National Doctoral Programme in
Space Science and Technology : 2024 PhD Days

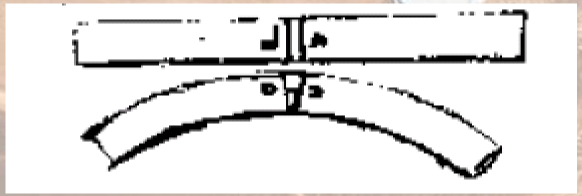
PhD SST
Space Science
and Technology

Gossamer technologies for human and robotic space exploration

Erasmo Carrera
Politecnico di Torino, Torino, Italy

7 June 2024

Gran Sasso Science Institute, L'Aquila, Italy

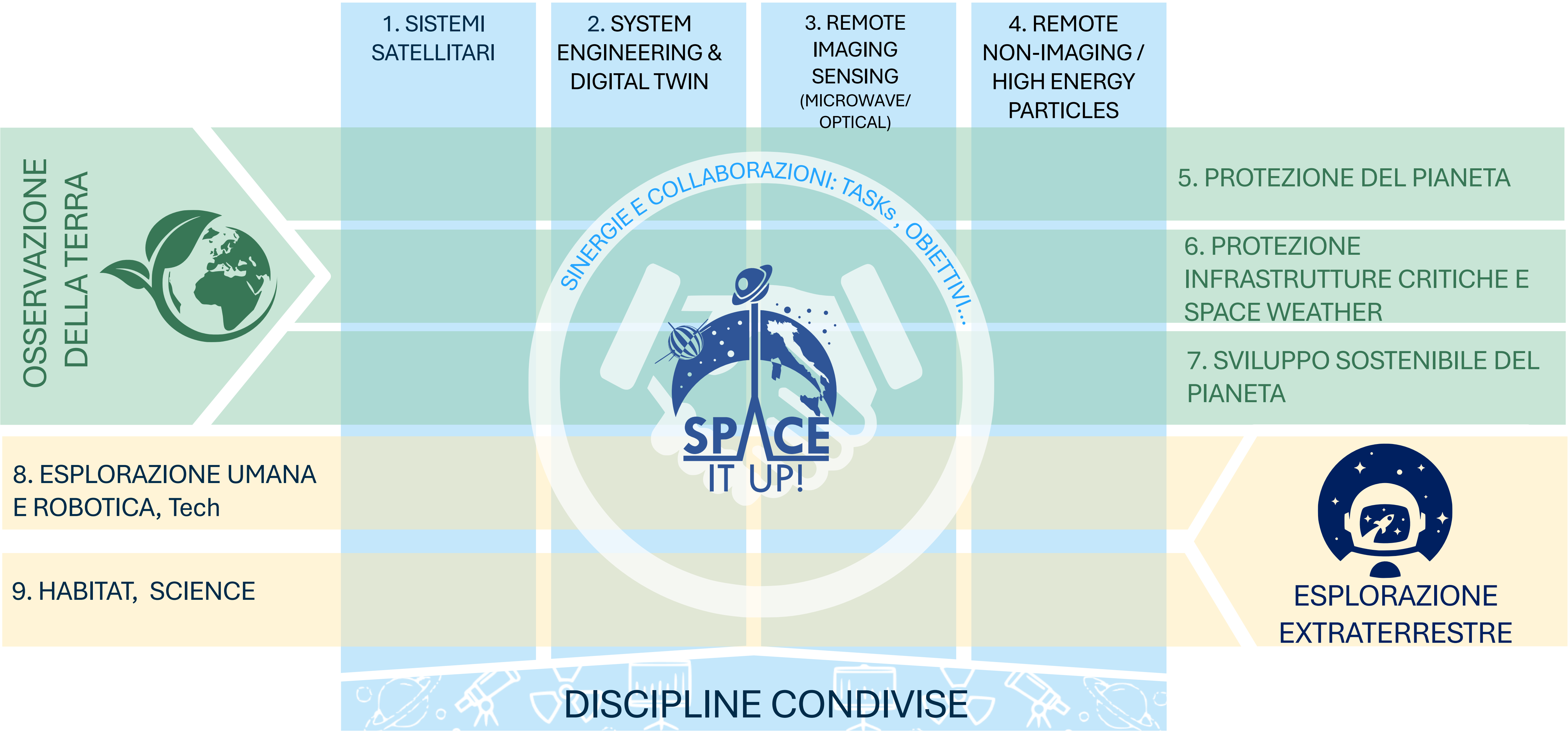


Space It Up un'opportunità eccezionale per la comunità italiana 'spazio'

Erasmo Carrera
Politecnico di Torino

Il progetto Space It Up, finanziato dall'Agenzia Spaziale Italiana (ASI) e dal Ministero dell'Università e della Ricerca (MUR), riunisce le competenze italiane nella scienza e nell'ingegneria spaziale, ponendo l'Italia all'avanguardia nella ricerca sull'osservazione e la protezione della Terra, l'esplorazione extraterrestre, i satelliti artificiali e il telerilevamento.

9 Spokes



1. SISTEMI SATELLITARI
2. SYSTEM ENGINEERING & DIGITAL TWIN
3. REMOTE IMAGING SENSING (MICROWAVE/ OPTICAL)
4. REMOTE NON-IMAGING / HIGH ENERGY PARTICLES
OSSERVAZIONE DELLA TERRA
5. PROTEZIONE DEL PIANETA
6. PROTEZIONE INFRASTRUTTURE CRITICHE E SPACE WEATHER
7. SVILUPPO SOSTENIBILE DEL PIANETA
SINERGIE E COLLABORAZIONI: TASKs, OBIETTIVI...
SPACE IT UP!
8. ESPLORAZIONE UMANA E ROBOTICA, Tech
9. HABITAT, SCIENCE
ESPLORAZIONE EXTRATERRESTRE
DISCIPLINE CONDIVISE

33 Partners: 13 Universities, 10 Research Center, 10 Enterprise

Politecnico di Torino
POLITECNICO MILANO 1863
UNIVERSITÀ DEGLI STUDI DI NAPOLI FEDERICO II
SAPIENZA UNIVERSITÀ DI ROMA
UNIVERSITÀ DEGLI STUDI DI PADOVA
UNIVERSITÀ DI TRENTO
GRAN SASSO SCIENCE INSTITUTE — SCHOOL OF ADVANCED STUDIES — Scuola Universitaria Superiore
Sant'Anna Scuola Universitaria Superiore Pisa

SISSA Scuola Internazionale Superiore di Studi Avanzati
IUSS Scuola Universitaria Superiore Pavia
ALMA MATER STUDIORUM UNIVERSITÀ DI BOLOGNA
UNIVERSITÀ DI PISA
Politecnico di Bari
UNIVERSITÀ DEGLI STUDI FIRENZE
UNIVERSITÀ DELLA CALABRIA
TOR VERGATA UNIVERSITÀ DEGLI STUDI DI ROMA

Consiglio Nazionale delle Ricerche
INAF ISTITUTO NAZIONALE DI ASTROFISICA
INFN Istituto Nazionale di Fisica Nucleare
ISTITUTO NAZIONALE DI GEOFISICA E VULCANOLOGIA
INRiM ISTITUTO NAZIONALE DI RICERCA METROLOGICA
iit ISTITUTO ITALIANO DI TECNOLOGIA
cmcc Centro Euro-Mediterraneo sui Cambiamenti Climatici

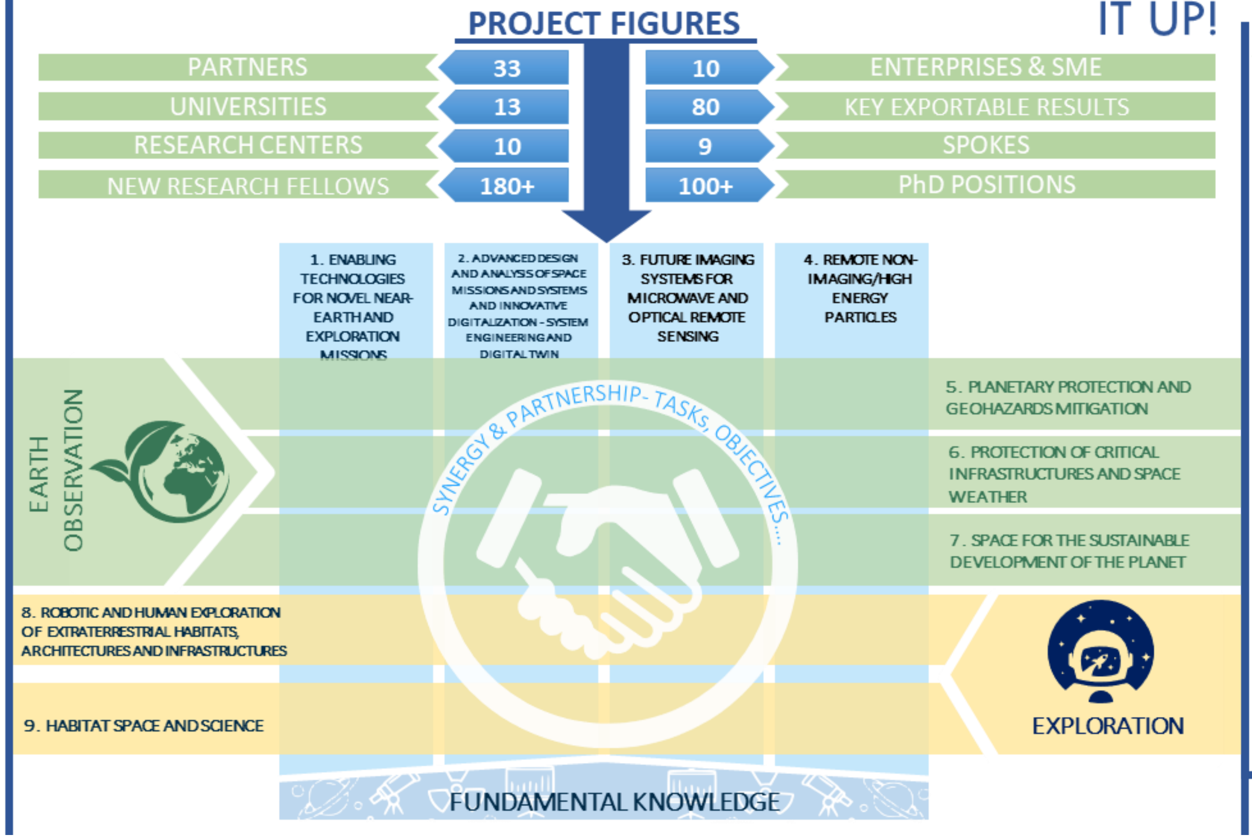
ENEA
FBK FONDAZIONE BRUNO KESSLER — FUTURE BUILT ON KNOWLEDGE
FONDAZIONE LINKS — PASSION FOR INNOVATION
LEONARDO
ThalesAlenia Space — a Thales / Leonardo company
TELESPAZIO a LEONARDO and THALES company
ALTEC

e-geos AN ASI / TELESPAZIO COMPANY
CIRA Centro Italiano Ricerche Aerospaziali
SITAEL AN ANGEL COMPANY
argotec
Tyvak International A Terran Orbital Corporation
mapSAT we see the world for you

