THE INNOVATIVE DEORBITING AEROBRAKE SYSTEM "IDEAS": THE GOSSAMER TECHNOLOGY FOR MICRO-SATELLITE DEORBITING

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OVERVIEW

The interest of using gossamer technologies for the MICROSCOPE satellite aerobraking system was demonstrated by a feasibility study performed by Astrium Space Transportation during 2005. Taking into account the developments performed at Astrium Space Transportation and the trade-off with other solutions performed by CNES, gossamer technology finally appears as being the best solution for deorbiting the satellite by passive aerobrake.

The trade-off between several inflatable technologies led to the selection of kapton/aluminium/kapton laminates, mainly because of the specific requirements of the mission (low available electrical power, long passive-life duration before deployment, no attitude control during deployment = non defined thermal conditions).

The phase B of the development of this aerobraking system called IDEAS (Innovative DEorbiting Aerobrake System) is ongoing. The satellite average braking area need leads to propose a two identical wings concept. Each sail is constituted with one central boom and two lateral membranes in two orthogonal planes. The Kapton/aluminium/Kapton laminate boom is folded with a tetragonal accordion pattern associated with a deployment control system adapted from other inflatable boom technologies. The folded boom height is 120mm for a deployed height of 4.6 metres. The membranes are folded with a chevron pattern associated with a specific deployment control system. The folded membrane height is 35mm for a deployed height of 4.5 metres

The boom is sized (thickness and diameter) with analytical methods to withstand membrane tension loads and kinetic loads due to the platform spin. During phase B, several development tests on breadboards are dedicated to verify the compatibility of the laminate and its folding pattern with the deployment control system, to characterise boom effective stiffness after rigidization, to validate the boom and membrane deployment (separately and together) conditions and to define the boom guidance system characteristics. Some of these tests are performed under zero G conditions during an Airbus zero G flight test campaign. Design activities on stacking system, inflation system, global architecture and layout are also in progress.

1. PRESENTATION OF THE PROJECT CONTEXT

From the birth of space adventure until now, a huge number of objects have been put in orbit. Today, space environment is more and more crowded. The assessed number of objects sizing more than 1 cm is 300000. About 9600 objects are referenced, with only 500 useful. 22% of satellites are non operating satellites.

For these reasons, space debris is becoming a real concern. The Inter Agency Space Debris Co-ordination (IDAC), composed of 11 space agencies, has defined a code of conduct to limit the space debris. In 2004, CNES decided to apply this code of conduct. As a consequence, the in-orbit life time (after operative life) of every satellite must be limited to 25 years.

In the frame of this code of conduct, Microscope satellite, whose scientific mission is the assessment of equivalence principle, is asked to reduce its natural deorbiting duration of about 67 years to a duration of 25 years. This satellite being equipped with electrical propulsion, the propulsion system is not powerful enough to ensure deorbiting: a specific system is therefore necessary.

Different solutions have been envisaged: solid or chemical propulsion, electrical propulsion or aerobraking.

The solution of slow deorbiting using passive aerobraking has been retained as baseline, because of it is the easiest to accommodate, because it offers the simplest electrical interface with the satellite, because it could be operated even on an underperforming spacecraft (as long as telemetry can be received), and because it does not need any specific satellite control. To ensure the deorbiting duration of 25 years, the apparent surface of the satellite shall be increased by 3 m^2 after operational life.

The Gossamer technology has been identified as the best solution to fulfil this functional requirement and to limit cost and performance impacts for the satellite (see § 3).

The IDEAS project is at the same time the development of an in-flight demonstrator of the Gossamer technology associated to passive aerobraking, and the development of a product for Microscope satellite.

2. GENERAL PRESENTATION OF GOSSAMER STRUCTURES CONCEPT

The Gossamer structures developed at Astrium are deployable and rigidizable in space.

