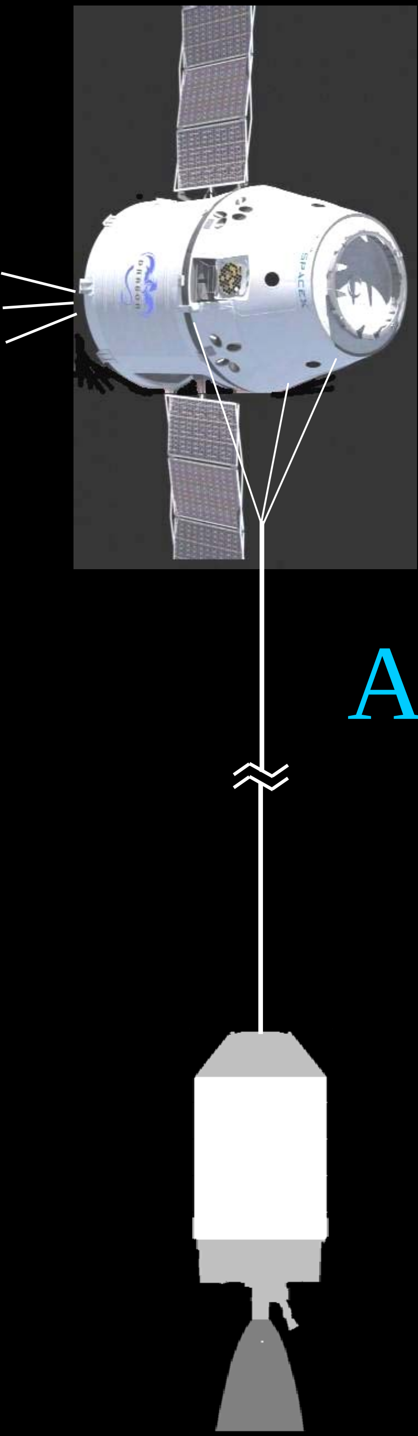
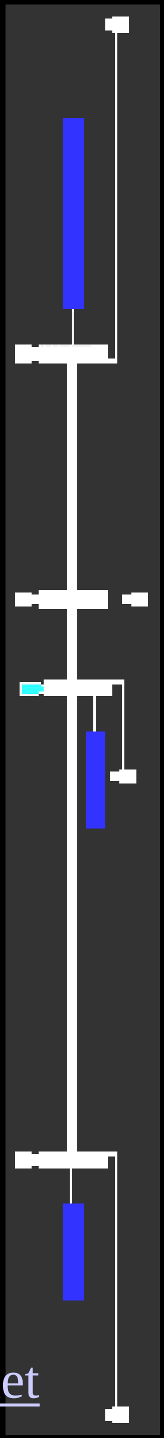


Design Concepts for a Manned Artificial Gravity Research Facility

2010 IAF Congress, Prague

Sept. 27, 2010; revised April 30, 2011



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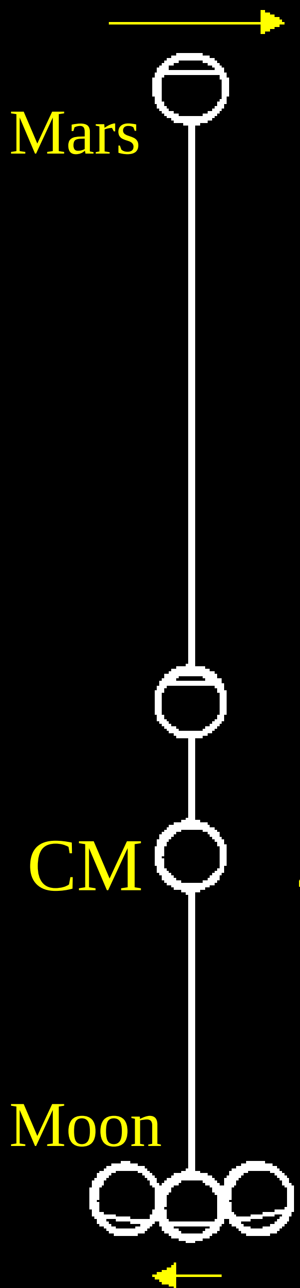
Possible Goals for Artificial Gravity Facility



1. Focus on the overall effects of long-term hypogravity

2. Allow realistic planning for Moon & Mars settlements

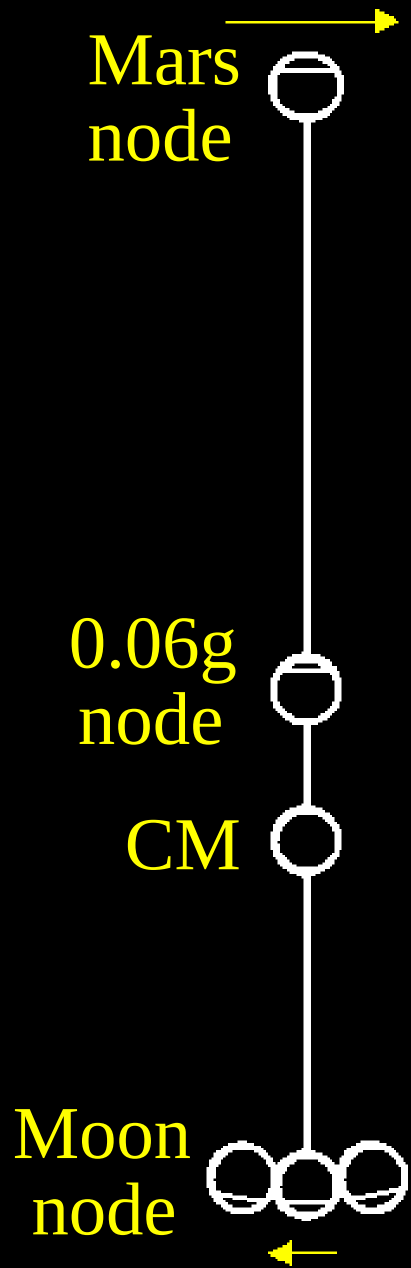
3. Such a facility can address questions like:

