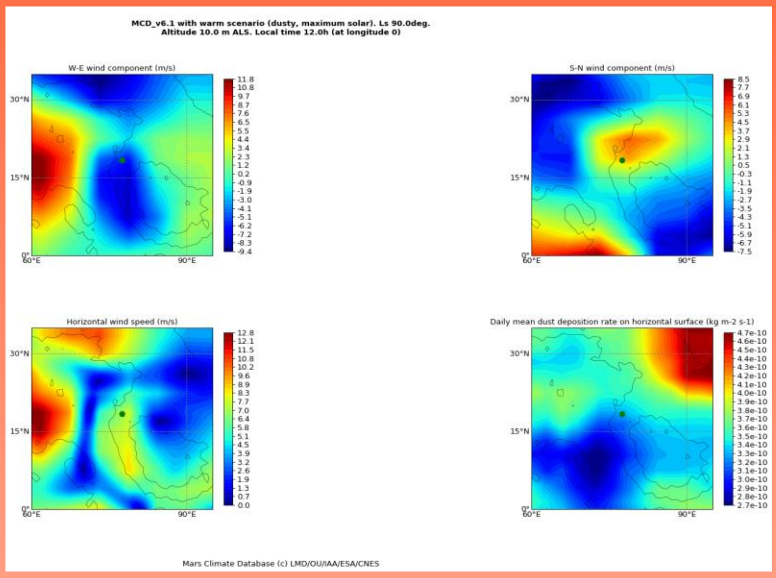
FEM analysis and manufacturing technology of a 3D-printed Martian habitat considering load and material selection

Context and objective



Conditions on the landing site generated from Mars Climate Database (https://www-mars.lmd.jussieu.fr)

Mars exploration

With plans for sustained Martian presence by space agencies like ESA and NASA, robust habitat design is crucial. These habitats must endure extreme environmental conditions, compared to buildings on Earth.

Aim of the thesis

This thesis proposes a 3D-printed Martian habitat using in-situ resources (ISRU) with structural analysis using the Finite Element Method (FEM). The objective is to determine material feasibility and structural resilience under Martian-specific loads, proposing framework for future design and construction challenges.

Methodology and tools

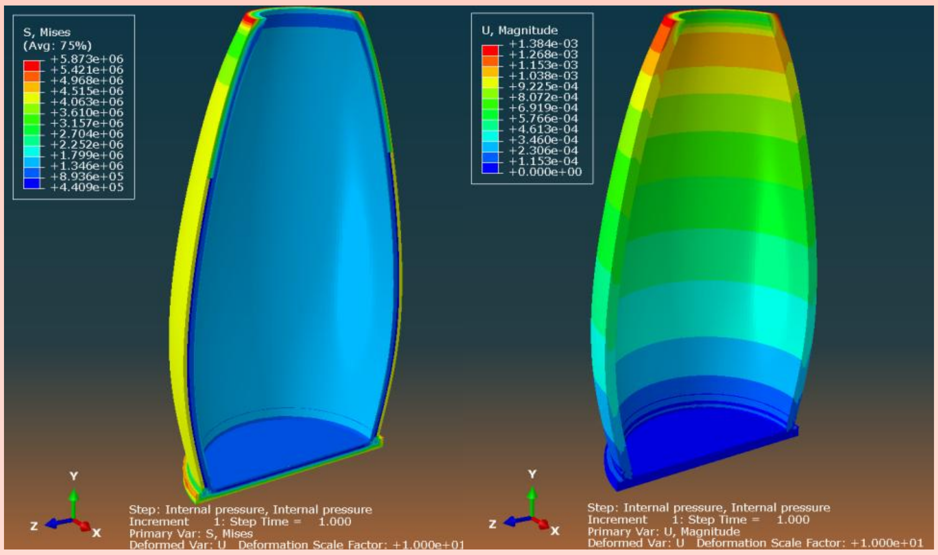
Table 3.5. Properties of Martian sulphur concrete. Based on various authors [18].

