Helium High Pressure Tanks at EADS Space Transportation
New Technology with Thermoplastic Liner

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Résumé

Bien qu'EADS ST s'investisse dans la production de réservoirs haute pression depuis 25 ans, EADS ST est toujours à la recherche de nouvelles technologies et de nouveaux produits innovants pour obtenir la meilleure solution pour répondre aux évolutions du marché en terme de performances et de coûts.
Afin d'atteindre les derniers objectifs de coûts, un nouveau saut technologique a été effectué depuis quelques années en remplaçant la technologie chère couramment utilisée d'un liner en titane forgé par un liner en matériau thermoplastique.
Cette nouvelle technologie de liner thermoplastique permet d'offrir une réduction de coût significative de 30% sur le coût de production du réservoir ainsi qu'un gain de cycle de plus de la moitié, tous deux intéressants au premier plan les responsables des programmes spatiaux.
Ce document présente l'état de l'art actuel pour l'application d'un liner thermoplastique sur le réservoir hélium 300 litres pour le lanceur ARIANE 5, réservoir actuellement réalisé à partir d'un liner titane. L'objectif de ce nouveau développement est de remplacer le liner titane par un liner thermoplastique afin de réduire les coût et cycle de production.
Cet article présente également la logique des travaux effectués depuis 3 ans pour cette application dont tous les résultats ont conduit au succès total du concept de liner thermoplastique.
Tous les travaux effectués dans le cadre de la faisabilité d'un réservoir 300 L à liner thermoplastique ont complètement démontré le respect aux exigences majeures demandées pour le lanceur A5. Ces travaux finalisent la phase de faisabilité de ce saut technologique qui est maintenant totalement mature dans l'objectif d'une qualification complète en vue de la production de tels réservoirs.

Abstract

Although EADS ST has been involved in high pressure tanks for 25 years, EADS ST is still developing new technologies and products to provide the best solution in response to the evolution of the market in terms of performances and costs.
In order to achieve the new target prices, a new disruptive technology has been performing for several years in using a thermoplastic liner instead the usual expensive concept of metallic forged liner.
This new thermoplastic technology offers a significant cost reduction by 30% at tank level and a tank cycle production half size both directly impacting the management of Space Programs.
This paper presents the state of the art in the domain of the thermoplastic liner applied on a new version of the 300 litres ARIANE 5 helium tank, currently produced for the A5 launcher with a titanium liner. The objective of this new development is to replace the titanium liner with a thermoplastic one in order to reduce both the cost of the liner and the tank cycle.
This paper also details the logic of the development chosen for this application and the results obtained for the last 3 years, which have all ended in a full success of the thermoplastic concept.
All the works made in the frame of the feasibility of a 300 L thermoplastic lined tank fully demonstrate the compliance to the major requirements of A5 launcher. These works finalise the feasibility phase of this new disruptive technology which is now rather mature with the aim of a complete qualification for the production of such tanks.

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1. INTRODUCTION

For high pressure tanks the optimum solution in terms of weight and strength was up to now achieved with a thin-walled metal liner over-wrapped with fibre composite material. The outer composite shell is designed to withstand high pressure loads while the liner fulfils the gas tightness requirements.

Due to strong requirements for cost reduction on ARIANE 5 launcher, EADS ST intends to find a new technology by developing a new liner technology using a thermoplastic material which offers both a great cost reduction at liner level by more than 70 % and a cycle reduction.

This paper presents the state of the latest works in progress at EADS ST on a new 300 L spherical tank with a thermoplastic liner, currently produced for the A5 launcher with a titanium liner.

2. HERITAGE

For this new 300 L helium tank development, the heritage is important coming directly from the current ARIANE 5 tank for the composite material based on a T800 carbon fibre.

The processes involved in the composite shell (winding and curing) are well mastered by EADS-ST since 1982. More than 660 liners of all types have been manufactured using these processes and no leak has ever been detected.

Materials are fully qualified and have been used on all EADS-ST tank products since 1982 for its high performance. More than 100 tanks have already been manufactured with this carbon composite material.

The following chart shows the different kinds of tanks manufactured since 1982.

