Artificial G Facility for Bioastronautics, Human Exploration Science, & HEDS Technology Demo Missions

"What's required to live and work on Mars?"
"What can we do to get an AGTV started?"

Tom Sullivan

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Program Goals and Objectives

- To get a major component of a rotating A.G. Transfer Vehicle designed, tested, and flown without the programmatic and political hurdles required for launching a nuclear reactor.
- To start a Human Exploration Program in a bite-size chunk, and earlier than it might otherwise be started if linked with nuclear reactors in space, thus spreading the funding profile over more years.
- To enable a later Mars AGTV to build upon this LEO AG Habitat, thus lowering technical and schedule risk, shortening development time, and reducing cost.

Technical Goals and Objectives

- When we land on Mars, it should NOT be the first time for extended stays at 0.38 g (i.e. more than 30 sec. parabolas). We must learn what is required to stay healthy and productive in that environment.

- By gaining experience at 0.38 g, we will improve designs for biomedical/countermeasure equipment, labs, tools, habitats, and other hardware, reducing risk and mass for items landed on Mars.
  - And 0.16 g studies for lunar programs

- Research at 0.38 g in LEO removes the confounding influence of Mars dust, interplanetary radiation, and transit time at 0 g, and will provide much more data than could be gathered on Mars.

- Transit to and from Mars at 1 g may reduce countermeasure requirements, and reduce or eliminate adaptation and rehab time at each end of the trip. Even short stays may then be worthwhile.
  - Rotating vehicle design issues are addressed in this program

Requirements (strawman)

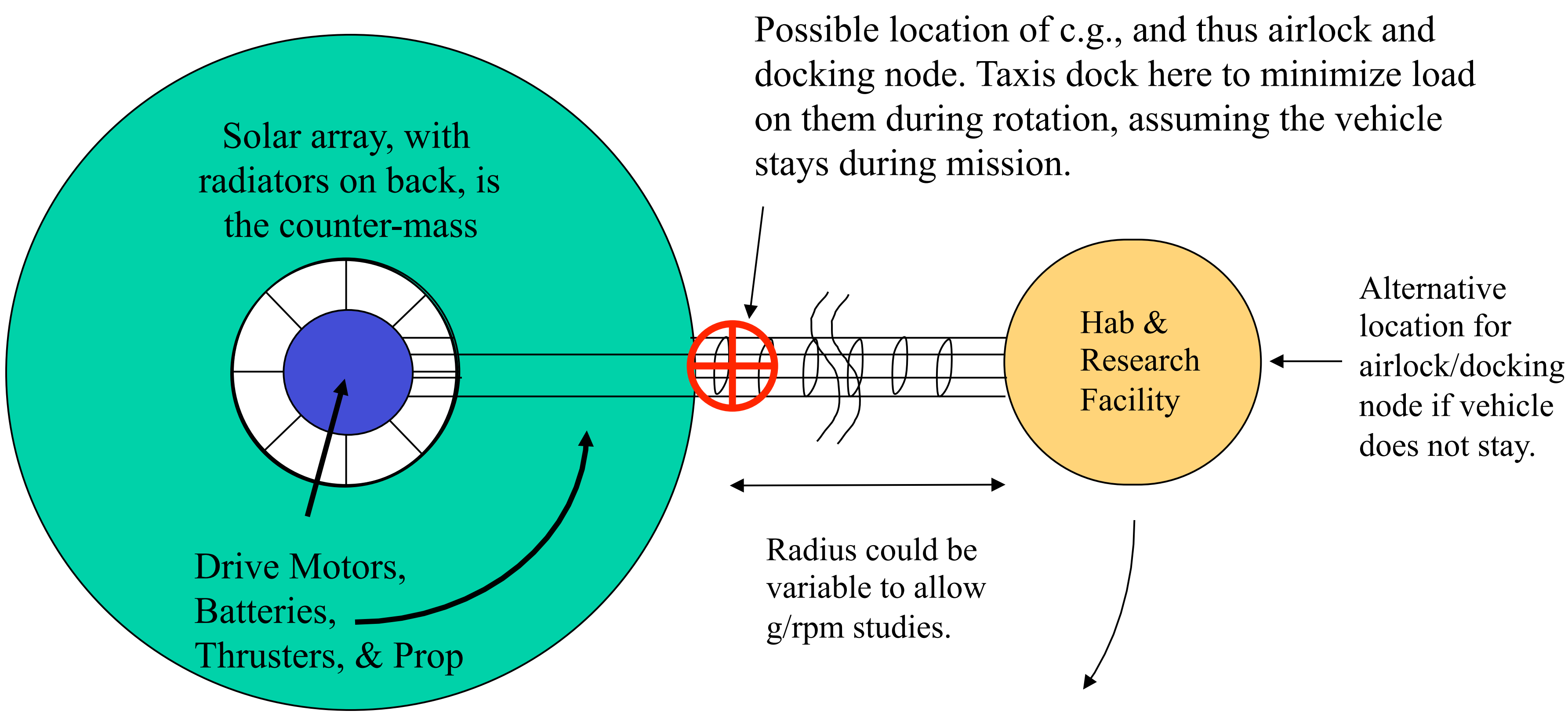
- The hypogravity facility shall provide 0.1 to 1.0 g at 6 rpm or less.
- The facility shall be usable in 2 or fewer missions.
- The facility shall be able to serve several missions over 5 years.
- Biomedical and Life Sciences Research shall be the major focus, with Exploration Science being a key element of this effort.
- Testing and development of Advanced Life Support Systems, EVA suits, and HEDS technologies shall be supported within the facility.
- The rotation rate shall be adjustable independent of the g level (variable radius.)
- Assured crew return, shuttle access, and multiple spin-up / spin-down capability shall be incorporated into the design or ops strategy.

