO	NO	NO
Forward Mid-Fuselage,LH							
#391142-015	NO	NO	NO	NO	Sewing repair	YES	NO
#391142-016	NO	NO	NO	NO	NO	YES	NO
Mid-Fuselage, LH							
#391142-017	NO	NO	NO	NO	NO	NO	NO
#391142-018	NO	NO	NO	NO	NO	NO	NO
Upper Wing, LH							
#195056-001	NO	NO	NO	NO	NO	YES	NO
#195056-002	NO	NO	NO	NO	C-9 Repairs	YES	NO
OMS Pod Sidewall, LH							
#391142-019	NO	NO	NO	C-9 Coating	C-9 Coating	C-9 Coating	C-9 Coating
Vertical Tail, LH							
#391142-021	NO	NO	NO	NO	C-9 Repairs	YES	NO
#391142-028	NO	NO	NO	NO	C-9 Repairs	YES	NO
Rudder/Speed Brake, LH							
#391142-023	NO	NO	NO	NO	NO	NO	NO
#391142-024	NO	C-9 Coating	C-9 Coating	C-9 Coating	C-9 Coating	C-9 Coating	C-9 Coating

SPACE TRANSPORTATION STRUCTURES AND MATERIALS WORKSHOP

LESSONS LEARNED

- MURPHY'S LAW ALWAYS APPLIES TO NEW MATERIALS
- BE SURE DESIGN REQUIREMENTS ARE NECESSARY AND REALISTIC
- TEST PROGRAMS MUST BE ADEQUATE AND EARLY
- CANNOT IGNORE DETAILS

NEW THERMAL PROTECTION TECHNOLOGY DIRECTED TOWARDS:

- SAVING WEIGHT
- LOWERING COST
- INCREASED TEMPERATURE CAPABILITY
- INCREASED DURABILITY
- IMPROVED RELIABILITY

FUTURE MISSIONS

- SPACE SHUTTLE UPGRADE
- NEXT GENERATION SPACE TRANSPORTATION SYSTEM
  - -NATIONAL AERO-SPACE PLANE
  - -SHUTTLE EVOLUTION-II/C
  - -NATIONAL LAUNCH SYSTEM (ADVANCED LAUNCH SYSTEM)
  - -ASSURED CREW RETURN VEHICLE FOR SPACE STATION (PERSONAL LAUNCH SYSTEM)
- SPACE EXPLORATION
  - -MARS SAMPLE RETURN
  - -LUNAR RETURN AEROBRAKES
  - -MANNED MARS AEROBRAKE AND RETURN
  - -PLANETARY PROBES: NEPTUNE, TITAN, VENUS, URANUS
- FLIGHT EXPERIMENTS
  - -AEROASSIST FLIGHT EXPERIMENT, 1996
  - -SWERVE-PEGASUS