ALTRI PARTNERS (ex art 15)

Overview

Extended Partnership: **SPACE IT UP!**
Duration of the program: **30 months**
Cost of the program: **80M€**



SPOKES – UNIVERSITIES

SPOKES	POLITO	POLIMI	UNINA	UNIROMA1	UNIPD	UNITN	GSSI	UNIBO	UNIPI	POLIBA	UNIFI	UNICAL	UNIROMA2
1	●	L	●			●		●	CL	CL			
2	CL	●		L	●		●			●			
3		●	L	●	●							●	
4			●			●	CL		●				
5	●			●		L			●		●	●	
6						●						CL	●
7	●	●			●	●	CL	●		●	●		
8	L		●	●	●		●	CL		●	●	●	●
9		●	●	●	L			●	●		CL		●

SPOKES – EPR

SPOKES	CNR	INAF	INFN	INGV	INRIM	IIT
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2					●	
3	CL					
4		●	L		●	
5	●	●	●	CL		
6		L	●	●		
7	L			●	●	
8	●	CL				●
9		●				

SPOKES – OTHER RESEARCH CENTERS

SPOKES	CMCC	ENEA	FBK	LINKS
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2				
3				
4			●	
5	●		●	●
6			●	
7	●			●
8		●		●
9		●		

SPOKES – INDUSTRIES

SPOKES	LEONARDO	TAS-I	TELESPAZIO	ALTEC	E-GEOS	CIRA	SITAEL	ARGOTEC	TYVAK	MAPSAT
1		●	●			●	●	●	●	
2		●	●				●			●
3		●								
4		●								
5	●	●			●	●		●		●
6			●							
7	●				●	●	●			●
8	●	●	●	●		●		●		
9										

OBJECTIVES

PROMOTE INNOVATION AND EXTEND FUNDAMENTAL KNOWLEDGE

FOSTERING A SUSTAINABLE FUTURE

ENSURE LONG-TERM HUMAN PERMANENT IN EXTRATERRESTRIAL SPACE

STRENGTHENING THE 'ECOSYSTEM' SPACE IN ITALY

PROMOTE INNOVATION AND EXTEND FUNDAMENTAL KNOWLEDGE

Da sempre, **l'esplorazione e lo sfruttamento dello spazio** hanno richiesto di spingere la conoscenza oltre i propri limiti. SPACE IT UP svilupperà **tecnologie innovative** per sostenere e promuovere le future attività spaziali. I contributi di SPACE IT UP avranno un impatto su diverse aree fondamentali, come i modelli numerici, le architetture e le **costellazioni satellitari innovative**, i **nuovi profili di missione**, la strumentazione avanzata e le applicazioni basate **sull'intelligenza artificiale**.

FOSTERING A SUSTAINABLE FUTURE

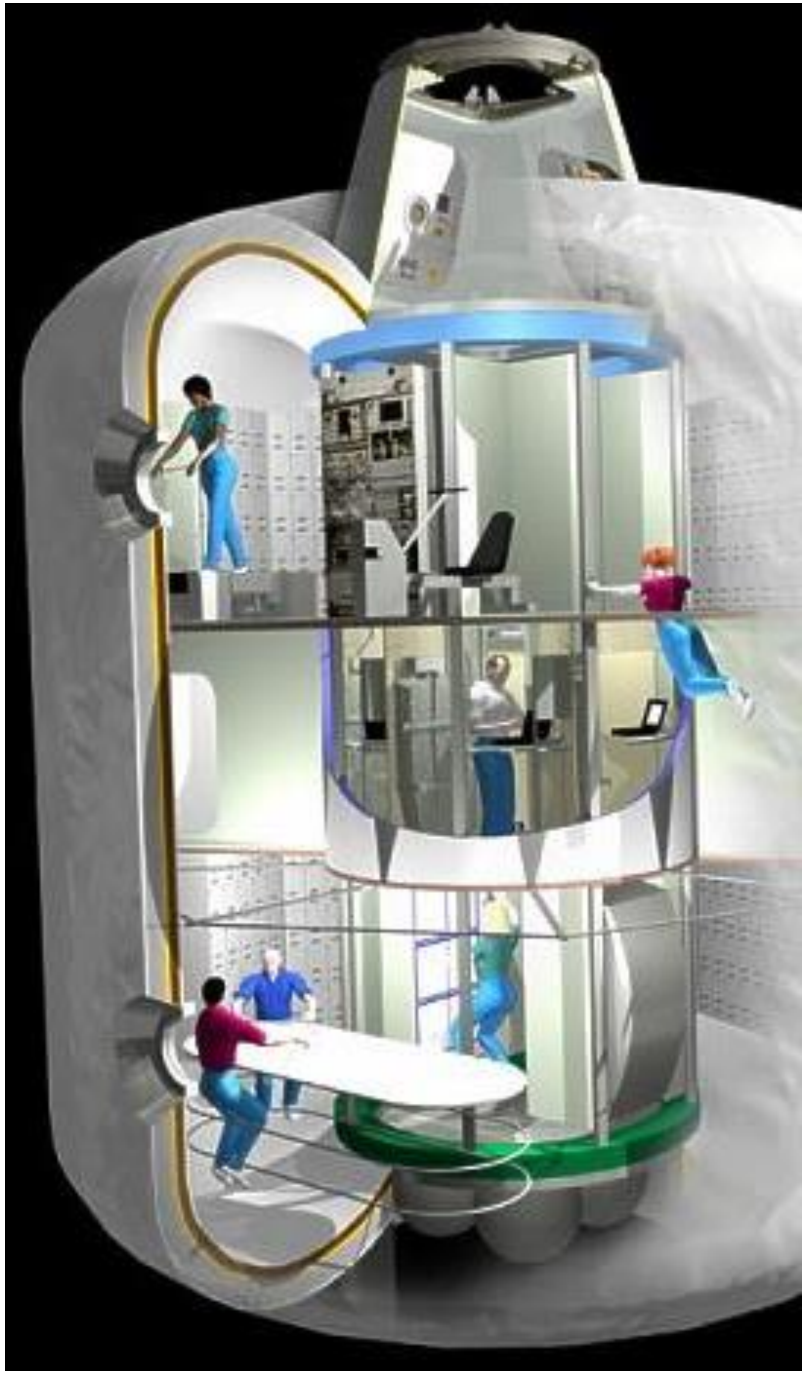
L'umanità deve preservare il pianeta e lo spazio per le generazioni future. L'implementazione di tecnologie spaziali innovative consentirebbe di **osservare i cambiamenti climatici** e di prevedere gli eventi meteorologici estremi. Inoltre, SPACE IT UP proporrà soluzioni innovative per migliorare la **resilienza delle infrastrutture spaziali e terrestri ai gravi fenomeni meteorologici spaziali.**

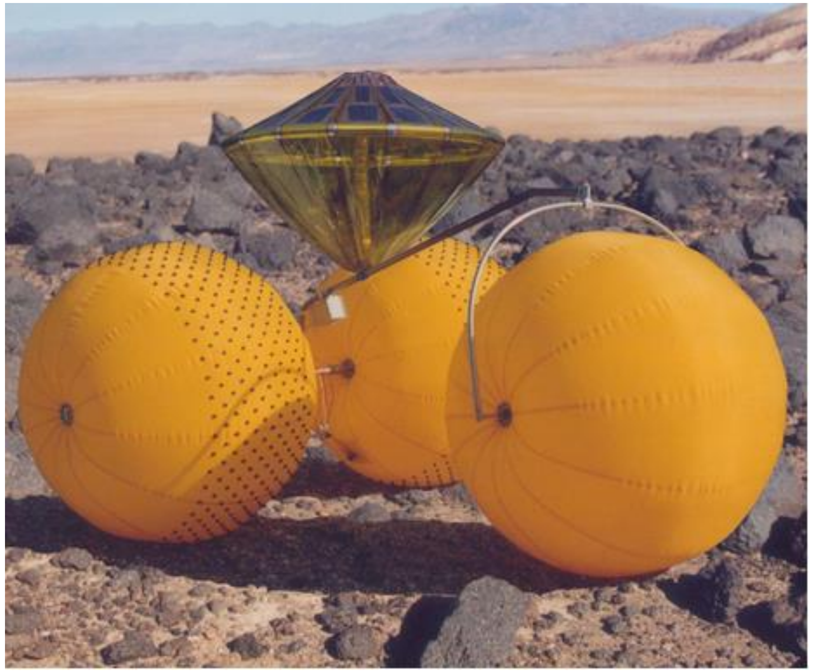
ENSURE LONG-TERM HUMAN PERMANENT IN EXTRATERRESTRIAL SPACE

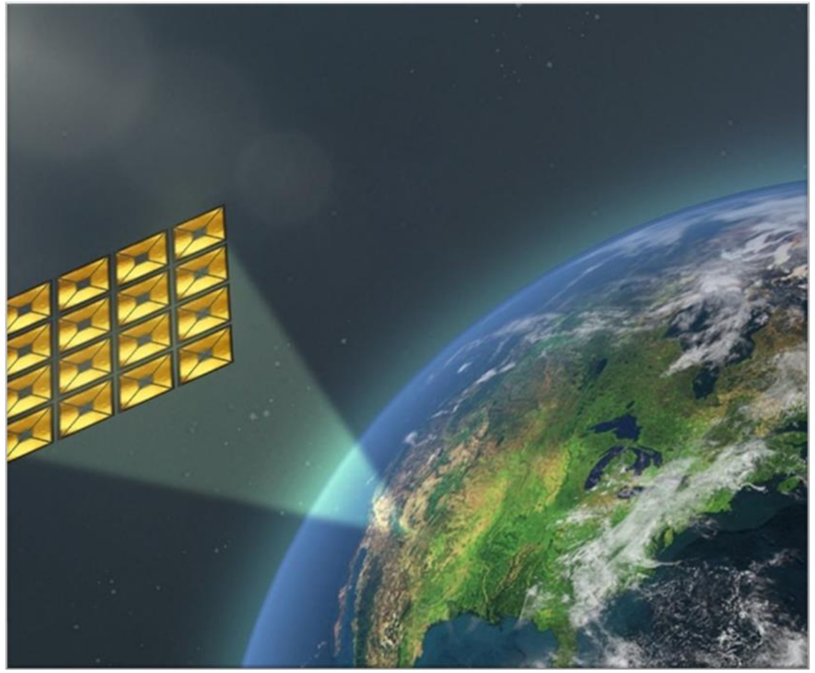
La permanenza umana a lungo termine nello spazio pone numerose sfide tecnologiche che richiedono soluzioni innovative per essere superate. SPACE IT UP promuove lo sviluppo di **nuove idee e la definizione di tecnologie abilitanti** per rendere l'umanità una specie multiplanetaria. Il progetto affronterà non solo le questioni tecnologiche, ma anche quelle relative **allo sfruttamento delle risorse**, **alla produzione in situ**, alle soluzioni **circolar**i per una **permanenza sostenibile** e agli **aspetti neurofisiologici**.