V (L)	Shape	liner/ winding	MEOP (MPa)	Flight Qual
18	spherical	Ti/kevlar	25	yes
35	spherical	Ti/ kevlar	27.6	yes
35	spherical	Ti/ carbon	27.6	no
51	spherical	Ti/ kevlar	29.5	yes
123	spherical	Ti/ kevlar	32.6	yes
300	spherical	Ti/ carbon	40	yes
68	cylindric al	Ti/ carbon	15 Xe 31 He	with Rosetta
80	cylindric al	Ti/ carbon	31	On board Stentor
70	cylindric al	Ti/ carbon	19 Xe	no
300	spherical	**TP**/ carbon	40	no
89.5	cylindric al	Ti/ carbon	31	no

Notes: TP means themoplastic liner (in progress)
Xe means xenon
He means helium

3. THERMOPLASTIC LINER FOR HELIUM LAUNCHER TANK

Due to very strong requirements for cost reduction on the Ariane 5 launcher, EADS ST intends to replace the usual and expensive titanium liner by a plastic one.
Indeed, in order to reach the cost target (25 to 30% cost reduction at tank level), a technological breakthrough at liner level was necessary which represents a cost reduction at liner level of about 70 % in comparison to the metallic current liner.
Currently the liner is made, as for spherical satellite tanks, out of two titanium blanks forging machined down to a thickness of 1.5 mm. The cost of that liner technology is mainly due to the mass of titanium involved (about 240 kg for the 300 L A5 tank), the cost of high capacity press (60 000 tons), the machining and the Electron Beam welding.

So, it rapidly appeared that the only solution to achieve such an objective was to investigate the possibility of a plastic liner technology, because no metallic solution would have been able to approach the target for such a geometry of liner (diameter = 850 mm).

The paper shows hereafter the feasibility works which have been implemented for three years by EADS ST. The feasibility phase has been co-funded by CNES and EADS ST the first year and by EADS ST alone after. The paper also provides the main experimental results obtained during that feasibility phase and concludes on this new technology which seems very promising.

The spherical 300 L tank is designed with a safety factor of 2 in accordance with the following standards and regulations:

- MIL STD 1522A
- CSG regulations

and with the A5 requirements, in particular:

- A5-SG-1-X-10 ASAI
- A5-SG-1-X-11 ASAI
- A5-SG-1-X-21 ASAI
- A5-SG-1-X-30 ASAI
- A5-SG-1-X-40 ASAI
- A5-SG-1-X-41 ASAI

The main characteristics of the spherical thermoplastic lined tank are:

	300 L He tank
Volume:	≥ 300 L
MEOP	40 MPa
Safety factor	2
Outer diameter at Proof	< 903 mm
Tank weight	< 95 kg
First natural frequency	≥ 100 Hz
Operating temperatures	-20°C, +50°C
External Leakage at MEOP Helium	~5 10^{-03} scc/sec

3.2 OBJECTIVES OF THE THERMOPLASTIC LINER FEASIBILITY

The liner has to satisfy the main following functions:

- to allow the winding process,
- to allow the thermal curing process,

- to be tightly enough to keep helium pressure according to the launcher requirements as A5,
- to enable the fixation on A5 stage,
- to sustain the flight conditions,

3.3 LINER TECHNOLOGY

This thermoplastic liner technology has been patented by EADS ST.

A material coupled with a process able to produce a monolithic liner, in order to avoid any other difficulty like plastic welding, has been identified as a good candidate to replace the current titanium material.

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The material identified should be able to have an acceptable level of tightness which is the first function of the liner. For that, elementary tests were performed on a 3 litre tank under 300 bars pure helium to evaluate the level of permeability of the thermoplastic material.
The result obtained, 3.4×10^{-4}scc/s, showed, by extrapolation on a 300 L tank (taking into account the volume, the thickness and the volume ratios), that the tightness would be acceptable and would meet the A5 needs.

The other liner task has been consisted in demonstrating at full scale the feasibility of the spherical liner with a volume close to 300 L.

The manufacturing of the first batches of liners (20 liners) has fully demonstrated the feasibility of the thermoplastic liner at full scale.

figure 1 - Batch of 300 L thermoplastic liner

After manufacturing, the liner is equipped with bosses in order to enable the interfaces on A5 stage and to sustain the flight loads.

The figure below shows a liner equipped with bosses and ready for winding.

figure 2 - Thermoplastic equipped liner before winding

The next challenges were to demonstrate the manufacturing of the tank both over-wrapping and curing without crushing the liner.
For that, the current winding process had to be adapted in order to take into account the low rigidity of the liner.