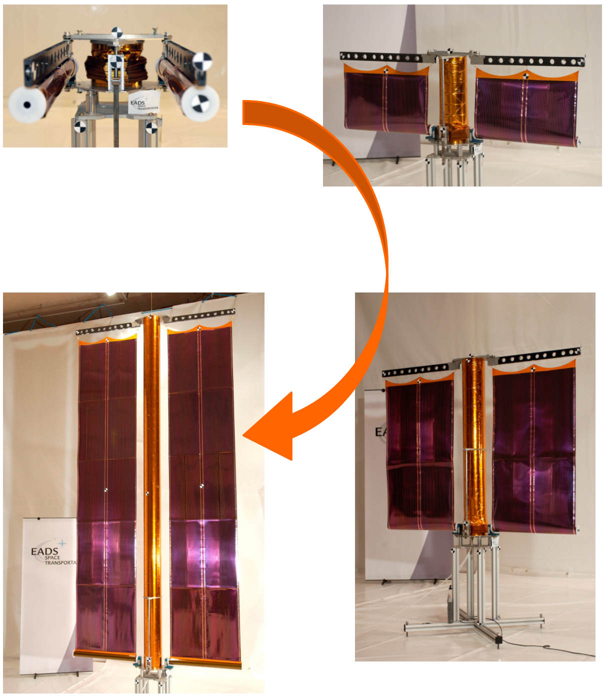

FIG.1 : Gossamer structure deployment concept

The major advantages of these structures are:

- The occupied volume during storage
- The mass
- The cost

To develop these structures, the following domains shall be mastered: folding, deployment control and rigidization.

Folding efficiency is necessary to maximise the ratio deployed volume over volume in folded configuration. Several folding techniques are possible, depending on the material stiffness and thickness and on the volume available in stowed configuration. Deployment control is necessary to ensure quality and repetitiveness of deployment. Rigidization is necessary to ensure correct mechanical behaviour of the structure deployed. Several rigidization techniques are possible: physical rigidization (solvent evaporation, Sub-Tg), chemical rigidization (thermal curing, photocuring) and mechanical rigidization (metallic laminate yielding,).

The Gossamer structures developed at Astrium are mainly composed of flexible membranes - ensuring the function itself of the product - and a flexible tube – ensuring the deployment function and the rigidization function. Deployment of the membrane is performed by inflating the tube. The tube is maintained inflated at the end of the deployment until rigidization of the tube is reached.

3. SELECTION PROCESS OF THE GOSSAMER TECHNOLOGY FOR IDEAS PROJECT

Different solutions to increase the apparent surface of the satellite after operational life have been identified and compared.

3.1. Deployed geometry selection

Several geometries of aerobraking surfaces have been compared in terms of added surface efficiency and feasibility:

- Spheres

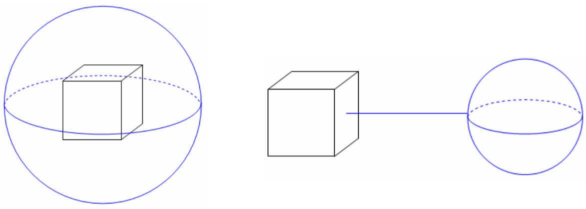

FIG.2 : Sphere geometries examples

- planar surfaces

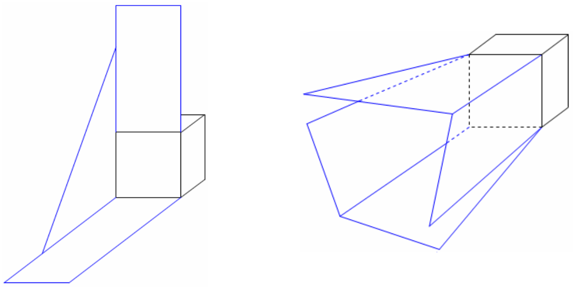

FIG.3 : planar surfaces geometries examples

- conical shapes

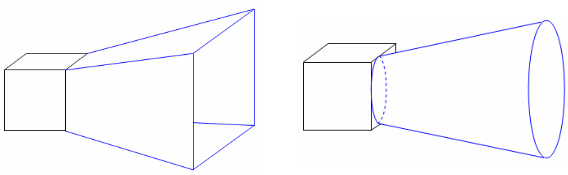

FIG.4 : conical geometries examples

The most efficient is the concept using planar surfaces, with a dihedral shape.