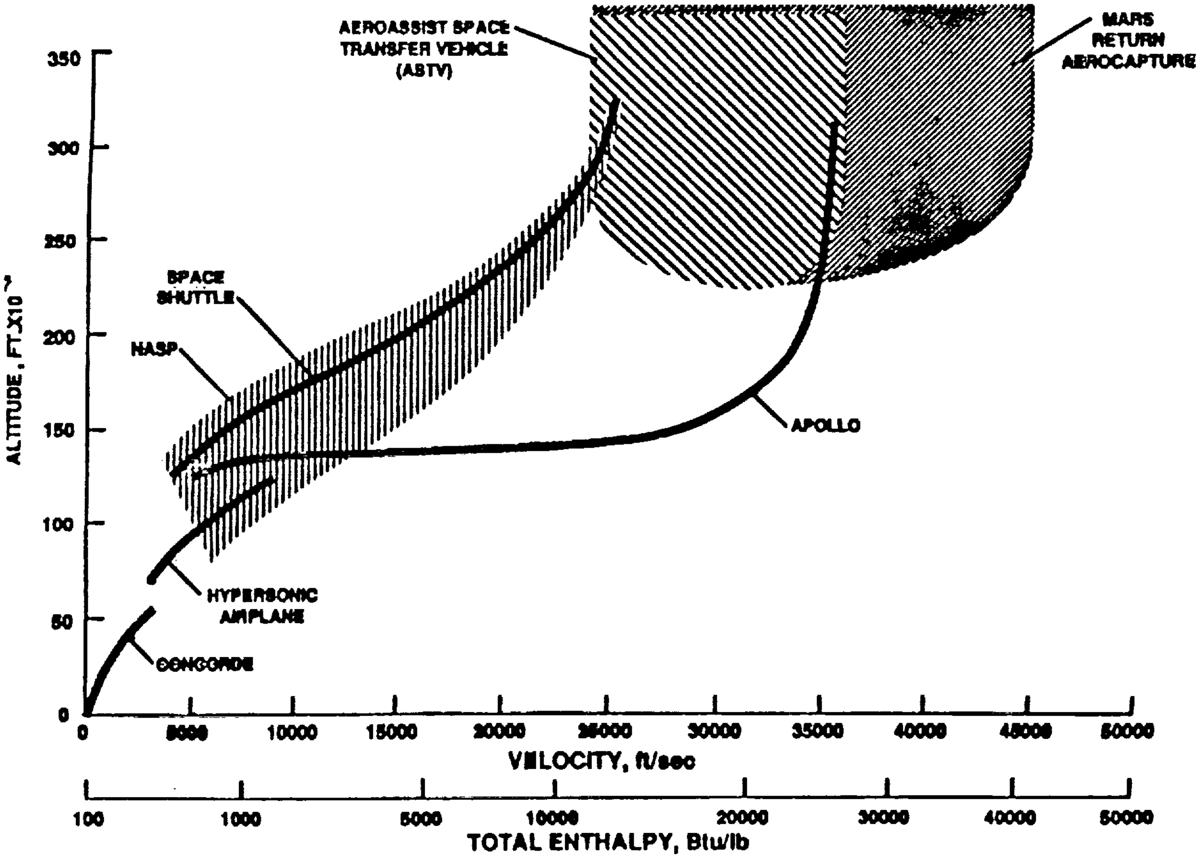
STATUS OF DEVELOPMENT

- RIGID LOW DENSITY CERAMIC
  - SHUTTLE TPS FLIGHT PROVEN
    - LI-900, LI-2200, FRCI-20-12
  - IMPROVED MATERIALS DEVELOPED
    FRCI, AETB, HTP
    - TOUGHENED COATING
  - OPTIMIZED MATERIALS TO BE DEFINED

- RIGID HIGH DENSITY CERAMIC
  - CERAMIC MATRIX COMPOSITES IN DEVELOPMENT
  - DIBORIDE COMPOSITES RESEARCH INITIATED

- FLEXIBLE
  - SHUTTLE TPS FLIGHT PROVEN
    - FRSI, AFRSI
  - IMPROVED MATERIALS UNDER DEVELOPMENT
    - TABI, CFBI, MLI CERAMIC COMPOSITES
- ABLATORS
  - MARS RETURN MISSION REQUIREMENTS BEING DEFINED
  - NON CATALYTIC REFLECTIVE ABLATOR DEVELOPMENT STARTING

