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Thermal Management Design for the X-33 Lifting Body

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Abstract:

The X-33 Advantage Technology Demonstrator offers a rare and exciting opportunity in Thermal Protection System development. The experimental program incorporates the latest design innovation in re-useable, low life cycle cost, and highly dependable Thermal Protection materials and constructions into both a ground based and flight test vehicle validations. The unique attributes of the X-33 demonstrator for design application validation for the full scale Reusable Launch Vehicle, (RLV), are represented by both the configuration of the stand-off aeroshell, and the extreme exposures of sub-orbital hypersonic re-entry simulation.

There are several challenges of producing a sub-orbital prototype demonstrator of Single Stage to Orbit/Reusable Launch Vehicle (SSTO/RLV) operations. An aggressive schedule with budgetary constraints precludes the opportunity for an extensive verification and qualification program of vehicle flight hardware. However, taking advantage of off the shelf components with proven technologies reduces some of the requirements for additional testing. The effects of scale on thermal heating rates must also be taken into account during trajectory design and analysis.

Described in this document are the unique Thermal Protection System (TPS) design opportunities that are available with the lifting body configuration of the X-33. The two principal objectives for the TPS are to shield the primary airframe structure from excessive thermal loads and to provide an aerodynamic mold line surface. With the relatively benign aeroheating capability of the lifting body, an integrated stand-off aeroshell design with minimal weight and reduced procurement and operational costs is allowed.

This paper summarizes the design objectives of the X-33 TPS, the flight test requirements driven configuration, and design benefits. Comparisons are made of the X-33 flight profiles and Space Shuttle Orbiter, and lifting body Reusable Launch Vehicle aerothermal environments.

The X-33 TPS is based on a design to cost configuration concept. Only RLV critical technologies are verified to conform to cost and schedule restrictions. The one-off prototype vehicle configuration has evolved to minimize the tooling costs by reducing the number of unique components. Low cost approaches such as a composite/blanket leeward aeroshell and the use of Shuttle technology are implemented where applicable.

The success of the X-33 will overcome the ballistic re-entry TPS mindset. The X-33 TPS is tailored to an aircraft type mission while maintaining sufficient operational margins. The flight test program for the X-33 will demonstrate that TPS for the RLV is not simply a surface insulation but rather an integrated aeroshell system.

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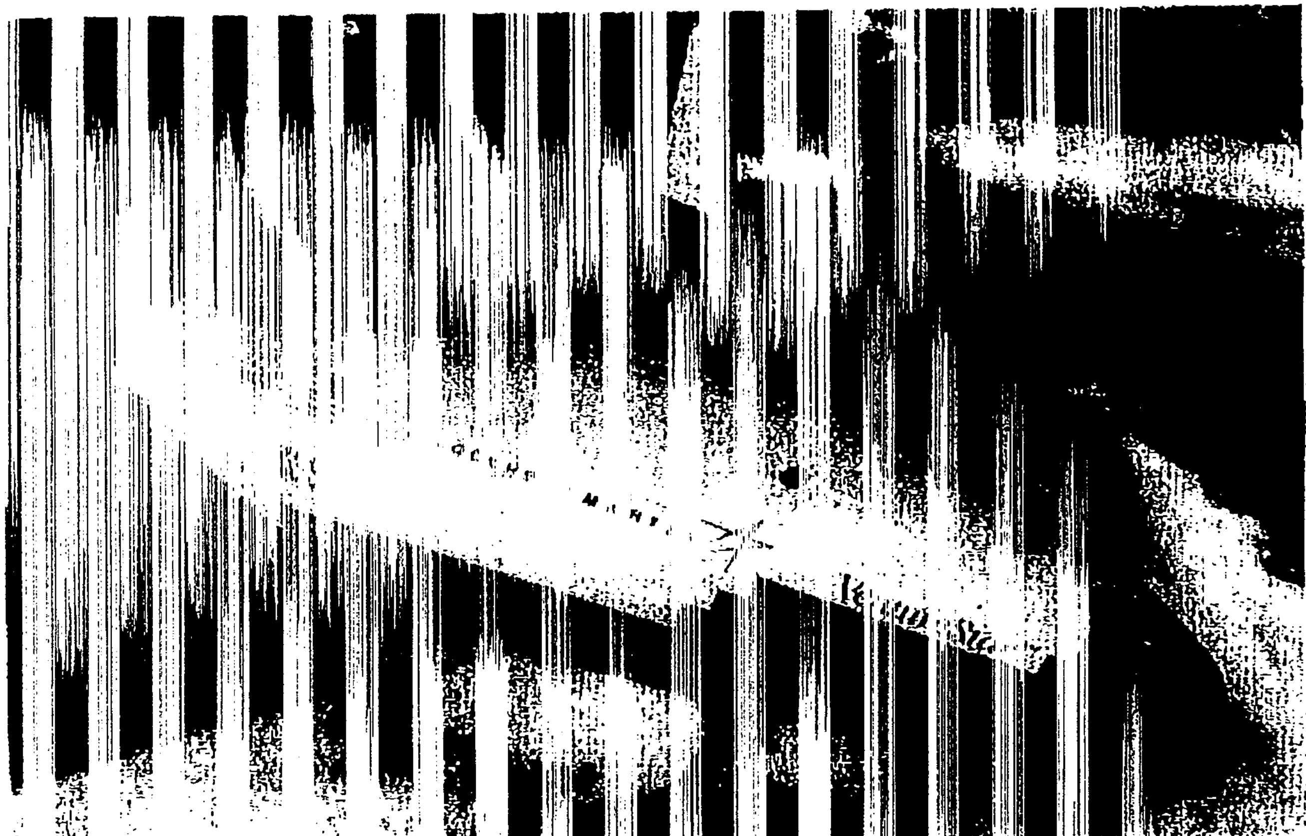
X-3 REUSABLE LAUNCHER



