# DEMISEABLE PROPELLANT TANKS

## Design and Test of Materials and Technologies

*- Final Results –*

ITT AO/1-8301/15/NL/SW

ESA CleanSpace Industrial Days

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# 01

## Scope of Technology

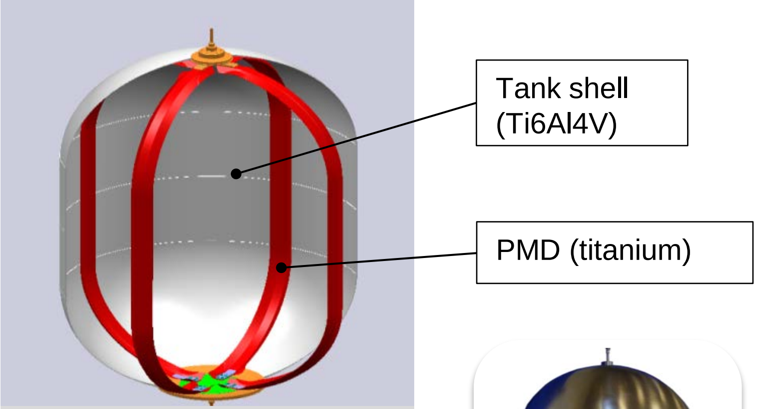
# DEMISEABLE PROPELLANT TANK – Scope of Technology

- **Applicability range**
  - **Priority 1: LEO platform medium size** (100-200L, < Ø600mm)
  - Priority 2: LEO platform small size (37-50L, < Ø420mm)

- **Actual Technology**
  - Titanium tank (melting point ~ 1600°C)
  - Surface Tension PMD or membrane

  ➔ **Non-demiseable**

- **Proposed Demiseable Technology**
  - Material: aluminium alloy (melting point ~ 600°C)
  - Surface Tension (PMD) or membrane (PED)

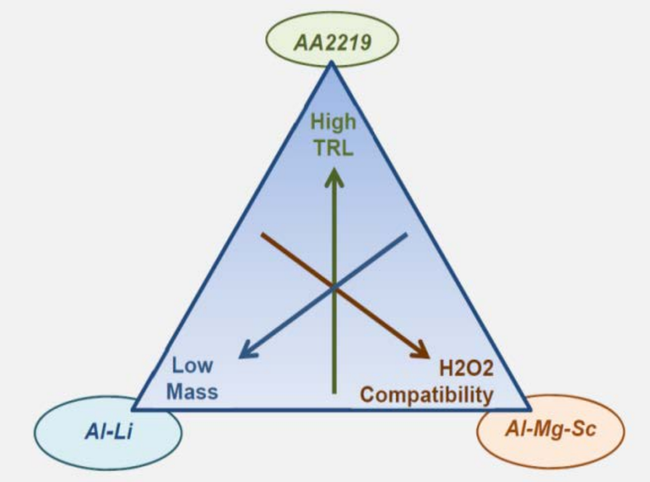



**NOT demiseable**

# DEMISEABLE PROPELLANT TANK – Scope of Technology

**In the study the following areas are investigated in order to support the demiseable tank trade-off:**

- Compatibility of Al-Mg-Sc alloy (5028) with hydrazine
- Wettability of PMD material with hydrazine and candidate aluminium alloys (AA2219, AA2050, AA5028)
- Aluminium pipe transition joint solutions (Ti3Al2.5V for pipeline → AA2219 for tank )
- Demise properties of candidate aluminium alloys (AA2219, AA2060, AA5028)