STRENGTHENING THE 'ECOSYSTEM' SPACE IN ITALY

L'Italia coprirà l'intera catena del valore della ricerca e dello sviluppo in campo spaziale, grazie a un efficace **coordinamento tra Università, Istituti di ricerca e un sistema di piccole, medie e grandi industrie**. Inoltre, SPACE IT UP promuoverà collaborazioni tra partner e nuove sinergie per proporre **soluzioni innovative e multidisciplinari**. Di conseguenza, SPACE IT UP **fornirà al Paese un ecosistema spaziale più solido e competitivo**







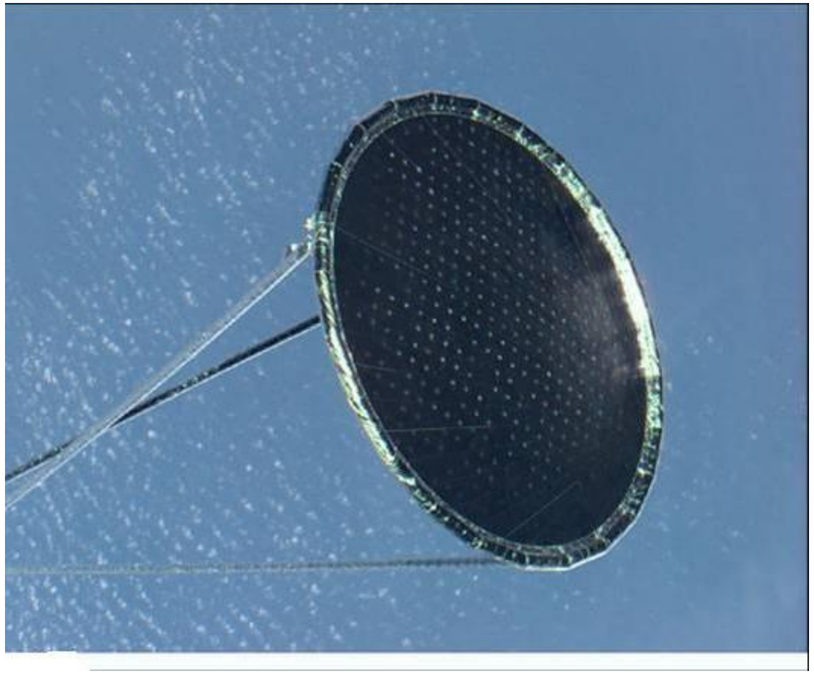
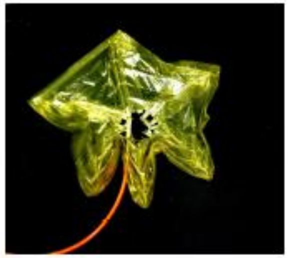
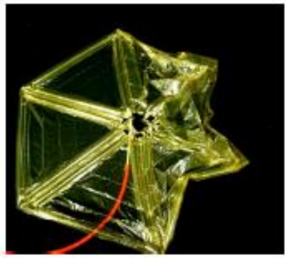


Fig. 11 Packed configuration

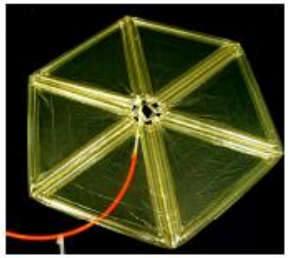
(a) initial configuration



(b) process-1



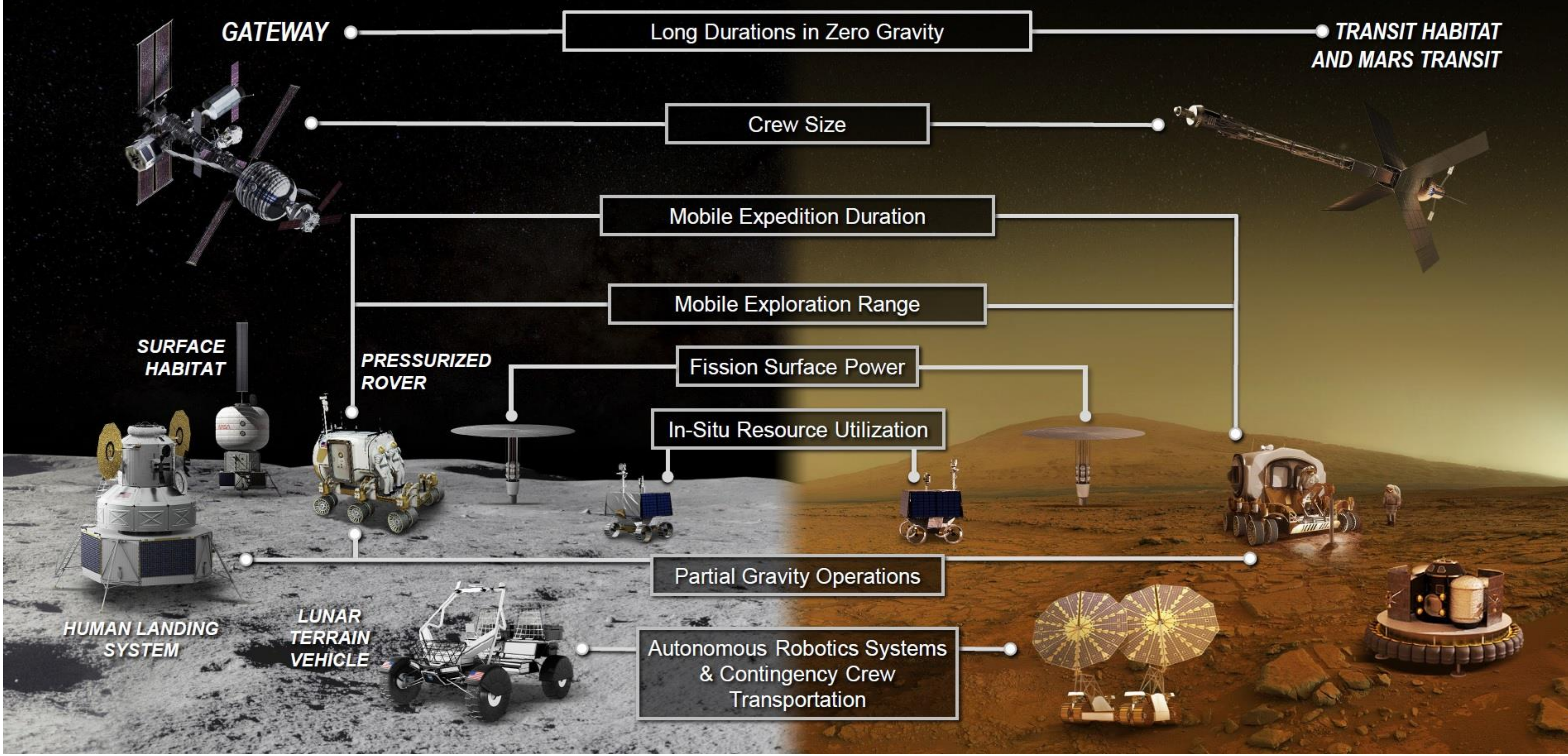
(c) process-2



(d) final configuration

Moon to Mars Exploration Strategy

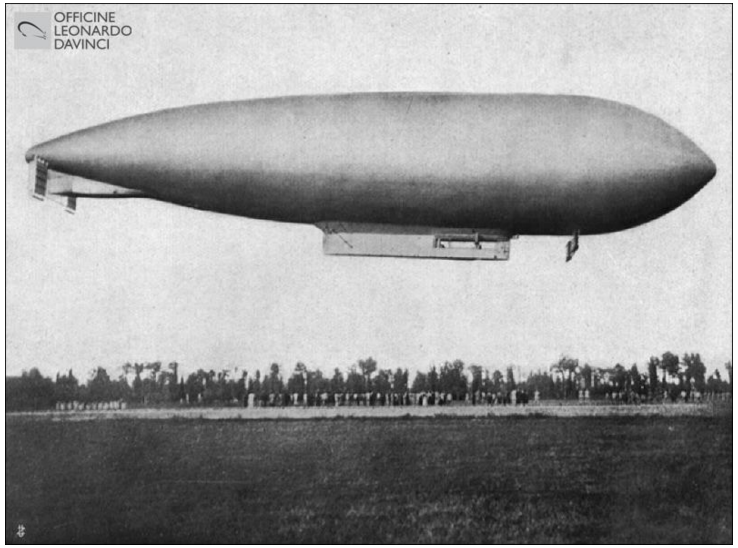
Operations on and around the Moon will help prepare for the first human mission to Mars



Contents

- Gossamer and/or Inflatable
- Unmanned and Manned Application
- Complicating effects for Manned IS
- Example of Simulation of simple/complex (unmanned) elements
- Conclusions

INFLATABLE STRUCTURE VS AERONAUTICS:



[Condor_video]

Why Inflatable Space Structures?

- ❖ Strong Weight reduction is mandatory
- ❖ Less volume available

ARIANE 5 (Pay-load dimensions)	
Diameter of fairing	4,5 m
Height fairing	10,3 m
Max Payload	27 t

Possible solutions:

- ❑ Deployable structures DS
- ❑ Expandable structures ES
- ❑ Inflatable structures IS
- ❑ **DS+ES+IS (Gossamer)**

Complicating Effects!

- ❖ **Use of IS as Manned Spacecraft**

SIERRA
SPACE

CONTENTS OF THIS TALK

- OVERVIEW OF INFLATABLE STRUCTURES FOR UNMANNED AND MANNED APPLICATIONS
- EXAMPLE OF SIMULATION OF SIMPLE STRUCTURAL ELEMENTS AND COMPLETE SPACECRAFT (IRDT, IMOD, AIRLOCK ..)

JUSTIFICATION OF THE INFLATABLE STRUCTURES

Many reasons are on the basis of the choice of inflatable structures for the construction of Space Structures

1. **Mainly the mass of these structures is less of that of the traditional metallic ones**

2. **The inflatable structures can be easily accommodated inside the launcher due to their possibility of folding**

3. **Greater volumes can be exploited in comparison with the traditional metallic structures**

4. **Different configurations can be easily obtained during their operative life (for example by the inflation of compartments in several periods)**

POSSIBLE UTILIZATION OF THE INFLATABLE STRUCTURES

IS can be classified as Unmanned and Manned Space Structures.

