



IC3

Carbon Fibers for Efficient Solid Rocket Motors

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Arcachon 06/06/2018

Carbon Fibers for Efficient SRM : Agenda

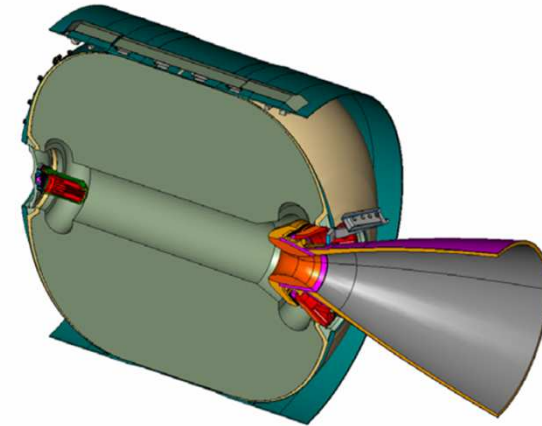
□ Solid Rocket Motors and Launchers

□ Carbon Fibers for CASES

□ Carbon Fibers for NOZZLE Parts

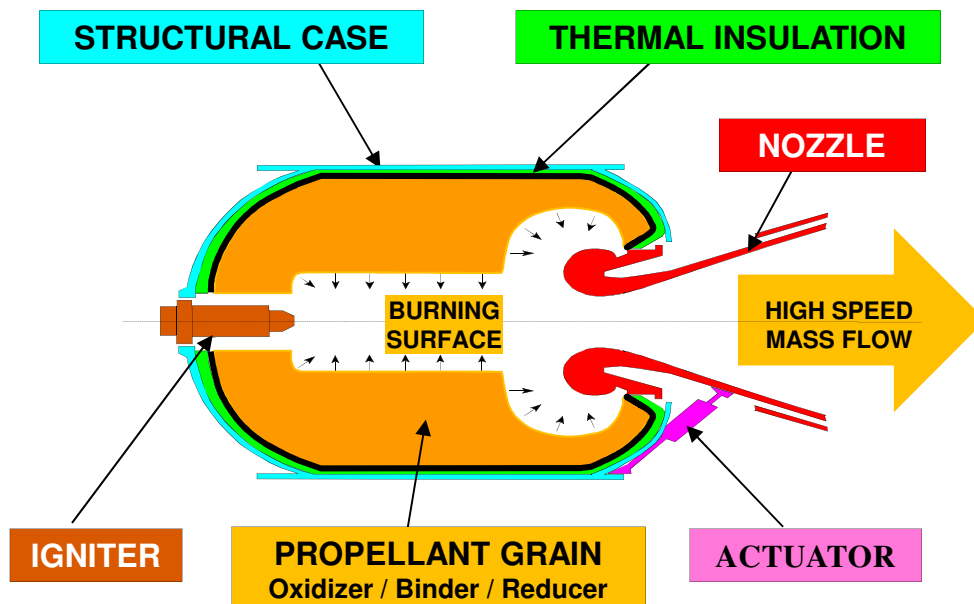
□ Carbon Fibers for IGNITER Cases

□ Conclusions

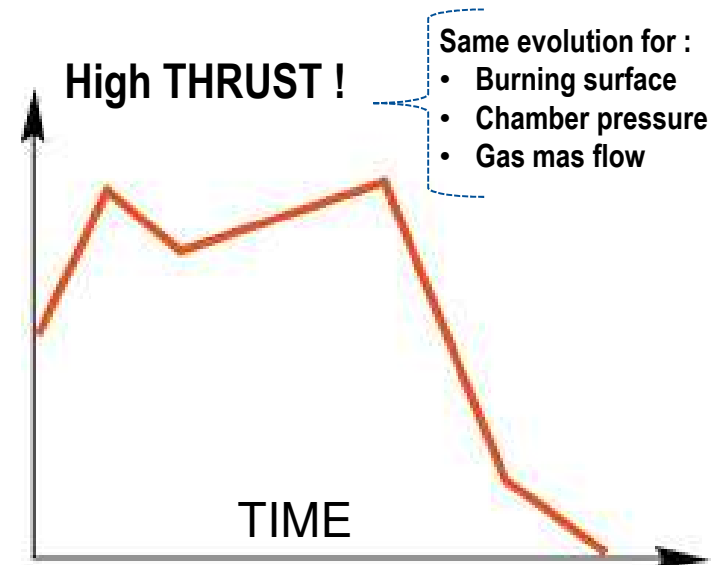