e.g. AA2050/60 e.g. AA5028

**→The material test performed within the study will focus on the above mentioned areas.**

# 02

# Material Testing

# DEMISEABLE PROPELLANT TANK – Test Plan

## — Hydrazine Compatibility Test (1 month @ 71°C)

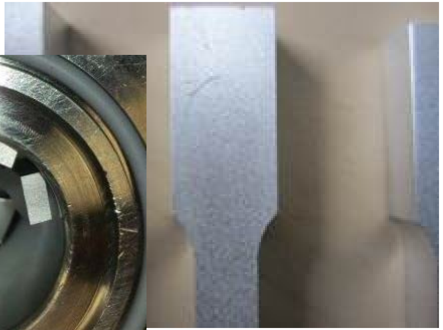
<table>
<tr><th rowspan="2">Material</th><th rowspan="2">Weld technique</th><th rowspan="2">Reference (w/o immersion)</th><th rowspan="2">Immersion in Hydrazine</th><th colspan="2">Test</th></tr>
<tr><th>Compatibility test</th><th>Additional test</th></tr>
<tr><td>AA5028 (Al-Mg-Sc)</td><td>Base material</td><td>(5) tensile sample</td><td>(5) tensile sample</td><td rowspan="3">• Visual insp.<br>• Mass change<br>• Prop. analysis<br>• Catalytic effect</td><td>• Tensile</td></tr>
<tr><td>Joint (1/4”) 6082 / 2219</td><td>Manual TIG</td><td>(7) welded pipe</td><td>(7) welded pipe</td><td rowspan="2">• Leak/proof<br>• Tensile<br>• Microsection</td></tr>
<tr><td>Joint (1/4”) 6082 / Ti6Al4V</td><td>RFW</td><td>(7) welded pipe</td><td>(7) welded pipe</td></tr>
</table>


# DEMISEABLE PROPELLANT TANK – Test Results

## — Hydrazine Compatibility Test (1 month @ 71°C)

Results for AA5028 (Al-Mg-Sc) :

- Visual inspection: no visual change OK
- Catalytic effects: req. < 2.5 bar/month OK
- Mass change: req. < 1.0mg OK
- Tensile strength: req. < 10% reduction OK
- Propellant analysis: within spec. MIL-PRF-26536 OK

Conclusion :

For **AA5028**, **basic compatibility with hydrazine has been shown.**

Verification for long term verification and increase of diagnostics after and during exposure is still needed.

# DEMISEABLE PROPELLANT TANK – Test Results

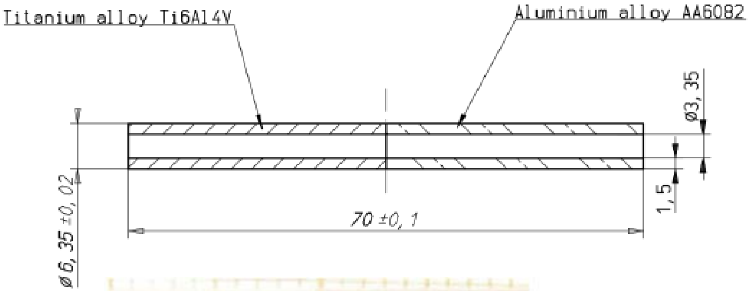
## — Hydrazine Compatibility Test (1 month @ 71°C)

Results for transition joint AA6082/Ti6Al4V (1/4”) :

| | | |
|---|---|---|
| • Visual inspection: | no visual change | OK |
| • Catalytic effects: | req. < 2.7 bar/month | OK |
| • Mass change: | req. < 1.0 mg | OK |
| • Tensile strength: | req. < 10% reduction | OK |
| • Propellant analysis: | within spec. MIL-PRF-26536 | OK |
| • Microsection: | no sign of corrosion | OK |
| • Leak test: | req. <1e-6 scc/s | OK |

Conclusion :

For the transition joint **AA6082/Ti6Al4V** (1/4”) , **basic compatibility with hydrazine has been shown.** All samples provided the required joint performance with and without immersion in hydrazine.



