Investigation into the Potential for Human Travel into Deep Space Using Current or Imminently Available Technology

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Presented by Russell Trahan

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Asteria

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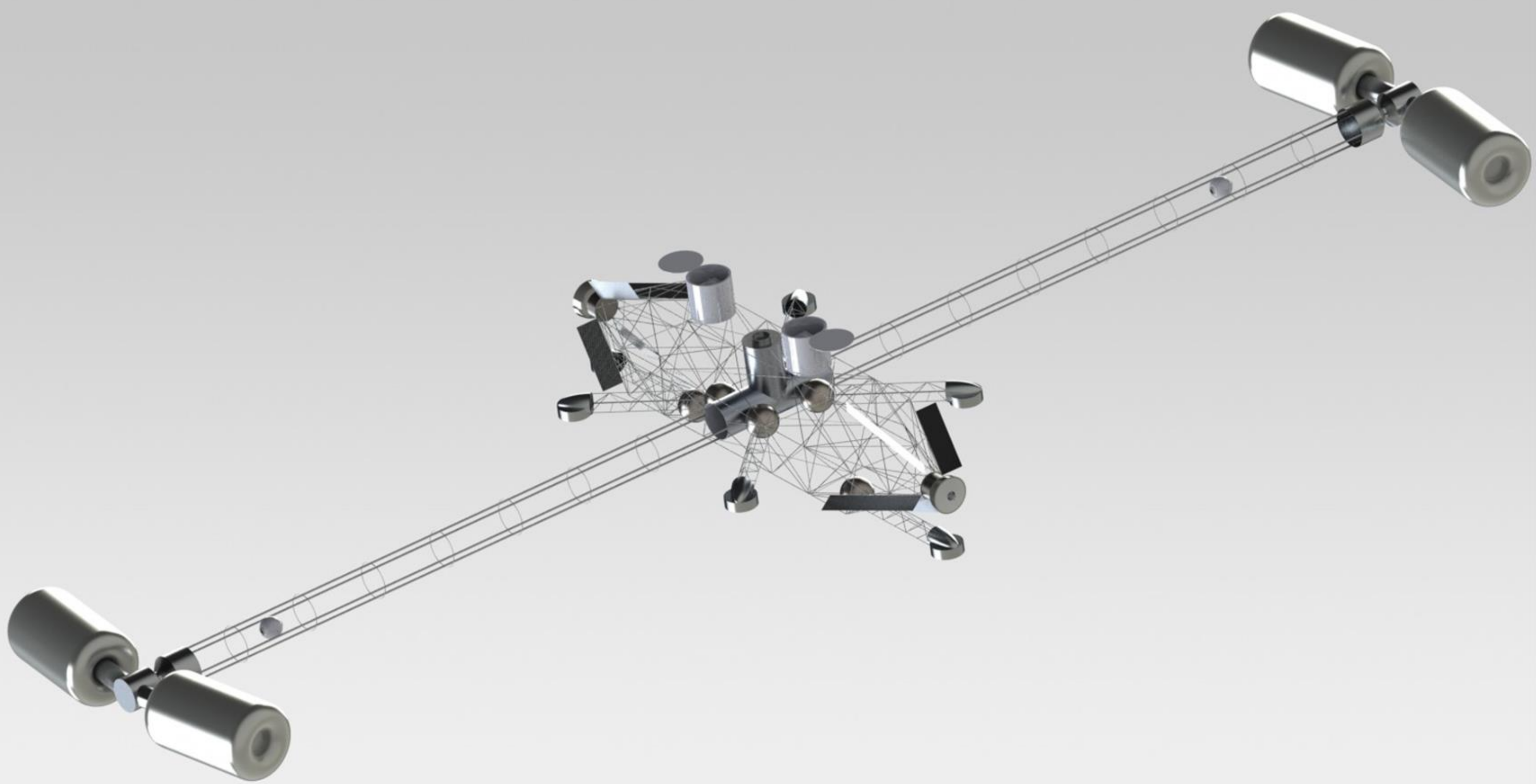

Outline

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- Introduction
  - Project goals and constraints
  - Design driver: artificial gravity
- Propulsion and Power Source
- Trajectory Design
  - Low energy transfer
  - Patched circular-restricted 3-body problem
- Control Concept
- Habitat Technology Study
- Conclusion

The Question

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No human has traveled beyond cislunar space since December 1972.

Can humanity explore the solar system beyond Earth suing only technologies that either already exist or are in an advanced stage of development?

Project Guidelines

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- Objective: a manned mission to a near-earth asteroid, 99942 (Apophis)
- Crew of six
- Spacecraft: capable of interplanetary exploration
  - Able to support the crew for no less than 30 months
  - Minimal, if any, resupply from earth
  - Long duration missions
  - Space-only spacecraft design (no atmospheric flight or reentry)
- Technologies used:
  - Must be credible based on current capabilities
  - Promising TRL5 or greater may be utilized
- No “miracle cures”; i.e., warp drives, matter transmission beams, etc.