Carbon Fibers for Efficient SRM : Functioning

SRM are 'simple' and 'powerful' propulsion system



Quite No Moving Parts



Predetermined Thrust Law

Carbon Fibers for Efficient SRM : Launchers



Taurus - Delta 2 - Titan 4B
PAST

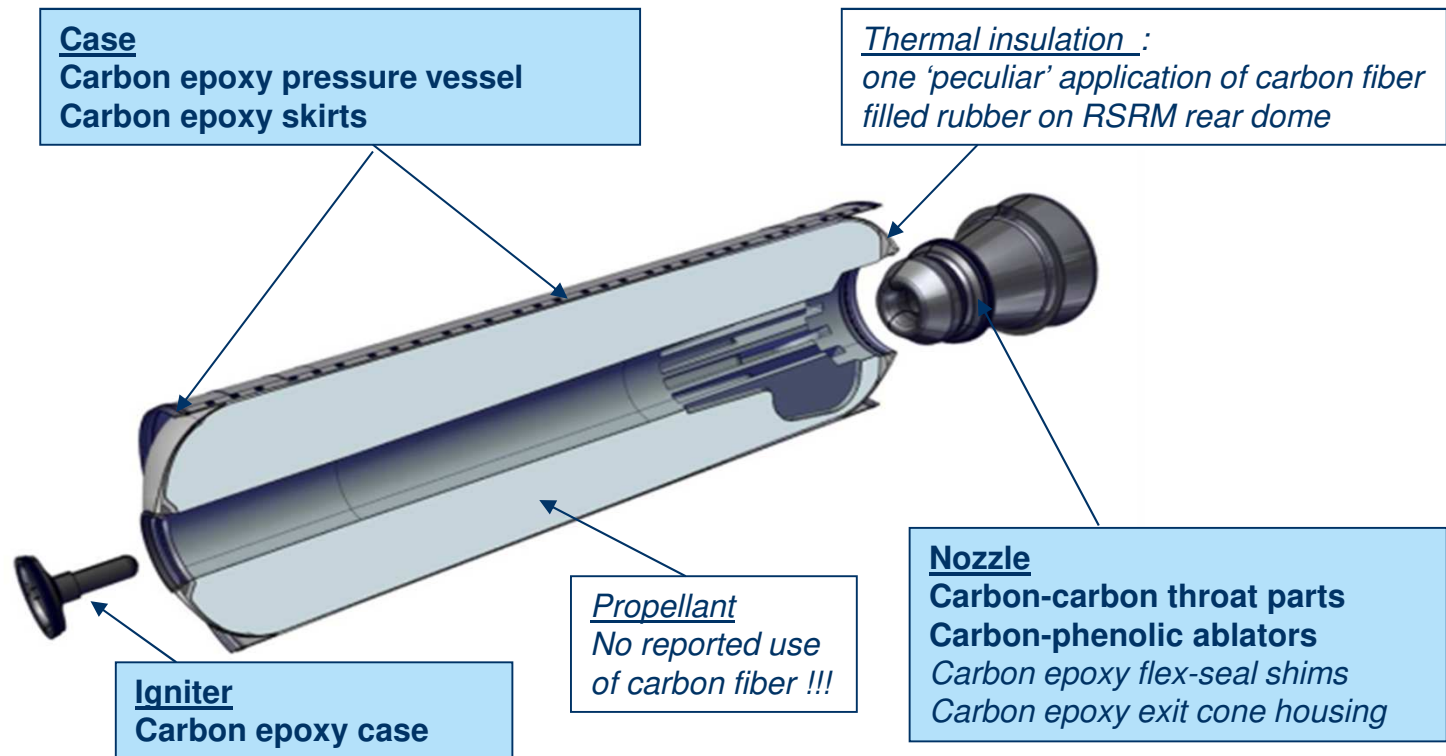


Vega - H2A - Atlas 5
CURRENT



A6 - Vulcan - Omega
FUTURE

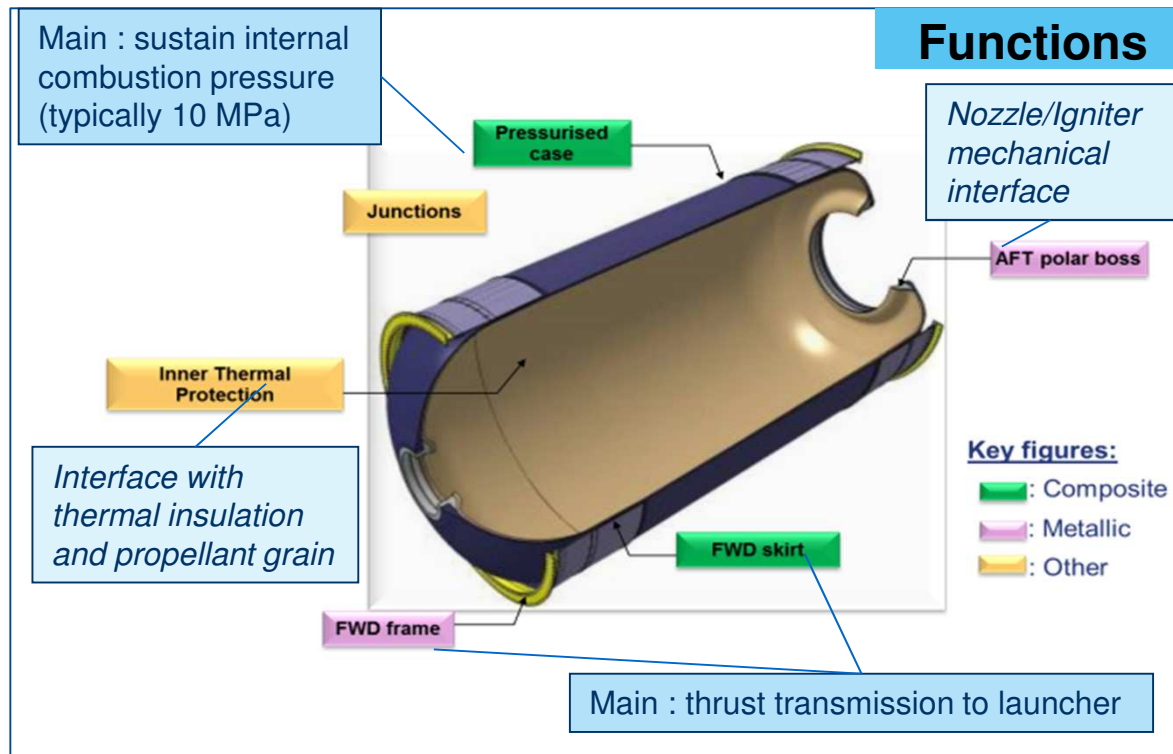
Carbon Fibers for Efficient SRM : Components



