Mechanical design, construction and testing of multi-functional systems

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XXXIII Cycle

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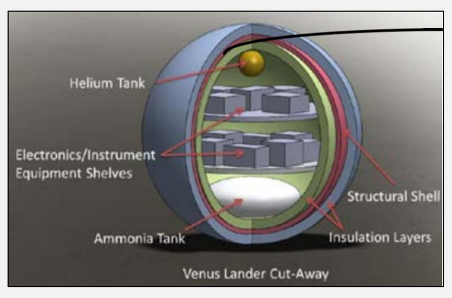
Collaboration with JPL: *Additive Manufacturing of Structural Shells for Atmospheric and Surface Probes* (E. Sunada, J.P. Borgonia)
JVSRP – JPL Visiting Student Research Program

1. Problem statement

New shell layouts of probes for planetary and deep sea exploration are currently being explored, considering integrated thermo-mechanical systems.
Venus harsh environment represents one of the most interesting and challenging applications.

Case study: Venus lander

Venus environment: p=93 bar, T=462°C – Mission target: survive 24h
Two main issues: A) buckling B) thermal control
New multi-functional shell:
A) Structural function: buckling resistance
B) Thermal function: evaporator for the thermal system integrated into the shell

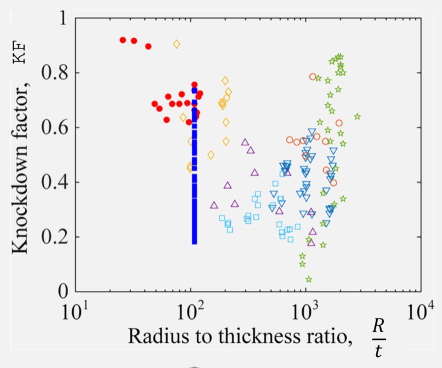


Buckling of spherical shells

Spherical shells subjected to external pressure are highly sensitive to geometry, machining or load imperfections. The theoretical critical pressure must be reduced by a knockdown factor (KF)
NASA standard: KF=14%

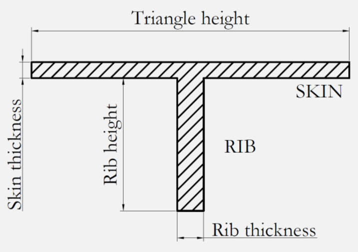
$$p_{theor} = \frac{2E}{\sqrt{(3*(1-\nu^2))}} \frac{t^2}{R^2}$$

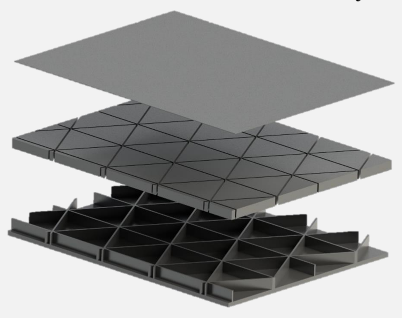
$$p_{cr} = KF \cdot p_{theor}$$



AM isogrid layout

Investigate:
- Manufacturability (additive manufacturing)
- Possible mass saving
- Robustness



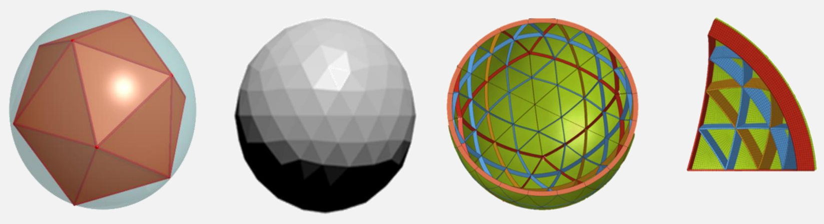


2. Isogrid layout

Isogrid spheres subjected to high external pressure were designed and optimized, using both analytical homogenization models and numerical simulations. Different types of buckling can occur, involving the general instability, the skin buckling and the rib crippling

The isogrid sphere

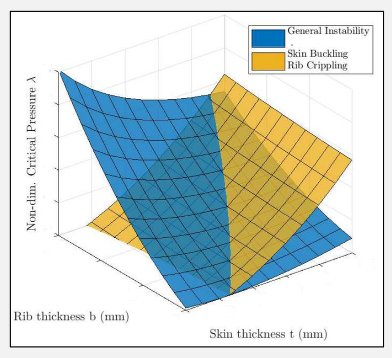
From the geodesic domes invented by R. Buckminster Fuller
Difficult to fabricate by conventional methods.
Due to the particular geometry, the behavior is isotropic.



Design and optimization

Triangular cell size, skin thickness and rib height and thickness must be optimized.

Two failure modes are possible:
A) Yielding
B) Buckling → General instability $p_{GI} = c_0 E \frac{t^2}{R} \beta * \frac{2}{R}$
→ Skin buckling $p_{SB} = c_1 E\, t\, (1+\alpha) \frac{t^2}{h^2} * \frac{2}{R}$
→ Rib crippling $p_{RC} = c_2 E\, t\, (1+\alpha) \frac{b^2}{d^2} * \frac{2}{R}$



The optimum structure is the one for which all the three modes of buckling take place at the same time

FEM simulations were performed, together with optimization algorithms (size, shape, topology opt); however, no considerable improvements have been obtained (due to the linear assumptions)

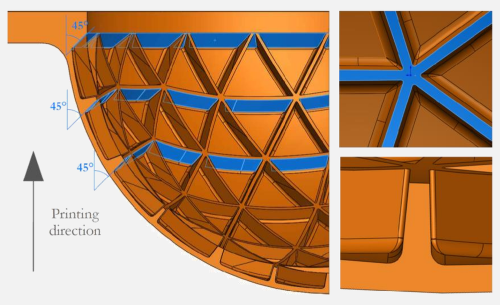
3. From ideal to real: subscale model

Sub-scale components (considering both plain and Isogrid layouts) were designed according to the analytical method previously described, fabricated by AM and tested, in order to: (1) check the manufacturability (2) validate the models.