The figure bellow shows the thermoplastic liner over-wrapped tank after winding and curing.

figure 3: Thermoplastic lined 300 L tank feasibility

So, the demonstration of the manufacturing was made and performed on 3 breadboards which were all successfully checked (geometrical and NDI: US and Xray);

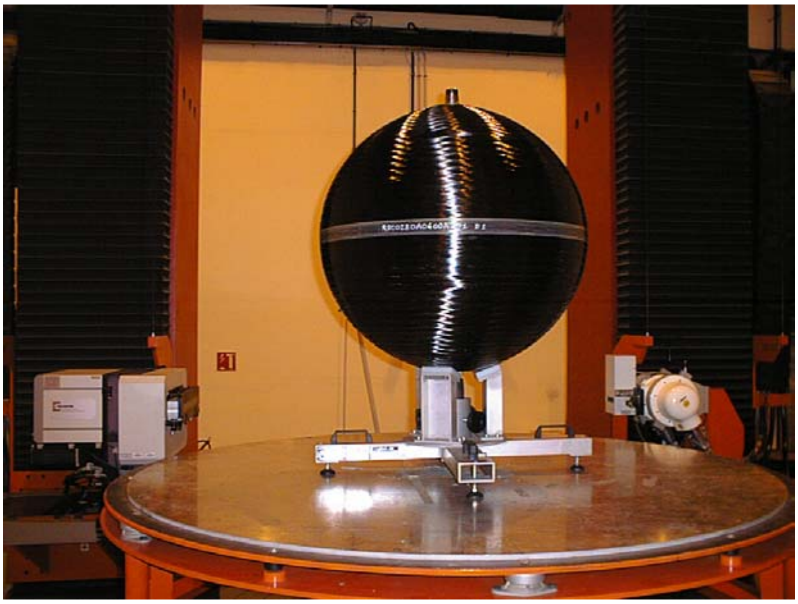

figure 4 : Xray Control of a 300 L thermoplastic lined Tank

4 DEMONSTRATION OF THE THERMOPLASTIC LINED TANK AT FULL SCALE LEVEL

4.1 DESIGN AND JUSTIFICATION

After the demonstration that all the thermoplastic lined tank technologies were made, a design and a justification of the 300 L tank has been performed in order to engage test validations at full scale to check the tightness and the mechanical performance of such new technology way for high pressure tanks.

Main characteristics

- Dry mass of the tank : <93Kg
- Outer diameter : <903mm @ Patm
- MEOP : 40MPa
- Minimum burst pressure : 2xMEOP
- Temperature range : -20°C up to +50°C in operating
- Stabilised External leakage : 5x10-3scc/sec @ GHe MEOP
- 1° eigen frequency: > 100 Hz

Design

- Thermoplastic lined tank overwrapped with T800 carbon composite
- Polar mounting with bearings
- Interface with propulsion system: a single port available (stub tube of 13mm inner diameter)

Safety:

- Designed to be safe life for the metallic bosses

The thermoplastic lined tank was modelled with SAMCEF software. The mesh model and the main results for internal pressure at 80 MPa are presented below.
The results have given comfortable margin to authorize the manufacturing of the tank at full scale.