- **a.** Can people stay healthy for years—and years later?
- **b.** Can mice and monkeys reproduce normally?
- **c.** Can monkeys raised in low gravity adapt to earth?
- **d.** What plants may be useful for food production?
- **e.** Does hypogravity allow advances in basic biology?

4. The facility can also resolve nearer-term issues, like:

- **f.** How much gravity should we use in cruise to/from Mars?
- **g.** How much gravity should we use on-station near NEOs
- **h.** What spin rates and designs are desired for cruise?
- **i.** What gravity countermeasures may ***still*** be needed?

Basic Moon/Mars Dumbbell Concept



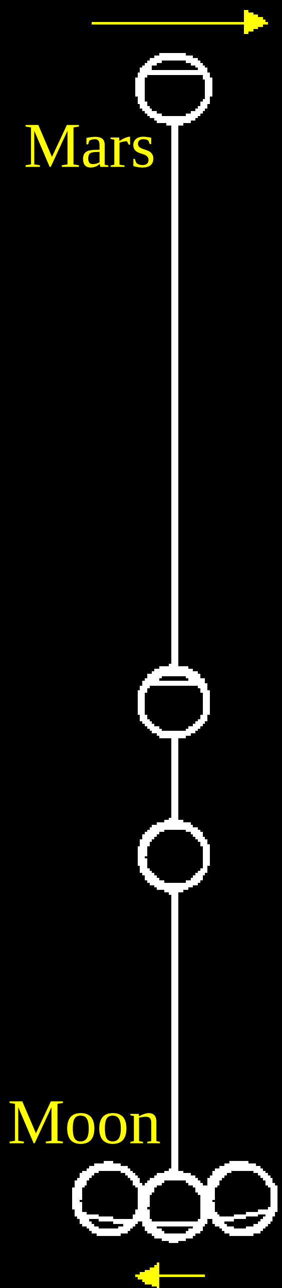
A Key Challenge:

We really don't know what rotation rates are reasonable, since ground-based rotating rooms have ***very*** different effects. We need better tests of rotation & Coriolis susceptibility for these facilities. Until then, we should consider a variety of lengths ***and designs***:

4 Options for Radial Structure:

Spin rate	Length	Radial structure	Key length-limiters:
>**2.0** rpm	<120m	Rigid modules	Mass of radial modules
>**0.80** rpm	<760m	Airbeam tunnels	Tunnel area, impact risk
>**0.55** rpm	<1600m	Tunnels+cables	Area; post-cut perigees
>**0.25** rpm	<8000m	Cables	Cable mass; node “

Why Aren't Rotating-Room Tests Adequate?



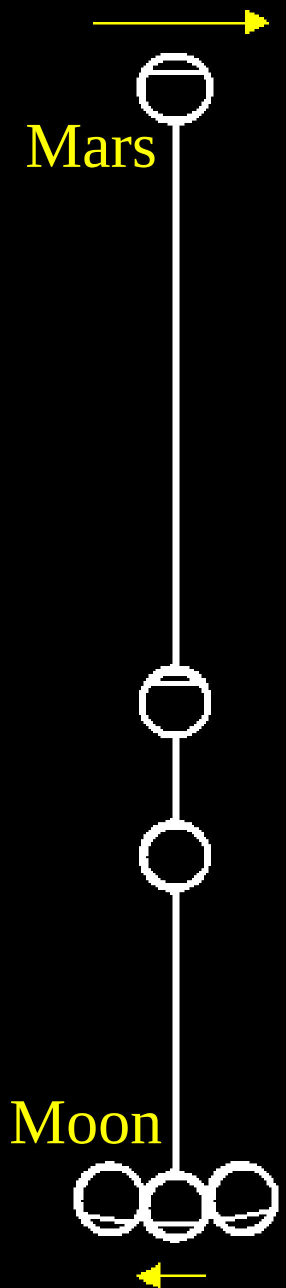
1. Different effects of rotation on the inner ear:

- In rotating rooms, the felt rotation axis and rate stay the same except when you tilt your head up or down.
- In orbit, the axis and/or rate change if you turn around.
- Ground tests show you can adapt to spin reversal, but it takes time. In orbit, spin reversal will be common.

2. Far different felt Coriolis accelerations:

- In rotating rooms, horizontal motion always causes the same felt side-force, and your weight does not vary.
- In orbit, you get heavier if you walk with the spin, and lighter against it. This may induce stumbling, as can occur if you walk in an elevator as it starts or stops.

How Can We Determine Allowable Spin?



1. Slowly rotate seat with subject's head tilted back

- Then ***part*** of the spin is in the same felt axis as in orbit.
- A co-rotating visual field is probably also needed.

2. Some ground tests can simulate Coriolis effects:

- A "research elevator" like the NASA Vertical Motion Simulator can move in response to occupant motion.
- Tests can evaluate whether visual cues aid adaptation.