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2.5 D C/C A ROBUST MATERIAL FOR REUSABLE LAUNCHER

APPLICATION TO X 33 NOSE CAP

B.Capdepuy, JM. Dupillier, JL.Cloutet, P.Lespade- AEROSPATIALE
P.Kukuchek - BFGoodrich

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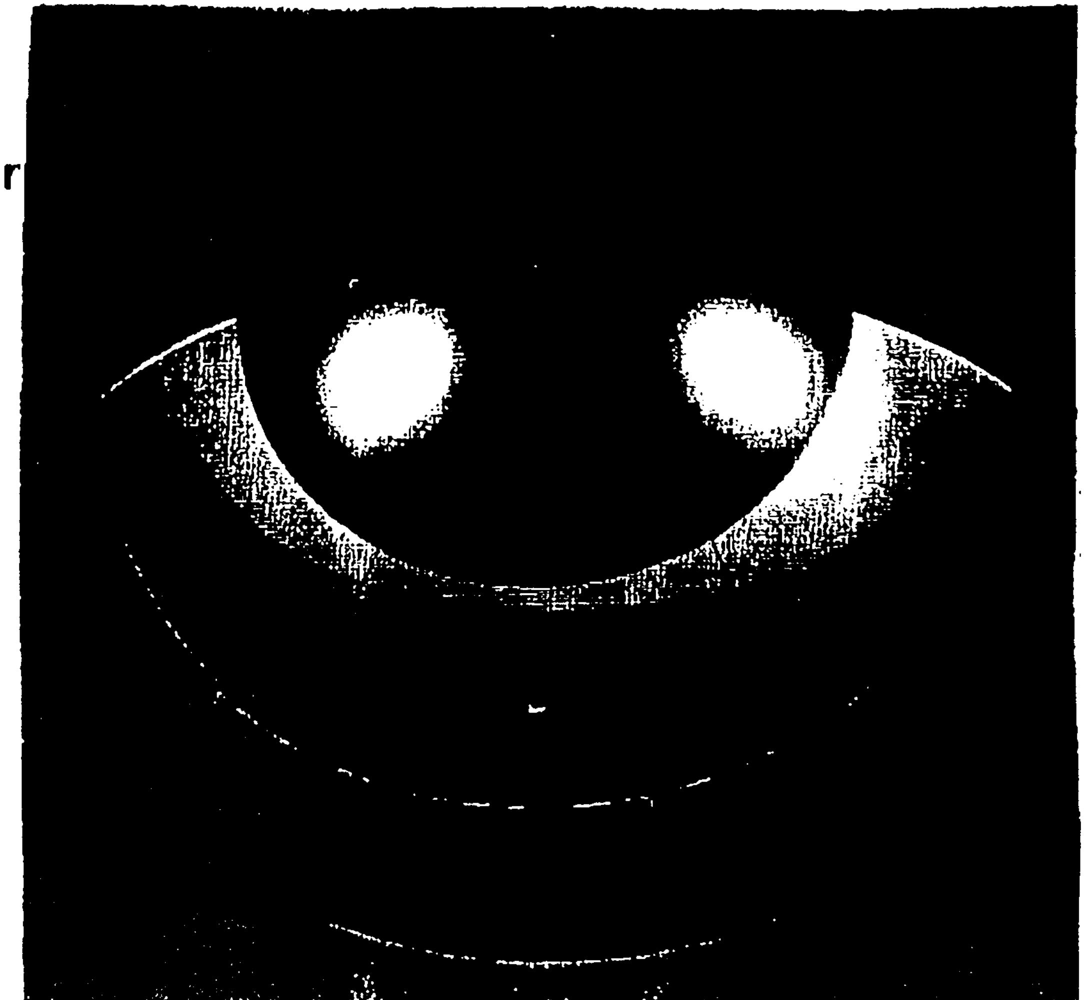
X33 Reusable launcher -Nose cap