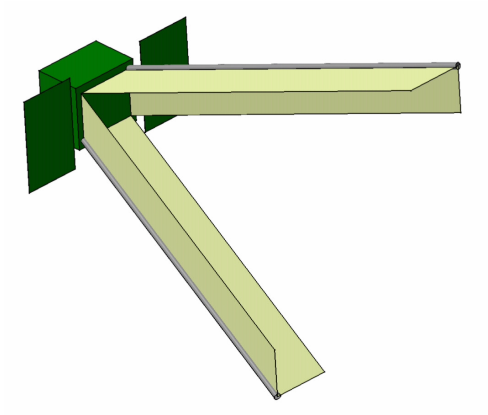

FIG.5 : Dihedral shape concept

3.2. Technological solution selection

The implementation of such a surface can be done using several technologies, which can be grouped in two families:

1. Solution using articulated panels
2. Solutions using flexible thin films stretched with a deployable structure

CNES has performed a selection of the best technological solution among the following ones:

- Classical rigid articulated panels (family 1, solar panels technology)
- Light articulated panels (family 1)
- Stretched membranes with a telescopic boom as deployable structure (family 2)
- Stretched membranes with an inflatable boom as deployable structure (family 2)
- Stretched membranes with a collapsible boom as deployable structure (family 2)
- Stretched membrane with collapsible ribs as deployable structure

Considering the feasibility with respect to surface requirement, the mass budget, folded volume, TRL, power need, development cost, recurring cost and the opportunity for other applications criteria, the retained solution is the stretched membranes with an inflatable boom as deployable structure.

3.3. Rigidization technique selection

The inflated boom of the selected technological solution has to be rigidized after deployment to ensure a correct mechanical behaviour of the deployed surface without maintaining pressure.

Several solutions have been analysed:

- solvent evaporation
- Sub-Tg
- thermal polymerisation
- photochemical polymerisation
- metallic laminate yielding

The criteria considered are power need, long in-orbit storage consequences (premature rigidization risk) and feasibility complexity.

The retained solution is the metallic laminate yielding.

3.4. Conclusion

After the various selection performed, the concept retained for the passive aerobraking system of Microscope – IDEAS – is two dihedral surfaces. The surfaces are realised by stretched membranes, deployed with an inflatable boom and maintained in deployed configuration by “metallic laminate yielding” rigidization process.

This system is presented more in detail in the following chapters.

4. PRESENTATION OF THE LAMINATE TECHNOLOGY

The principle of folding, deployment and rigidization of the IDEAS boom is described in the following illustration.

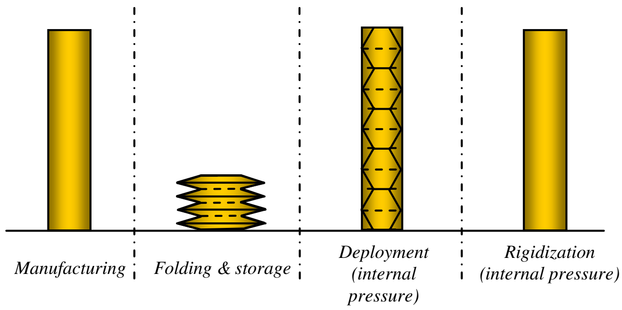

FIG.6 : Boom folding, deployment and rigidization concept

The rigidization process chosen, “metallic laminate yielding”, consists in applying to the boom material a sufficient deformation - applied by internal pressure - to suppress geometrical defect created by yielding of the material during folding. Once the defects are suppressed, the mechanical behaviour of the boom is ensured by its own stiffness.

The boom material used to ensure this function is kapton/aluminum/kapton laminate.

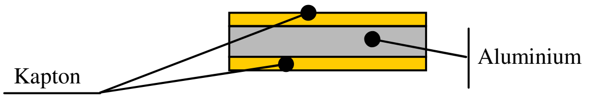

FIG.7 : Laminate definition

The aluminium layer ensures the mechanical behaviour after rigidization. The kapton internal layer ensures the protection of the aluminium layer from internal mechanical “aggressions” and the tightness during boom inflation. The kapton external layer ensures the protection of the aluminium layer from external mechanical “aggressions” and has a thermal protection function.

The main advantages of this solution are the good material stability during storage phases and the use of the same source of energy as for the deployment (no electrical power is necessary to rigidize).