Example of Unmanned Space Structures are:

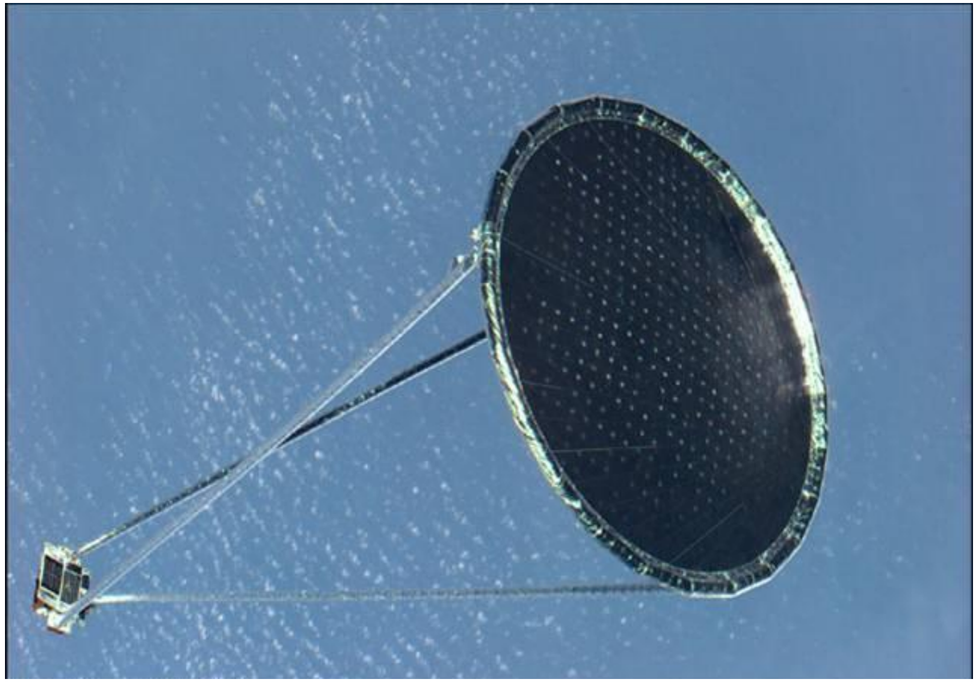
- **RE-ENTRY CAPSULES**
- **AIR BAGS FOR SHOCK ABSORBER AND DECELERATION SYSTEMS**
- **SOLAR ARRAYS**
- **ANTENNAS AND REFLECTORS**
- **HEAT SHIELDS**
- **SOLAR SAILS**
- **ROVER AND LANDER (R/L ELEMENTS)**

POSSIBLE UTILIZATION OF THE INFLATABLE STRUCTURES

Example of Manned Space Structures are:

- **SPACE STATION (!)**
- **PRESSURIZED MODULES PERMANENTLY ATTACHED TO THE SPACE STATION**
- **PRESSURIZED MODULES FOR INTER-PLANETARY TRANSFERRING**
- **PERMANENT BASES FOR PLANETARY EXPLORATION**

UNMANNED /INFLATABLE STRUCTURES



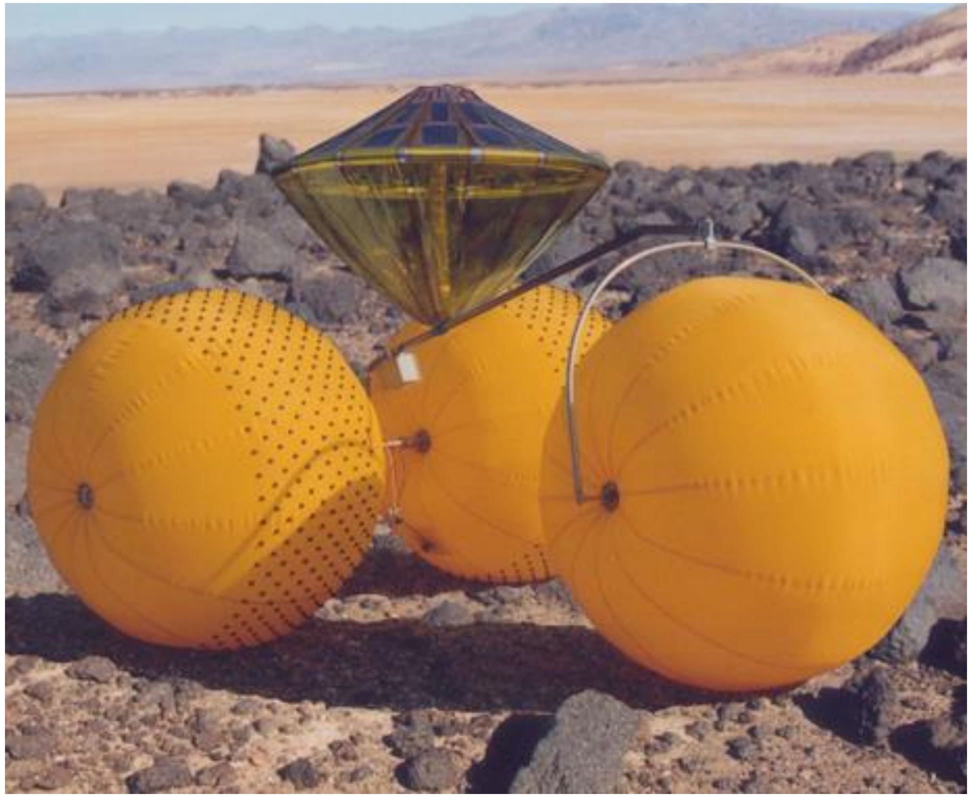
L'Garde Inflatable Antenna

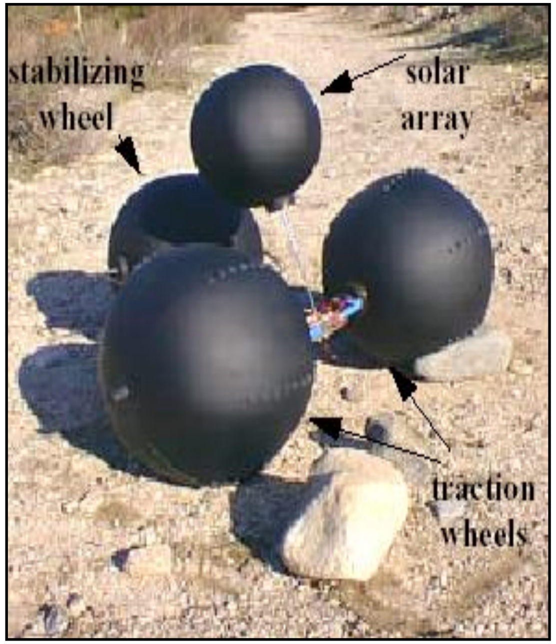
NORMALLY THESE ANTENNAS ARE LAUNCHED IN A ROLLED CONFIGURATION AND THEN THEY ARE DEPLOYED IN ORBIT BY THE USE OF NITROGEN

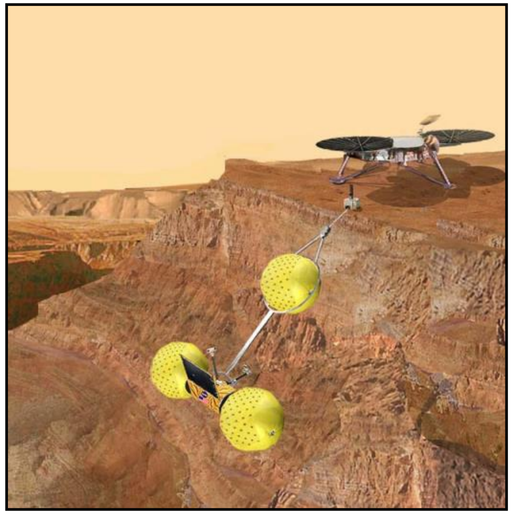
THE REFLECTOR, WHICH IS MADE OF THIN LAYERS, IS TENSIONED BY THE INFLATION OF THE TOROIDAL SUPPORT.

EXAMPLE OF UNMANNED INFLATABLE STRUCTURES

Use of Inflatable Capsule for planetary exploration and for Rover construction







JPL Inflatable Rover per l'esplorazione della superficie di Marte alimentato da Inflatable Mars Rover Solar Array (ILC Dover, Inc.)

Constraints Introduced By Manned Configuration

1. **The shell modules can become very thick due to the necessity of protection against the meteorites**

2. **The air containment become crucial for the crew survival**

3. **Then the connections between flexible and rigid parts become a critical topics, not only for the assurance of a suitable mechanical strength but also to avoid air leakage**

4. **The reaching of a precise operative shape can become sometimes mandatory, then deployable mechanisms can be used as guide to reach this final shape**

5. **The assurance of a suitable strength of this thick shell to the folding and unfolding stress, as well as to the internal pressure, become very important for the structure survival**

Advantages Introduced By IS for Manned Configuration

Due to the fact that these structures must house the crew, the Manned Inflatable Space Modules can exhibit one of their main characteristic:

1. **The exploitation of a large habitable volume**

2. **The possibility of increasing the number of crew members and a more comfortable on board life**

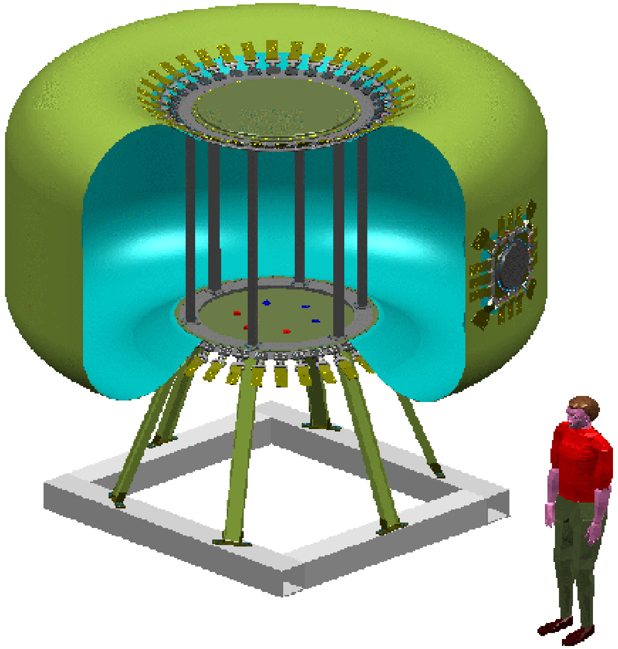
3. **A more comfortable internal environment, can give high benefit to the crew, especially for long duration missions**

1. **The Manned Inflatable Modules can offer this large habitable, which can be 4 times greater then that offered by the traditional metallic modules.**