COMPARISON OF VEHICLE REGIMES IN EARTH'S ATMOSPHERE



SEI/PATHFINDER

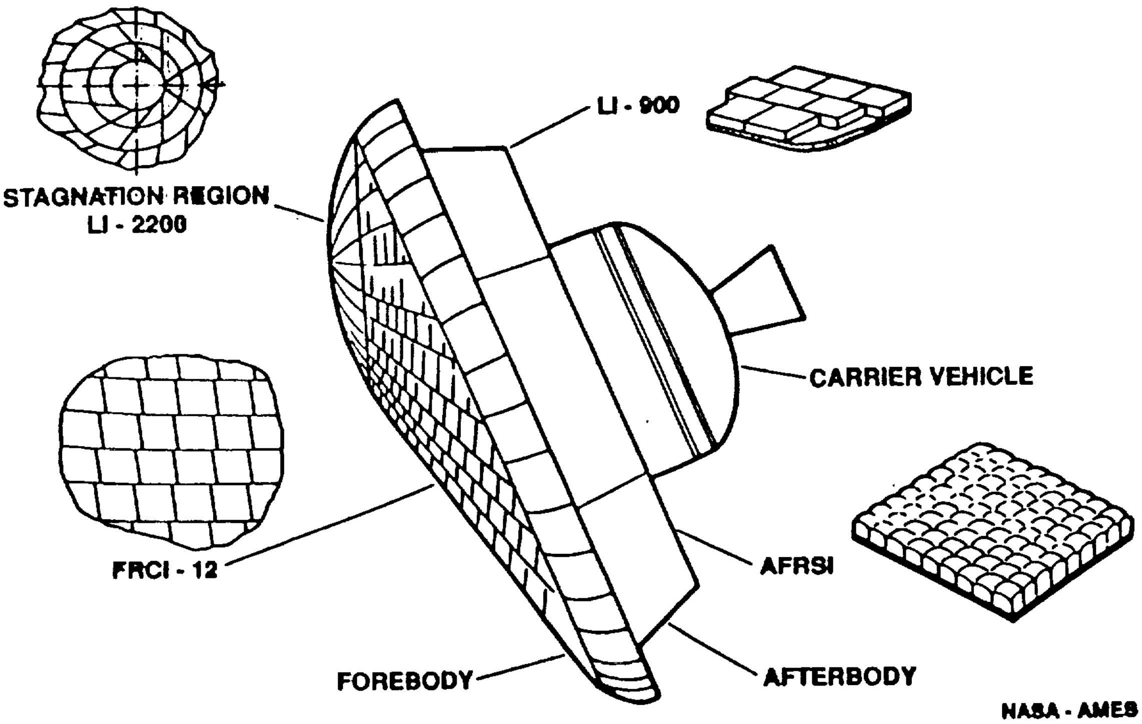
COMPARISON OF ASTV AND SHUTTLE TPS REQUIREMENTS

	SHUTTLE	LUNAR RETURN ASTV	MARS RETURN ASTV
• PEAK CONVECTIVE HEATING BTU/FT²-SEC	60	3-60	80-1000
• PEAK VELOCITY, MI/SEC	4	7+	11+
• PEAK RADIANT HEATING, BTU/FT²-SEC	< 2	30-3	25-800
• PEAK DYNAMIC PRESSURE, PSF	200	< 30	< 30
• TURBULENT HEATING	YES	NO	YES
• ENTRY HEATING TIME, SEC	1200	< 400	< 400
• EXPOSURE TO ADVERSE ENVIRONMENTS			
- HANDLING	YES	NO*	NO*
- RAIN/WEATHER	YES	NO	NO*
- AEROACOUSTICS (dB)	160+	< 90	< 90
- DEBRIS IMPACT			
- LAUNCH	YES	NO	NO
- ON ORBIT/IN FLIGHT	LESS	MORE	MORE

*ONCE DEPLOYED

THERMAL PROTECTION SYSTEM FOR AEROASSIST FLIGHT EXPERIMENT (AFE)

BASELINE DESIGN AS OF 10/89



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AEROASSIST FLIGHT EXPERIMENT

ALTERNATE THERMAL PROTECTION MATERIALS

- AETB-12 RIGID TILE

  ALUMINA-ENHANCED THERMAL BARRIER AT 12 LB/FT^3 DENSITY (AETB-12) HAS GREATER COMBINED STRENGTH AND TEMPERATURE CAPABILITIES THAN EARLIER LOW DENSITY RIGID INSULATORS. THE REACTION CURED GLASS (RCG) COATING IS THE SAME AS THAT USED ON BASELINE TILES.