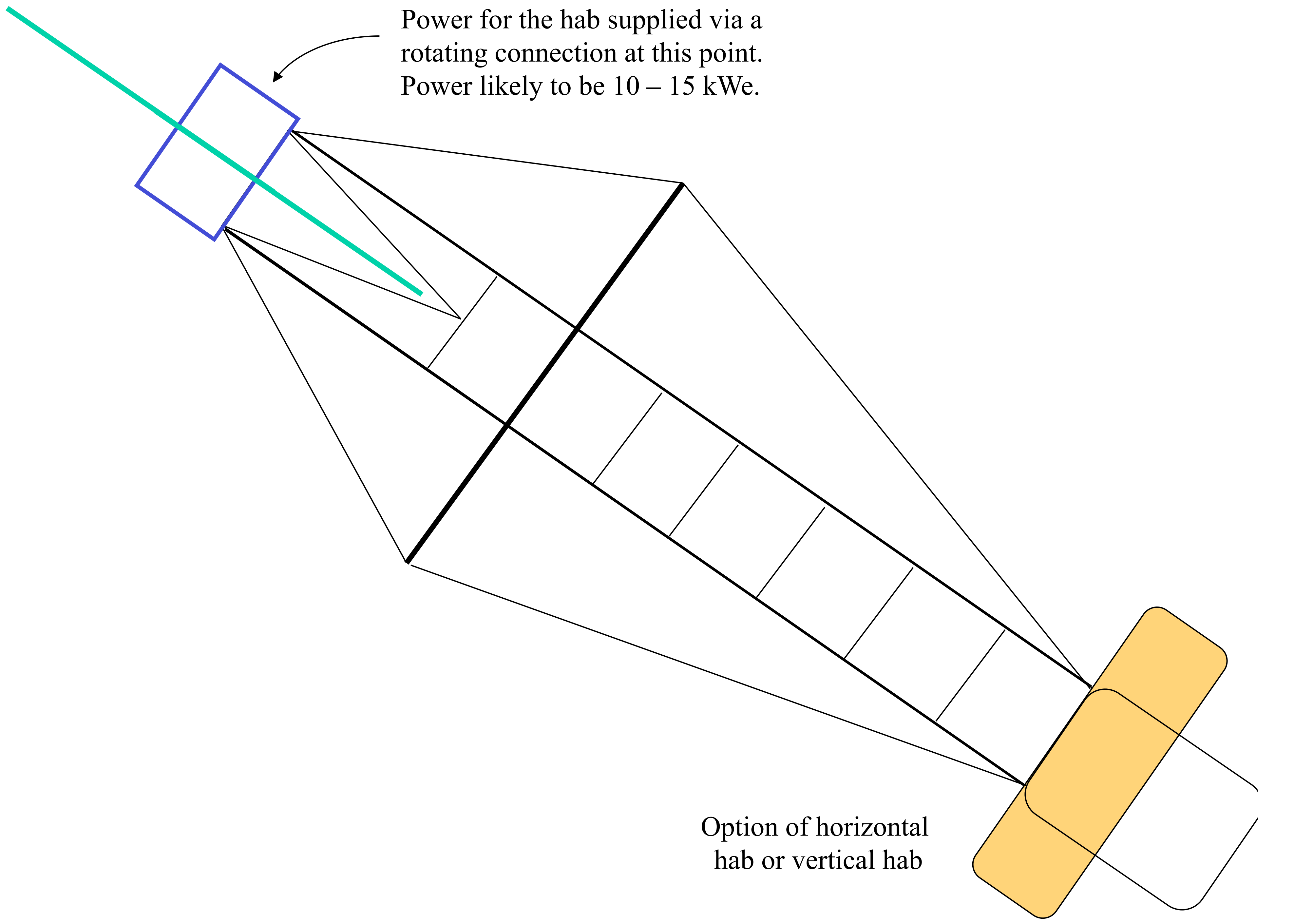
Design Concept

- Rotation around the c.g. of a vehicle requires a large countermass for the habitat
- Launching mass is expensive
- Use what we already have to have (double duty)
- Use the principle of conservation of angular momentum to spin-up and spin-down without the use of propellant
- If possible, do not require 2 elements to have the same mass for counterweight purposes, but rather spin them at different rates.