Manned Spacecraft

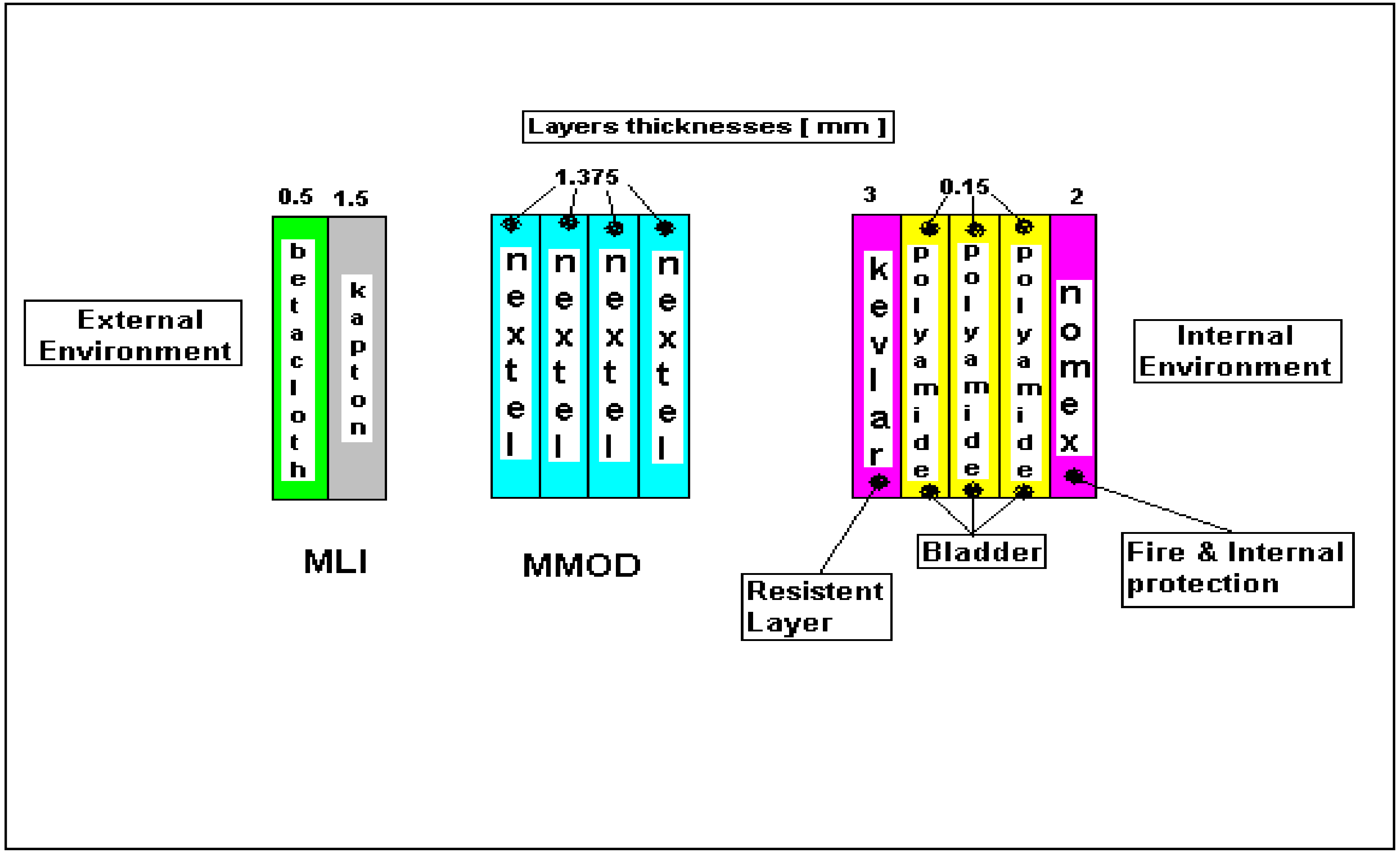
Transhab –ISSA (NASA)

Transhab_video



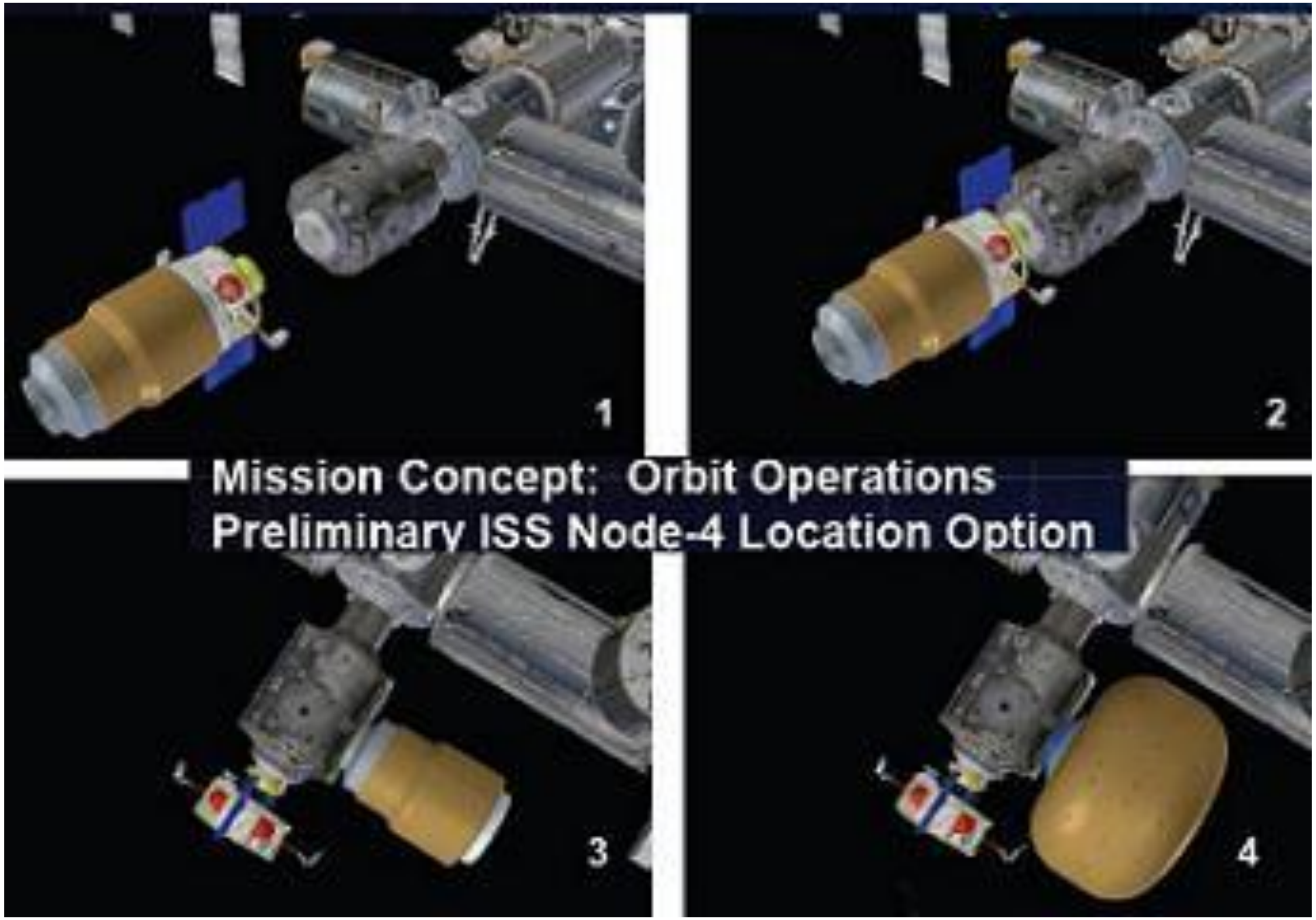
I-MOD (ESA, TASI)

Typical Multilayered Sequence



Inflatable Modules shell structure possible sequence

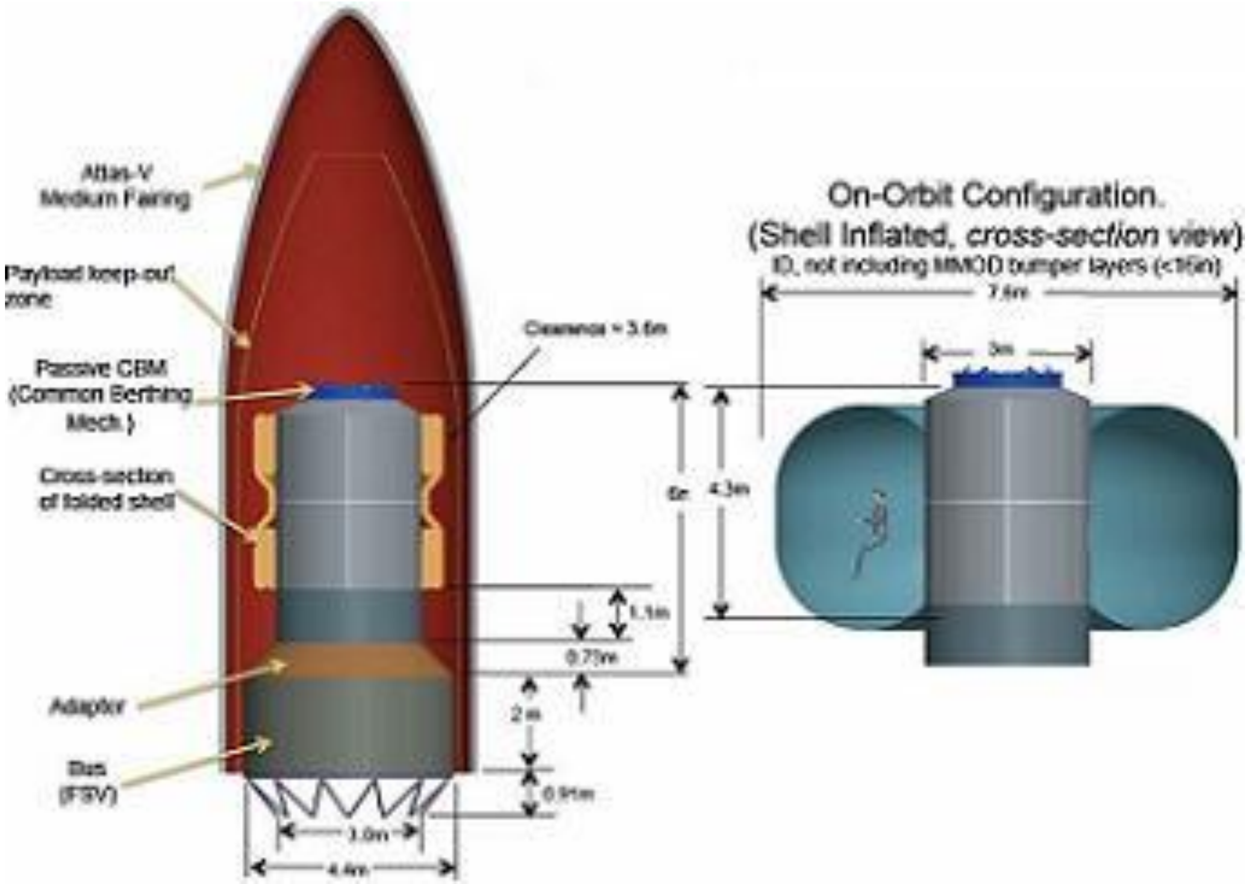
THE MOST RECENT
GENESIS I & 2 FROM BIGELOW



Bigelow would provide the inflatable and inner core structure of the module, and perform all required flight analysis.

"An inflatable module has a rigid center core where the equipment is typically located and where the fabric is stowed for launch. After the module is berthed, it is inflated resulting in a pressurized fabric shell with a cylindrical core structure that houses equipment, etc."

In-spite of their soft shell, Bigelow's inflatable modules are more resistant to Micro Meteoroid Orbital Debris (MMOD) strikes than current metallic-shelled l ISS modules



Beam @ ISS

- https://www.designboom.com/technology/nasa-bigelow-beam-iss-space-habitat-module-12-06-2017/

Simulations: Involved Disclplines

- Multibody Dynamics of rigid bodies
- Multibody Dynamics of flexible bodies (FE)
- Membrane flexibility and Membrane/bending Shell Theories
- Layered Structures (manned!)
- Inflation simulation (Large areas can be in contact)
- Deployment simulation by inflation
- Available codes (FE: Ls-dyna, Abaqus, …..)
- Nonlinear phenomena are largely involved
- Experiments are mandatory!

THREE FLAT RECTANGULAR MEMBRANES

The following Figures 12 and 13 show respectively : the three membranes geometry and the

Finite Element Model. The applied uniform pressure load time history is a ramp from 0 to 1.