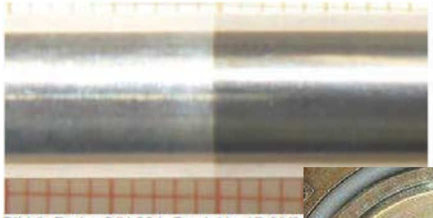



Bild 3: Probe S/N 001, Prod. Nr. 17-09/0

Bild 4: Probe S/N 001, Prod. Nr. 17-09/03-1, nach Zugversuch, Titan rechts, 1.4307 eingeschnürt, Stützdorn verklemmt

# DEMISEABLE PROPELLANT TANK – Test Results

## — Hydrazine Compatibility Test (1 month @ 71°C)

Results for welded joint AA6082/AA2219 (1/4”) :

| | | |
|---|---|---|
| • Visual inspection: | no visual change | OK * |
| • Catalytic effects: | req. < 2.7 bar/month | OK |
| • Mass change: | req. < 1.0 mg | OK |
| • Tensile strength: | req. < 10% reduction | OK |
| • Propellant analysis: | within spec. MIL-PRF-26536 | OK |
| • Microsection: | no sign of corrosion | OK |
| • Leak test: | req. <1e-6 scc/s | N/A** |

*  some discoloration observed
** leak test not possible due to porosity in the welds

Conclusion : For the transition joint **AA6082/AA2219** (1/4”) , **compatibility with hydrazine was partly achieved** due to the fact that the welding process  (at this stage of development) does not yet provide the required weld quality.

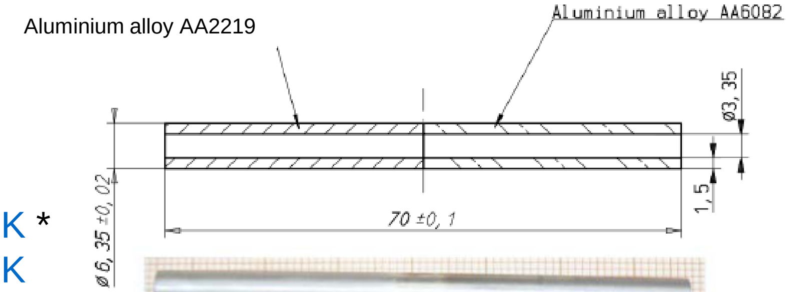




Figure 1: ATJ AA2219-AA6082 S/N 07 as delivered

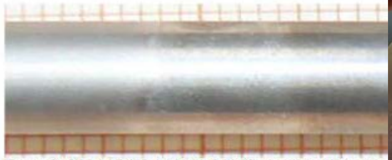


Figure 2: ATJ AA2219-AA6082 S/N 07, detail welding zone

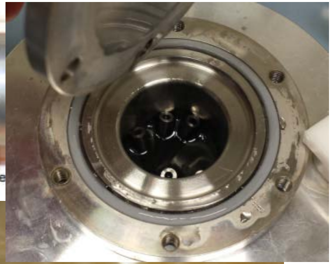
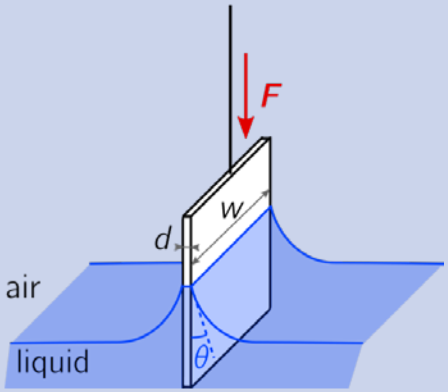



Figure 3: ATJ AA2219-AA6082 S/N 07, after tensile testing, supporting pin jammed in the clamping area

# DEMISEABLE PROPELLANT TANK – Test Plan

## — Hydrazine Wettability Test (1 month @ 71°C)

| Material | Weld technique | Reference (w/o immersion) | Immersion in Hydrazine | Test |
|---|---|---|---|---|
| **AA2219** | Base material | (3) contact angle | (3) contact angle | • Visual inspection<br>• Contact angle measurement (Wilhelmy plate method) |
| **AA2060** | Base material | (3) contact angle | (3) contact angle | |
| **AA5028** | Base material | (3) contact angle | (3) contact angle | |




# DEMISEABLE PROPELLANT TANK – Test Results

## — Hydrazine Wettability Test (after 1 month @ 71°C)

There have been measurements of the contact angle at five temperatures for three types of Aluminium at probes which were immersed in Hydrazine and not immersed reference probes.