Design Drivers

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- Maintain artificial gravity of 1-g at main floor of habitats
- Low energy trajectory
  - Earth Moon Lagrange Point 2 (EM-L2) to asteroid 99942 (Apophis)
  - Utilize the patched circular-restricted three-body problem (CRTBP) trajectory design methods
- Electrical power generated by nuclear power plant
- Electric propulsion
- On-board cultivation of food crops
- Radiation protection for up to 30 months

Asteria and Artificial Gravity

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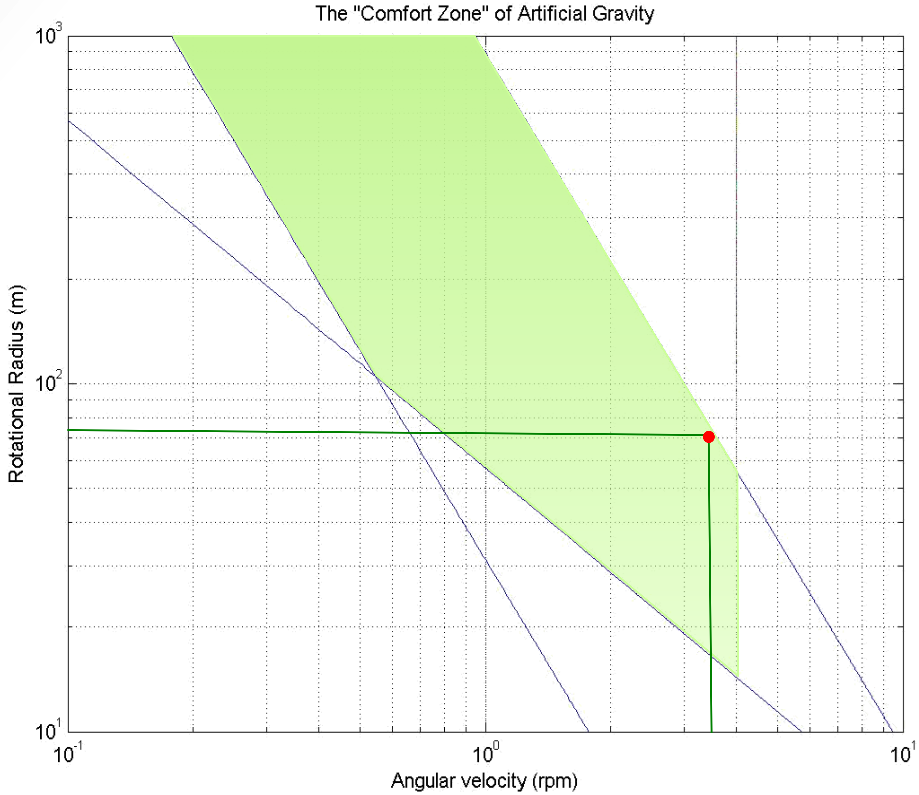
Based on this plot, the team decided on a rotation radius of 73 m and an angular rate of 3.5 rpm to produce 1-g in the habitat modules



Is Rotation the Best Answer?

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- Currently, if gravity is desired, it's the only answer
- Question: Does the g-level have to be 1-g?
- What if 0.5-g will mitigate the negative effects of long term micro-g exposure?
  - A 0.5-g level could be created on Asteria with a 36.5 meter radius at 3.5 rpm, and still be in the "Comfort Zone"
- What about a 0.5-g level at 2.0 rpm?
  - Radius increases to 112 meters
  - 2.0 rpm would be much easier for the crew to adapt to

Propulsion System

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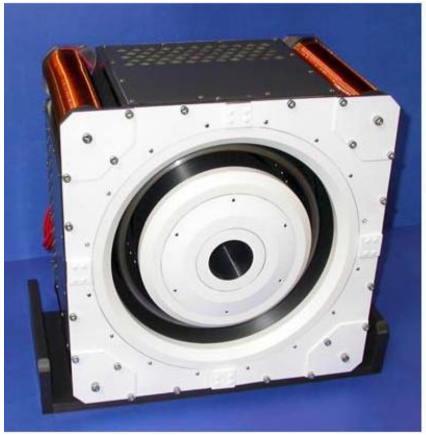
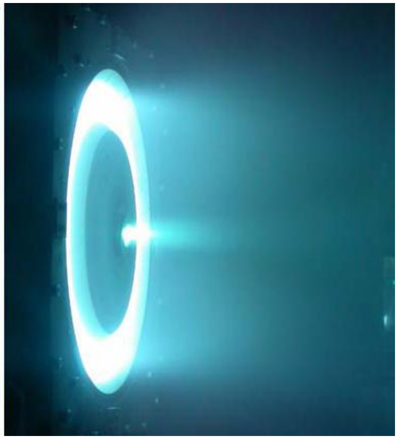
Busek BHT-20K Hall-Effect Thruster

Dimensions: 34x34x22 cm

Propellant: Krypton

Xenon was original choice, but availability is a problem (as well as cost)





Characteristic	Xenon	Krypton
I_{sp} (s)	2320.40	2432.91
Thrust per engine (mN)	1080.00	905.65
Mass Flow (mg/s)	40.00	37.95
Mass of Propellant (kg)	60723	70414