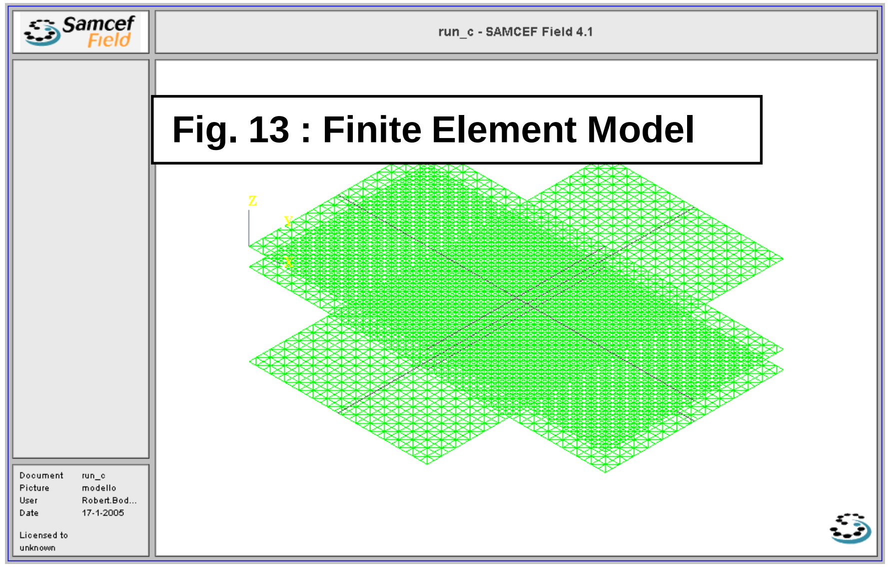
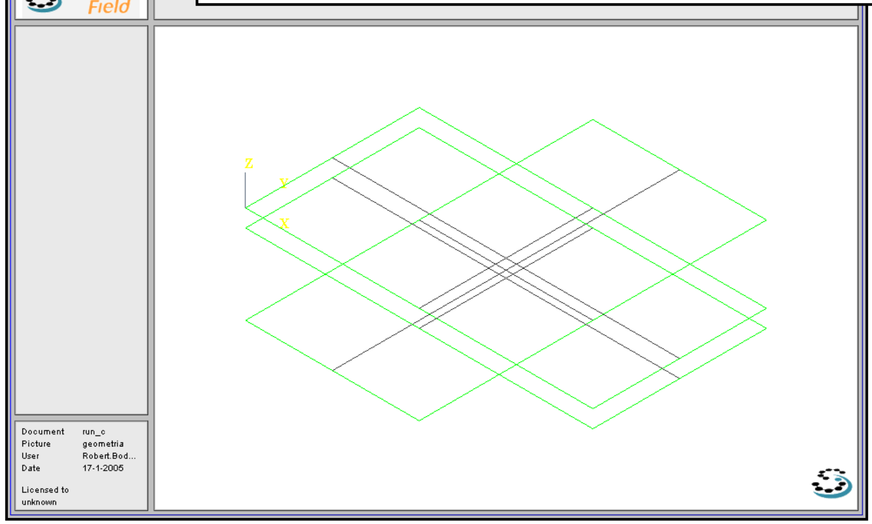


Fig. 13 : Finite Element Model

FIG. 12 – Membranes geometry



FLAT & TUBULAR MEMBRANE STRUCTURES

Next Figures 34 and 35 show the geometry of the tubes and of the flat shell respectively

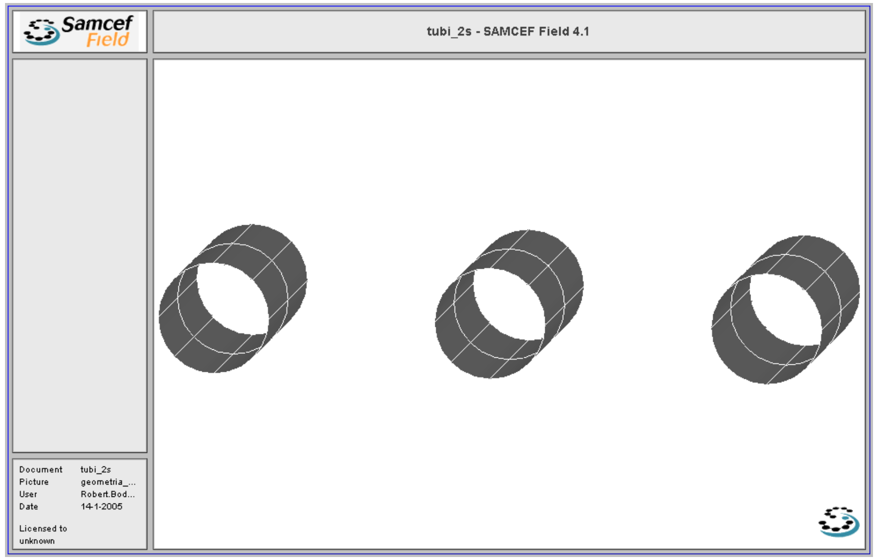


Fig. 34 :Geometry of the tubes

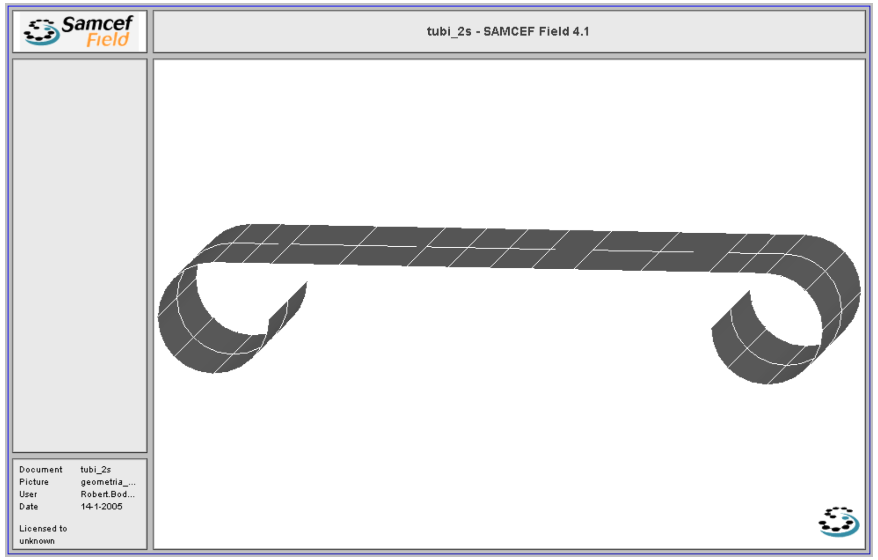
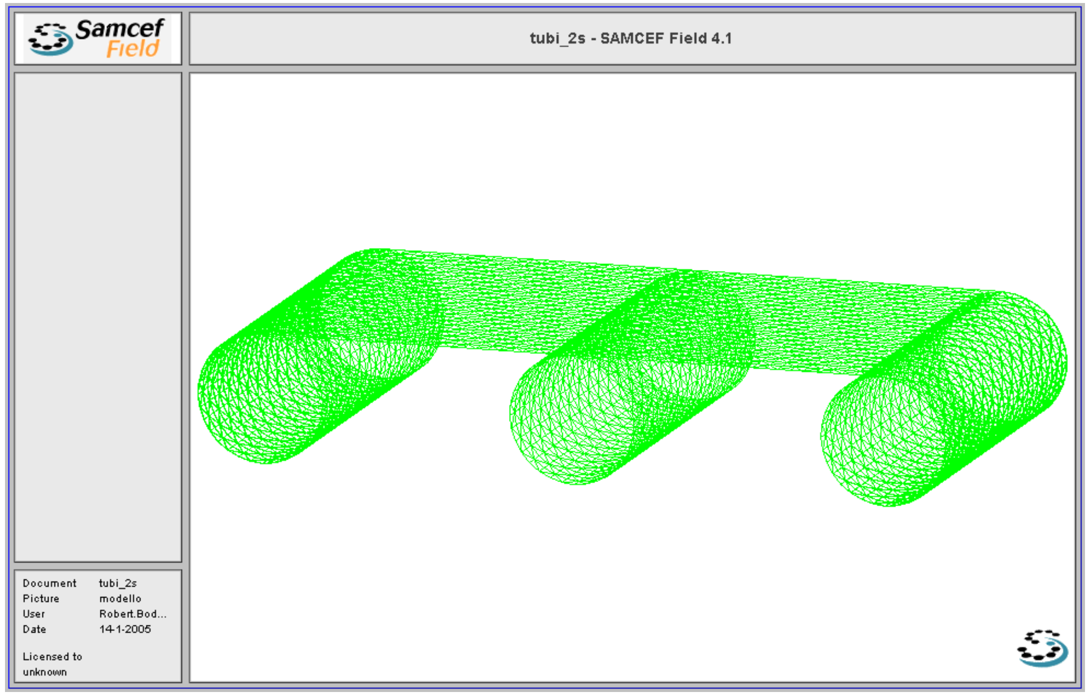


Fig. 35 :Geometry of the shell

FLAT & TUBULAR MEMBRANE STRUCTURES



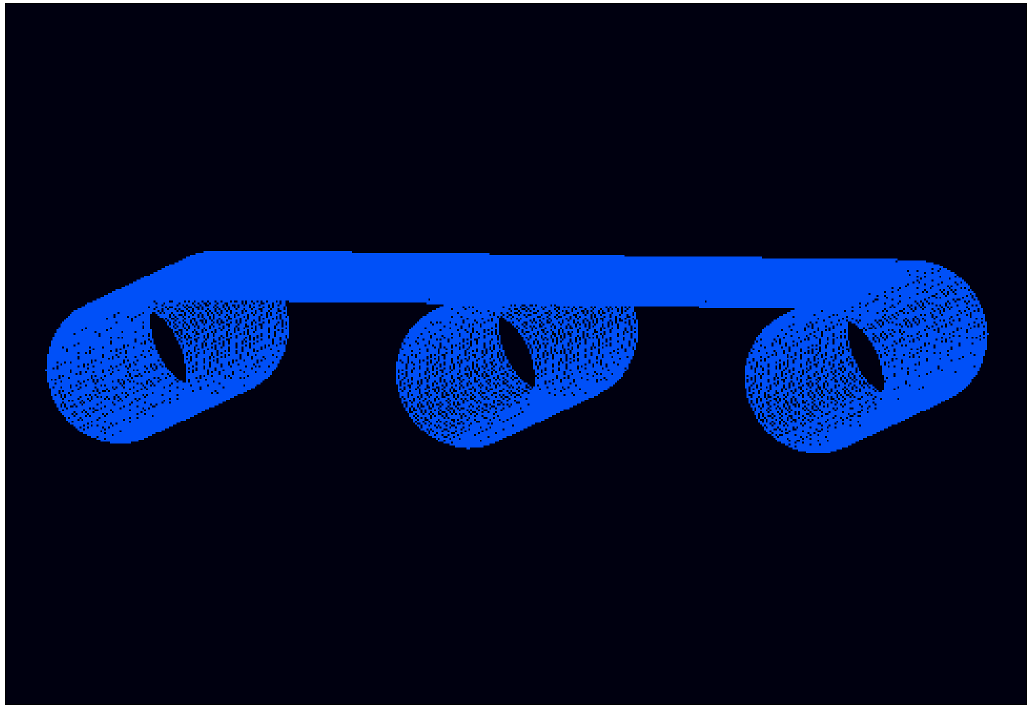
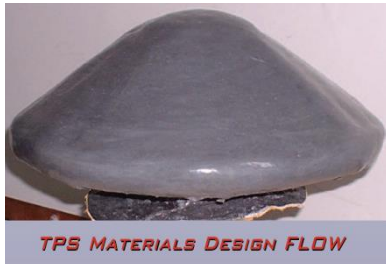
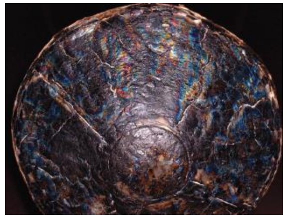


Fig. 36 :Finite Element Model

Example of Inflatable Re-entry capsule analysis

The CAD model of the capsule is shown in the next Figures 39, while the Figure 40 shows the 1/8 CAD model used to perform the analyses.