CARBON EPOXY CASE

Carbon Fibers for Efficient SRM : Insulated Case

Quite all new motor cases are carbon epoxy based



Rationale

Versus steel case :

- + Large mass reduction in the range of 50 % !!
- + Same order of magnitude for cost !!
- Larger deformation under pressure
- Less thermal capability and thicker insulation

Technologies

- Main process : filament winding
- Mandrel : extractible, dismountable, sand...
- Fibers : IM7, T800S, M30S, IMA, C30,...
- Skirts : FW + hand lay-up or AFP/ATL
- Resin process : wet winding or dry winding
- Resin system : 120/180C class, long pot life

Carbon Fibers for Efficient SRM : Insulated Case

Large case developments in Europe

ArianeGroup DEMO CPP : Ø 3.7 x 8 m

- Vessel : T800S, in house prepreg, very light steel mandrel
- Skirts : IMA fiber, automated fiber placement, highly loaded !!

MTA FORC: Ø 3.5 x 6 m

- Vessel : dry fiber winding, resin infusion, composite mandrel
- Skirts : dry fiber placement + TP binder + hoop FW

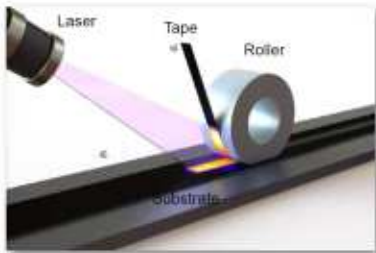
Avio P120C Case : Ø 3.4 x 11 m

- Vessel : T800S filament winding with in house prepreg
- Skirts : Automated Tape Lay-up



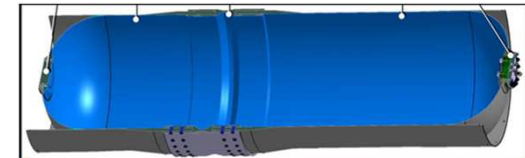
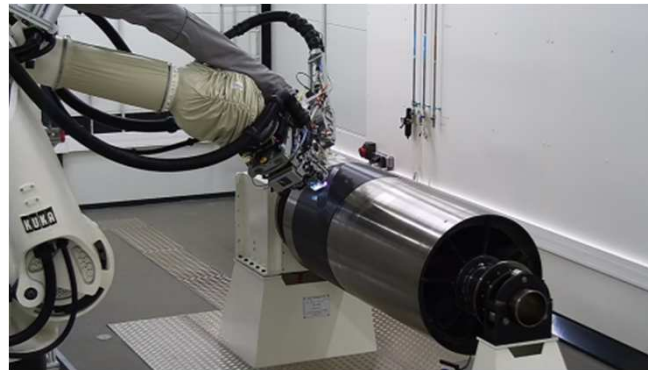
Carbon Fibers for Efficient SRM : Insulated Case

Composite Thermoplastic



A kind of 3D printing technology !!

- Prepreg tape with thermoplastic resin (PEEK, PES,...)
- Filament winding with in situ consolidation
- Fiber placement with laser heat for in situ consolidation
- Welding capability for assembly



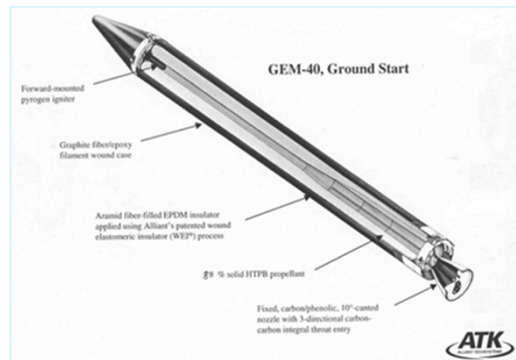
MTA COMBO TP Breadboard



ArianeGroup TP Breadboard

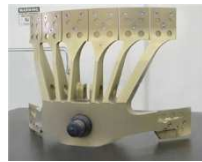
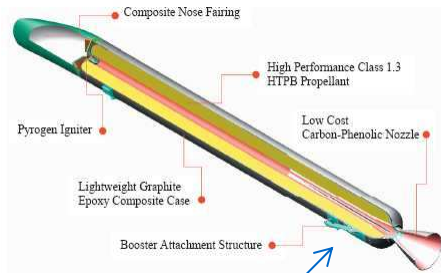
Carbon Fibers for Efficient SRM : Insulated Case

Architecture for motor and insulated cases



Strap-on	Monolithic	Segmented
L : 10 to 17 m	L : up to 10 m	L : 10 m / segment
Ø : 1 to 1.7 m	Ø : up to 3,7 m	Ø : up to 3,7 m

Carbon Fibers for Efficient SRM : Strap-on Case

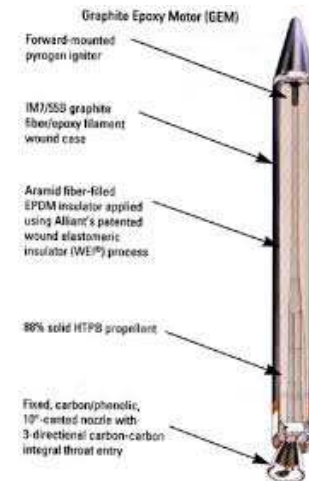


ORBITAL ATK GEM (40 to 63)

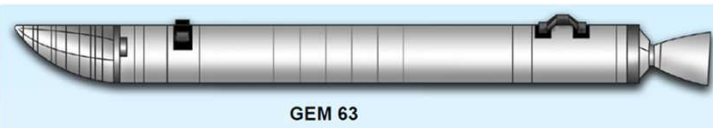
- Full aft opening / pin junction
- Dismountable mandrel
- C-curing of rubber insulation with case resin
- Bracket bolted in rear skirt or in the pressure vessel (GEM 63)
- IM7 fiber

AEROJET AJ 60-A

- Case cut in two parts to remove the mandrel, re-connected by bolts
- Co-curing of rubber insulation with case resin
- Thrust bracket bolted in pressure vessel
- C30 fiber and wet resin



Orbital ATK employees loading a GEM 80 motor at Cape Canaveral Air Force Station onto the TTT (Traveling Trunnion Trailer) in preparation for ULA transportation to the pad for Delta IV mating.