5. IDEAS MISSION & REQUIREMENTS

The IDEAS lifecycle profile is the following:

phase	configuration
Manufacturing, acceptance	
On-ground storage (up to 2 years)	folded
Integration on the satellite	folded
On-ground storage on the satellite (up to 2 years)	folded
Launch and insertion	folded
In-orbit storage (3 years)	folded
Deployment, rigidization, venting	folded -> deployed
Passive aerobraking (up to 20 years)	deployed

TAB. 1 : IDEAS lifecycle profile

The IDEAS system main requirements are:

- To increase the medium apparent surface of Microscope by 3 m^2
- To be operational in deployed configuration in less than 24 hours after beginning of deployment phase
- To be activated with only 4 electrical orders coming from Microscope
- To be functional in deployed configuration between 790 km and 580 km and during 20 years without generating debris
- To weight less than 12 kg
- Respect an allowable volume in folded configuration of 700 x 630 x 155 mm^3
- To be maintained in folded configuration with frequencies higher than 150 Hz
- To support an in-orbit storage of 3 years
- To avoid to generate micropertubation of the satellite measurement

The main environment constraints are:

- mechanical environment (mainly launcher phase)
- thermal environment (storage and passive aerobraking phase)
- in-orbit environment (vacuum, atox, radiations)

6. IDEAS GENERAL ARCHITECTURE

The IDEAS system is composed of several sub-systems, each of them ensuring one or several specific functions.

The hold down sub-system function is to maintain IDEAS in folded configuration and to ensure the unlocking before deployment.

The inflation sub-system function is to ensure the boom deployment and rigidization. It is also ensuring the venting of the boom in folded configuration during launcher phase, and in deployed configuration after rigidization.

The MLI (Multi Layer Insulation) sub-system function is to ensure the thermal protection of IDEAS system from the external environment.

The wings function is to ensure the deployment of the aerobraking surface for IDEAS operating life. The two wings have the same definition and are composed of 1 boom and two membranes. The boom is ensuring the deployment and the rigidization to maintain the wing in deployed configuration (with inflation sub-system), and the two membranes are ensuring the aerobraking function.

The following table synthesize, for each sub-systems, the phases during which they are functional.

		sub-system			
		Hold-down	Inflation	MLI	Wing
phase / event	launch	X	X		
	in-orbit storage	X		X	
	deployment initiation	X			
	deployment		X		X
	rigidization		X		X
	venting		X		
	passive aerobraking				X

TAB. 2 : Phases – Sub-systems functions diagram

The layout of the system IDEAS is presented hereafter:

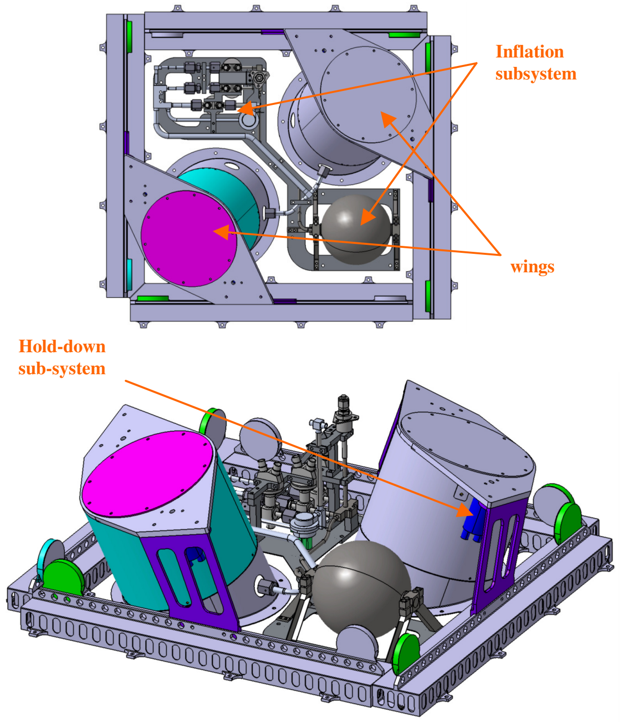

FIG.8 : IDEAS layout in folded configuration

7. IDEAS WING CONCEPT & TECHNOLOGICAL CHALLENGES

7.1. Wing characteristics & concept

The IDEAS wing is composed of one flexible inflatable boom, two flexible membranes and structural rigid parts ensuring interfaces between flexible parts, and with hold-down sub-system in folded configuration.