The main conclusions concerning the usage of Aluminium are:

- The standard deviation of all measurements is less than 10%. Therefore **reproducibility is proven.**
- Nearly all measured forces at Aluminium are slightly higher than the measured forces at Titanium. This denotes a tendency for smaller contact angles at Aluminium surfaces.
- There is **no significant difference** between immersed and non-immersed probes and different types of Aluminium.

The following assumption is therefore confirmed for wettability of Aluminium in Hydrazine:

Since the wetting conditions are very similar for Aluminum and Titanium when using Hydrazine it can be stated that all functional design aspects used with titanium **PMD can be used as is also with Aluminum.**

# DEMISEABLE PROPELLANT TANK - Test Plan

## — Thermophysical Test

Instead of performing “real” demiseability testing in plasma wind tunnel, it is proposed to analyse precisely thermos-physic properties of the aluminium alloy selected during the first phase of the project.

| Material | Weld technique | Test |
|---|---|---|
| **2219** | Base material | • Density<br>• Specific heat Cp<br>• T(melting)<br>• Heat of Melting |
| **2050** | Base material | |
| **5028** | Base material | |

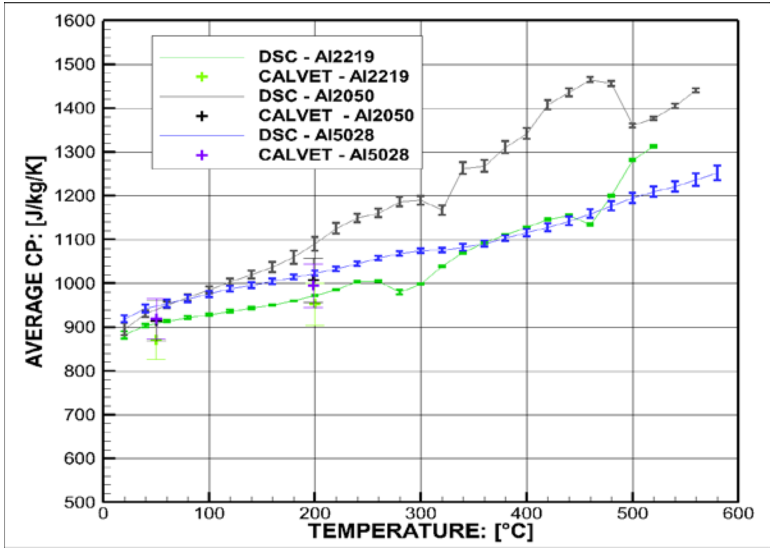
# DEMISEABLE PROPELLANT TANK – Test Results

- **Thermophysical Test**

Results synthesis:

The ranking of the aluminium alloys based on the total specific energy criteria brings **AA2219 as the most suitable material for a demiseability point of view** (for the same initial tank mass). On contrary, aluminium AA2050 presents the highest values for the total specific energy criteria. This represents an increase of less than 7 % of the criteria compared to the alloys AA2219.