Carbon Fibers for Efficient SRM : Segmented Case

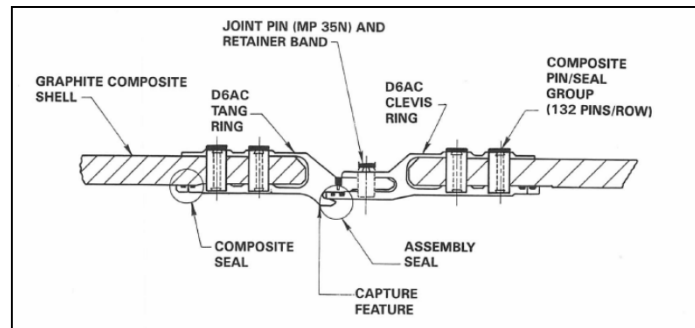


EXAMPLES

- Thiokol RSRM tested twice in development firing tests in the 80's
- Hercules SRMU developed in the 90's with 40 successful flights
- ORBITAL ATK running Castor 300 and Castor 600 developments

TECHNOLOGIES

- Rubber insulation deposited after case curing (like for steel case)
- Steel frame joining with pins in carbon epoxy thickened zones



Carbon Fibers for Efficient SRM : Segmented Case

Castor motor case development for OMEGA launcher 2020 flight



Solid Propulsion Future is Bright

Orbital ATK

C300

C600

C1200

First CBS Filament Wound Cured Case
31' Long, 12.25' in Diameter

First CBS Case Wind

First CBS Insulated Tang

First CBS Insulated Clevis

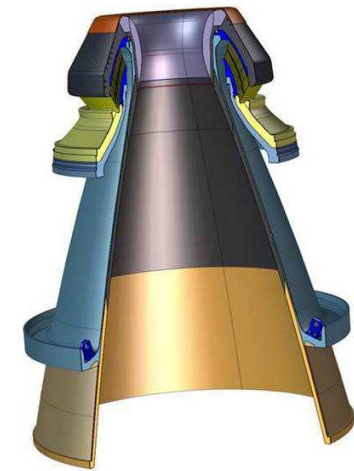
This document does not contain technical data as defined in the (FAR (22 CFR 120.10) for technology as defined under the EAR (15 CFR 730-774).

Orbital ATK Proprietary - Competition Sensitive



CARBON FIBERS FOR SRM NOZZLE :

Main Applications



Carbon Fibers for Efficient SRM : Nozzle Parts



Carbon-Epoxy parts

- flex-seal shims
- exit cone housing

Carbon-Carbon

- throat
- nose



Carbon-Phenolic Insulators

- exit cone 'thermal liners'
- submerged thermal protection

Motor gas flow characteristics

- Temperature $\approx 3500\text{K}$
- Pressure $\approx 10\text{ MPa}$
- Burning time \approx two minutes...



CARBON - CARBON

Carbon Fibers for SRM Nozzle : C/C Preforms

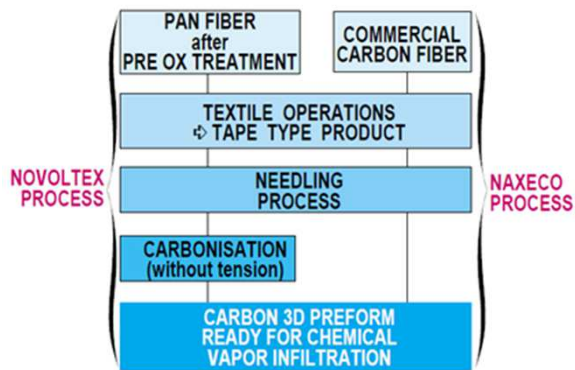
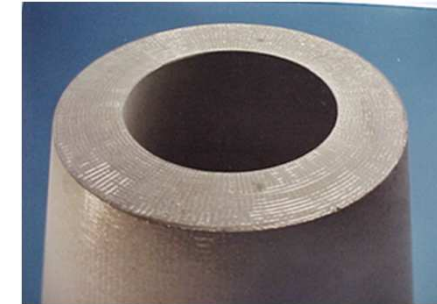


4D PREFORM (specific AGS)

Based on pultruded rods of carbon fibers oriented the 4 diagonals of the cube

3D PREFORM

Weaving of carbon yarn in 3D axisymmetric arrangement for throat

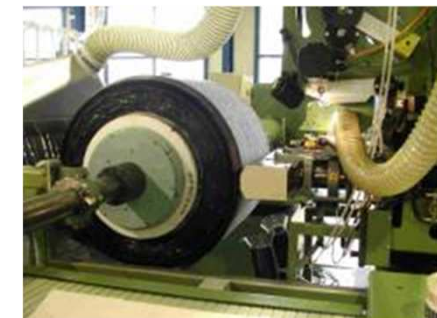
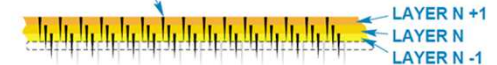


NEEDED PREFORM (specific AGS)