In deployed configuration, the wing has an angle of 21° with respect to the vertical direction. The angle between the two membranes is 90° in the horizontal plane. The length of the wing is about 4,5 meters and the membrane width is about 0,5 meter.

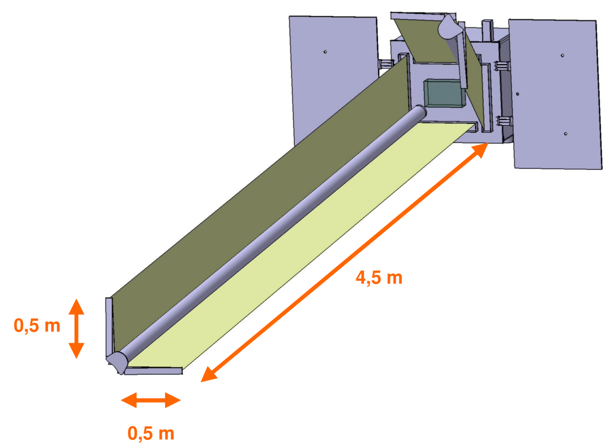

FIG.9 : deployed wing dimensions

The boom is ended by aluminium ends. The bottom one is linked to satellite interface. Each membrane is linked to upper part of the boom via an upper arm, and linked to the satellite interface via a container (ensuring also a protection of the folded membrane). A aluminium cylinder located around the boom is ensuring the link between upper part (deployable) and lower parts (fixed) in folded configuration, via the hold-down sub-system.

7.2. Folding techniques

The first technological challenge is the folding of flexible parts, that is to say the boom and the membranes.

The boom is folded with a tetragonal pattern allowing reaching a folding ratio (folded height over deployed height ratio) of less than 3% with a reasonable folded volume (25% higher than boom diameter).

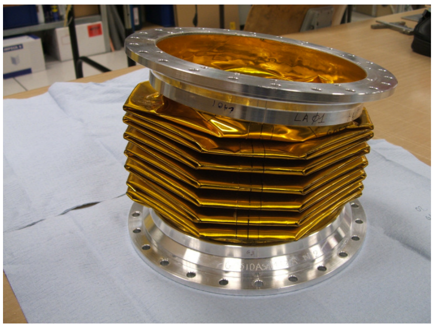

FIG.10 : 1 meter boom folded with tetragonal pattern

Due to the angle between the deployment direction and the vertical direction, the membrane has not a rectangular shape but a parallelogram. The folding pattern retained - called 2nd order chevron - allows the folding of this shape in a parallelepipedic volume whose rectangular section is 500 x 70 mm^2 and height 30 mm. The folding ratio of the membrane is therefore less than 1%.

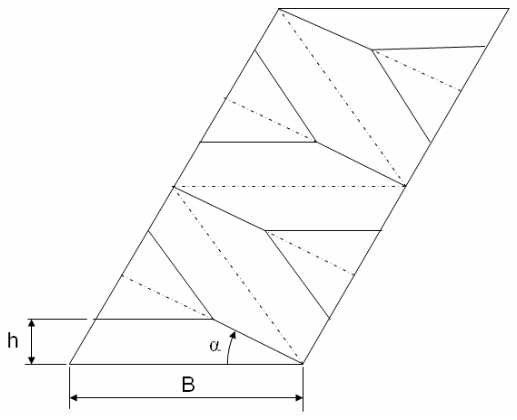

FIG.11 : membrane folding pattern

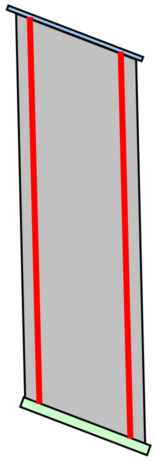

FIG.13 : membrane DCS concept

7.3. Deployment control

As said before, deployment control is necessary to ensure quality and repetitiveness of deployment.

For the boom, the deployment control system (DCS) consists of a petal ensuring the stacking of the folds not deployed yet and the correct transition from folded state to deployed state. This system is completed with a guide whose function is to limit boom movements around its deployment direction.