- AETB-8 RIGID TILE

  AETB-8 IS AN 8 LB/FT^3 VERSION OF THE AETB-12 MATERIAL. LOWER DENSITY AND GOOD TEMPERATURE PROPERTIES ENHANCE ITS ADVANTAGES AS A HEAT SHIELD MATERIAL.

- ASMI RIGID TILE

  ALUMINA SOL-MODIFIED INSULATION (ASMI) WITH ABOUT 15 LB/FT^3 DENSITY HAS LOW SHRINKAGE CHARACTERISTICS AND IS MADE USING SOL-GEL PROCESSING TECHNOLOGY. THE COATING WILL BE RCG.

- SPECTRALLY REFLECTIVE COATINGS

  SPECTRALLY REFLECTING COATINGS APPLIED TO BASELINE AFE TILES WILL BE CAPABLE OF REDUCING VEHICLE HEATING BY REFLECTING AWAY PART OF THE SHOCK LAYER RADIATION.

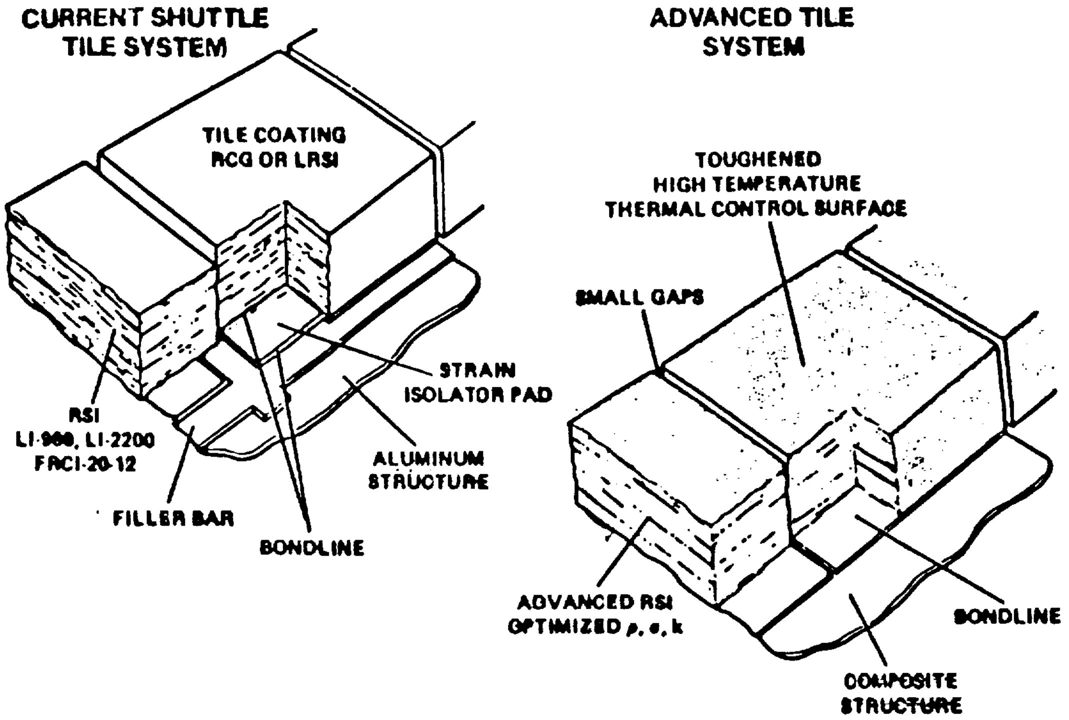
- TABI FLEXIBLE BLANKET INSULATION

  TAILORABLE ADVANCED BLANKET INSULATION (TABI) IS FORMED AS A INTEGRALLY WOVEN FABRIC STRUCTURE THAT HAS INTERNAL CHANNELS FILLED WITH LOW DENSITY ALUMINA FIBER INSULATION. TABI WILL BE WOVEN FROM SILICON CARBIDE YARN FOR HIGH TEMPERATURE CAPABILITY.