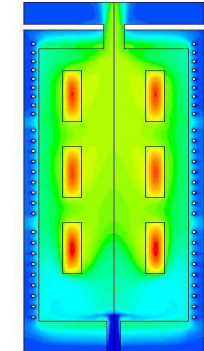
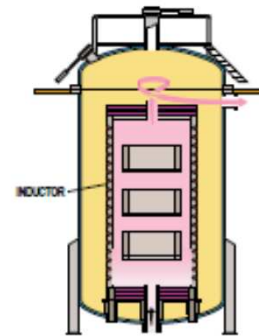
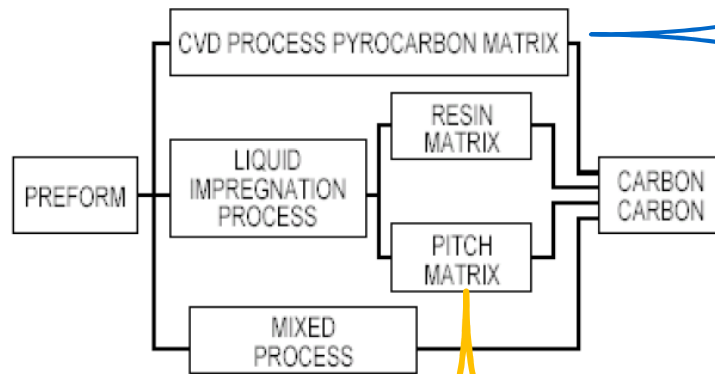
Needling of multidirectional tape to transfer some fibers in the third direction leading to a material non sensitive to delamination. Two families :

- Novoltex® : fabric of PAN Pre-Ox fibers (Bluestar) followed by a carbonization
- Naxeco® : multidirectional layer of stretch broken ex-PAN fibers (Panex 35)

CARBON FIBER TRANSFERRED
WHEN NEEDLING LAYER N +1

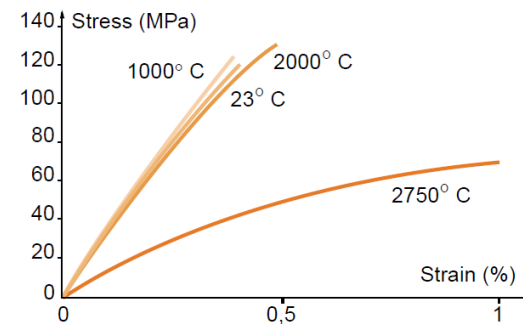


Carbon Fibers for SRM Nozzle : C/C Parts Matrixes



Chemical Vapor Infiltration for Needed Preforms

Hot Isostatic Process with **PITCH** for 3D/4D preforms



CARBON PHENOLIC

Carbon Fibers for SRM Nozzle Phenolic Parts

Carbon-Phenolic Materials

Combustion Chamber Heating Flow

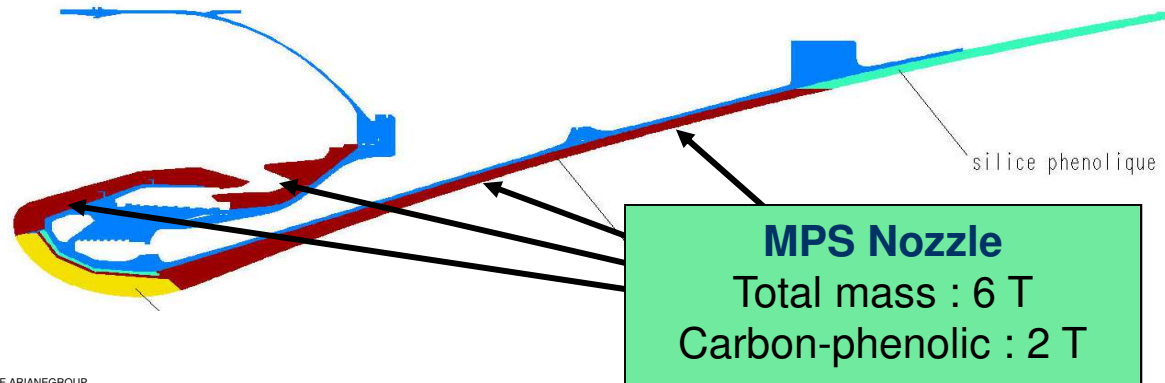


Resin Pyrolysis and Carbon Ablation



Part Thickness adapted to Firing Time

- Ex-rayon carbon fibers are the best reinforcement for carbon phenolic insulator of SRM nozzle, due to :
 - Low thermal conductivity
 - Low erosion rate coming from good char performances
- Alternate materials exist but present some drawbacks :
 - Lyocells : still under studies after many years of R&D
 - Ex PAN : limited performances under high thermal environments



Carbon Fibers for SRM Nozzle Phenolic Parts

ArianeGroup TC2 manufacturing line story

- **End of 90's facts :**
 - Suppliers of ex-rayon carbon fiber repeatedly ceased their production
 - IRC, American Viscose, American Enka, Avtex, NARC, Cydsa,
- **Decision to develop and invest beginning of 2000 in a European source : TC2 !!**
 - New rayon cloth preparation hall in Le Haillan
 - New pyrolysis and Carbonization shop in Le haillan
- **Qualification of two rayon yarn sources issued from high tenacity rayon tire cord:**
 - Glanzstoff Viscord Super 3 (active)
 - Accordis Cordenka 700 (back-up)
- **By 2010 following a manufacturing stop of Glanzstoff Austrian plant :**
 - Qualification of Glanzstoff Super 2 rayon from Bohemia plant
 - Confirmation of Accordis Cordenka 700 as back-up
- **Continuous production since 15 years :**
 - Around 15 tons per year of ex-rayon fabric
 - Exportation to the US for SRM applications