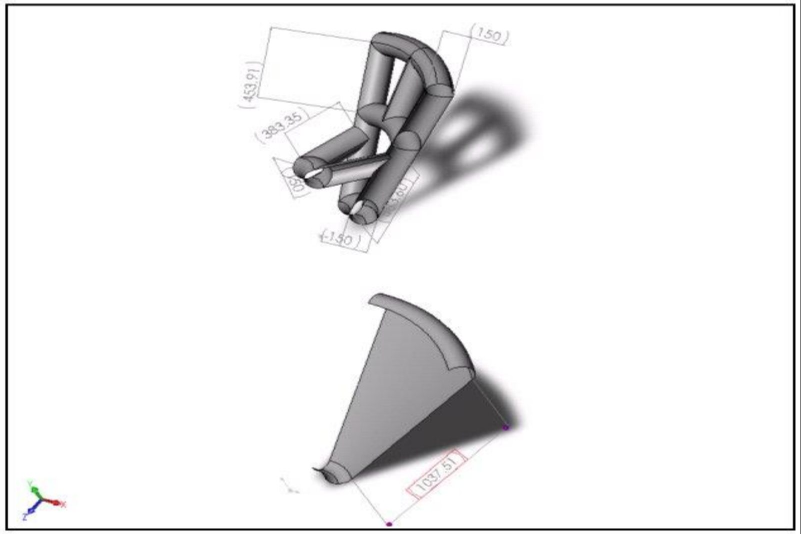


Fig. 40 :–1/8 CAD model – exploded view

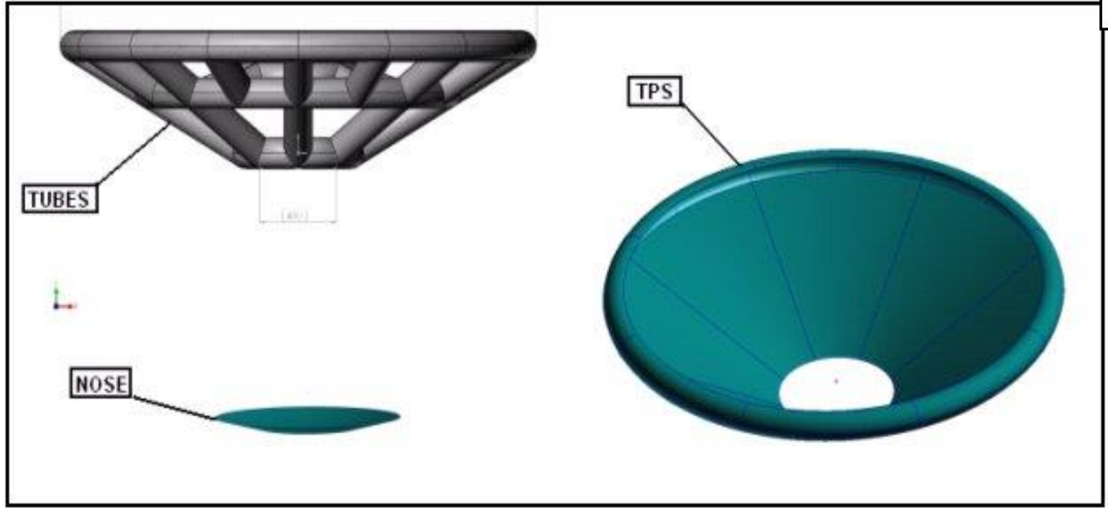


Fig. 39 :– IRT CAD model – exploded view

EXAMPLE OF INFLATABLE RE-ENTRY CAPSULE ANALYSIS

- **The results in term of displacements is shown in the next Figures 48**

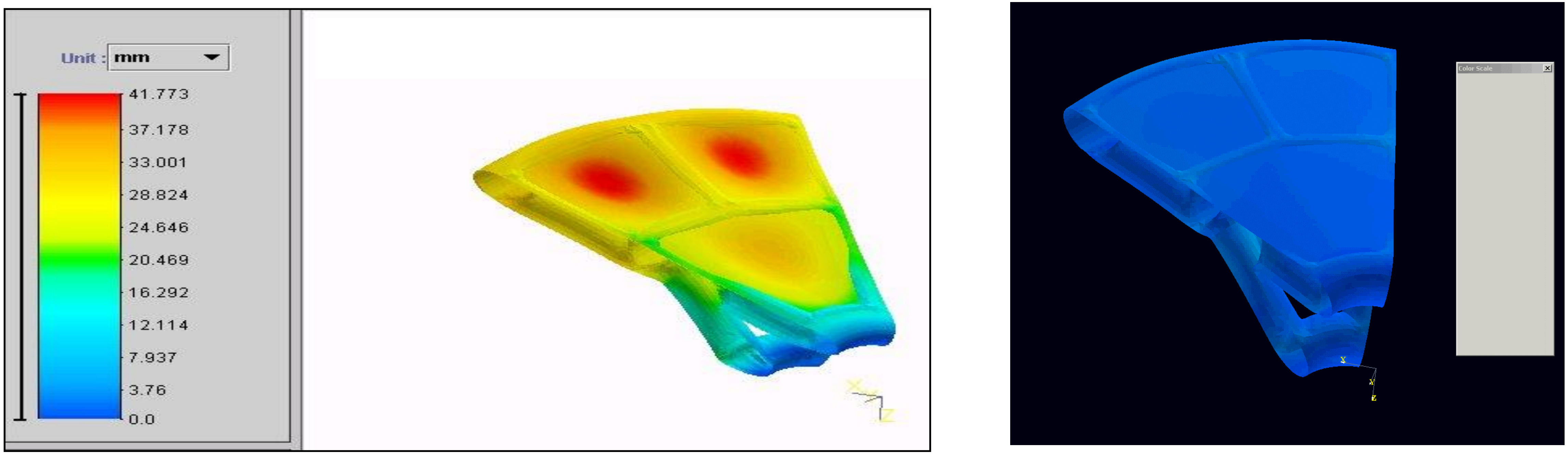
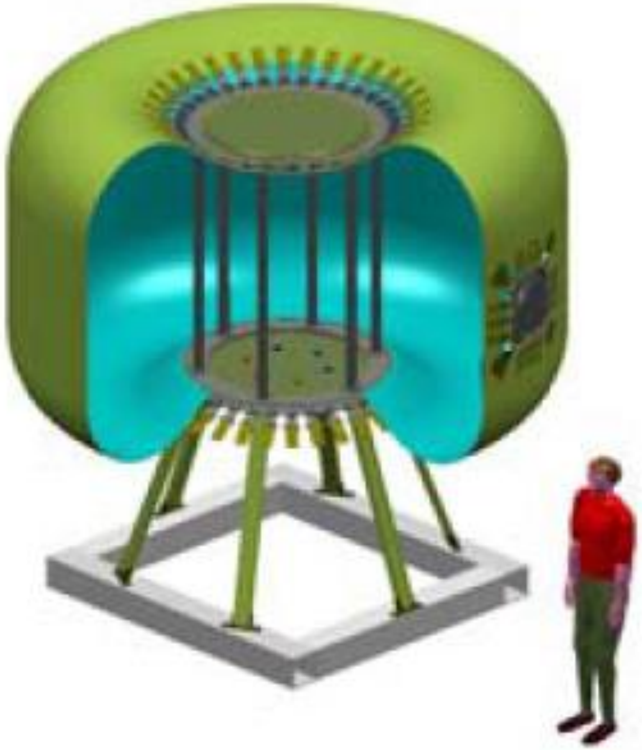
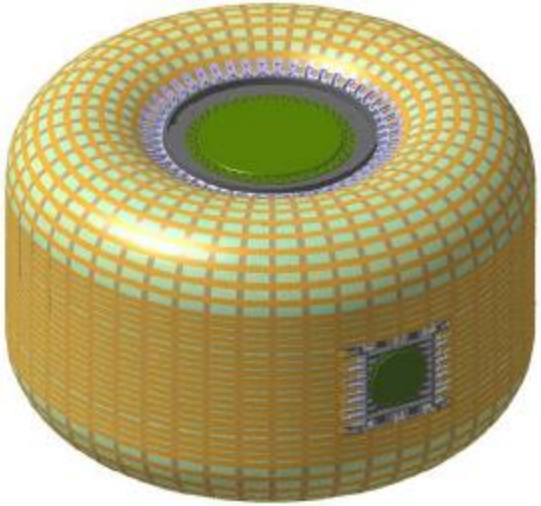
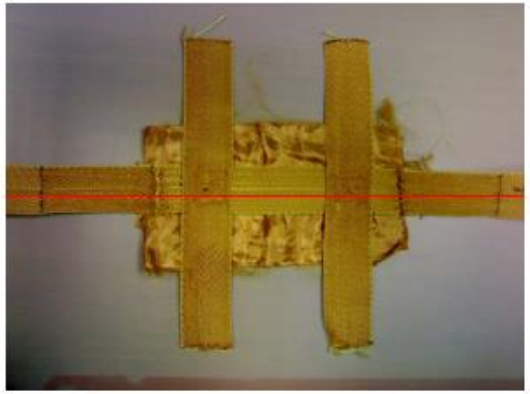