BF Goodrich choice for nose cap coated Carbon/Carbon

- protection of external surface exposed to temperature >1100°C (1900°F)
- experimental flight duration 25mn

15 flight-test program

- 1 Nose dome ϕ=1.4m
- 3 Skirts 1m x 0.5m
- 2 chin panels 1m x 0.5m



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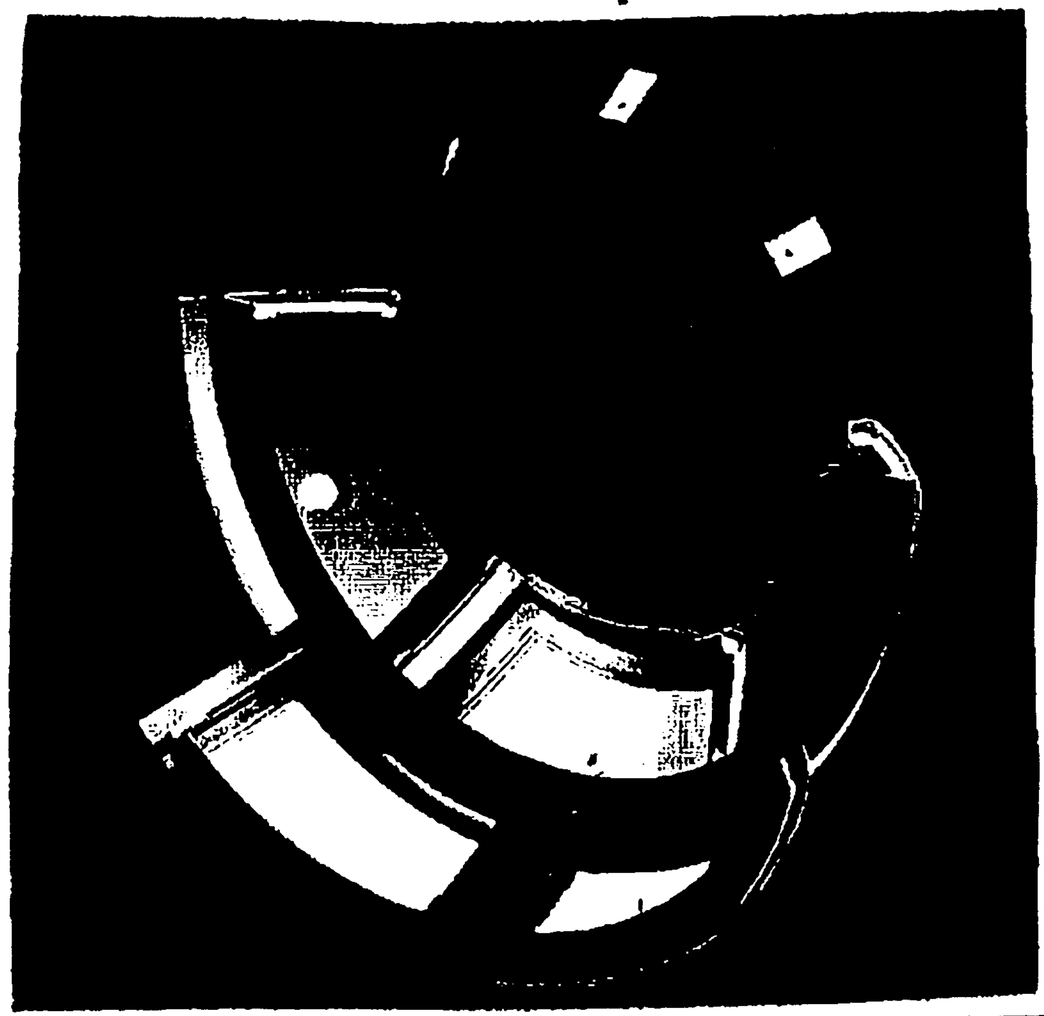
X33 Reusable launcher-Nose cap