LEO Variable G Research Facility Concept

Uses principle of counter-rotation for spin-up and spin-down

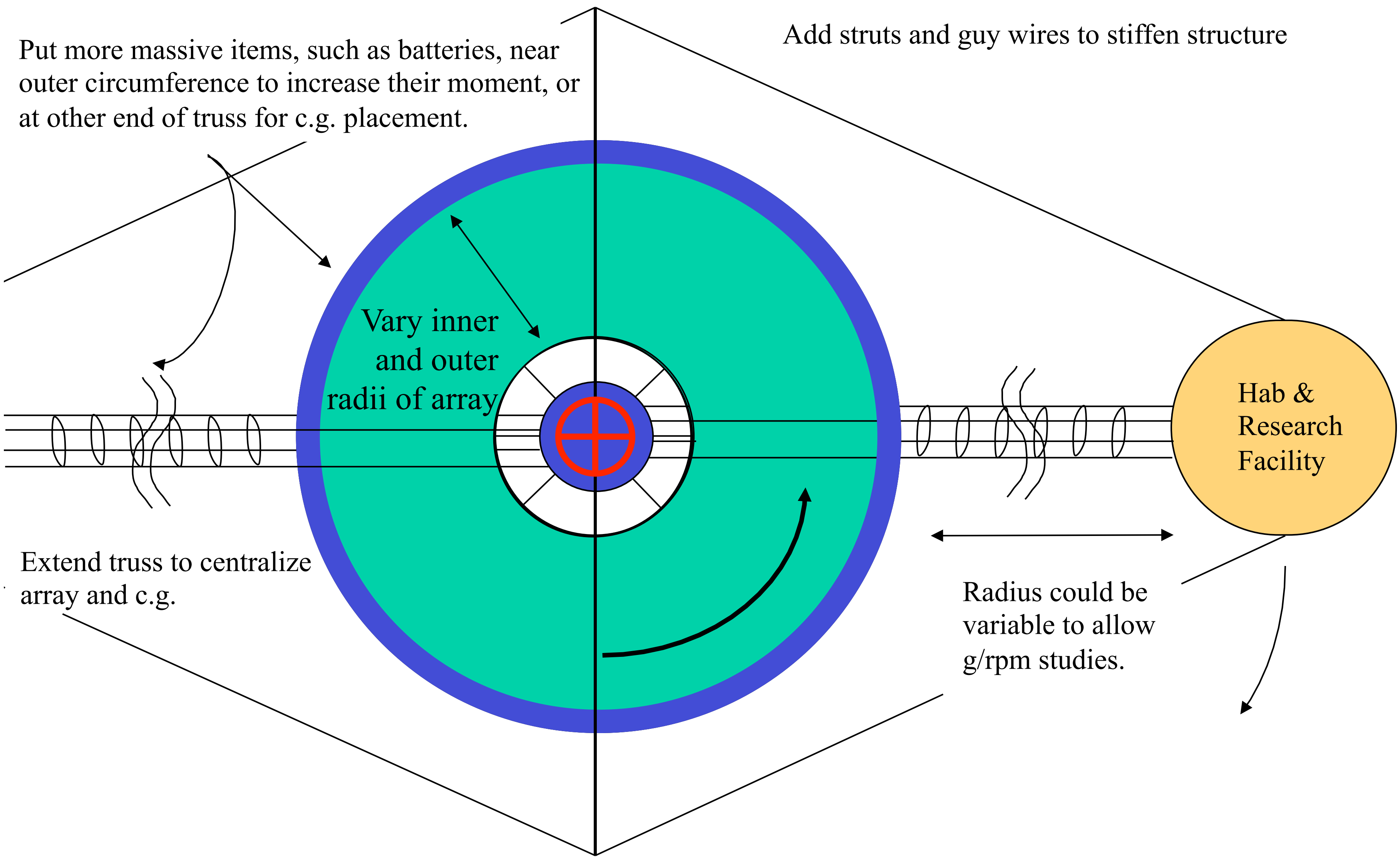



Power for the hab supplied via a
rotating connection at this point.
Power likely to be 10 – 15 kWe.
Option of horizontal
hab or vertical hab

Conservation of Angular Momentum

- Angular momentum = m x v x r = 0 at start
- m_1 x v_1 x r_1 + m_2 x v_2 x r_2 = 0 after spin-up
- 3 parameters to work with in balancing the 2 portions of the spacecraft: mass, rotation rate, and radius
- Use the mass you already have
  - Power module (arrays, radiators, batteries, thrusters, propellant)
  - Habitat, docking module with airlock
- Adjust radii so that rpms and g-levels are acceptable

Alternate Design Options for LEO Variable G Research Facility



Tests, demos, and research could include:

Bioastronautics

- Bone density vs. time as a function of A.G. level.
- Muscle alteration & atrophy vs. time as a function of A.G. level.
- Cardiovascular alterations vs. time as a function of A.G. level.
- Neurovestibular adaptation to a rotating environment at varying rates.
- Behavior & Performance in a rotating, confined environment
- Clinical capability and emergency care procedures at 0.38/0.16 g
- Countermeasure requirements remaining at 0.38 g or 0.16 g.
- Testing and demo of Advanced Life Support Systems (or components) in a rotating environment at 1, 0.38, and 0.16 g.
- Habitability and stowage designs, issues, and opportunities at 0.38 and 0.16 g.
- Gene expression of cells at hypogravity 'fills the gap' for BioTech.