However, DRAMA analysis show that these variations are marginal for tank demiseability (within 1% in terms of demise altitude) – *see next slide*



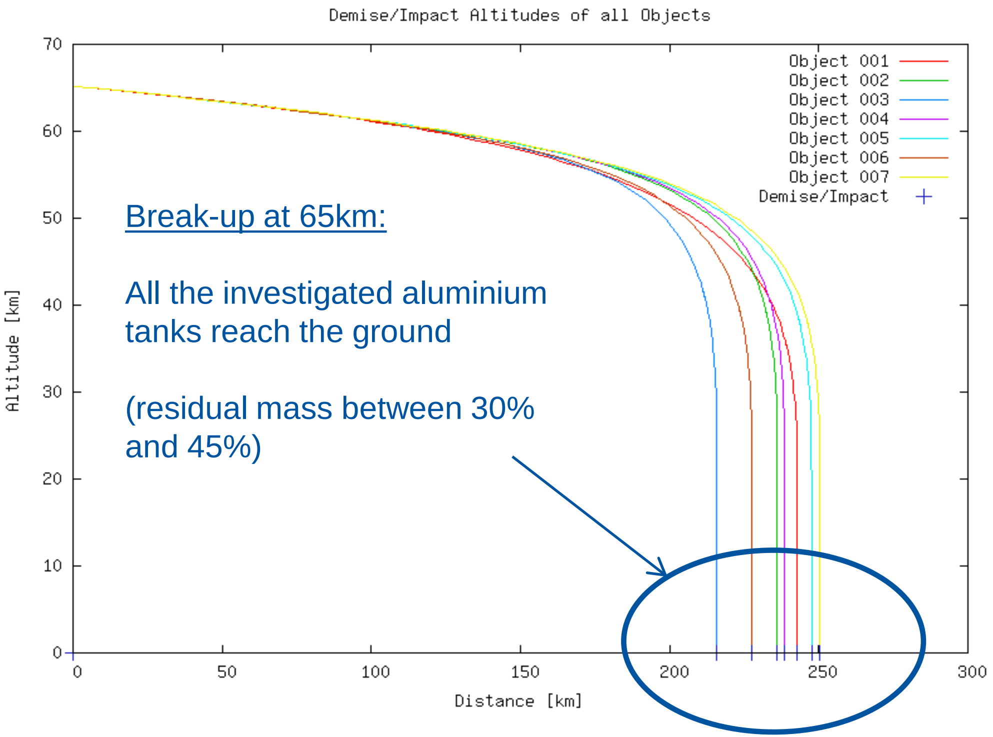

| DEMISE ENERGY | $\int_{T0}^{Tm} cp.dT + \Delta H_m$ (kJ/kg) |
|---|---|
| Material | |
| AA2219 | 949 (ref.) |
| AA5028 | 972 (+2.4%) |
| AA2050 | 1014 (+6.8%) |

# **DEMISEABLE PROPELLANT TANK –** Demise Analysis

## DRAMA Analyses

Results:

- The analysis performed with DRAMA indicates that the **aluminium tanks always demise for a break-up altitude of 78km, however none of the alloys is found to demise for break-up altitude of 65 km.**
- The choice of aluminium alloys, the tank size (within 100L - 200L) and the safety factors used for dimensioning have little influence on the results. **Variations on material properties (melting point, Cp, heat of fusion, emissivity) and the different tank masses have a negligible impact on demiseability** when compared to the break-up altitude.
- Titanium tanks do not demise at all