Several stiffeners

- Nose cap on launcher attachment
- sensors and insulators support



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MATERIAL REQUIREMENTS FOR X33 NOSE CAP

- To be compliant with technical requirements:
  - definition file compliance,
  - thermomechanical performance,
  - reusability
- To be compliant with X33 schedule
  - reliable and tolerant process
- To be as inexpensive as possible
  - use existing industrial facilities

➩ **AEROTISS® 2.5 D C/C PROTECTED AGAINST OXYDATION IS A GOOD CANDIDATE**

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AEROSPATIALE MANUFACTURING PROCESS FOR X33 NOSE CAP

Textile preform manufacturing shaping and stitching

↓

Liquid hardening

↓

Machining

↓

Liquid resin densification

↓

Machining

↓

Protection against oxydation

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FIBER PREFORM CHOICE JUSTIFICATION : 2,5D

	2D	2,5 D	3D evo
Advantages	Mechanical performance (high in plane characteristics)	Mechanical performance (high in plane characteristics + **no delamination risk during processing** **+reliable shear strength (non catastrophic failure behaviour)** **Ease of shaping**	Mechanical performance (high in plane & through plane characteristics + no delamination risk during processing + reliable shear strength (non catastrophic failure behaviour)
Drawbacks	Manual lay-up Process reliability (delamination risks) Delamination risks in service (catastrophic failure behaviour)	**Automatic weaving process** Size limitation for width (<1500mm)	Automatic weaving process Specific weaving for each part

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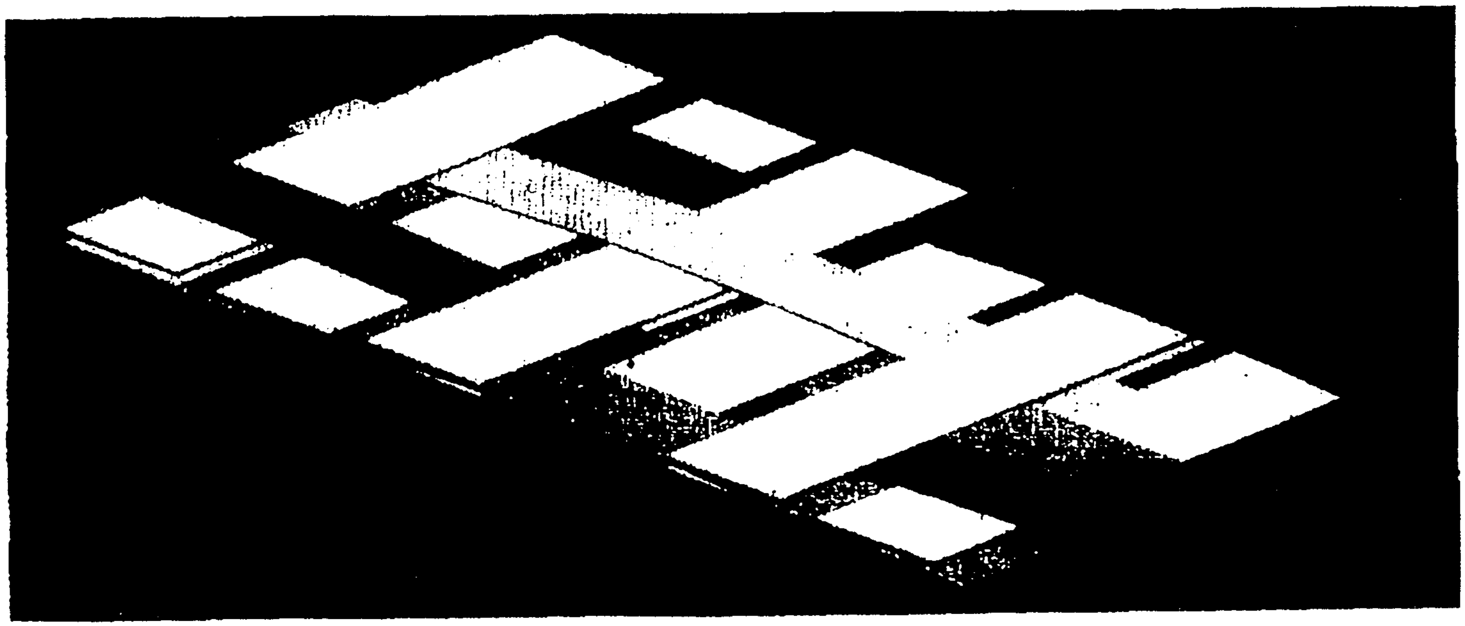
AEROTISS® 2.5D INTERNAL STRUCTURES