Propulsion Arrangement

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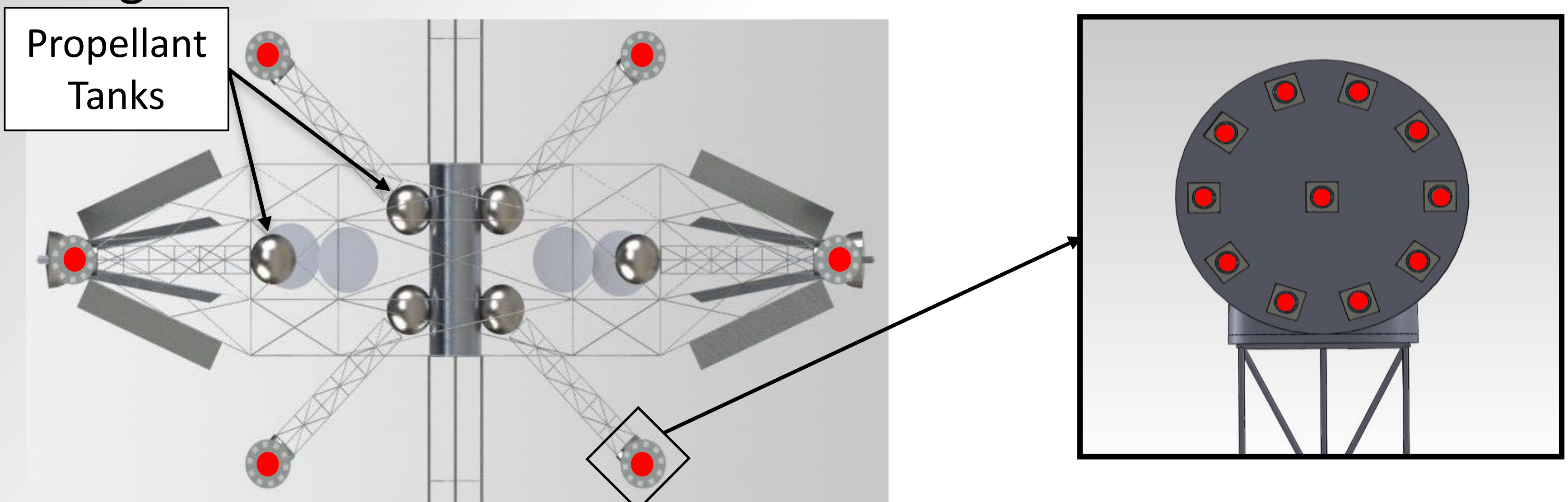
- Asteria has six arms, each with a pod that contains 11 BHT-20K engines



- The propulsion arms can rotate about their axis individually or in concert
  - Must be done slowly to avoid adversely affecting the crew
- As shown above, each arm has its own propellant tank

Plume Impingement

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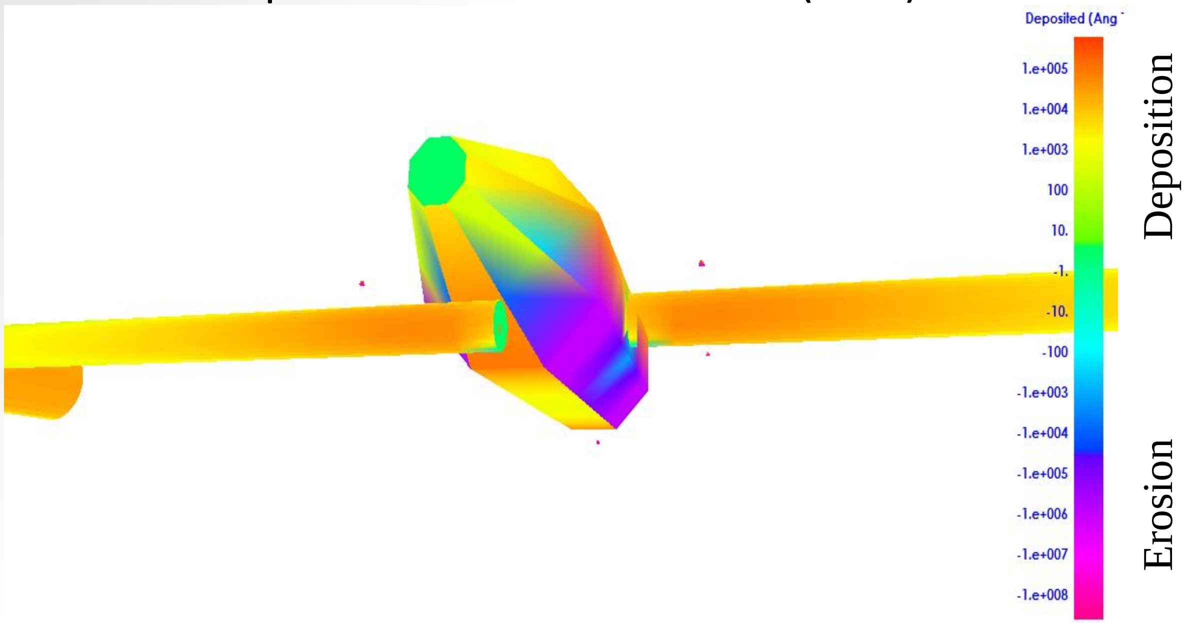
- Plume deposition and erosion analyzed
  - NASA's Electronic Propulsion Interactions Code (EPIC)



- Over the duration of the mission
  - Erosion: ≈ 0.12 mm
  - Deposition: ≈ 3.5 X 10-3 mm

