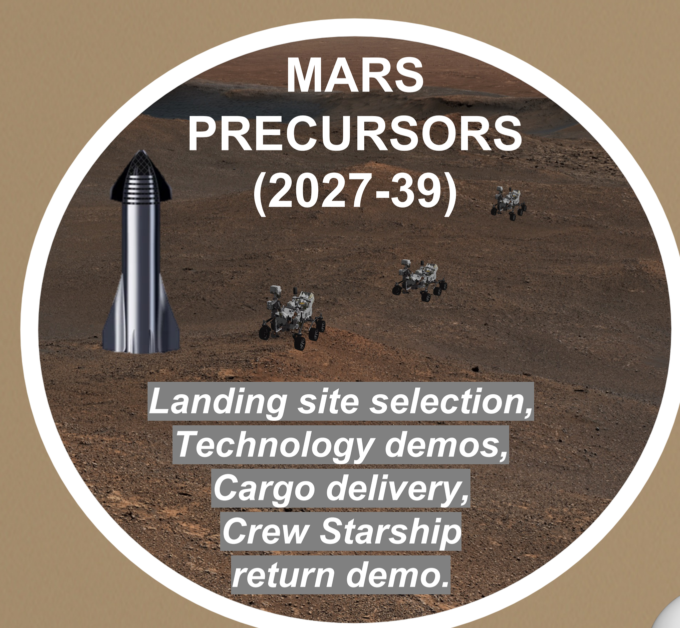
Pale Red Dot

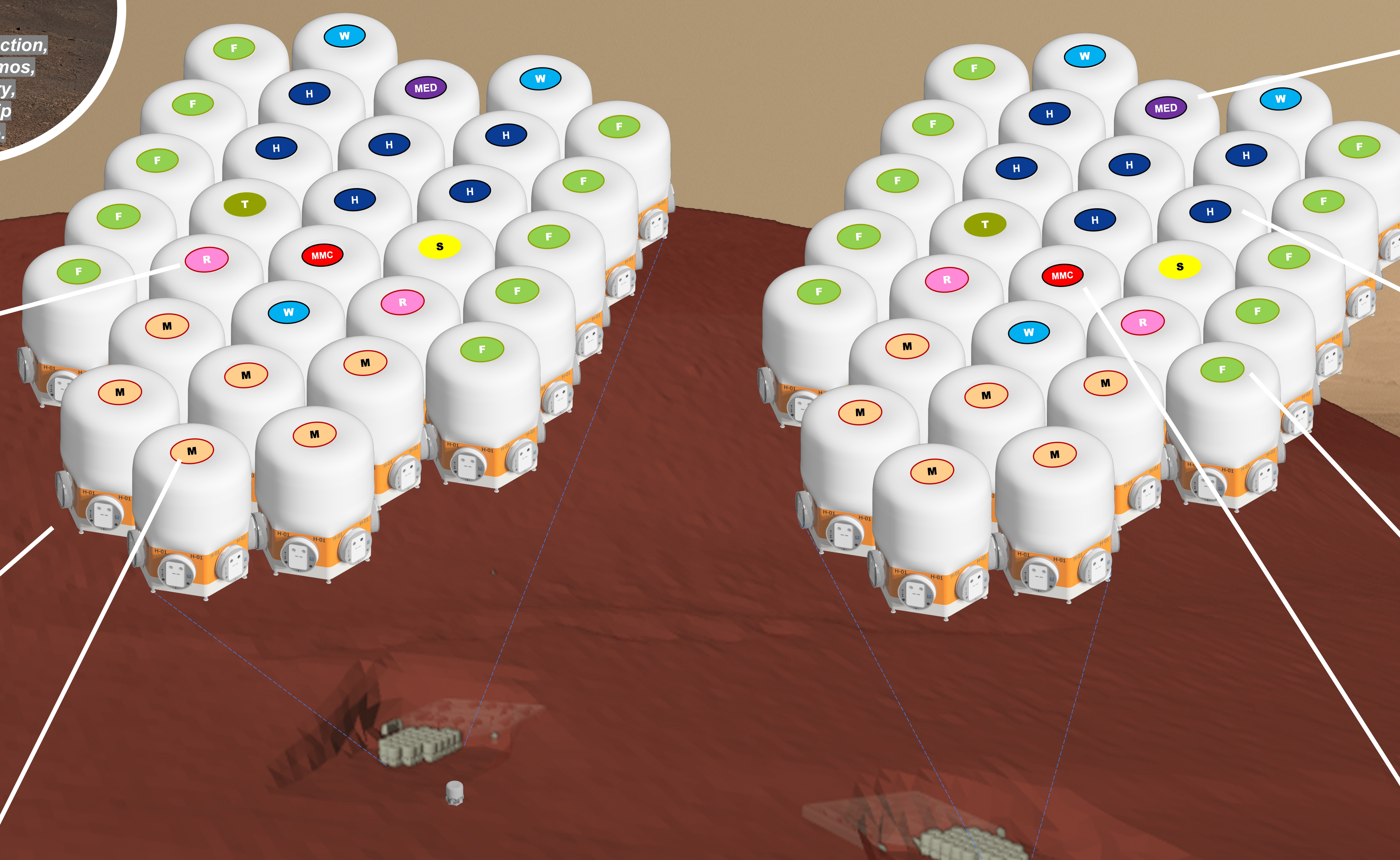
Polis-based **A**rchitecture for the **L**ong-term **E**xploration of the **R**ed planet, with **E**xciting and **D**iverse **D**evelopmental **O**pportunities to **T**hrive