Tests, demos, and research (cont.)

<u>Astrobiology, HES, and HEDS Technology</u>

- Astrobiology/Gravitational Ecology/Microbiology at hypo-g.
  - Research in this area may not be allowed on Mars due to planetary protection policies, yet it is critical to know how the lower gravity at Mars affects the liquid/solid/gas interfaces, which provide niches for microbial growth in a hab on Mars and which can affect elements of the life support system.
  - Understanding how 'g' affects growth, phase separation, gas exchange, etc., helps us to know where to explore for possible life on Mars.
- ALS can also embrace some fundamental biology studies of plant growth at 0.38 and 0.16 g.
- EMU evaluation at 0.38 and 0.16 g (similar to MMU prototype tests flown inside Skylab.)
- EVA tools and ops evaluation at 0.38 g.
- IVA Laboratory tools and procedures at hypo-g.

Tests, demos, and research (cont.)

- In-space test of A. G. habitat (without a nuclear reactor as counterweight or program complication)
- By varying the rotation radius, the same g level can be provided at different rotation rates.
- Tests at 1 g are of value, too, since transit could be at 1g. Also, they act as rotating controls for 1 g Earth-based studies.
  - Rotating studies on Earth are all > 1 g, with g-vector 'wrong.'
- All of this can be done in conjunction with testing of other HEDS hardware, such as truss, control mechanisms, hypo-g habitat, docking mechanism / strategy, and A.G.-compatible subsystems.
- The affect of a 24 h 36 minute day can also be introduced at some point, if desired.

Mission Concept

- Launch the habitat on a single launch vehicle, which deploys, inflates(?), and outfits(?) the hab, and returns to Earth.
- The research crew goes up in a second shuttle, which deploys the "power disk" and truss from the payload bay.
- This first crew shakes down the facility, including the first spin-up. The shuttle crew can be their 0-g controls.
- Facility is de-spun for EOM docking with shuttle.
- Permanent crews and crew rotations can be delivered on additional missions. Hardware for evaluation and research is also delivered.
- A CRV is necessary if crews are to stay after shuttle departure.
- Crews of 6-7 (capability of the TransHab) are possible.
- Only 3 - 4 can be rotated on a single mission, similar to ISS.
- Higher crew numbers allow a high "n" to be achieved quicker.

Design Issues

- Power - presumably solar arrays will be used, but how will they hold up under A.G. rotation? Rotating connection.
- 0-g periods may require bi-g systems or stand-by modes.
- Unlike RCS at tips of boom, torque from middle requires stiff structures. Struts and guy wires likely to work.
- Current TransHab design may not work under 1 g load.
- 'Single-level' hab may be preferred over multi-level hab.
- What rotation rate for hab? Power disk? What g-load for disk?
- Crew Rescue Vehicle required for missions once shuttle leaves.
  - Soyuz? OSP? CTRV?
  - Can it remain berthed via its attach point while spinning? Relocate?
  - Dock at C.G. and access via tunnel? EVA?
  - Ops issues with entering it while spinning? Departing?

Concept Pros and Cons

Pros:

- We will learn how humans adapt to Mars' or Lunar gravity.
- It tests an AG vehicle and its subsystems without putting nuclear reactors in LEO.
- This gets TransHab away from ISS politics.
- It removes a microgravity disturber (centrifuge) from ISS.

Cons:

- It is a new research thrust and program start. Another ISS?
- It smells like a Mars program start (or at least a lunar base.)
- ARC Fundamental Biology effort focuses on CAM, with 0-g controls. 0-g controls are problematic on a Hypo-G Facility.
- Inflatable Hab may still be politically undesirable.

Program Issues/Embarrassing Questions

- Why are we flying 0-g on ISS if we need to learn about hypo-g?
- How does this meld with the Critical Path Research Project?
- Would we forego the ISS/CAM (UF-7 4/06 Rev. F) for this facility?
- Are we gutting 0-g Life Science research by flying at hypo-g?
- Is this another huge mega-project?
- Are we declaring an intent to go to Mars by doing this?
- Is this a thinly veiled way to fly Trans-Hab?
- Will animal studies be done on this vehicle? PETA problems?