Electric Power Generation

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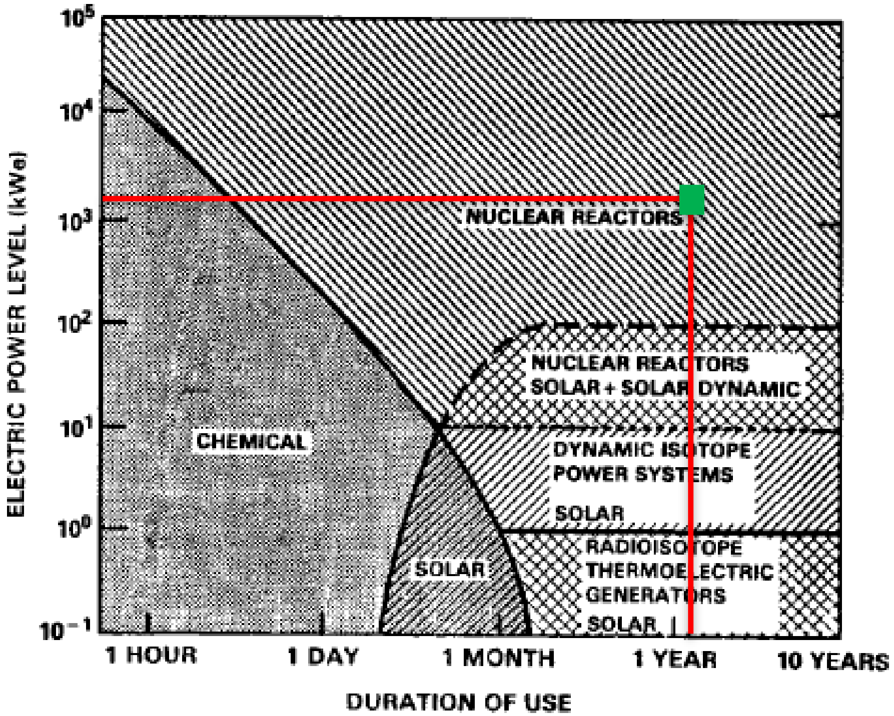
- Deep space exploration will require abundant and reliable source of power
- Nuclear power, while a controversial solution, is the only source that is both reliable and abundant
- US Navy nuclear submarine fleet
  - Outstanding safety record since the launching of the USS Nautilus in 1954
  - Never been a fatality attributable to the use of nuclear power
  - Soviet Union record is not so exemplary



The Nuclear Reactors

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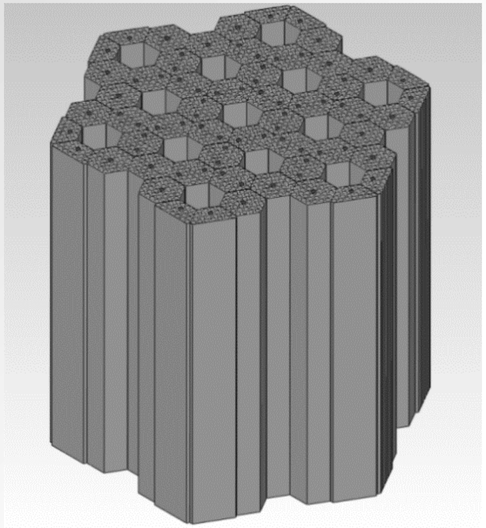
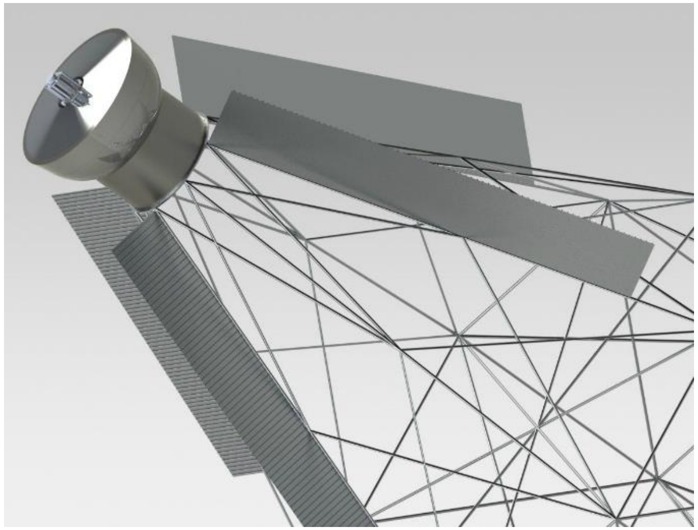
- Little development of nuclear power for use in space since ~1980
- Nuclear power is not part of the typical Aerospace curriculum
  - Students went to the Nuclear Engineering Department for help
- Designed a reactor able to produce 1.6 MWe at maximum output
- Asteria utilizes two reactors, one at each end of the central body