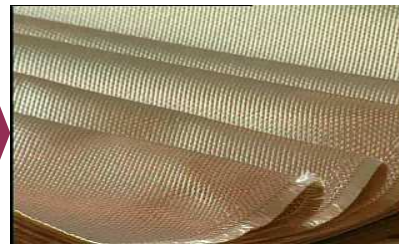
Carbon Fibers for SRM Nozzle Phenolic Parts

Cellulose Wood Pulp



Rayon fiber manufacturing

Fabric weaving



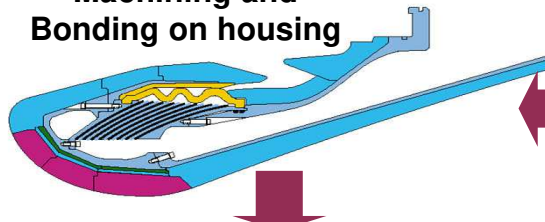
Pyrolysis (400°C)



Carbonization (1000°C)



Machining and Bonding on housing



Flight or Bench Firing



Autoclave resin curing



2D tape wrapping



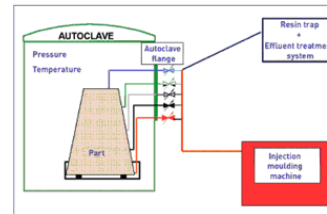
Impregnation with phenolic resin

Carbon Fibers for Efficient SRM : Nozzle Parts

‘Naxeco-resin’ : an innovative material/process for phenolic insulators

2D Carbon / Resin	NAXECO® / Resin
Ex-rayon carbon fabric in rolls	Ex-PAN carbon layer in rolls
Fabric Impregnation	----
Prepreg cutting	Tape cutting
Prepreg wrapping	Preform Needling
----	Phenolic RTM
Resin Curing	Resin Curing
Machining	Machining

- **2D carbon phenolic are excellent ablative materials but**
 - Expensive due to ex-rayon specific process
 - Sensitive to delamination, ply-lift, pocketing
- **Demonstration of a ‘Naxeco-resin’ material for Vega P80 nozzle :**
 - Needed preform with fiber in the 3rd direction preventing delamination
 - Common cheap PAN based carbon fiber (Panex 33 and 35)
 - RTM process for phenolic resin impregnation
- **Two parts flying on the Vega P80 nozzle**
 - Flex-seal cowl
 - Aft exit cone
- **Complementary R&T activities on :**
 - Resin system and RTM process optimization
 - Preform optimization



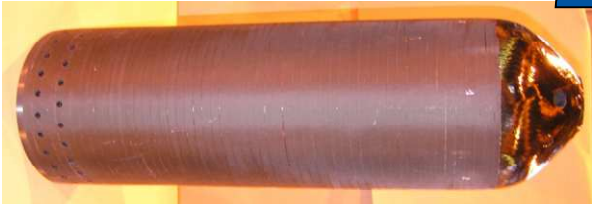
View of naxeco-resin



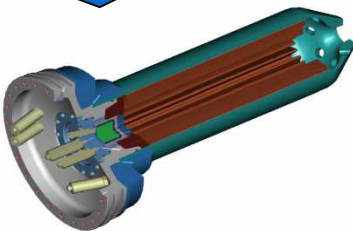
View of 2D phenolic

CARBON COMPOSITE IGNITER CASE

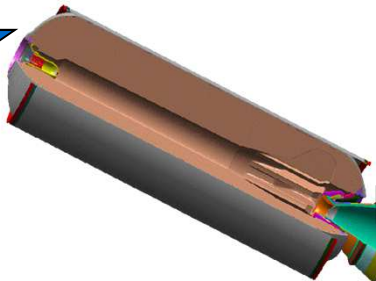
Carbon Fibers for SRM : Consumable Igniter Case



CARBON COMPOSITE CASE



IGNITER ASSEMBLY



SOLID ROCKET MOTOR



OPEN AIR TEST



'NOZZLES' EROSION !



PYROLYSED CASE !!

Carbon Fibers for SRM : Consumable Igniter Case

Principle : Pyrolysis of the carbon epoxy case

Rationale : Multi-functional part

- Pressure vessel during igniter acting time (1s)
- Integrated nozzle function during igniter acting time
- Thermal insulation during motor firing time preventing heating of the internal igniter face : 1 or 2 minutes...
- Large mass and cost reduction versus metallic case with nozzle inserts and external thermal insulation !!

Current status in Europe

- Flying on all Vega SRMs
- Selected technology for A6 P120
- Test of new resin system more adapted to pyrolysis



CONCLUSION

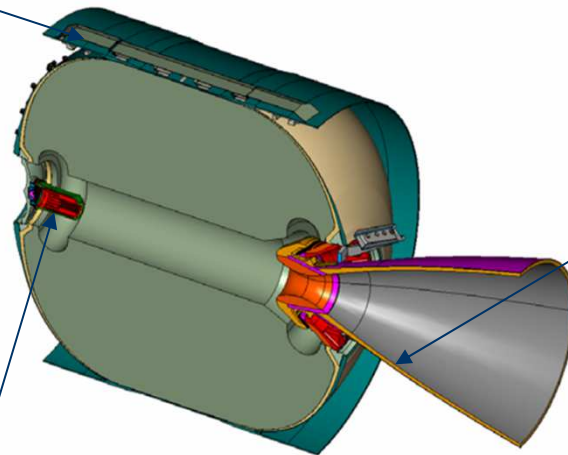
Carbon Fibers for Efficient Solid Rocket Motors

Carbon-epoxy case

- Widely used filament winding technology for pressure vessel
- Widely used AFP/ATL for skirts
- Key impact on mass reduction at 'similar' cost to metallic case
- High strength fiber favored
- Some hundreds of tons per year
- Specific processes and joining technologies for segmented and long strap-on motors