3. Finally, do Gemini-like tests on the way to ISS:

- Dragon can use its spent booster as a counterweight.
- Spend 2-3 days phasing at lunar to Mars gravity levels.

Why 0.06 Gee, and not Just Moon and Mars?

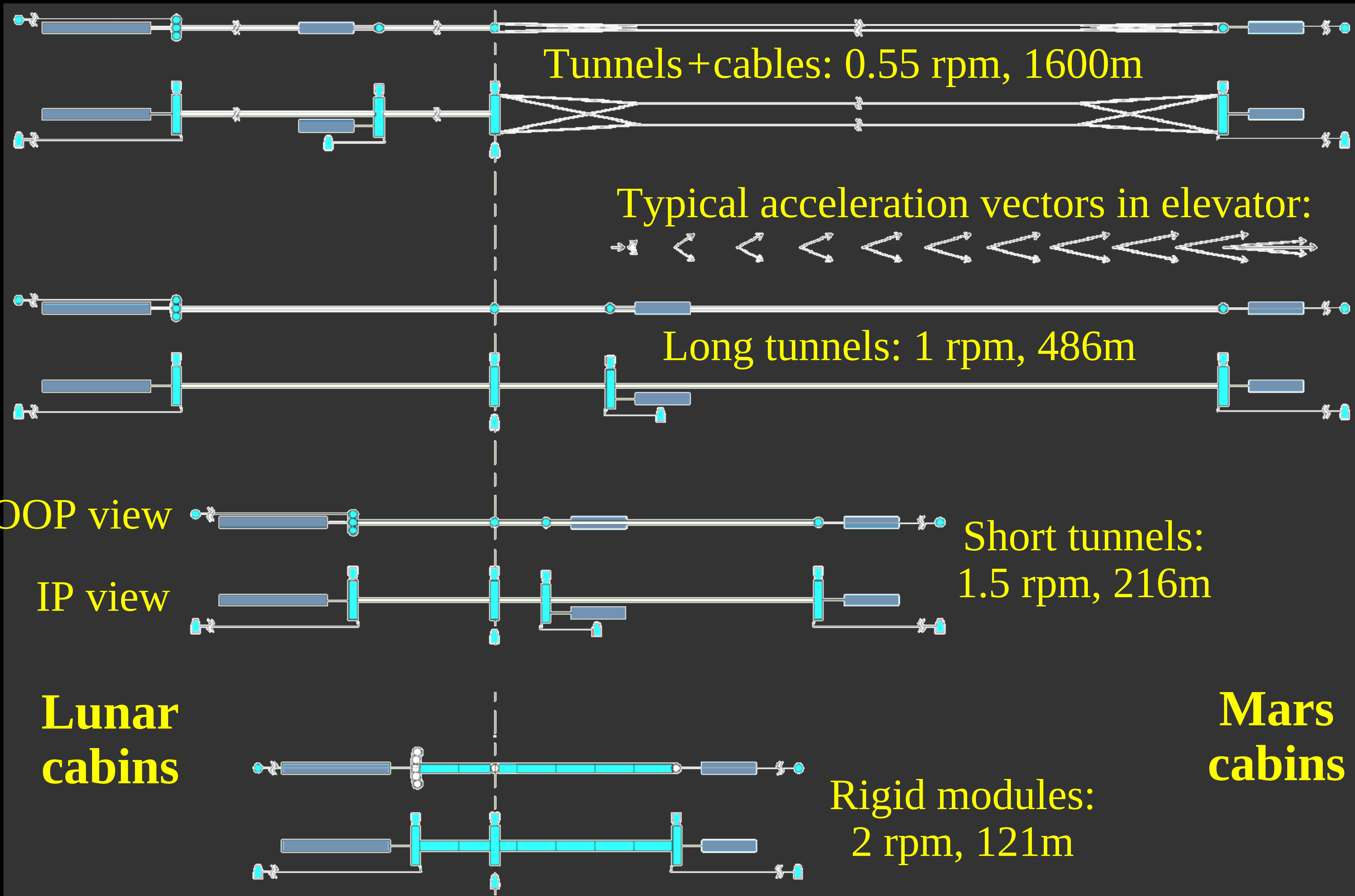
1. It's the next ~1/e step, after Earth—Mars—Moon
- This makes it a useful step for fundamental bio studies.
- Nobody knows what levels trigger gravity responses.

2. It may be the lowest level allowing intuitive behavior
- Sitting, using a desk, hygiene, even rolling over in bed.
- It may not require days of accommodation—or may aid it.
- It may be popular with tourists, or for unique exercises.