Design updates for manufacturability

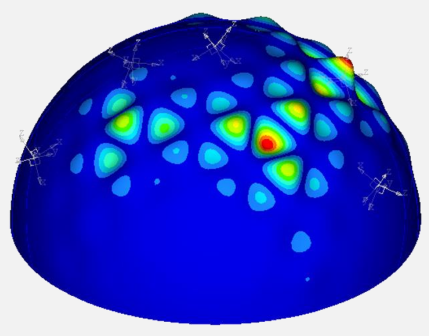
A sub-scale model has been designed, using the analytical method and considering the manufacturing constraints (powder bed size, min feature)

Fillets, chamfers and supports are added, to improve the manufacturability (avoid overhangs, reduce thermal distortions)



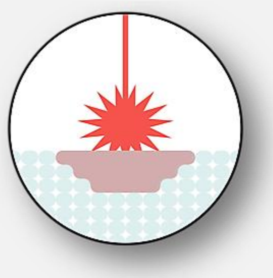
Numerical model

The mechanical behavior of the sub scale model has been investigated, considering the new geometry and using both linear and non linear FEM simulations.



Fabrication

DMLS (bed size: 250x250, min thickness: approx. 1 mm):
- 7 isogrid hemispheres
- 1 plain hemisphere
- 3 tensile bars per hemisphere are printed



Post-processing: heat treatments, support removing, flange machining

4. Testing

Experimental activities were performed on both plain and Isogrid hemispheres. Room temperature tests to failure were used to validate the models; one full sphere was tested in Venus-like conditions.
The Isogrid components exhibited a better behavior (higher KF, lower error in the predictions)

Model validation – Hydrostatic test

Hydrostatic pressure test // Test articles: 3 Isogrid hemispheres + 1 plain hemishere
Pressure: ramp to failure // Temperature: ambient temperature // Time: approx. 30 min
Instrumentation: pressure gauge, camera recording (severe time restrictions)
Results post-processing: visual inspection, 3D scanning of the geometry before/after testing, fracture surface analysis

Relative environment test

Hot Isostatic Pressing facility // Test articles: 1 full plain sphere
Pressure: ramp to approx. 100 bar // Temperature: ramp to approx. 500°C // Time: approx. 6h
Instrumentation: chamber pressure and temperature gage
Results post-processing: visual inspection, 3D scanning of the geometry before/after testing

Results

Hydrostatic tests:
Plain: buckling near the manufacturing imperfection
linear buckling KF ≈ 30% (according to the literature data, in spite of the defect)
non linear analysis – pred vs exp error = 60% (the imperfection is not simulated)
Isogrid: good match between predictions and experimental results
buckling KF = 44% (higher than the plain sphere)
non linear analysis – pred vs exp error = 9%

Results and details are not disclosable at the moment. Authorization for releasing is pending.

On going activity

Tensile tests on coupons, to assess the material properties of the production lot

Analysis of the experimental results: failure mode? local buckling?

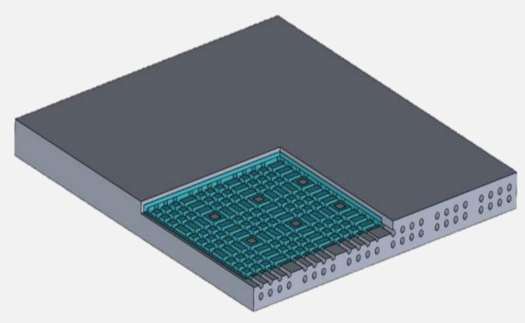
Processing CT / Blue light scanning to detect manufacturing and geometric imperfections (before testing) and to measure displacements (after testing)

Evaluation of mass saving and fabrication time saving, as a function of the size of the component

Future work

In the frame of the integration of the structural and the thermal systems, the mechanical performance of AM metallic porous wick need to be investigated, by means of tensile and compressive tests on coupons.

In addition, different types of stiffeners can be explored. For example, for components subjected to a compressive stress state, lattice structured could be investigated. Cell type and size, as well as strut size, should be examined.



Publications

E. Brusa, R. Sesana, **E. Ossola** (2017) “Numerical modeling and testing of mechanical behavior of AM Titanium alloy bracket for aerospace application”, Procedia Structural Integrity, 5, 2017, pp.753-760.

E. Brusa, **E. Ossola**, (2018) “Control of thermomechanical anisotropy of high speed rotor with permanent magnets in micro energy harvesters”, Mechanics of Advanced Materials and Structures, in press.

S.Pagliassotto, R.Sesana, **E. Ossola**, E.Brusa (2018) “On the role of material processing and assembling upon the fatigue life of bearing balls”, submitted to Engineering Failure Analysis

E. Ossola, S. Pagliassotto, S. Rizzo, R. Sesana, (2018) “Microinclusion and Fatigue Performance of Bearing Rolling Elements”, submitted to Mechanical Fatigue of Metals – Experimental and Simulation Perspectives, Structural Integrity

Attended classes

Automotive transmissions	(05/12/17, 20h)	Politecnico di Torino
International Project Management in CFRP	(21/12/18, 3h)	Politecnico di Torino
LabVIEW Core 1	(04/06/18, 24h)	Politecnico di Torino
Project management	(04/09/18, 5h)	Politecnico di Torino
Giunzioni strutturali	(to validate, 30h)	Politecnico di Torino
Spacecraft Thermal Control Workshop	(19/03/18, 24h)	The Aerospace Corp

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