# 03

# Summary & Conclusion

# DEMISEABLE PROPELLANT TANK – Final Trade-off

| Weight | Demiseable Tank - Master Trade-off | Tank 1a | Tank 1b | Tank 2a | Tank 2b | Tank 3a | Tank 3b |
|---|---|---|---|---|---|---|---|
| | **Material** | **2219** | **2219** | **5028** | **5028** | **2060** | **2060** |
| | Condition | T8 | T8 | H116 | H116 | T8 | T8 |
| | Weld process | TIG | TIG | *tbd* | *tbd* | *tbd* | *tbd* |
| | Forming process | forging | forging | *tbd* | *tbd* | *tbd* | *tbd* |
| | Propellant Delivery System | PED | PMD | PED | PMD | PED | PMD |
| | Mounting | equator | equator | equator | equator | equator | equator |
| | Pipe I/F transition | bolted joint (*) | bolted joint (*) | bimetal | bimetal | bimetal | bimetal |
| **Weight** | **Criteria** | *Evaluation* | *(Max: 5 / Min: 1)* | | | | |
| *10* | Demiseability | 5 | 4 | 5 | 4 | 5 | 4 |
| *10* | Metal propellant compatibility - hydrazine | 4 | 4 | 3 | 3 | 3 | 3 |
| *6* | Metal propellant compatibility - green ADN | 2 | 2 | 2 | 2 | 2 | 2 |
| *4* | Metal propellant compatibility - green H2O2 | 1 | 1 | 3 | 1 | 1 | 1 |
| *10* | PMD wettability / PED compatibility - hydrazine | 5 | 5 | 5 | 5 | 5 | 5 |
| *6* | PMD wettability / PED compatibility - green ADN | 2 | 3 | 2 | 3 | 2 | 3 |
| *4* | PMD wettability / PED compatibility - green H2O2 | 2 | 1 | 2 | 1 | 2 | 1 |
| *5* | Dry Mass | 3 | 3 | 3 | 3 | 5 | 5 |
| *5* | Development cost | 4 | 4 | 2 | 2 | 2 | 2 |
| *5* | Development time | 4 | 4 | 2 | 2 | 2 | 2 |
| *5* | Development risks | 4 | 4 | 2 | 2 | 2 | 2 |
| *10* | Recurring cost | 4 | 4 | 3 | 3 | 3 | 3 |
| *5* | Material procurement (lead time, etc.) | 4 | 4 | 4 | 4 | 3 | 3 |
| | **Score** | **311** | **303** | **269** | **253** | **266** | **258** |

# DEMISEABLE PROPELLANT TANK – Main Outcomes

- The replacement of Titanium with an Aluminium alloy is confirmed to be the most promising approach given the major impact in terms of tank demiseability.
- The **break-up altitude was found to be the major parameter** to drive demiseability, much more than the choice of the aluminium alloy.
- In order to minimize development risks and cost, the recommended approach is to use the **conventional 2219 alloy technologies**, available from launchers, and to extend it to LEO platform application. It is expected that the mass penalty (4kg heavier than titanium) is acceptable when compared to the necessity of a controlled re-entry.
- A **membrane tank (PED)  is the preferred solution** rather that surface tension tank (PMD) due to the fact that its impact on tank demiseability can be neglected (low point of fusion of polymeric diaphragm) and the tank can be better represented within the demise analysis tools
- Innovative tank technologies, involving Al-Li or Al-Mg-Sc aluminium alloys, may be developed and introduced later on to optimize the performance.

# DEMISEABLE PROPELLANT TANK – Further Work

- Demiseability :
  - Further tests are necessary in order to better characterize some specific aspects of the Aluminium alloys selected.
  - Representativeness of the simulation taking into account re-entry phenomenon (tumbling, heat repartition, material behaviour evolution) has to be shown during next maturation phase

- Material compatibility:
  - Stress corrosion cracking performances still have to be verified by a dedicated SCC test campaign.
  - The compatibility with green propellants such as ADN based is still to be demonstrated as data are not available today.

- Transition joints:
  - The need of replacing Titanium with Aluminium for the manufacture of propellant tanks introduces the problem of producing a joint between the tank and the chemical propulsion system pipework which generally is made of Titanium 3Al2.5V
  - There is an existing joint Ti6Al4V/AA6082 developed under ESA contract. The study showed that the welding of AA6082 to AA2219 (material assumed for the tank) is feasible. However, several issues have been met with this weld (e.g. weld porosity), which can only be solved in the frame of qualification program, when the design of the weld is frozen. In general it is recognized that a design involving multiple transition welds in series will decrease the reliability of the connection; therefore the development of a specific A2219/Ti6Al4V (or A2219/Ti3Al2.5V) transition joint is recommended. Otherwise a bolted solution should be adopted.

# DEMISEABLE PROPELLANT TANK

*Thank you for your attention!*