Evolution/Options

- Use as an ECLSS/ALS Demo facility for HEDS missions
- Use as a Fundamental Biology Research Facility vice the Centrifuge Accommodation Module on ISS (which won't fly to ISS until UF-7, in 2/06 per Rev. F, if ever)
- Move the facility to Earth-Moon L1 as HEDS Test Facility, or even as the L1 Gateway.
- Other?

Back-Up Charts

Rotation Rate vs g-Level for Various Radii

$$a_c\ (m/s^2) = [\omega(rad/sec)]^2 \times r(m)$$

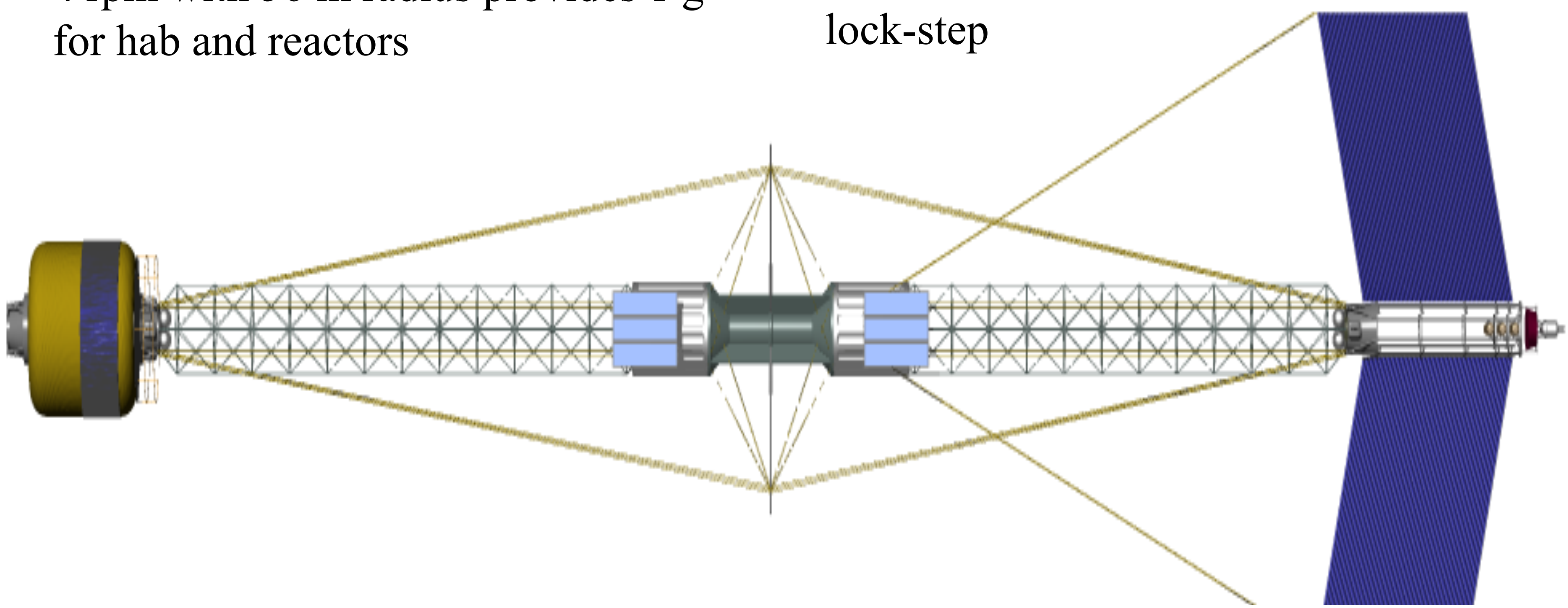
$$a_c\ (m/s^2) = 1.097 \times 10^{-2}\ [\omega(rpm)]^2 \times r(m)$$