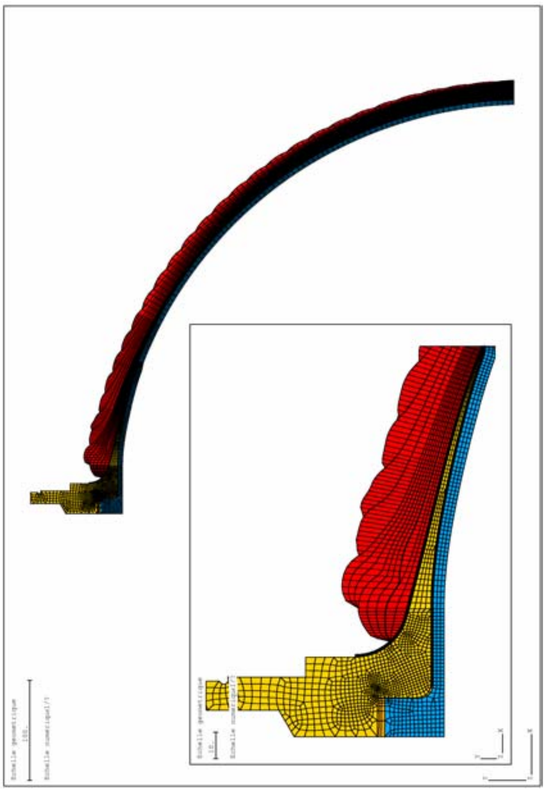

figure 5 – Tank mesh model

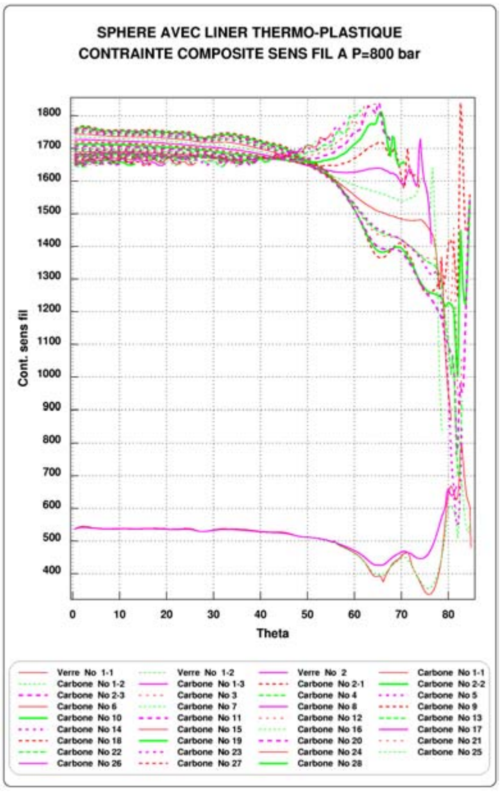

figure 6 – E.F. justification of the tank for internal pressure

4.2 TESTS AT TANK LEVEL

At this stage, it was still necessary to verify at tank level:

- the level of tightness of the full scale tank,
- the mechanical performance of the tank.

These major technical objectives required the following tests to perform:

- a proof test at 60 MPa with water medium,
- a leak test with He gas at MEOP pressure (40 MPa),
- a burst test to demonstrate the capacity of the tank to withstand the pressure loads up to a safety factor (SF) of 2.

All theses tests were performed between June and September 2004 and led to the following results:

- Proof test successfully performed at 60 MPa with acoustic emission survey, strain gauges and displacement sensors. After testing, the tank was checked by NDI (ultrasonic, Xray) and dimensional control. All the controls concluded in the total integrity of the tank.
- Leak test successfully performed at 40 MPa with a result of 5.10^{-03} scc/sec compatible with the A5 needs.
- Burst test performed with water medium at a pressure level of 90.5 MPa for 80 MPa minimum expected, result which completely demonstrate the good level of margin of the thermoplastic lined tank for a safety of 2 taking into account all the environment loads.

The figures here bellow show the tank before and after the burst test.