Igniter

- Carbon fiber case leads to low cost 'consumable' design



Nozzle C/C Throat

- Very low erosion with C/C leading to better overall ISP
- 3D and 4D HIP are performing technologies but at high cost
- Novoltex®/Naxeco® needed ArianeGroup technologies well adapted for large parts with CVI

Nozzle carbon-phenolic insulators

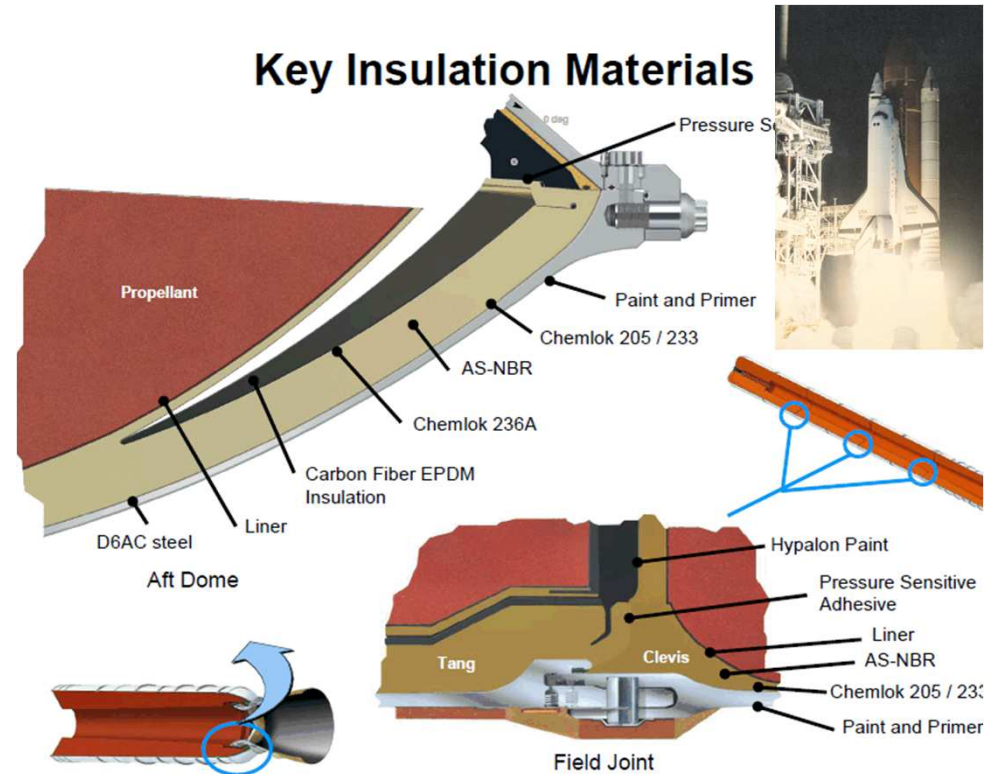
- Outstanding performance of ex-rayon based carbon fiber
- Unique European production line in Le Haillan (TC2)
- Few tenths of tons per year

Carbon Fibers are key components for large SRM

THERMAL INSULATION

Carbon Fibers for SRM Case Thermal Insulation

- Thermal insulation are rubber based layer preventing excessive heating of the case structure
- Commonly used material are EPDM, or NBR with fillers like alumina particles or Kevlar chopped fibers
- The rear dome of the Space Shuttle motor was locally protected by an EPDM containing carbon fiber...
- Very peculiar and unique application of carbon fiber for this purpose !!!



Carbon Fibers for SRM Case Thermal Insulation

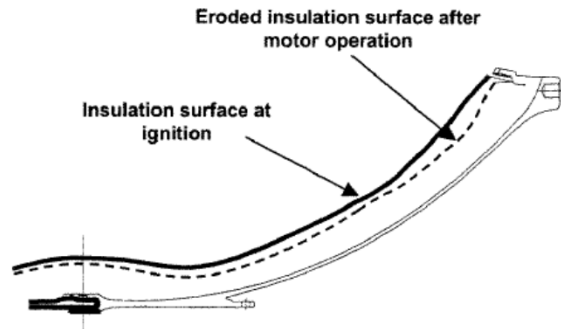


Figure 5 Aft dome insulation profiles – prefire initial surface and postfire eroded surface