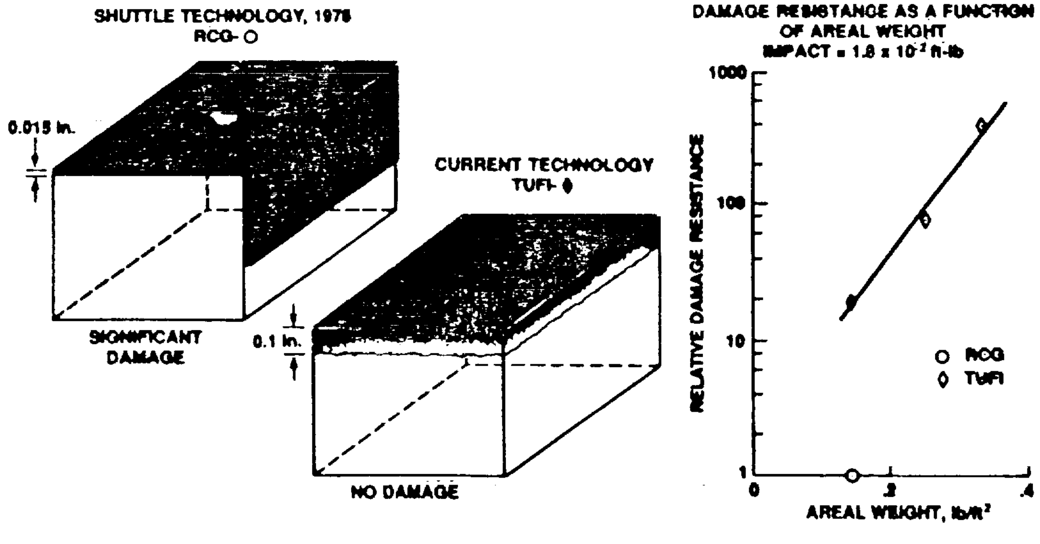
- CFBI FLEXIBLE BLANKET INSULATION

  COMPOSITE FLEXIBLE BLANKET INSULATION (CFBI) IS FORMED FROM A SILICON CARBIDE FABRIC AS AN OUTER SURFACE, A LAYER OF LOW DENSITY ALUMINA FIBER INSULATION, AND MULTIFOIL INSULATION AT THE BOTTOM FOR REDUCED RADIATION HEAT TRANSFER. THE LAYERED COMPONENTS ARE FASTENED TOGETHER BY STITCHING. THIS INSULATION HAS GREATLY REDUCED THERMAL CONDUCTANCE AT THE LOW PRESSURE CONDITIONS OF AEROPASS MANEUVER.