NIA / NASA 2023 RASC-AL Forum | June 2023

Massachusetts Institute of Technology

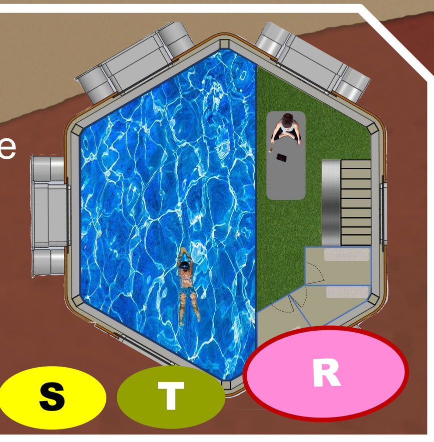
EARTH-INDEPENDENCE ESTABLISHING MISSION (2040 - 2050): TWO VILLAGES WITH 36 CREW





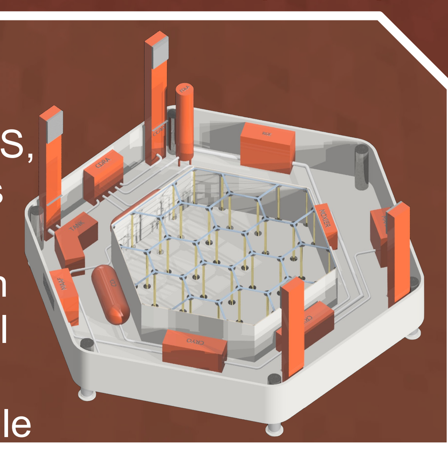
THRIVING, NOT JUST SURVIVING

- ✓ 7-10 year mission: must support non-work living
- ✓ 1,100 m^2 for social leisure
- ✓ Lab, terrarium, pool, bar, restaurant, arts, games
- ✓ Large mission, 2 villages infuse essential social diversity and complexity



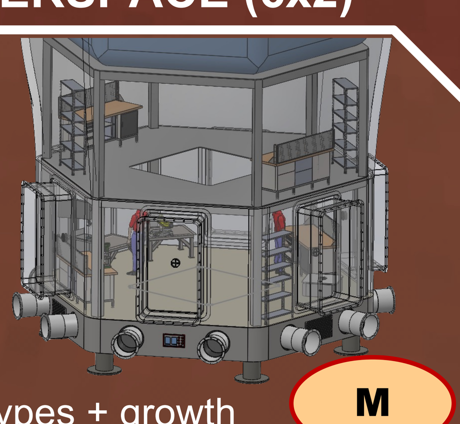
MACHINES PROTECT HUMANS: DUAL-MODE LIFE SUPPORT SYSTEMS (31x2)

- ✓ Similar redundancy (31)
- ✓ Dissimilar redundancy: open + closed loop ECLS, 2 physico-chem sources for O_2, N_2, CO_2
- ✓ Water tanks for radiation protection, H2O, thermal
- ✓ All waste pyrolyzed, sterilized in offsite module



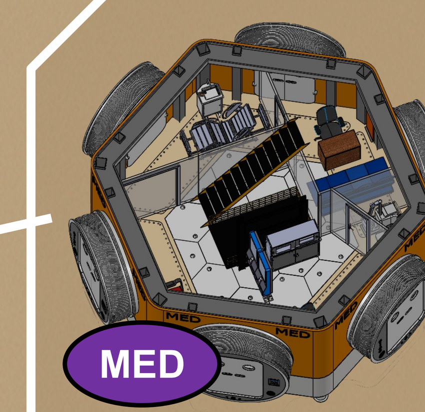
HUMANS PROTECT MACHINES: LARGE, FLEXIBLE MARS MAKERSPACE (6x2)

