P05

衛星用複合材推薬タンクの再突入安全性の評価状況

Evaluation Status of Re-entry Survivability of Spacecraft Composite Propellant Tank

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ミッション終了後の低軌道周回衛星が自然落下して大気圏に再突入する際、チタン合金製の推進薬タンクは溶融せずに地上まで到達するため、安全上のリスクとなっている。地上の安全性向上のためには推進薬タンクが溶融するのが望ましく、JAXA では溶融させることを目指してアルミ合金製ライナの複合材推薬タンクの研究・開発を 2010 年より実施してきた。当時、複合材の樹脂が再突入時の加熱で熱分解し、気流の効果で炭素繊維が飛散して露出したライナが溶融すると想定していたものである。
2016 年に JAXA のデブリ対策活動を再編してデブリ低減（非デブリ化）に関する研究を立ち上げた際、この複合材推進薬タンクの溶融性について追加評価が必要と判断して検討を行ってきた。今回、試作タンクから採取した実態テストピースのアーク加熱試験結果を中心に、現在までの検討状況を報告する。

A propellant tank for spacecraft is usually made of titanium alloy, it would not demise during atmospheric re-entry of the LEO spacecraft and cause a risk to the ground. So, it is desirable that a propellant tank would demise.
Since 2010, JAXA conducted research to develop an aluminum-lined, carbon composite overwrapped tank for reducing impact risk to the ground. In the early phase, it expected that the resin of CFRP would decomposed by aerodynamic heat and residual carbon fibers were blown away by the effect of airflow.
However, JAXA started reevaluation of the survivability of this composite propellant tank when debris mitigation study in JAXA was reorganized at 2016.
This year, we conducted arc wind tunnel tests of material samples which were cut off from the EM tank. We report test results and current reevaluation status.

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Introduction

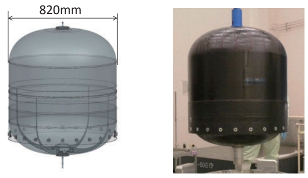
A propellant tank for spacecraft is usually made of titanium alloy, it would not demise during atmospheric re-entry of the LEO spacecraft and cause a risk to the ground. So, it is desirable that a propellant tank would demise.

Since 2010, JAXA conducted research to develop an aluminum-lined, carbon composite overwrapped tank for reducing impact risk to the ground. In the early phase, it expected that the resin of CFRP would decomposed by aerodynamic heat and residual carbon fibers were blown away by the effect of airflow [1].

However, according to the misgiving inside and out, JAXA started reevaluation of the survivability of this composite propellant tank when debris mitigation study in JAXA was reorganized at 2016[2]. We report the recent test results and current reevaluation status.

Configuration of Tank

The current configuration of the composite propellant tank is shown below.



Tank configuration

Tank specifications

Parameters	Requirements
MEOP	2.76MPa
Proof Pressure	3.45MPa
Burst Pressure	≥4.14MPa
Temperature Range	5～60°C
Tolal Volume	0.43m^3
Propellant	Hydrazine
Expulsion Efficiency	≥99.5%
Mass	≤23.3kg

Preliminary Analysis

The purpose of preliminary analysis is to examine a possibility that the aluminum alloy liner covered by CFRP char layer may reach melting point. But, in this analysis, the several effects caused by CFRP's ablation process are not included.

(1) Tool: ORSAT-J

- Developed by JAXA based on NASA's ORSAT (Object Reentry Survival Analysis Tool) version 5.0. Basic shape objects can be analyzed.
- CFRP is treated as a metal-like material with imaginary melting temperature and heat of melting.

(2) Initial Condition

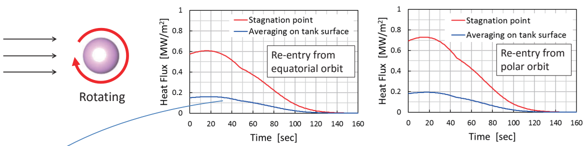
Common Parameters

Re-entry Interface Altitude [km]	122
Break up Altitude [km]	78
Mass of Satellite [kg]	1000
Size of Main Structure [m]	2.1×2.1×5.0
Mass of Tank [kg] (nominal value, skirt is excluded)	16.4
Outer Radius of Tank [m] (approximation as sphere)	0.88

Initial condition

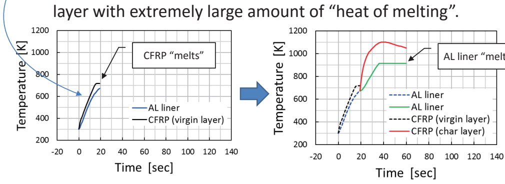
Re-entry from	Equatorial Orbit	Polar Orbit
Altitude [km]	78	78
Inclination [deg]	0	95
Longitude [deg]	73	350
Latitude [deg]	0	-22
Velocity [km/s]	6.84	7.27
Flight Path Angle [deg]	-1.24	-1.33
Temperature [K]	300	300

(3) Heat Flux for tank after breakup of satellite



(4) Tank Temperature by ORSAT-J with tumbling condition

- After ORSAT-J judges CFRP reaches to "melting point", calculation is continued by changing material properties of CFRP from virgin layer to char layer with extremely large amount of "heat of melting".