ADVANCED RSI THERMAL PROTECTION SYSTEMS



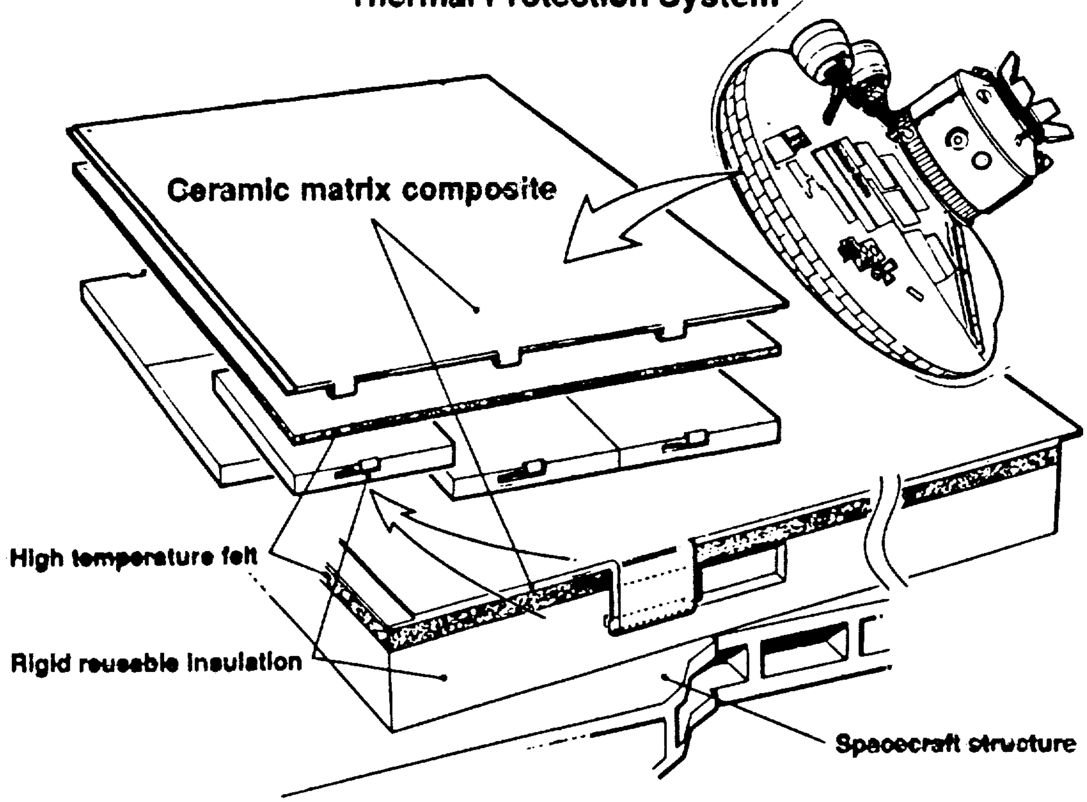
IMPACT RESISTANCE OF RSI COATING SYSTEMS



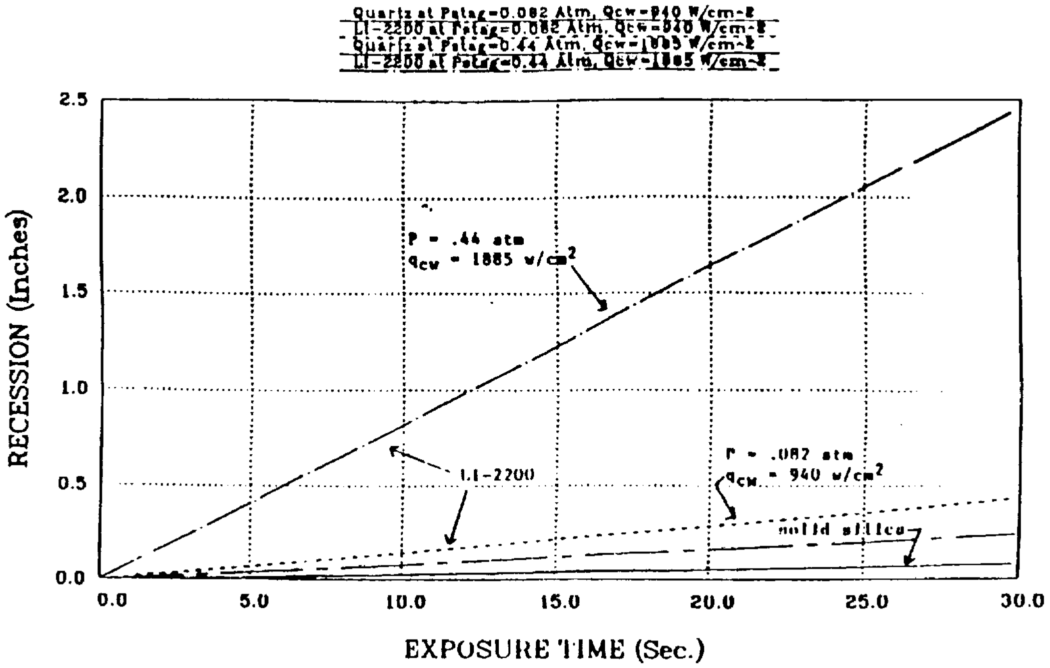
RIGID RSI PROPERTY COMPARISON

PROPERTIES	RIGID RSI MATERIALS			
	LI-900	LI-2200	FRCI-12	AETB-12
TENSILE STRENGTH				
IP (PSI)	68	181	256	157
TTT (PSI)	24	73	81	120
MODULUS				
IP (KSI)	25	80	50	32
ITT (KSI)	7	27	10	16
TEMPERATURE CAPABILITY (ISOTHERMAL SHRINK.)				
2700°F - 1 HR (%)	91		77	42
2500°F - 1 hr (%)	53		44	12
THERMAL CONDUCTIVITY PRESSURE = 10^3 ATM				
T = 1000°F BTU-IN/FT^2-HR°F	0.021	0.030	0.027	0.024

TOP HAT
Thermal Protection System



RECESSION DATA FOR ABLATION OF LI-2200 (RSI) COMPARED TO SOLID QUARTZ (AMES 60 MW Arc-Jet)



MANNED MARS/EARTH RETURN
THERMAL PROTECTION ABLATOR MATERIALS COMPARISON*