- Interlock architecture gives to AEROTISS® 2.5D both high mechanical in plane properties and delamination risk reduction

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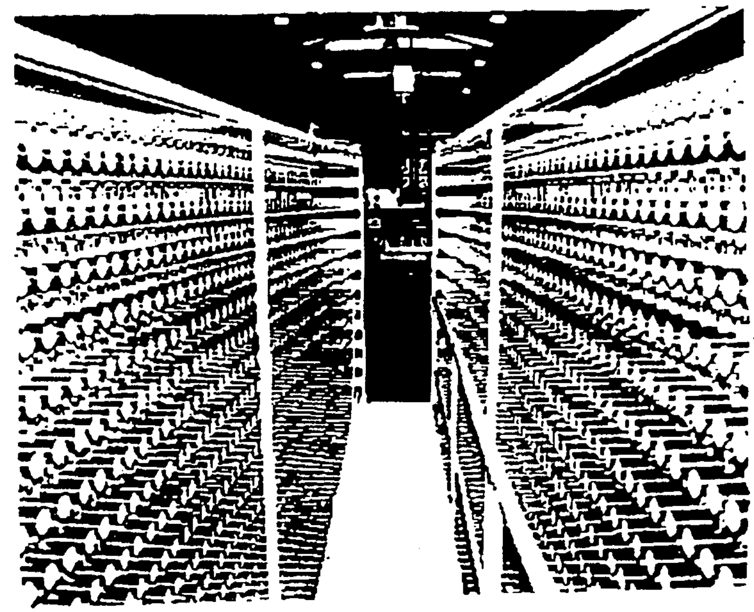
AEROTISS® 2.5D WEAVING FACILITIES (AEROSPATIALE ST MEDARD-BORDEAUX)

☛ Loom preparation based on the design department requirements:



- elementary mesh definition
- fiber rate on each direction
- total fiber rate or / and thickness

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AEROTISS® 2.5D WEAVING FACILITIES (AEROSPATIALE ST MEDARD-BORDEAUX)

- X33 weaving activities
- about 30 meters long fabric
- ready for test specimen and flight part shaping

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AEROTISS® 2.5D SHAPING MODELIZATION

- based on CATIA 3D model and the fibers directions required
- T25 AEROSPATIALE software converts 3D piece drawing in 2D flat blank drawing
- cutting facility prepares the blank
- manufacturing operator receives cut piece of fabric ready for shaping without additional cutting and stitching