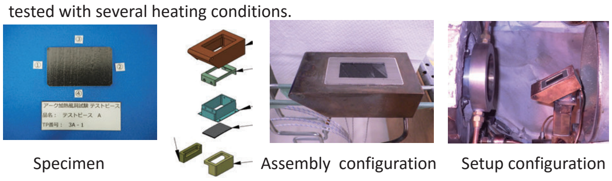
For thermal analysis in ORSAT-J, thickness of tank is nearly equivalent to the specimen from dome. The thickness of CFRP layer of specimen from dome is twice that of dome shoulder.

Arc Wind Tunnel Test

To examine the effect of ablation, heating tests were conducted at the 750kW arc wind tunnel facility in the JAXA Chofu Space Center.

(1) Specimen

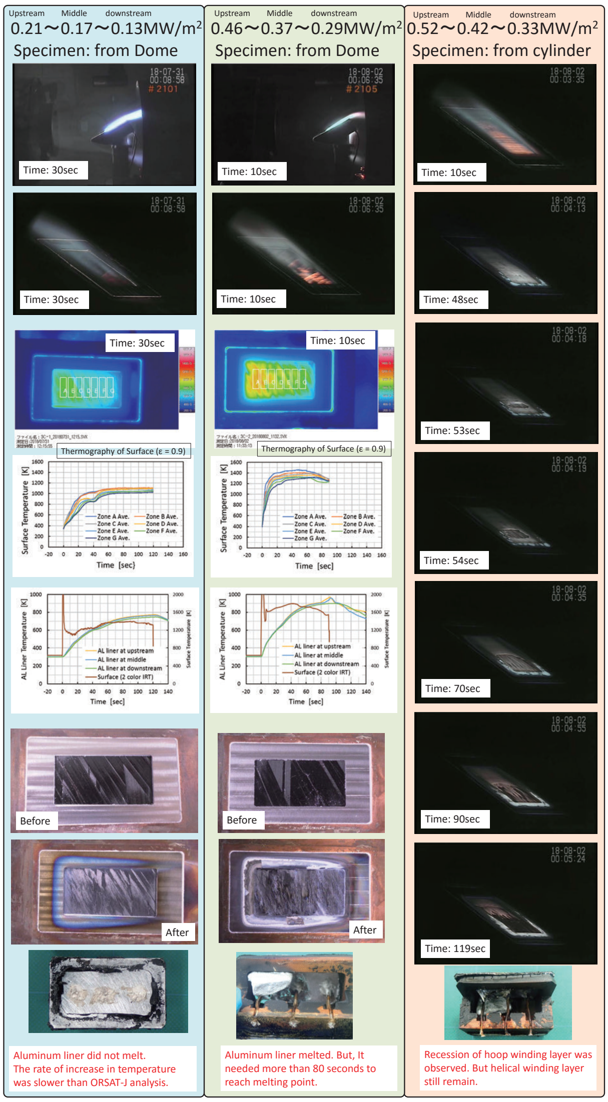
The specimens were taken from a developing model of the composite propellant tank. At the test configuration, a titanium cover protected the open edges of a specimen to prevent detachment of CFRP by delamination. 18 specimens were tested with several heating conditions.



Specimen Assembly configuration Setup configuration

Arc Wind Tunnel Test (Cont.)

(2) Test Results (Example)



Aluminum liner did not melt. The rate of increase in temperature was slower than ORSAT-J analysis.

Aluminum liner melted. But, It needed more than 80 seconds to reach melting point.

Recession of hoop winding layer was observed. But helical winding layer still remain.

Current Evaluation Status

- To improve survivability analysis method, the thermal properties and the ablation effect of CFRP should be adapted appropriately.
- After detail analysis of the test results, we would try to introduce the effect of ablation. Then, survivability analysis about the real shape composite propellant tank would be done by using additional tool.

Reference

1. T. Masuoka et al., "Demise characteristics evaluation for Melting-Promotion Type Tank" AIAA Paper 2013-3984
2. T. Lips et al., " About the demisability of propellant tanks during atmospheric re-entry from LEO" Eighth IAASS Conference, Melbourn, Florida, USA, May 18-20, 2016