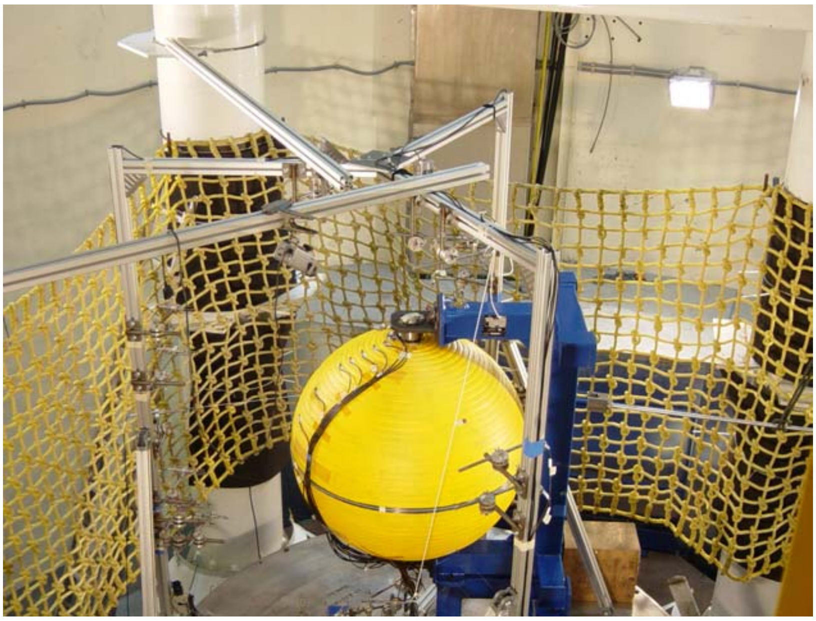

figure 7 : Thermoplastic lined tank before burst test

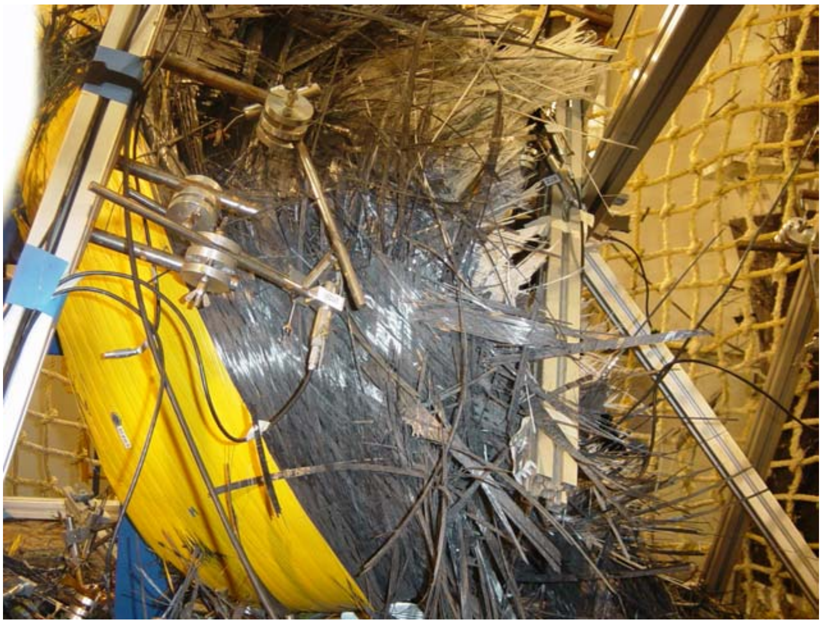

figure 8 : Thermoplastic lined tank after burst

All the results obtained in the frame of the feasibility of a 300 L thermoplastic lined tank fully demonstrate the compliance to the major requirements of A5 launcher and finalise the feasibility phase of this new technology which is now rather mature with the aim of a complete qualification and development phase.

5 COST AND CYCLE REDUCTIONS FOR THE THERMOPLASTIC LINED TANK WAY

The cost of the liner is generally of the order of 40 - 50 % of the cost of the tank for a metallic liner.

So, for the case of a thermoplastic liner at 300 L scale, the cost of the liner due to the thermoplastic way is reduced by more than 70 % at liner level and by 30 % at tank level which is very significant to strengthen the return for investment of such a development.

Furthermore, the cycle reduction to deliver such thermoplastic lined tanks at 300 L scale is very attractive too, because reduced by more than 250 % due to the cycle of the liner manufacturing.

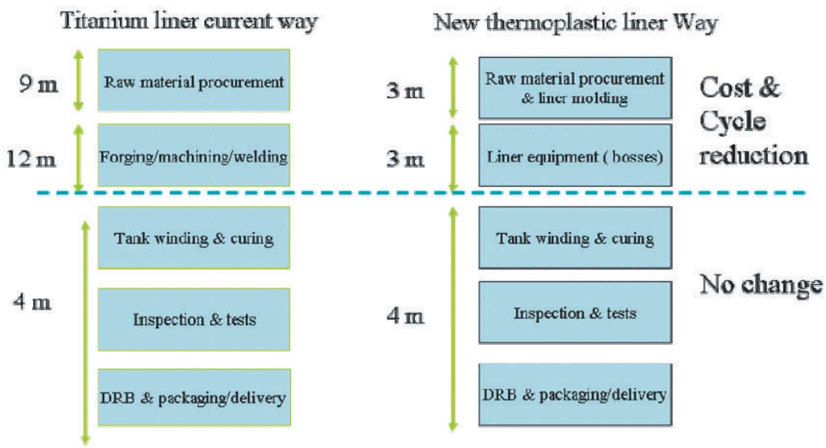

figure 9 : Current titanium lined tank flow chart and future thermoplastic lined tank flow chart

6 CONCLUSION

The latest works concerning the high pressure tanks in progress at EADS ST are focused on both objectives of cost reduction and cycle reduction.

The application of a thermoplastic lined tank for the A5 launcher with the aim of replacing, for recurring cost and cycle reasons, the current tank achieved from an expensive titanium liner is now rather mature for a complete development phase. This thermoplastic liner technology constitutes a real new disruptive technology, alone able to achieve the last challenges in cost and cycle reductions.

Indeed, this technology is really cheaper than the current titanium lined tank (by -70% at liner level leading to -30% at tank level) and also offers a significant cycle reduction (10 months instead of 24 months for the titanium liner version).

All the results obtained in the frame of the feasibility of a 300 L thermoplastic lined tank fully demonstrate the compliance to the major requirements of A5 launcher of this new disruptive technology. The main demonstrations concerned the manufacturing feasibility of the liner, the manufacturing feasibility of the tank (winding and curing), and the last tests such helium tightness and mechanical performance with a burst pressure on a full-scale demonstrator are fully compliant with the A5 requirement (90.5 MPa for 80 MPa minimum expected). All these results give very high confidence in this new strong design to replace the current 300 L helium tank.

This technological breakthrough would be also relevant for satellite transfert GEO phase if the tightness requirement is relaxed.