Reactor Core Cladding

Reactor Assembly



Reactor Assembly on Asteria

Traveling the Interplanetary Super Highway

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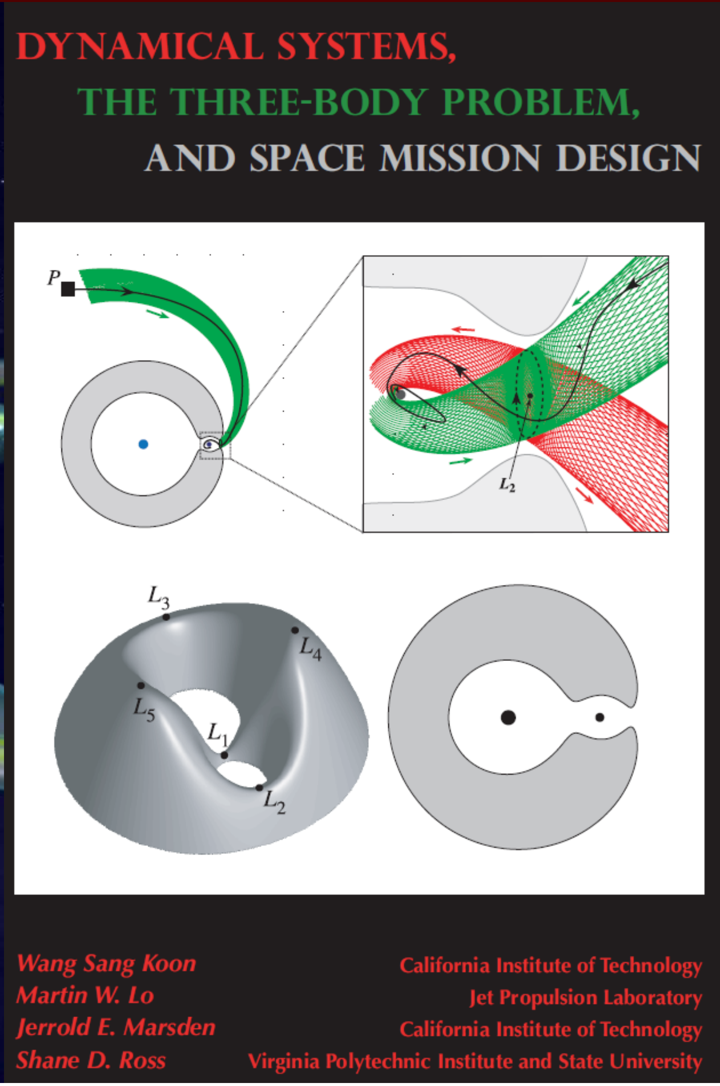
Our studies indicate that propulsion system and propellant mass would be prohibitive unless we use the Patched 3-Body Problem method for low-energy trajectory design (and accept the downside of longer trip times)



3-Body Problem Basics

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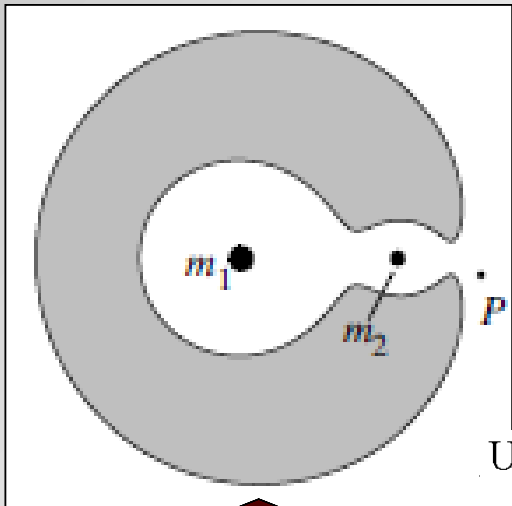
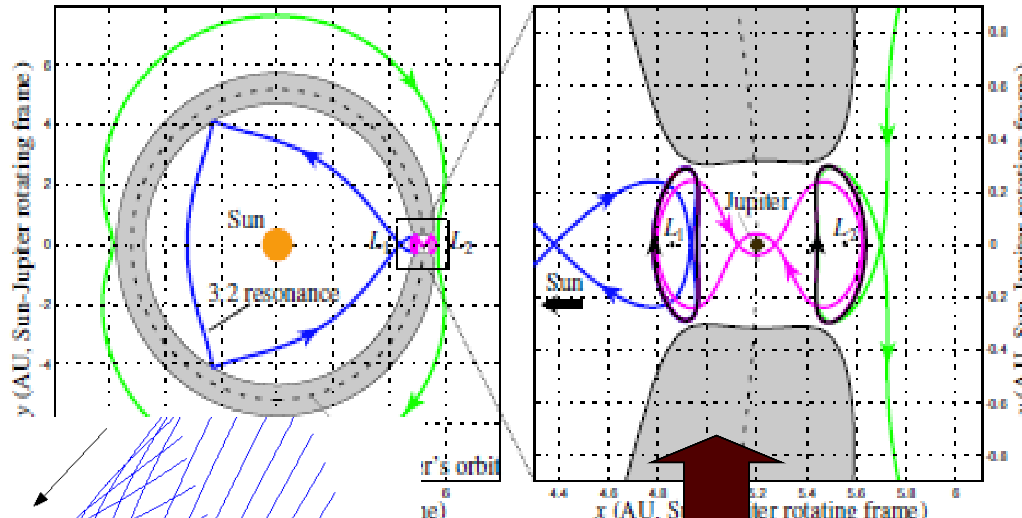
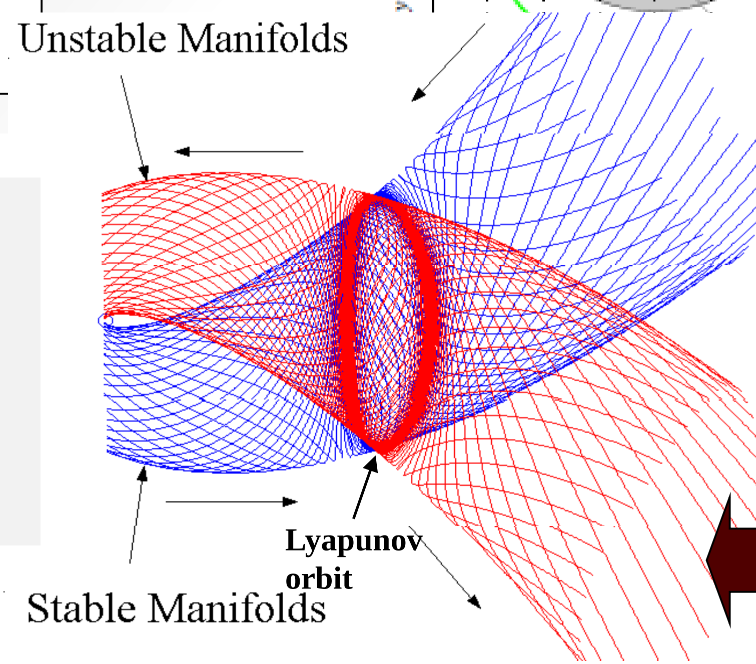


Stable and unstable invariant manifolds issue from the periodic orbits around the L-points





Interest centers on energies just enough to open the "neck" regions near the Lagrange L1 and L2 points

The manifolds are like ocean currents that can be linked to carry the ship huge distances without propulsion.