(RAKED CONE GEOMETRY) $R_N = 1$ METER

$V_E = 14$ km/sec, $L/D = 0.5$, $\beta = 300$ kg/m^2

	CARBON[1] PHENOLIC	CARBON[2] CARBON	AVCOAT[3]	RSI (LI-2200)[4]	AVCOAT (APOLLO)†
ABLATOR THICKNESS (IN)	1.1	1.75	1.75	2.75	0.5 - 2.5
INSULATION ** THICKNESS (IN)	2.0	2.0	1.0	1.0	(—)††
AVERAGE MASS LOADING (lbm/ft^2)	9.66	17.26	5.71	5.79	1.5 - 7.0
TPS MASS	3478	6210	2056	2084	1635
TPS WT.%	23.2%	41.4%	13.7%	13.8%	13.2%

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* FOREBODY HEATSHIELD ONLY; BASED ON NON-OPTIMIZED DESIGN, I.E. UNIFORM THICKNESS; DOES NOT INCLUDE TPS SUPPORT STRUCTURE

** LI-900 RSI INSULATION

† APOLLO ENTRY VELOCITY, $V_e = 11$ km/sec, $R_n = 15$ ft, $\beta = 350$ kg/m^2

†† APOLLO INSULATION IS Q-FELT/STAINLESS STEEL HONEYCOMB (Q-FELT INCLUDED IN TPS MASS)