- ✓ ~1,000m^2 makerspaces
- ✓ 5-axis CNC, metal and plastic AM, full machine shop & electronics shop
- ✓ Feedstock production
- ✓ Parts fabrication
- ✓ Integration, assembly
- ✓ Low-level repairs of all types + growth



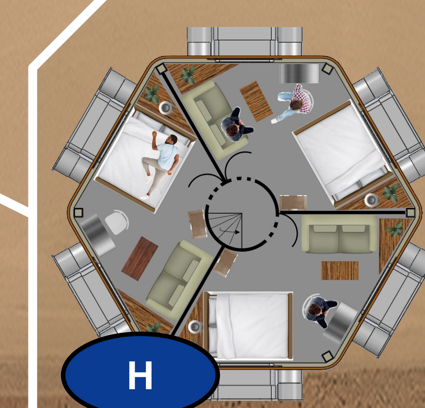
Total Mass	5,828 MT
Power demand / available	15.9 MWe / 30 MWe
Pressurized Volume	15,963 m^3 + 21,408 m^3 tunnels
Lifecycle Cost	$81.2 billion (incl. 30% margin)
# launches	81 + refueling
Crew and duration	36 crew for 10 years

LEVEL V MEDICAL CARE FACILITY (1x2)



- ✓ 6 medical specializations
- ✓ Incl. psychosocial care
- ✓ Doctor on call, pharmacy
- ✓ Emergency Department
- ✓ Surgery and ICU
- ✓ Exam room & imaging
- ✓ Quarantine facilities
- ✓ Second hospital in other village for concurrent ops

LARGE, PRIVATE, QUIET BEDROOMS WITH SPACE FOR GUESTS (18x2)

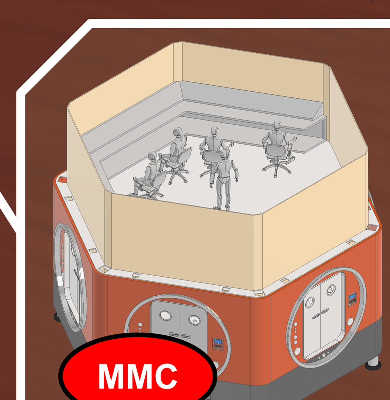


- ✓ Radiation shield from 3m water tanks directly above
- ✓ 10 m^2 of private space
- ✓ Full queen bed and sofa
- ✓ Desk and chair, TV screen
- ✓ No traffic by the door
- ✓ Spaces below offer leisure facilities: games, music, private video messaging

FARM MODULES SIZED FOR 200% OF DAILY FOOD REQUIREMENT (10x2)

- ✓ ISS heritage hydroponics
- ✓ 1,600 m^2 of growing area
- ✓ Using highly manufacturable farm systems
- ✓ Provides plant, aquatic and poultry products
- ✓ Seeds budget included
- ✓ Nutrient recycling using aquaponics and pyrolysis

HUMANS ON THE LOOP: MARS MISSION CONTROL (1x2)



- ✓ **Mars Mission Control (MMC)** in each village
- ✓ The two villages alternate between prime and backup
- ✓ High-bandwidth comms
- ✓ Can teleoperate any asset on Mars surface or in orbit
- ✓ Training and simulations

SAFE, VALUABLE AND SUSTAINABLE APPROACH

Selected two villages of 18 crew each as best combination of safety, value

- ✓ Four Mission-value full-time equivalent (MVFTE) for surface exploration
- ✓ Radiation dose 528 mSv, 48 hour workweek, cost $290m per MVFTE per yr
- ✓ Capacity to expand habitat: construct tunnels, make new habitat systems