The slightest impulse can send the vehicle millions of miles in either direction

Voyage to the Operational Base at EM-L1

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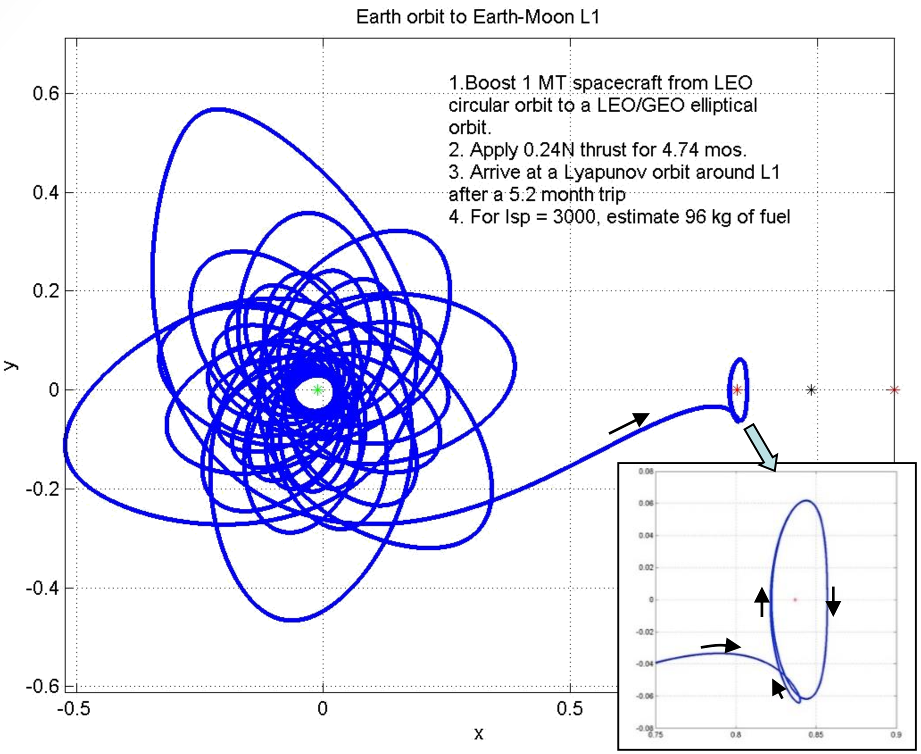
- We assume infrastructure for repair, re-supply and crew exchange at the Lagrange points, including EM-L1.
- To provide the most opportunities for repair and re-supply, we go first to EM L1 rather than directly to EM-L2. The L1 Lyapunov orbit is considered the operational base.
- The ship is constructed at LEO, then transferred (unmanned) to L1 where the crew boards.
- Subsequent trips go from and to this operational base.



"Grand Tour" to Apophis- in 3 Links

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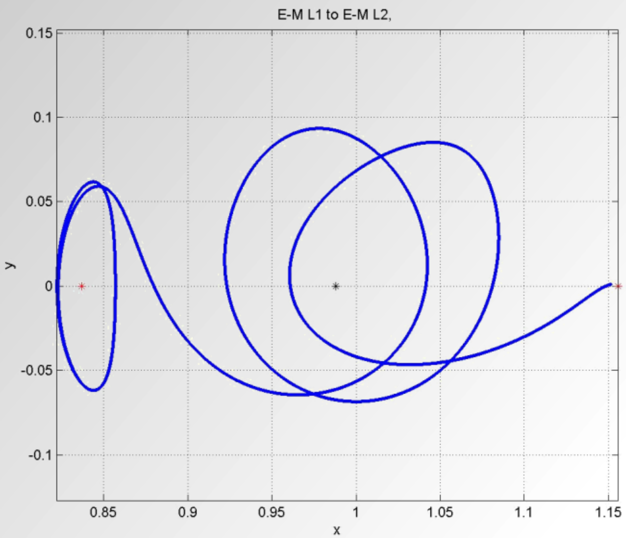
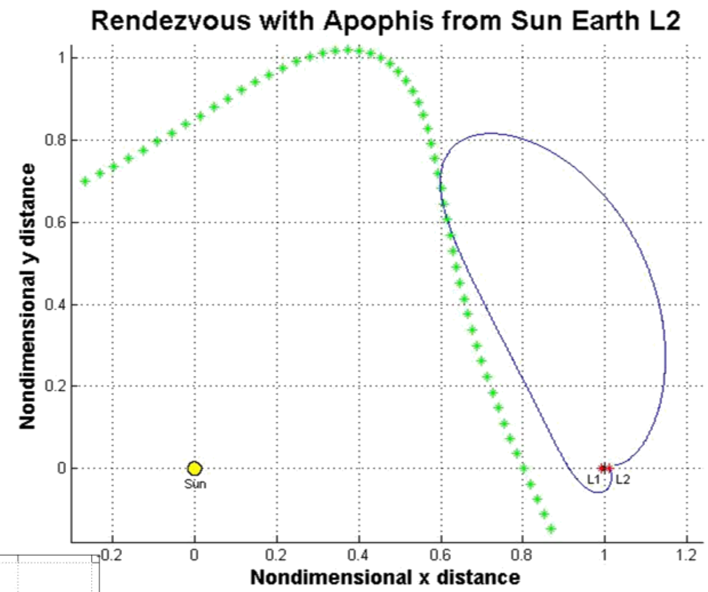