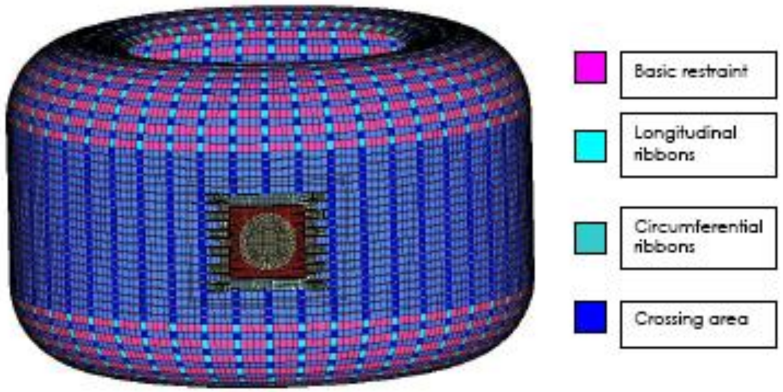
Fig. 48 – IRT displacements field

FE ANALYSY OF IMOD INFLATBALE MODULE

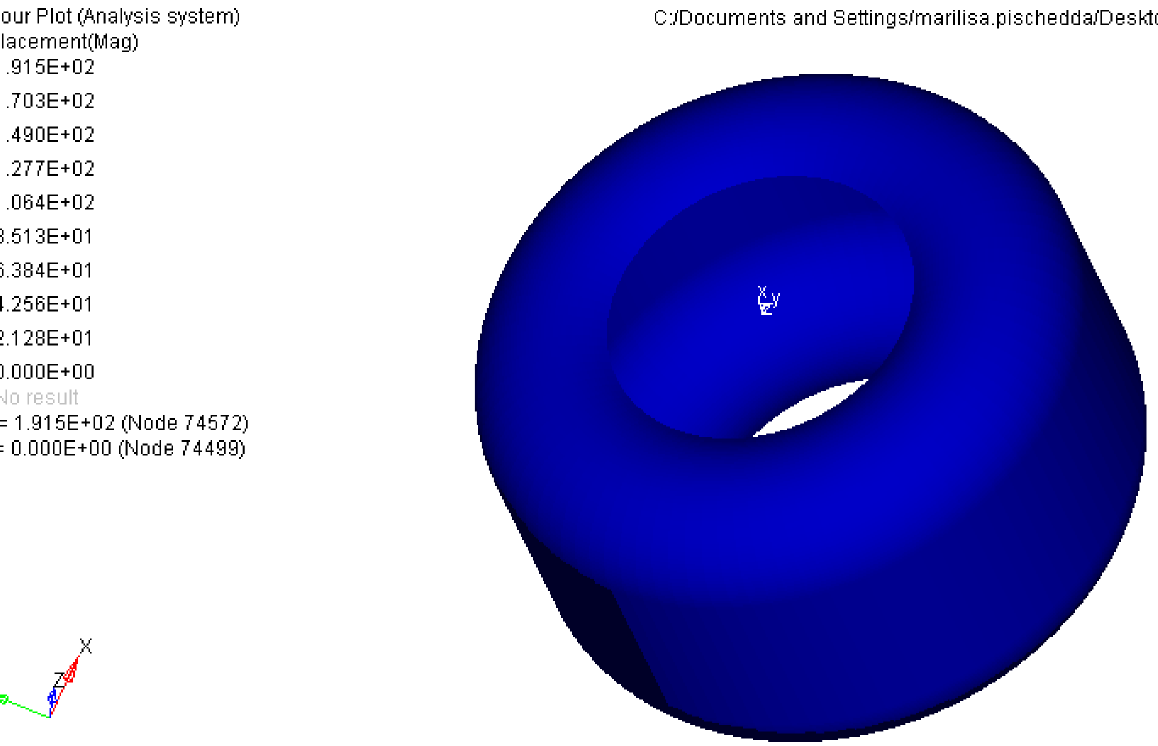


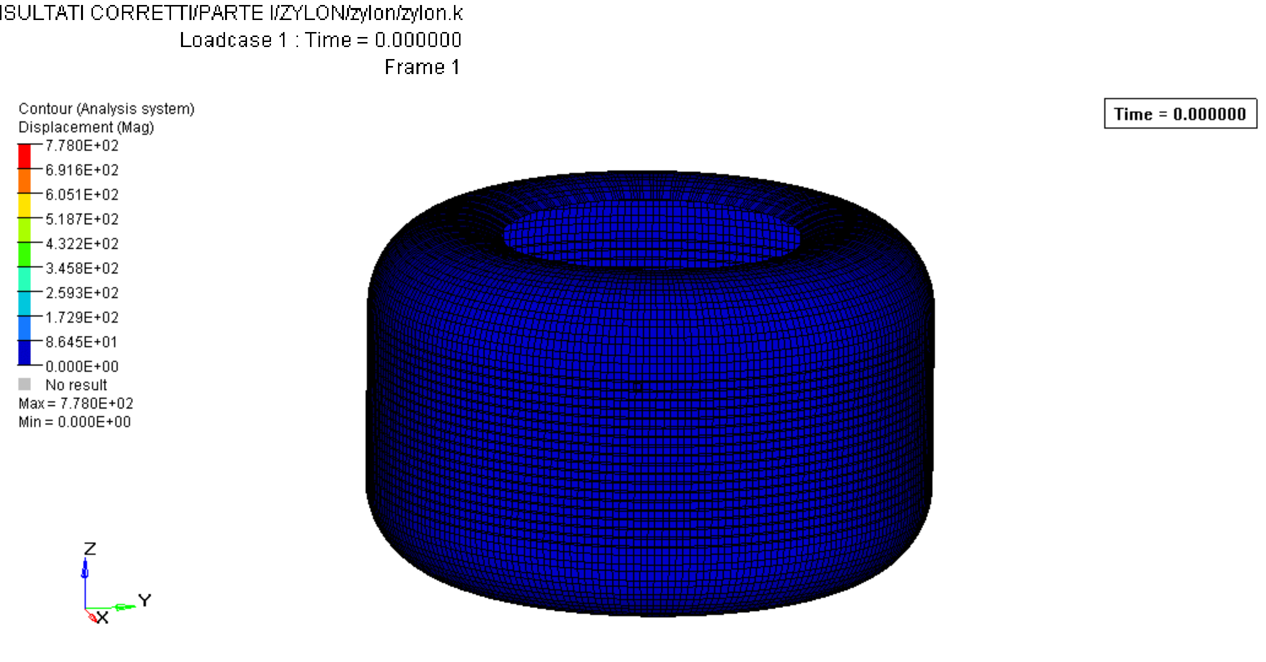






FE ANALYSY OF IMOD
INFLATABLE MODULE



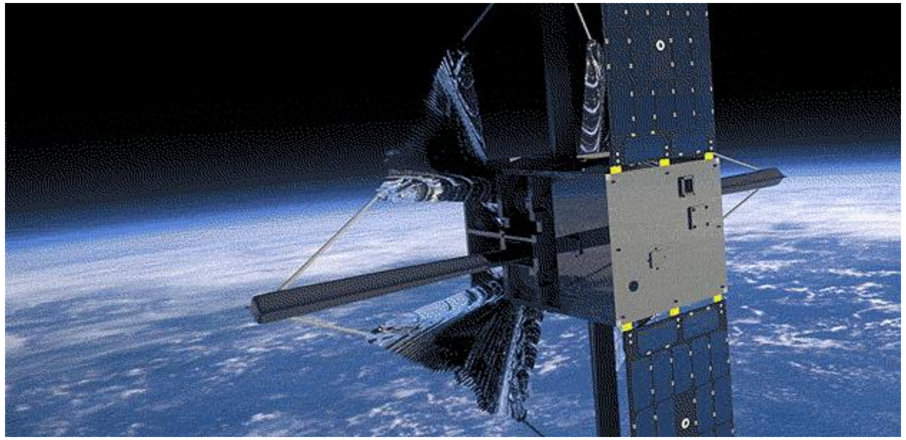


IMOD INFLATABLE MODULE

Deployable space booms – State-of-the-art (2) and current modelling issues

Two ways of deploying thin-shells structures:

Controlled



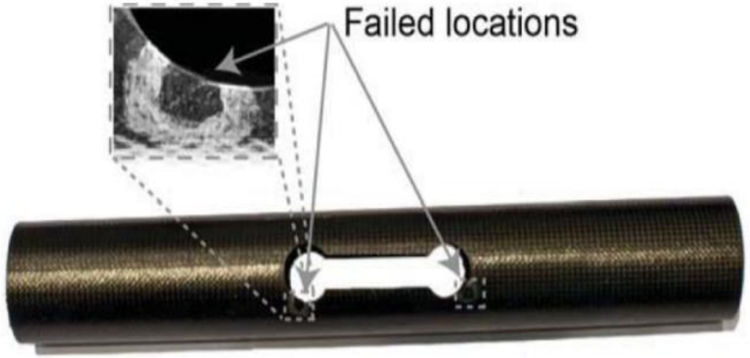
Advanced Composite Solar Sail System (ACS3) - *Credits: NASA*

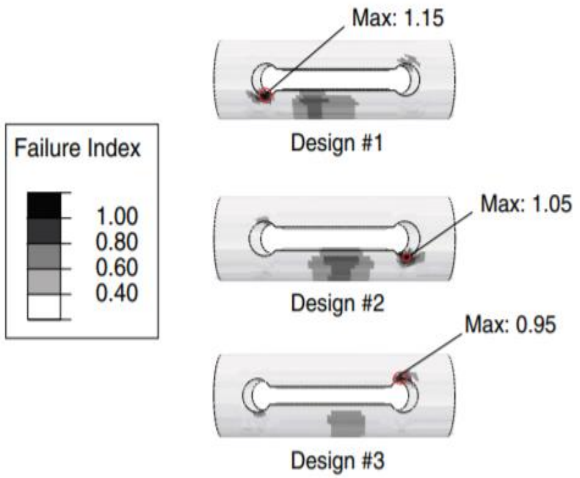
Unconstrained

Wrapped rib reflector - credit: Oxford Space Systems

free-edge cracks may occur

Mallikarachchi & Pellegrino, Journal of Spacecraft and Rockets, 2014.



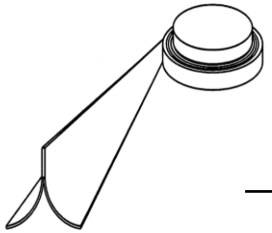


POLITECNICO DI TORINO

Caltech

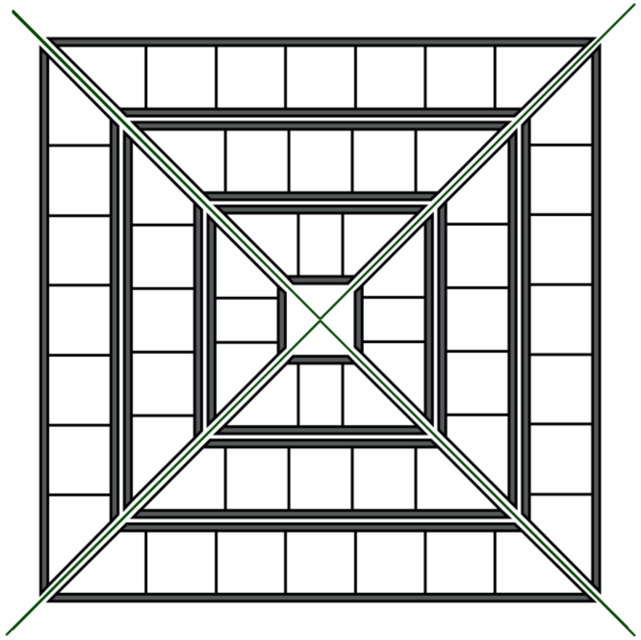
Deployable space booms – Space Solar Power Project (1)

- Solution for harvesting solar energy in space
- Collects sunlight and wirelessly transmits power to Earth



Triangular Rollable And Collapsible (TRAC) longeron

Strip
two TRAC longerons connected by battens



CONCLUSIONS

- IS represent a valuable technique to be considered in next generation manned and un-manned space structures
- IS are ‘probably’ the only solution to construct large spacecraft
- Computational mechanics can be able to make simulation of Inflatable structures with some limitations (adequate capabilities are requested)
- Available materials can be very much improved, dedicated one would be welcome (development on nanotech's could play a very significant role)
- Experiments are mandatory
- There are many ‘Ideas’ of FUTURE INFLATBALE spacecraft but difficult to implement