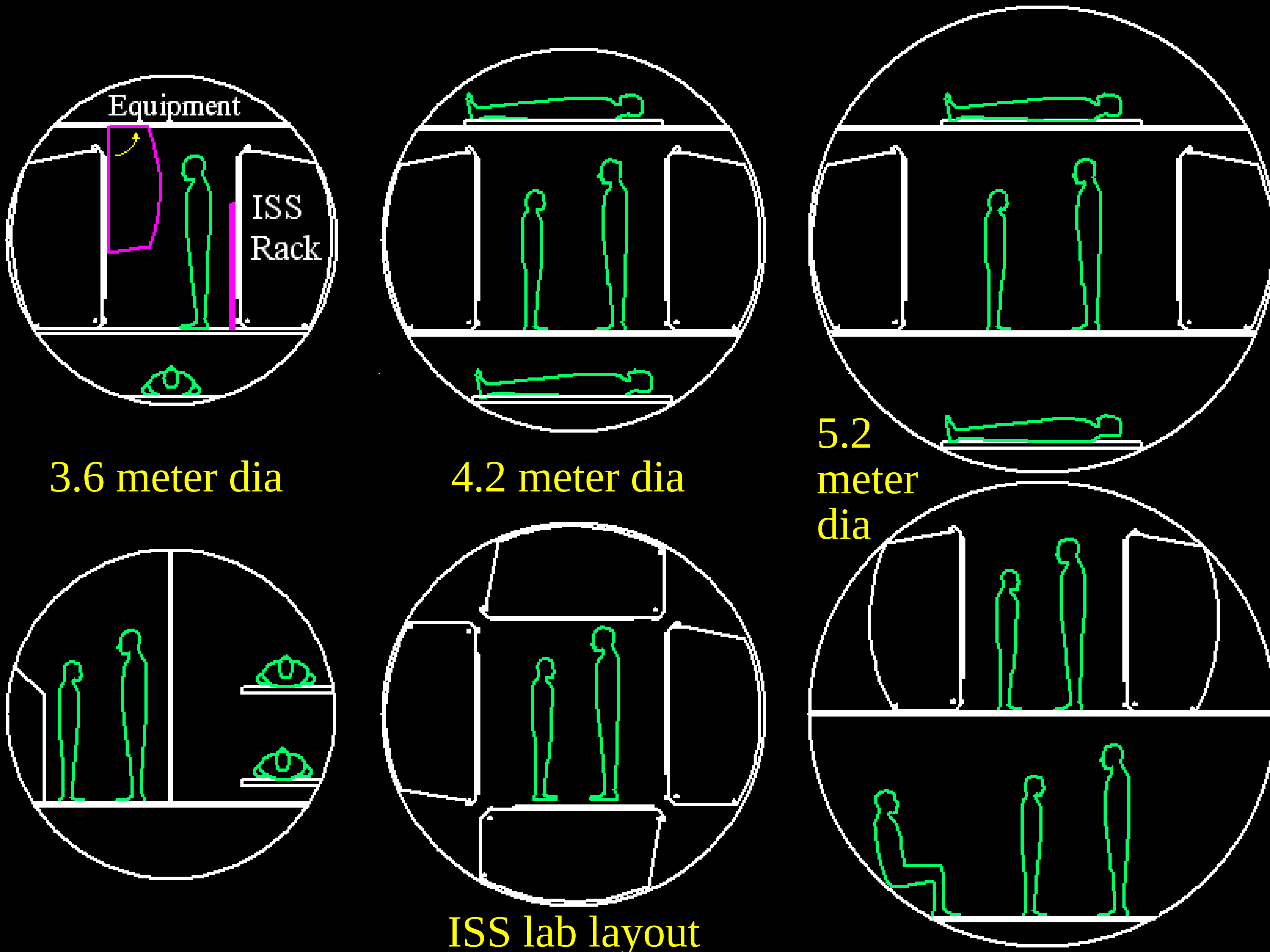
3. It's also good if you want some gravity, but not much
- Plant growth tests; satellite assembly, etc.