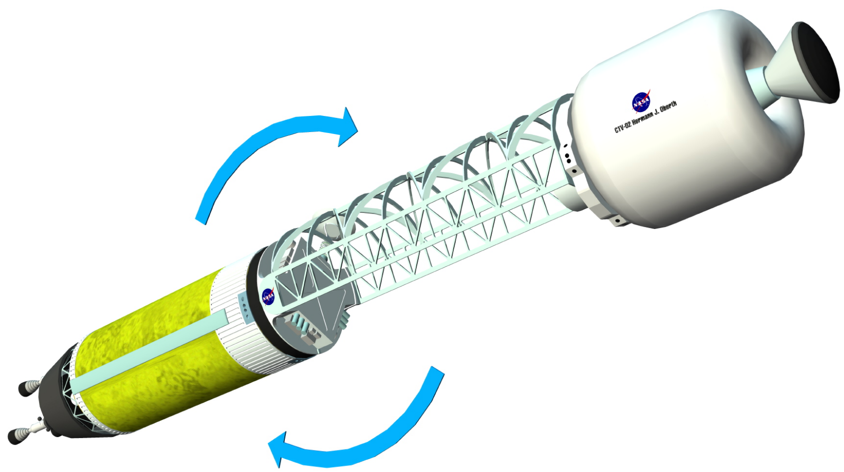
	Radius			
	20 m	30 m	40 m	
1 g = 9.8 m/sec ^{2}	6.7	5.5	4.7	rpm
0.38 g = 3.7 m/sec ^{2}	4.1	3.4	2.9	
0.16 g = 1.57 m/sec ^{2}	2.7	2.2	1.9	

Artificial Gravity Transfer Vehicle Design Concept

(EX, in work)

- Total vehicle spins – no moving parts
- RCS used to spin up – requires prop
- Prefer not to spin down – requires more prop
- Docking of taxis and landers is problematic.
- 4 rpm with 56 m radius provides 1 g for hab and reactors
- Slewing thrust is difficult and slow due to angular momentum
- Reactor and crew are constrained by same g and rpm limitations
- Mass distribution driven by c.g., radius, and 1g requirement
- Hab and reactor must grow or shrink in lock-step





Bimodal CTV operating in “AG” mode

“Artificial Gravity” Bimodal NTR Crew Transfer Vehicle (CTV)

Functions

- Common BNTR “core” stage provides propulsion for all major burns
- Also provides 50 kW_e for crew life support, active refrigeration of LH_2 & high data rate transmission
- CTV rotation (w ~ 6 rpm) provides near-Earth gravity levels