Villages x Crew per Village	1 x 4	1 x 6	1 x 9	1 x 12	2 x 12	2 x 15	2 x 18	2 x 21	3 x 18	3 x 21
Workweek [hrs]	83.9	67.7	64.5	61.6	53.7	53.5	48.0	40.5	37.6	29.6
Year 10 Hab Volume [m3/crew]	374	291	277	312	906	927	955	927	983	975
Mobile MVFTE	0.0	0.0	0.0	0.0	3.3	3.9	4.0	4.3	4.5	4.4
In-habitat MVFTE	0.9	2.2	4.2	6.3	9.6	13.4	13.1	13.3	12.9	11.4
Unutilized MVFTE	0.0	0.0	0.0	0.0	1.9	3.7	10.8	21.9	35.0	56.3
Mission duration [years]	7	7	7	7	7	7	10	10	10	10
Radiation dose [mSv]	653	682	679	682	565	563	529	498	503	465
Non-value crew time liens	94.8%	91.5%	88.9%	87.4%	85.3%	83.4%	81.5%	77.6%	76.9%	72.7%
Manufacturability %	15%	30%	50%	75%	90%	90%	90%	90%	90%	90%
In-situ food %	4.5%	18.8%	18.8%	50.0%	50.0%	100.0%	100.0%	100.0%	100.0%	100.0%
+ Carrying Capacity p.a. [crew]	0	0	0	0	0	47	36	30	8	0
5T resupppply constraint	84%	95%	121%	102%	179%	97%	99%	98%	98%	101%
Number of Launches	234	238	256	319	526	589	773	809	1088	1200
Lifecycle cost [$m]	$33,893	$34,283	$37,358	$42,150	$59,265	$67,283	$81,148	$84,024	$111,135	$119,965
Cost per MVFTE p.a. [$m]	$5,593	$2,277	$1,277	$949	$571	$459	$290	$213	$213	$166
Peak annual cost [$m]	$2,488	$2,522	$2,769	$3,227	$4,826	$5,508	$6,639	$6,907	$9,181	$10,016

Image Credit: NASA/JPL-Caltech/MSSS

CONCEPT: LARGE MISSION, DIVERSE CAPABILITIES TO MEET NASA NEEDS

All other things equal, a large mission offers:

- ✓ Capability to manufacture systems from ISRU
- ✓ Economies of scale with respect to crew time
- ✓ Productivity gains from crew specialization
- ✓ More international and commercial partners
- ✓ More science, exploration & mission value time
- ✓ Diversity of crew and genuine social life on Mars
- ✓ Capability to build, outfit radiation-proof habitats

Cost benefits of large vs small missions:

- ✓ Amortizes DDT&E of 30 types over 503 units
- ✓ Lower costs per mission-value person on Mars

MULTI-LAYERED STRATEGY TO MITIGATE SYSTEMS FAILURES

First line of defense – high redundancy

- ✓ Similar redundancy in modular systems
- ✓ Dissimilar redundancy in critical functions
- ✓ Energy-rich, water-rich, food-rich, air-rich, time-rich

Second line of defense – high commonality

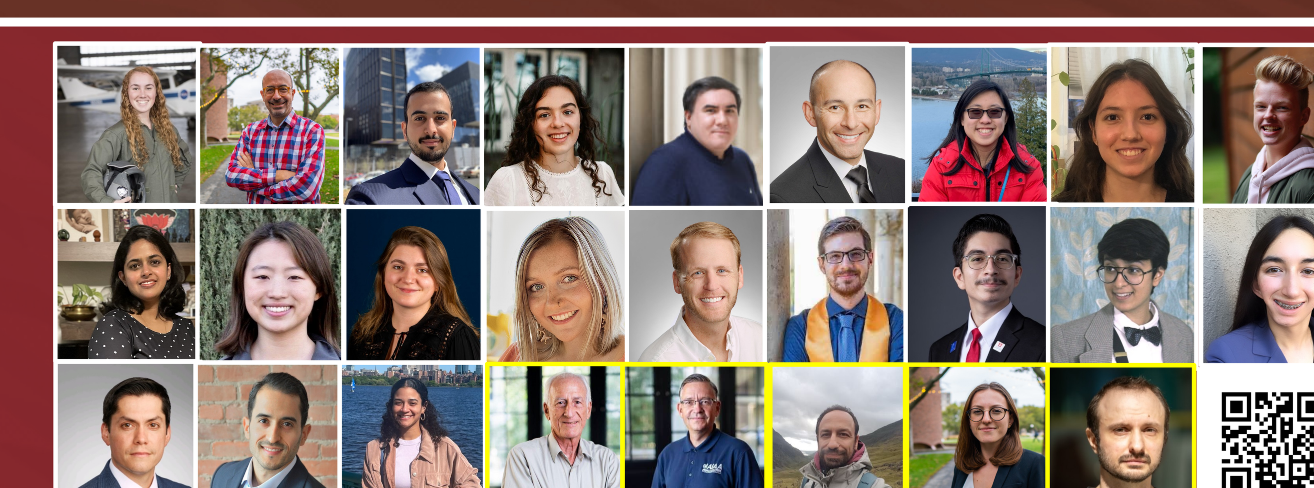
- ✓ Subsystem- and part- level commonality for easier maintenance logistics, tactical cannibalization

Third line of defense – high manufacturability

- ✓ High manufacturability of all systems plus free crew time to support any repair & within resupply limit

Last line of defense – 'blast radius reduction':

- ✓ Farm airflows set to minimize cross-contamination
- ✓ Villages can rescue each other in case of disaster



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