4. Finally, it's very easy to add: same hardware, etc.

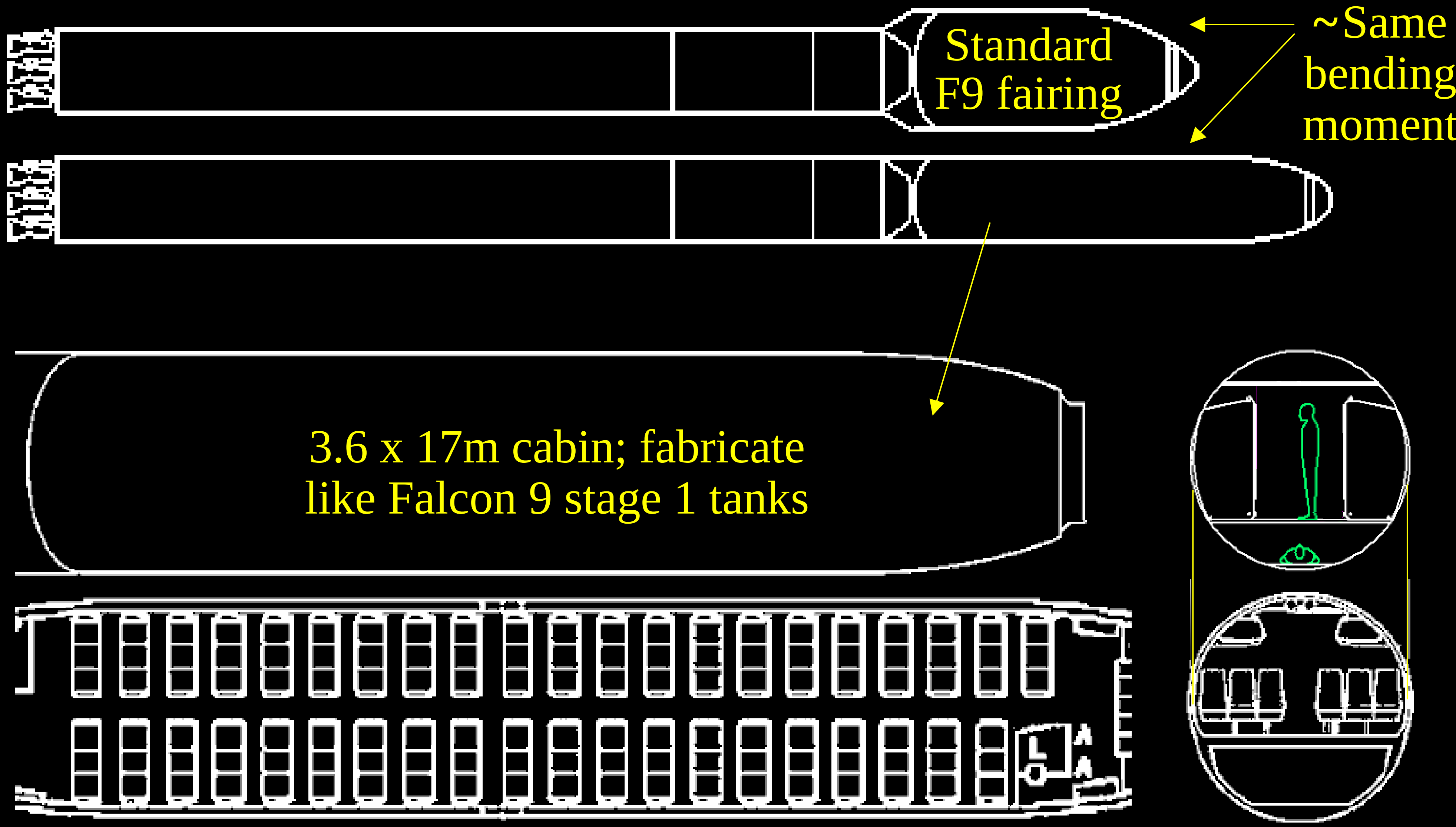
Radial Structure Options vs Length



Some Cabin Layout Options



Falcon 9 Cabin Compared to 737-600



3.5 x 18m 737-600 cabin

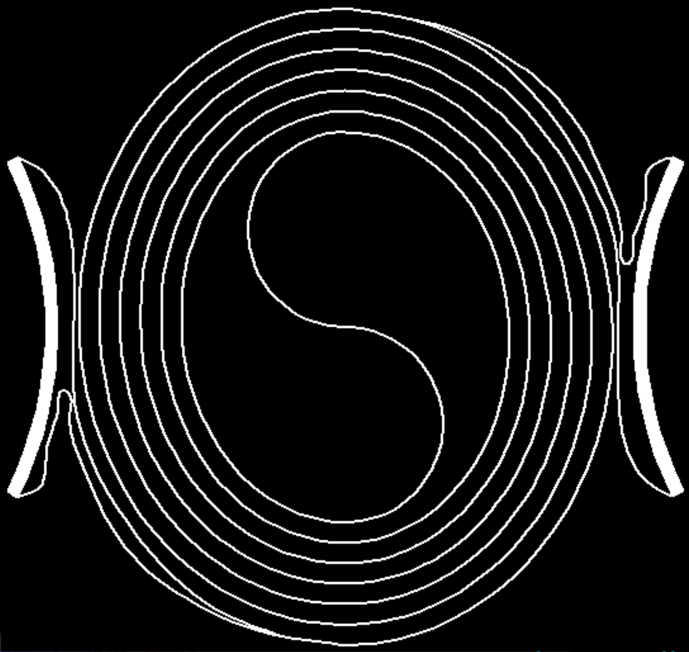
Airbeam Tunnels for Radial Structure

Inflatable airbeams

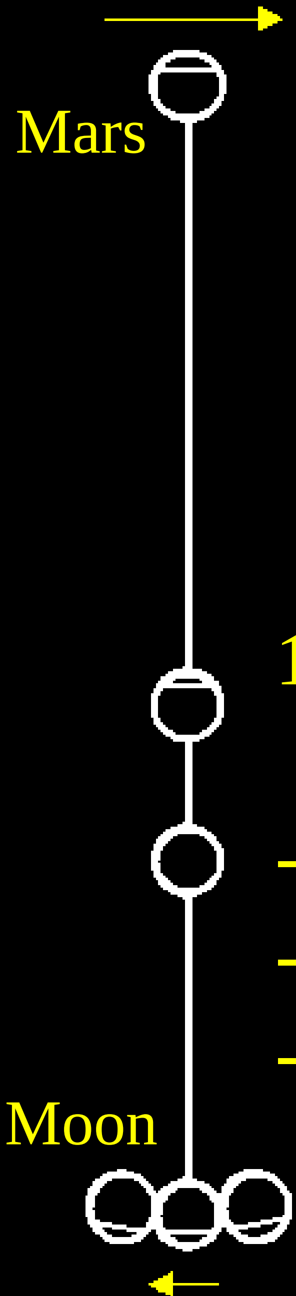
- Vectran fiber in flexible matrix
- Damage tolerant; easy to customize
- Two people can carry beam at left

Tunnel stowage for launch

- Fold deflated beam in half & roll up
- Keeps rigid end fixtures on outside:



Five Stages of Facility Development

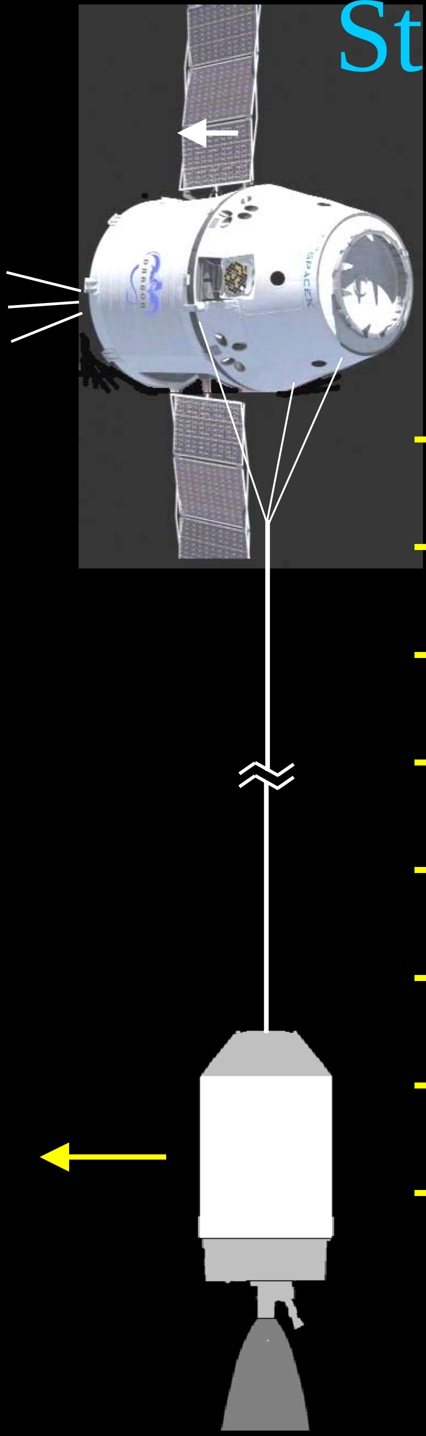


<u># cabins and key new operations</u>

0	Tether crewed Dragon to booster, on the way to ISS
1	Launch 1 cabin, berth capsule, spin up with booster
3	Launch 2 more cabins; join; use any counterweight
6	Launch 3 more cabins + tunnels; join to lunar node
14	Launch 8 more cabins, despin; attach; & spin up

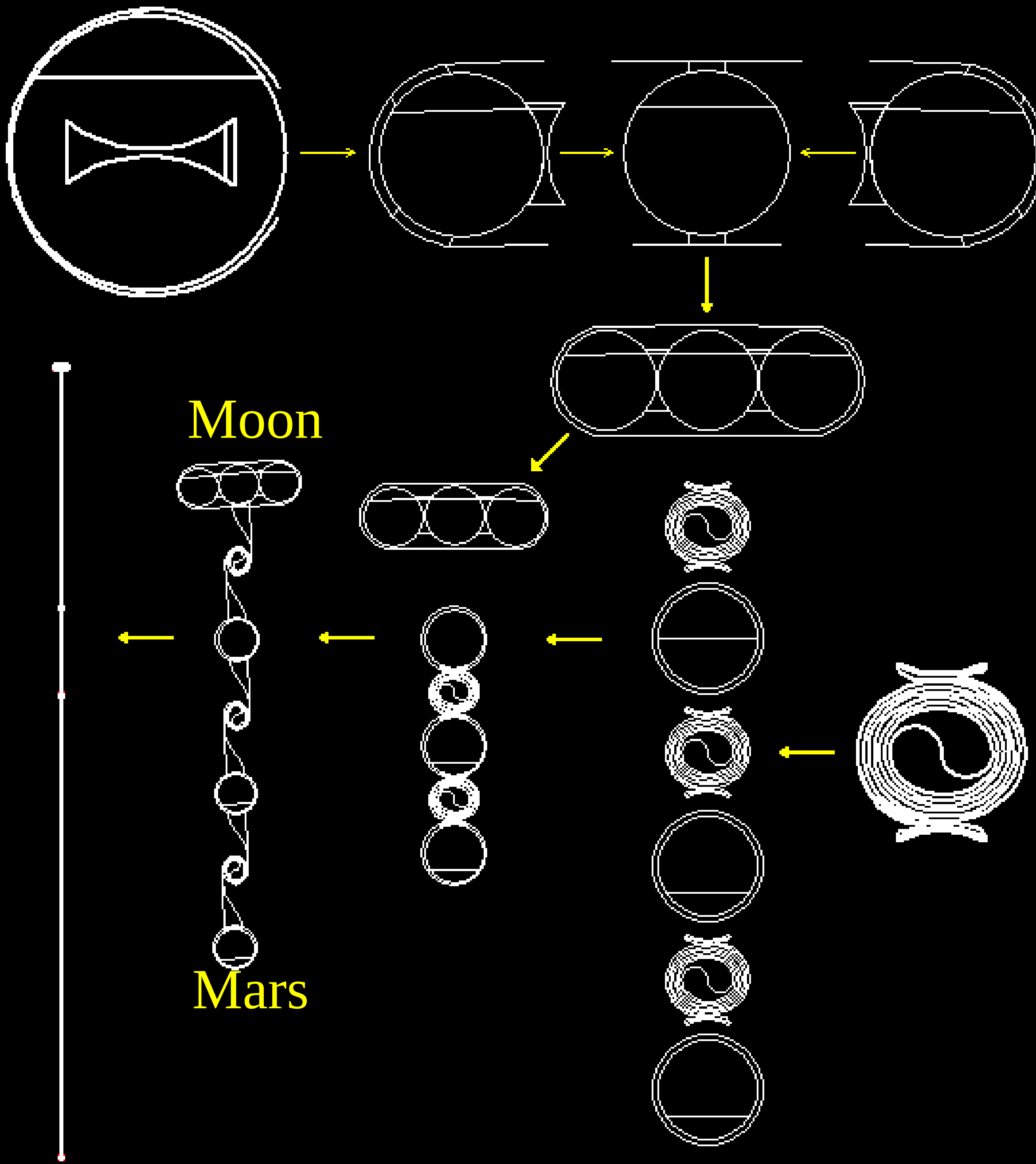
- The first 3 stages are developmental precursors.
- A final decision on radial structure is needed by stage 4.
- Stage 5 requires 8 more cabins; do only when needed.