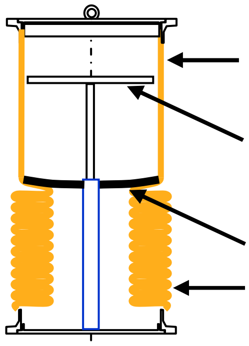

FIG.12 : boom DCS concept

For the membrane, the deployment control system consists of two thin guiding cables slightly tight limiting the movements of the membrane out of its deployment plane.

These systems are validated in phase B by test on different breadboards, at ambient temperature. The deployment speed used for the tests is 3 meters per minute.

Boom DCS is selected and defined with the support of deployment tests on 1 meter laminate boom in laboratory conditions (1g) and validated on 1 meter laminate boom in zero gravity conditions (on Airbus zero G).

Membrane DCS is validated on 2 membranes (one of 1 meter to simulate end of deployment and one of 4,5 meter to simulate beginning of deployment) deployed with a laminate tool boom. Membrane deployment tests are performed in laboratory conditions (1g) and in zero gravity conditions (on Airbus zero G).

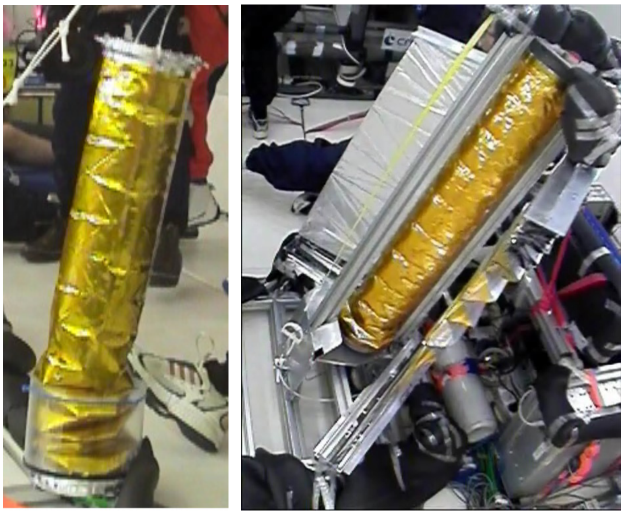

FIG.14 : 1 meter boom & 2 membranes breadboards

The functioning at wing level is validated on the deployment test of a 3 meter wing, with mass compensation device.

FIG.15 : 3 meters wing breadboard

7.4. Rigidization

The efficiency of rigidization technology retained for IDEAS shall be mastered to find the optimum pressure regarding the mechanical behaviour (compression and bending) of the boom deployed.

Tests and analyses have been performed in the previous phase to identify the effect of rigidization pressure on the mechanical behaviour. On the basis of this work, the rigidization pressure range is defined as [0,8 bar ; 1 bar].

During phase B, tests on 1 meter laminate boom breadboards are performed. The objective is to characterise the mechanical behaviour - in compression and bending directions - of rigidized boom at 0,8 and 1 bar, in ambient temperature conditions. The data will be used to establish mechanical margins on IDEAS wing.

7.5. Inflation sub-system

During phase B, a preliminary design of the inflation sub-system is performed after identification of the requirements and selection of an industrial responsible for the inflation sub-system development. The concept proposed by Air Liquide is retained. The inflation sub-system is inflating the two wings at the same time.

Its main performances are:

- Maximum wing deployment speed = 3 m/min
- Maximum duration for deployment of 2 wings = 25 min
- Maximum duration for deployment + rigidization of 2 wings = 50 min
- Minimum rigidization pressure = 0,8 bar
- Maximum rigidization pressure = 1 bar

8. CONCLUSION

The use of Gossamer technology for IDEAS has been identified as the more suitable solution.

The development is ongoing. General architecture and sub-system concepts are defined. Technological solution for deployment and rigidization are chosen and validations are well advanced. The foreseen short term activities are mainly dedicated to the validation of deployment and rigidization in cold conditions, the protection against orbital environment and the design & justification of the hold-down sub-system.

The end of IDEAS development is foreseen beginning of 2010, with the delivery of the flight model for Microscope.

IDEAS project is, more than the development of a product dedicated to Microscope, the development of a concept and its associated technology that can have other potential applications.

9. REFERENCES

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