Earth-Moon L2 to Sun-Earth L2

Shown in the Sun-Earth rotating frame

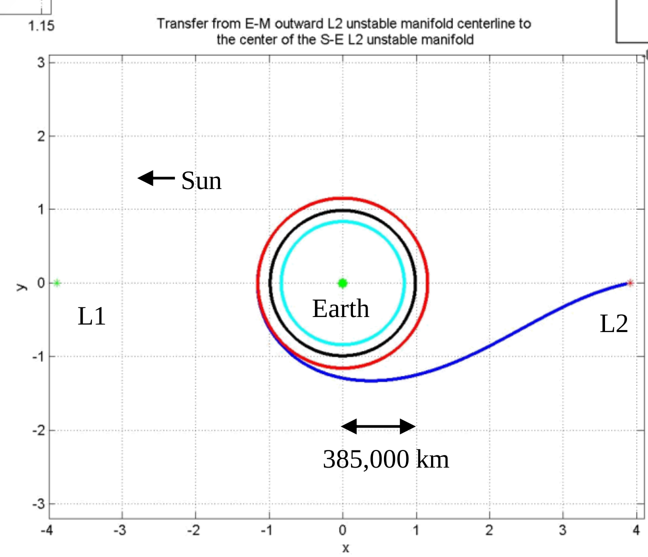
(negligible thrusting)



Earth-Moon L1 to Earth-Moon L2

Shown in the Earth-Moon rotating frame

(negligible thrusting)



Sun-Earth L2 to Apophis and back.

(thrusting only at the ends of the oval)

Return =These links in reverse

Coasting Nearly All the Way…

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	Time (Days)	58N Burn Time	0.8N Control Burn Time	Leave Date
Earth to Earth-Moon L1	62.1	45	15	
To Earth-Moon L2	43.5	0	0	11/14/2027
To Earth-Sun L2	39.6	0	0	12/27/2027
To Apophis and Back to Earth-sun L2	604.5	276	204	2/5/2028
To Earth-Moon L2	39.6	0	0	10/1/2029
To Earth-Moon L1	43.5	0	0	11/9/2029
Total	832.8	321	219	12/23/2029

Yes, undergraduates generated all these results!

Asteria’s Control Systems

- Flight control system:
  - Autonomous
  - Integrates the control moment gyros (CMGs) and thrusters
- Control Moment Gyros
  - Assist the main thrusters with steering the spacecraft
  - Assist in damping perturbations to maintain smooth angular motions
  - Maintain the alignment of thrust and velocity vectors
- Asteria’s propulsion configuration is beneficial to the control system design
  - Three Proportional-Integral-Derivative (PID) controllers

Propulsion/Control System

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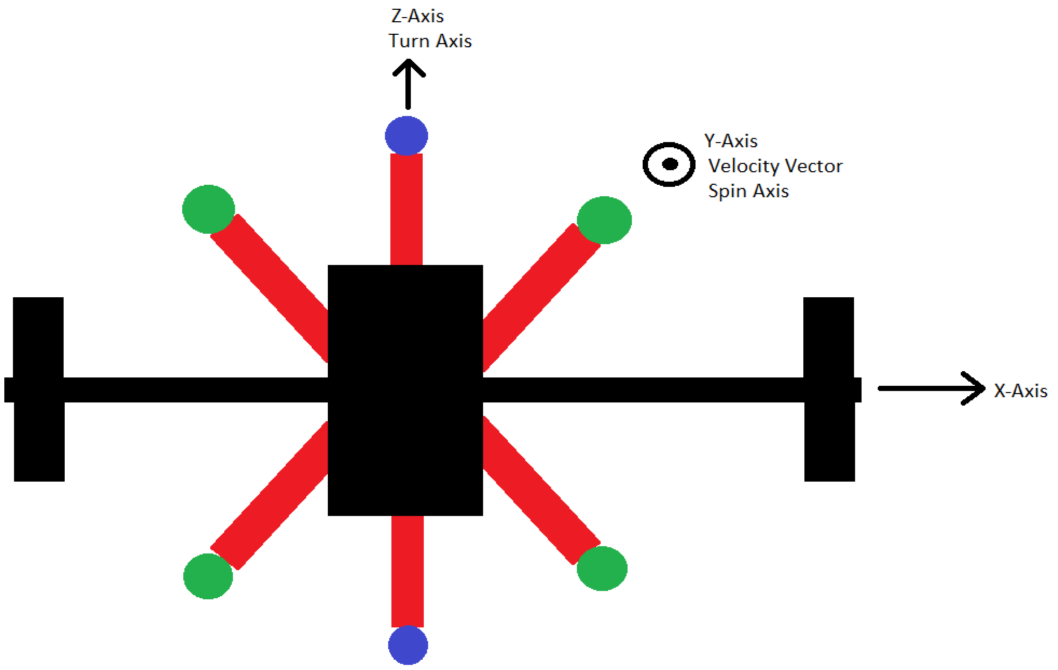
Red: Symmetric rotation of the Engine pods about the arm axis permits correction about the spin axis (Y- Axis)