Stage 1: Gemini-like Tether Tests



- After MECO, pay out tether from Falcon to Dragon
- Can be done during phasing, on any flight(s) to ISS
- Spin up w/pulsed posigrade burns during phasing
- Kite bridle on manned end can stabilize its attitude
- Like Gemini XI test, but longer tether & faster spin
- 150m from CM, 0.6-1 rpm gives 0.06-0.16 gee
- Release spent booster when it is moving backward
- To deorbit booster, boost in south & release in north

Stages 2-4: Initial Cabin Assemblies



Stage 2: 1 cabin

- 1 cabin + spent booster
- Can test trapeze capture

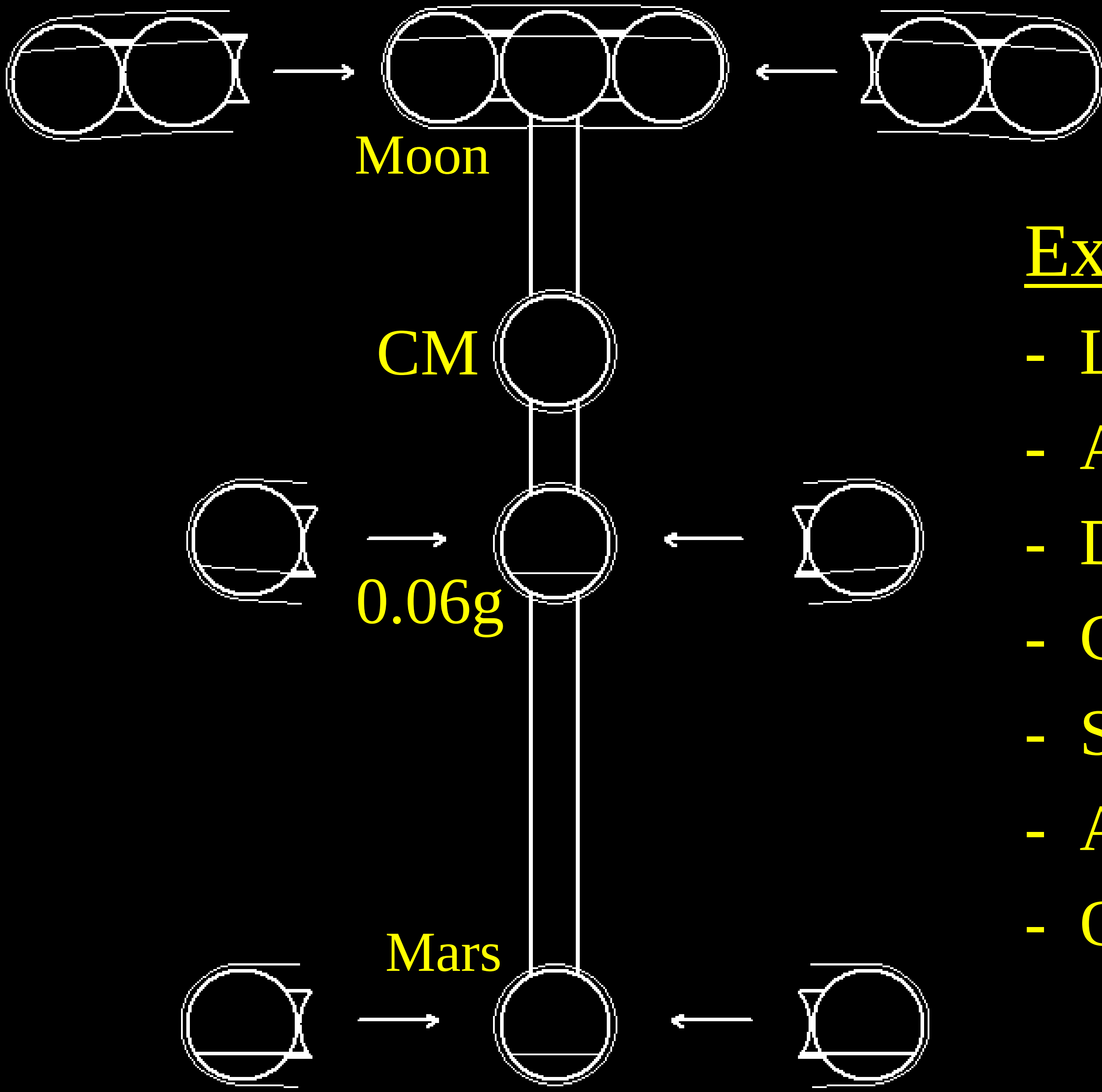
Stage 3: 3 cabins

- Attach 2 more cabins

Stage 4: full assembly

- Launch 3 cabins + tunnels
- Join 6 cabins w/tunnels
- Deploy tunnels 1 by 1
- Inflate slightly to deploy
- Spin up from Mars end