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STITCHING OPERATION

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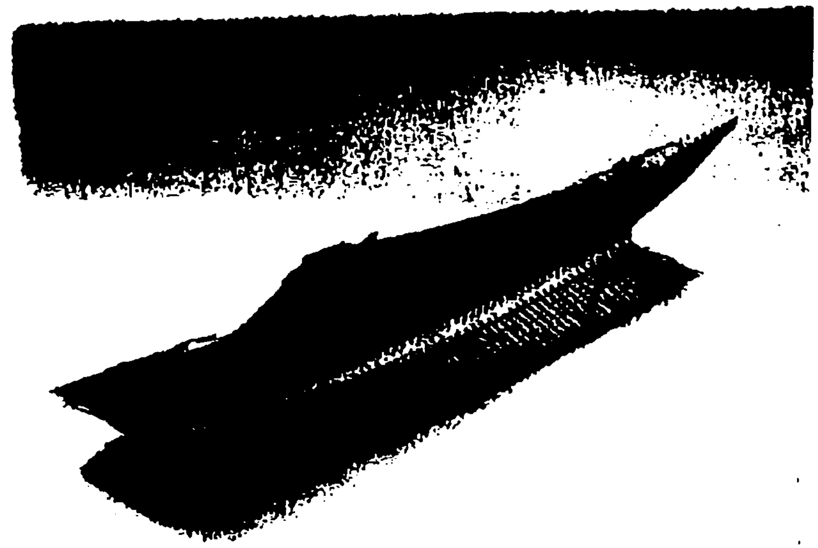
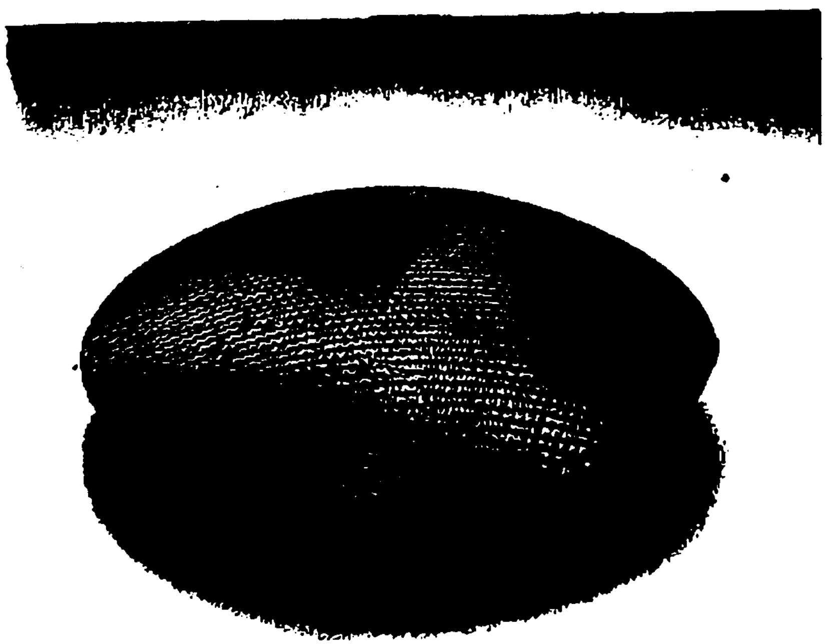
AEROTISS® 2.5D SHAPING EXAMPLE

- Spherical and conical shape





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AEROSPATIALE Densification and coating method FOR X33 Nose cap

- Phenolic resin route (developed and used for more than 20 years in St Medard plant)
- Coating developed and tested in the frame of HERMES program
  - -C/C Conversion to SiC by HT reaction : compliance layer
  - -SiC CVD layer: high temperature tightness
  - -Healing by oxides, sol/gel process: low temperature tightness
- Coating simulation developed for both pack cementation and CVD process in order to determine tooling design

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BEHAVIOUR IN OXYDATIVE ENVIRONMENT
RADIANT TESTS

- RESULTS IN BLOX (LASER HEATING FACILITY)

T°C / (cycles numb)	Pressure (mbar)	mass/loss %/cycle
800 /(10)	10	0.015
1000 /(10)	10	0.015
1450 /(45)	10	0.015
1600 /(40)	10	0.025