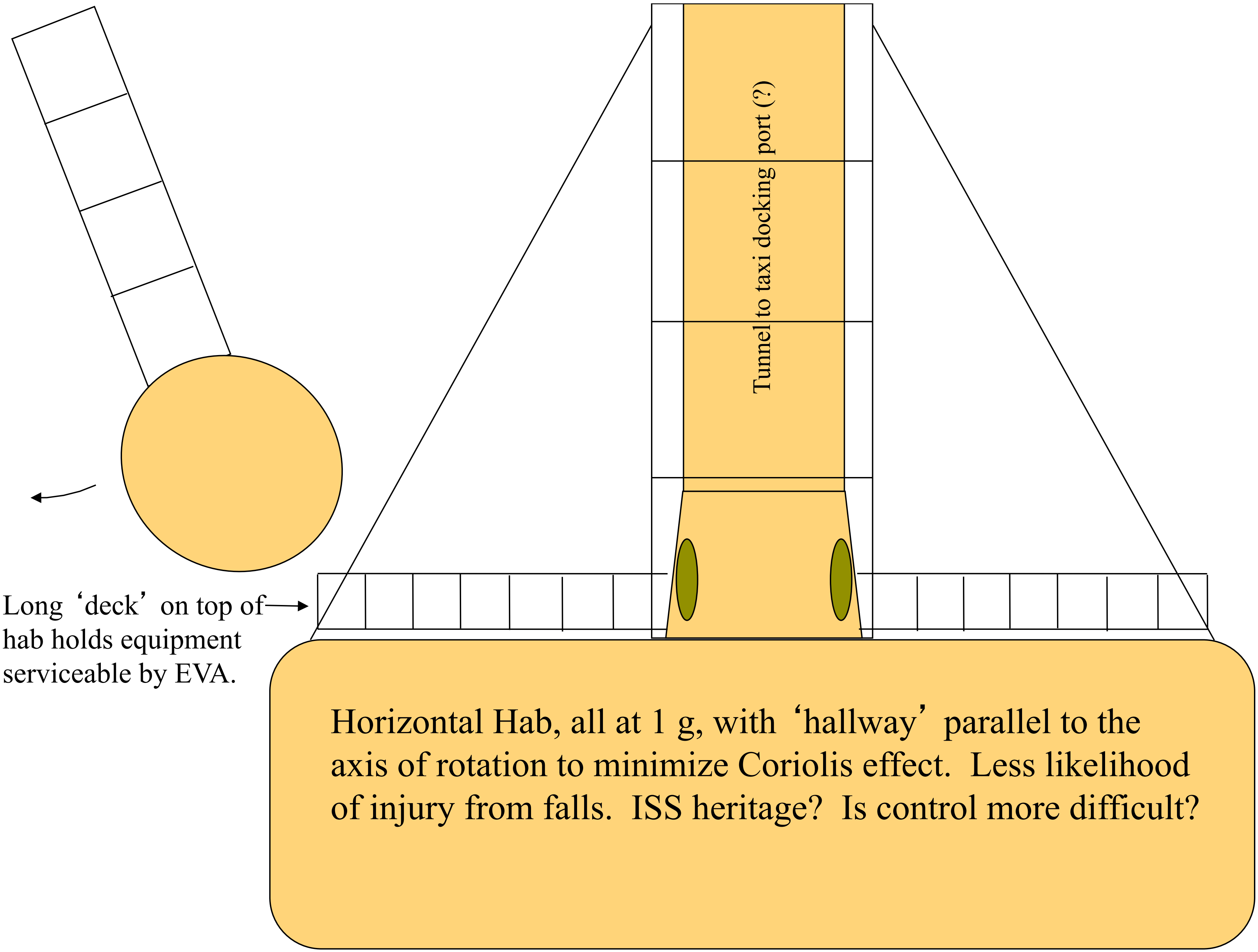
Technologies

- High performance bimodal NTR engines
  - Use ternary carbide or cermet fuels
  - 15,000 lb_f thrust / 25 kW_e per engine
  - Multiple engine restarts
  - Short burn times and low fuel burn-up
- High temp (1300 K) Brayton power conversion
- Active refrigeration, “zero-boil off” LH_2 storage
- Lightweight composite LH_2 tanks and structure

Sizing Parameters

Specific Impulse / Propellant:	955 s / LH_2
Total Thrust / Power:	45 klb_f / 50 kW_e
“Core” Stage Dry Mass:	27.32 t
Truss / LH_2 Tank Assembly:	12.85 t
TransHab:*	14.19 t
4 Crew Return Capsule:	4.27 t
Max. Propellant Load:	≤ 91.55 t
RCS Propellant Load:	4.08 t

*Crew consumables depend on mission duration


Tunnel to taxi docking port (?)
Long ‘deck’ on top of hab holds equipment serviceable by EVA.
Horizontal Hab, all at 1 g, with ‘hallway’ parallel to the axis of rotation to minimize Coriolis effect. Less likelihood of injury from falls. ISS heritage? Is control more difficult?