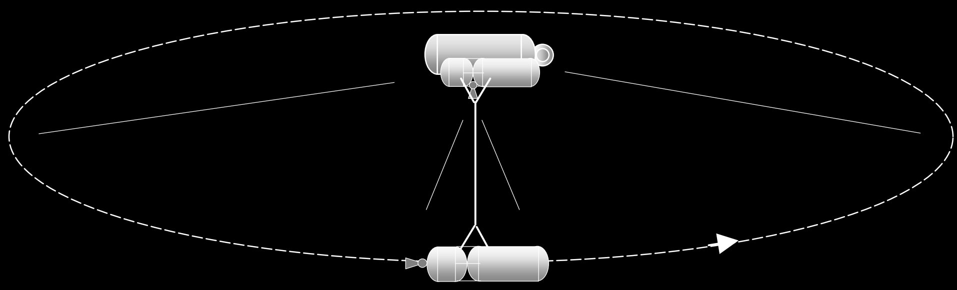
Stage 5: Facility Expansion



Expansion sequence:

- Launch **8** new cabins
- Assemble lunar pairs
- Despin (or slow down?)
- Capture & berth cabins
- Spin facility up again
- Adjust ballast, to balance
- Outfit new cabins later

Two Operational Derivatives

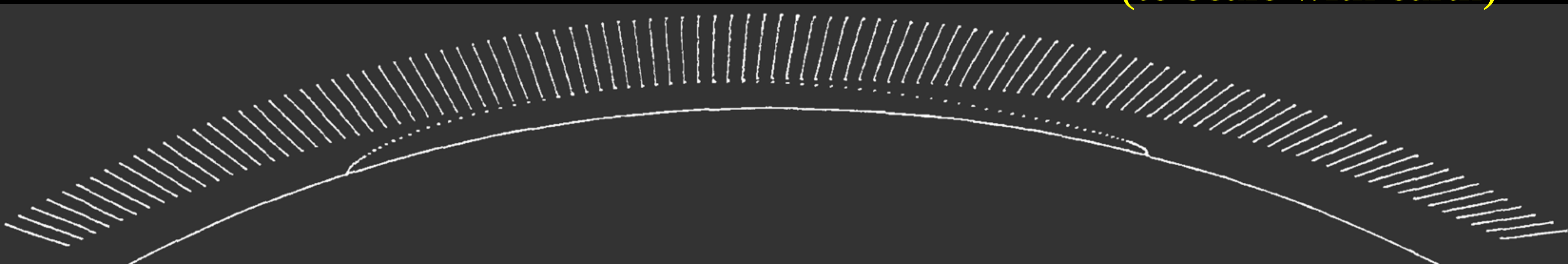


Spinning exploration cruise stage

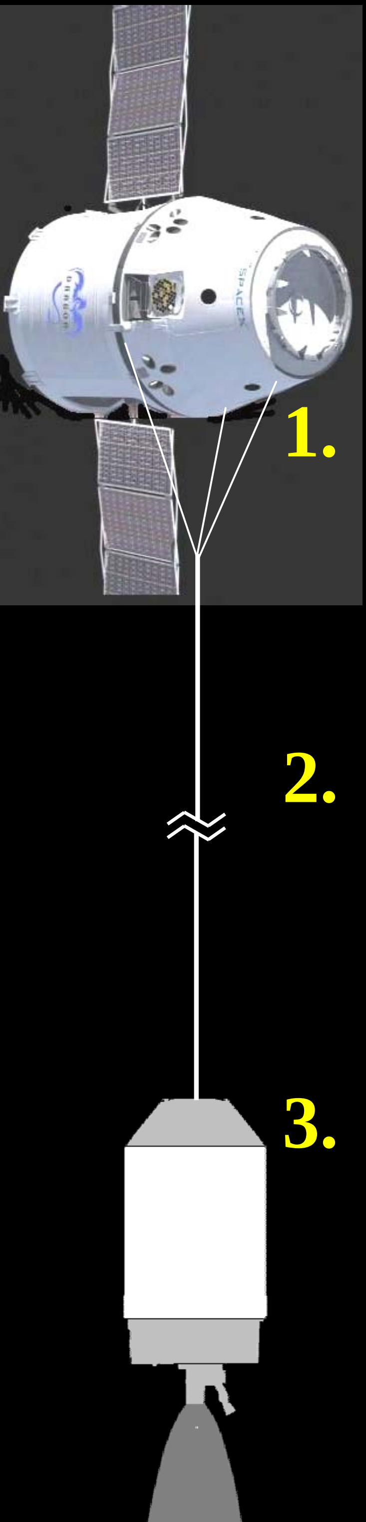
- Uses spent departure stage as ballast
- Can retain stage through maneuvers
- Tether cut: lose gravity, not mission

High-deltaV spinning LEO sling

- 2-3.2 km/sec above ***and*** below V_{LEO}
- Similar trapeze accelerations (0.5-1g)
- Low capture altitude, for soft reentry
- Shown: 1.2 km/s ΔV; 290 km tether (to scale with earth)



Conclusions



1. Man has been going into orbit for 50 years, but we seem stuck. Maybe it's time for us to take human physiology seriously ***before*** planning long missions.

2. A manned artificial gravity facility in LEO lets us learn more about our future and any limits on that future, ***and*** lets us test ways around those limits.

3. We can start with spinning tether tests as done on Gemini XI, to assess spin-related artifacts. This lets us determine a suitable facility spin-rate and design.