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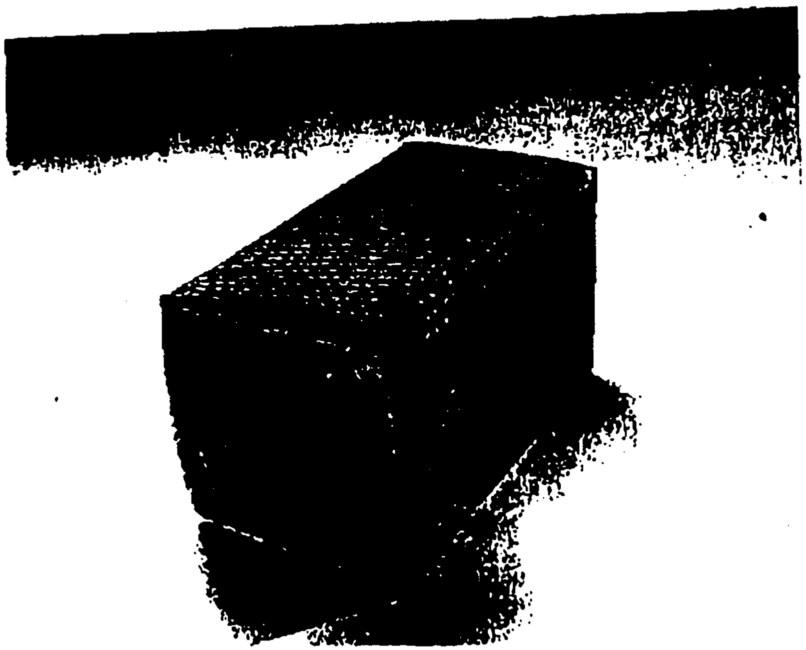
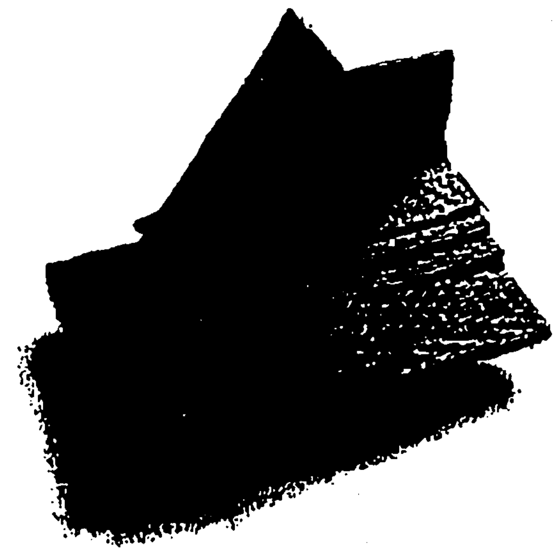
AEROTISS® 2.5D SHAPING EXAMPLE

- Corner area (box corner, skirt corner)





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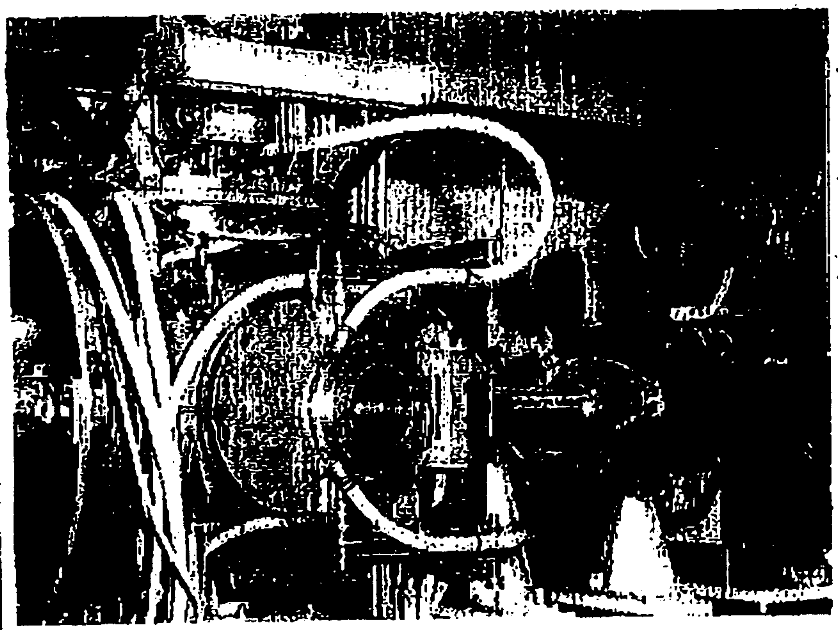
C/C + PAO : OXYDATION BEHAVIOUR

- **RESULTS IN PLASMA TORCH SIMOUN**



T°C	Pressure (mbar)	mass loss %/cycle
1300	75	0.015 (5 cycles)
1500	75	0.020 (30 cycles)