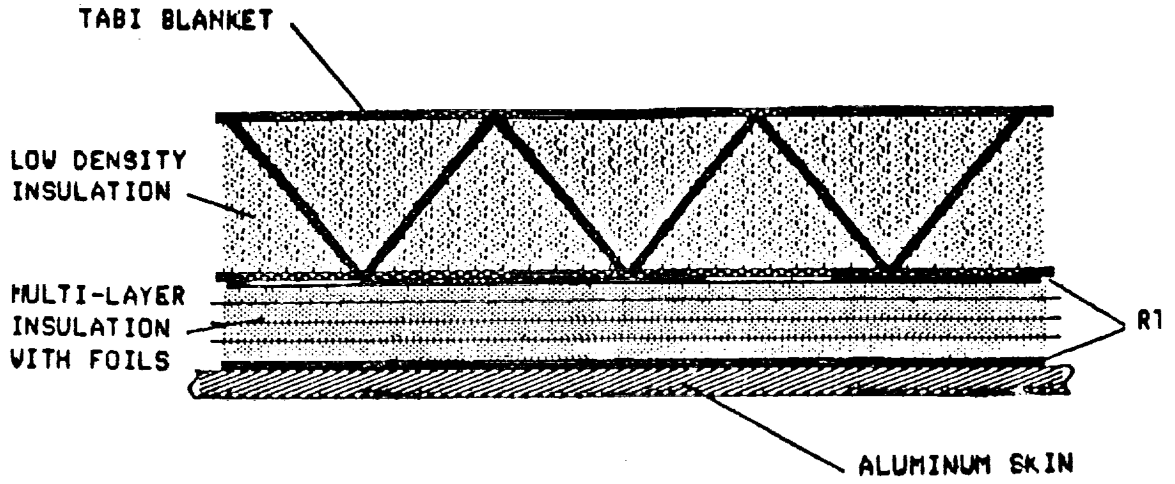
[1] INITIAL DENSITY, $\rho_o = 89$ lb/ft^3

[2] INITIAL DENSITY $\rho_o = 108$ lbm/ft^3

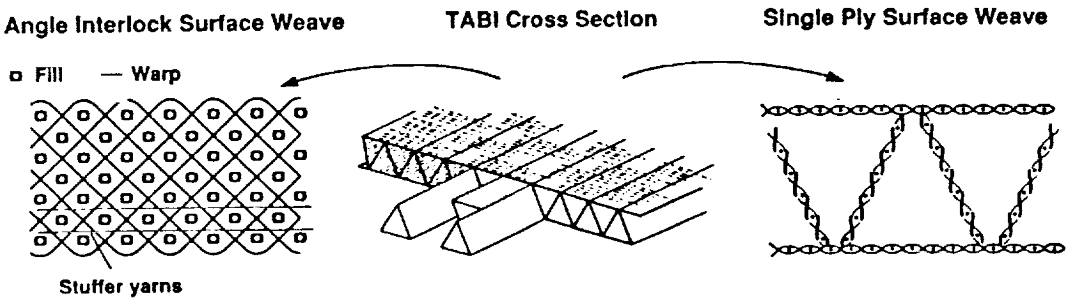
[3] INITIAL DENSITY, $\rho_o = 34$ lbm/ft^3

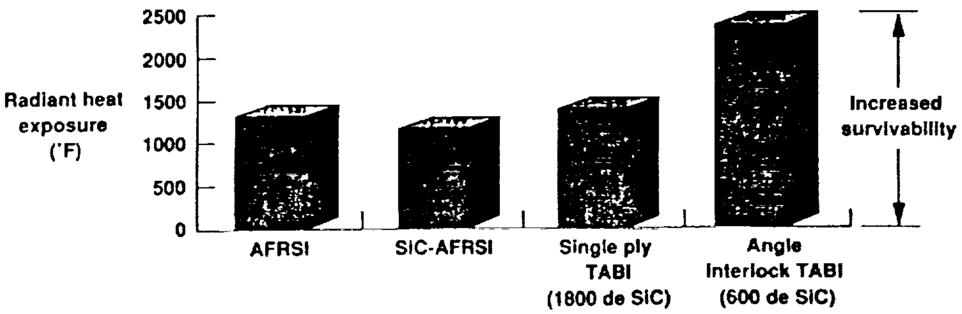
[4] INITIAL DENSITY $\rho_o = 22$ lbm/ft^3

FLEXIBLE TPS CONSTRUCTION



SURFACE TOUGHENING OF TABI TO AEROACOUSTIC ENVIRONMENTS





Aeroacoustic survival of flexible TPS after 600 sec at 170 dB
(after exposure to radiant heat cycle)

10.3.10 Thermal Protection Materials at NASA Ames Research Center by Daniel J. Rasky, NASA ARC