Aggregate Type	wt%	Binder type	wt%	E [GPa]	ν	f_{cm} [MPa]	f_{ctm} (flex) [MPa]	f_{ctm} (split) [MPa]	ρ [kg/m³]	γ_m [kN/m³]	α (×10⁻⁶) [1/°C]	
JSC M-1A	50	sulphur	50	6.5	0.18	56	3.7	4.4	1990	7404		[100] [19]
JSC M-1A	57.5 -60	sulphur	40-42.5			17	0.2		1990	7404		[100]
JSC M-1A	50	sulphur	50			58-63	1.6	2.8-5	1990	7404		[100]
JSC-1 L	65	sulphur	35			15.9-17.2						[106]
JSC-1 L	65	sulphur	35			33.8	3.7	3.7	2200	8186		[110]
MGS-1	50	sulphur	50	20.3	0.25							[117]
MGS-1S	50	sulphur	50	36	0.25							[117]
MMS-1	50	sulphur	50	21.6	0.25							[117]
Quartz	70	sulphur	30	10		12.5	2.6		2428	9034		[107]
"S"[20]	73.1	mod. sulphur	26.9	29.1		63.3		3.6	2389	8889	17.2	[98]
"F"	71.4	mod. sulphur	28.6	40.4		88		6.6	2447	9105	13.8	[98]
"R"	68.9	and ashes	31.1	32.5		76.6		4.4	2302	8565	14.8	[98]
JSC-M-1A	40	sulphur	60	9.2-9.9		3.4-3.9	5.2		1974	7345		
JSC-M-1A	30	sulphur	70	3.6-5.9		0.4-1.3	5.7-6.2		1958	7285		[109] [21]
JSC-M-1A	50	sulphur	50	9.0		3.3	1.6		1990	7404		
MMS-1	50	sulphur	50			54	4.2	2.9	1990	7404		[112] [22]
MMS-1	40	sulphur	60			36	4.3	2.6	1974	7345		
MMS-1	50	sulphur	50			34	2.7	2.5	1990	7404		[112] [23]
MMS-1	40	sulphur	60			34	3.7	2.1	1974	7345		
Silica sand and magnetite	60	sulphur	40			16.1-18.7			2997	11150		[104] [24]
	60	sulphur	40			10.2			2997	11150		[104] [25]
terrestrial aggregate	various	sulphur	various	35-50		60-115	10-16		2400	8930		[118] [26]
JSC-1 L	60	sulphur	40			53.4 - 55.8		8.6	2504	9317		[102]
(-)	0	sulphur	100			10-14.4		1.6	1910	7107		[102]

Tabular overview of the regolith-based materials discussed (left). Basalt fibres possible to use for 3D printing (right).

- Possible materials have been discussed with focus on their usability and mechanical parameters. Regolith composites, specifically sulphur concrete - *marscrete*, have been chosen as most promising materials for the 3D-printing technology.
- 3D-printing-based construction technology has been proposed and discussed.
- A simplified model of a Mars habitat based on NASA's 3D-Printed Habitat Challenge have been prepared.
- The thermal, internal pressure, wind, and cumulated dust analysis under extraterrestrial parameters based on local climate parameters for the chosen location of Jezero Crater (Perseverance landing site) has been performed.

Results and significance



Equivalent stress in MPa calculated according to HMH criterion (left) and total deformation in m across the structure (right) for the load combination.

Innovative edge and key findings

- Habitat structure safely able to withstand Martian environmental and operational loads as shown through FEM-based validation model
- Internal pressure as the dominant design constraint
- Mars-specific adaptation of Eurocodes proves valid and functional
- Mars regolith's abundance combined with the recent discovery of pure sulphur in deposits enabling efficient ISRU technologies
- ISRU using regolith-based *marscrete* proved credible
- Eurocode- based approach adapted to Martian conditions
- Bibliography including over 150 papers and other sources from the fields of materials science, space architecture, and planetary geology.
- Framework for future design challanges proposed, further development of structural codes for space applications needed

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