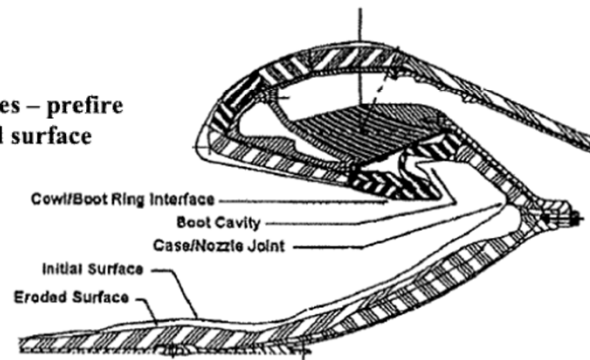


Figure 2. RSRM Submerged Nose Nozzle Geometry

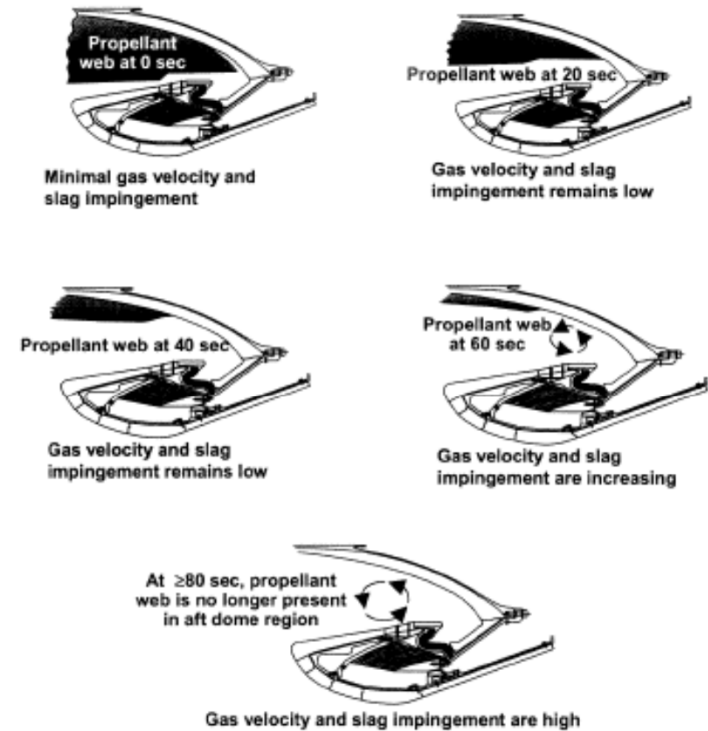
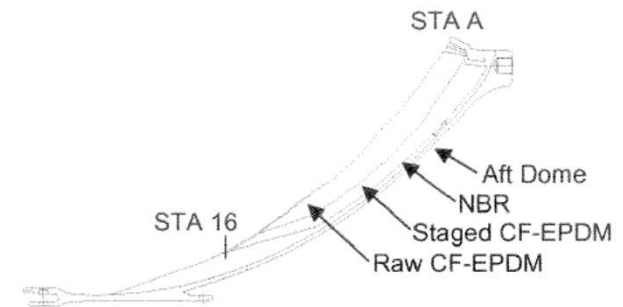
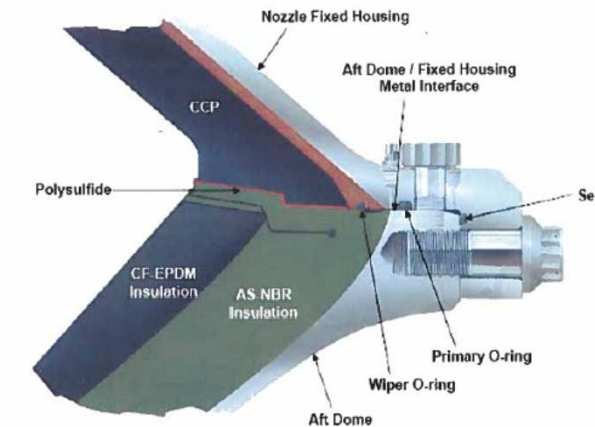


Figure 3 Axisymmetric cross sections of aft dome propellant web showing changing flow boundaries with time

Carbon Fibers for SRM Case Thermal Insulation

- **Complex physical phenomenon's**
 - Impingement of alumina droplet from the flex-seal cowl creating a slag pool of liquid alumina in the rear dome
 - Thermal heating and chemical reactions with thermal protection material at high temperature
 - Resulting surface recession
- **Test of Kevlar filled EPDM that is recognized as a better insulation material but worst results on scale 1 motor**
- **Keep on with carbon for RSRM 5S for SLS !!!! As indicated by ETM3 DEMO TEST**
- **Very peculiar and unique application !!!**



ETM-3 Aft Dome Insulation Configuration

BACK UP

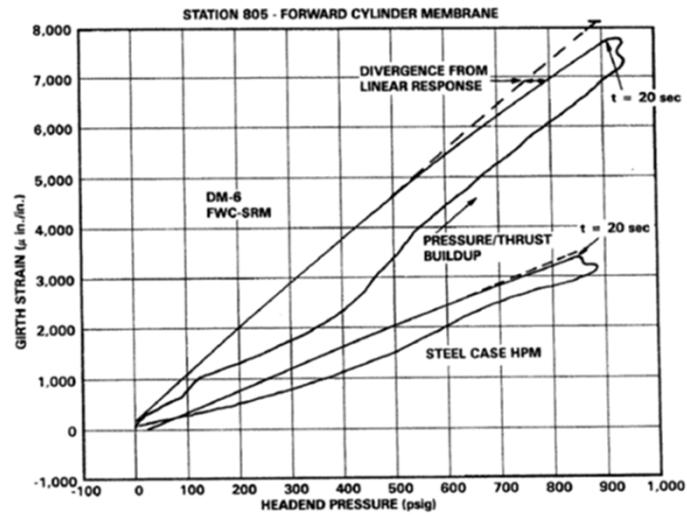


Figure 13. Comparison of Hoop Strain vs Headend Pressure for DM-6 FWC and Steel Case HPM

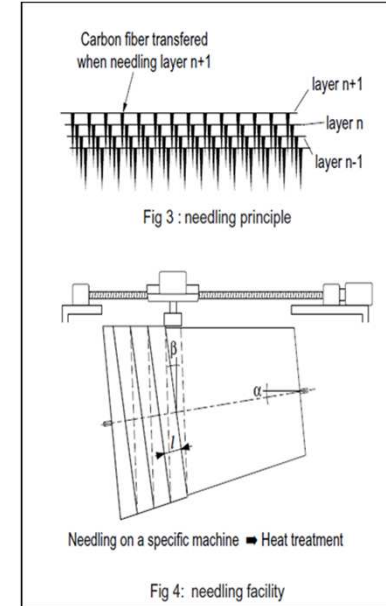


Fig 3 : needling principle

Fig 4: needling facility



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