Green: Variable thrust levels allows for rotations about Z-Axis

Blue: Variable thrust levels allows for rotations about X-Axis

Spin Axis (Y): Spinning to maintain artificial gravity

Turn Axis (Z): Turning to keep thrust vector aligned with velocity vector along trajectory



Habitat Technology

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- Integration of technologies that enable humans to be independent of an external supply chain
  - Generate a portion of their consumables
  - Protection from galactic cosmic radiation (GCR)
  - Process and dispose of waste
  - Fabricate tools and repair parts to recover from mechanical failures
- Three primary areas studied for the Asteria project
  - Habitat shell
  - Regenerative Life Support
  - On-board Plant Cultivation

Habitat Shell

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- Purposes of the shell
  - Protection from galactic cosmic radiation (GCR) and solar proton events (SPE)
  - Protection from micrometeorite impacts
  - Maintain a comfortable and healthy internal living environment
- Asteria habitat shell modeled on NASA's Transhab shell
- Eleven different layers resulting in shell walls approximately 16" thick
- Predicted level of exposure based on a 30 month mission:
  - 1.56 Sv (not insignificant: lifetime limit ≈ 1 – 4 Sv); but,
  - Within NASA requirements for 35 year old males and females

Regenerative Life Support

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- Primary tasks
  - Maintain and recycle the internal atmosphere
  - Recycle water
- Waste processing and recycling
  - Another technology not included in the typical aerospace curriculum
  - Received help from experienced NASA engineers
- Asteria system is similar to that of the International Space Station (ISS)
  - Primarily focused on air recycling
  - Water recycling technology requires more time than available
  - A schematic of the air recycling system is on the next chart

Asteria Air Recycling System

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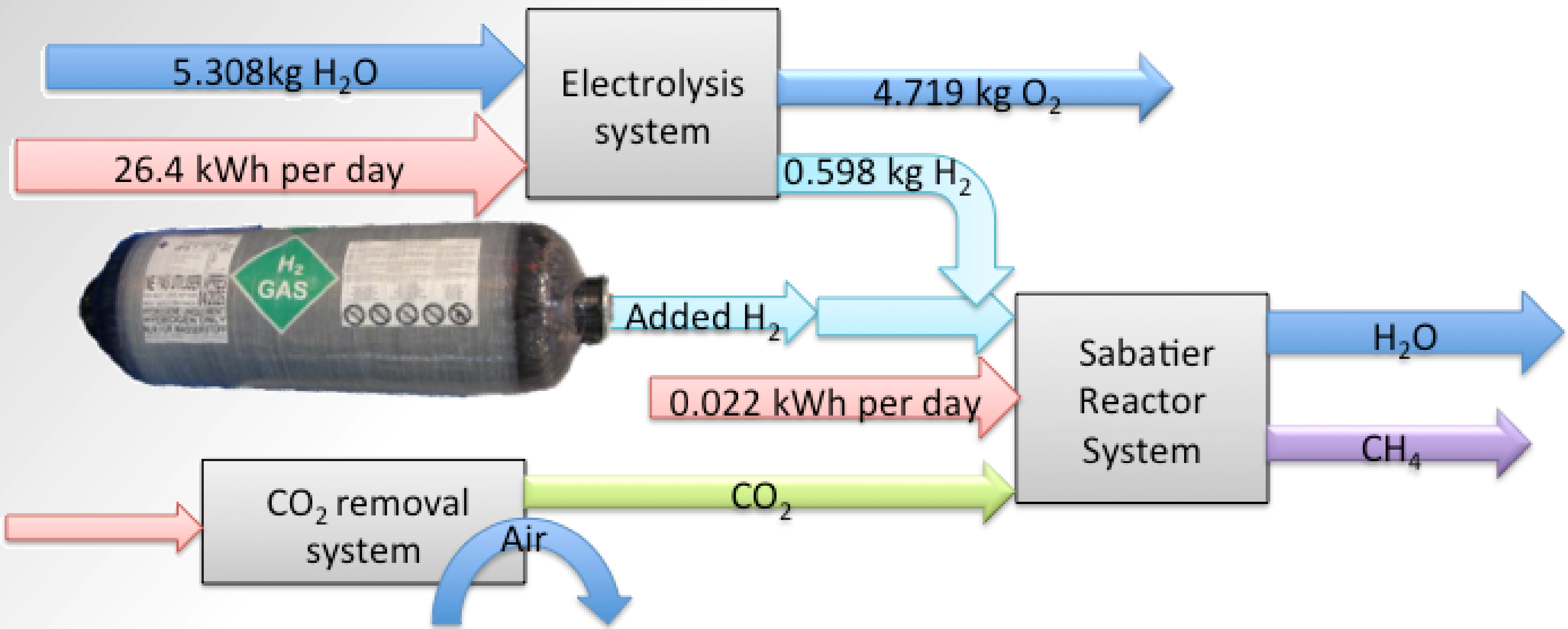

On-Board Plant Cultivation

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- Two of the four modules are dedicated to plant growth
  - Protein and other consumables that cannot be generated on-board are stored preflight in Asteria's freezers
  - Plants are grown using Aeroponics
- Roots are exposed to a nutrient-rich mist of water
  - Ideal for on-board cultivation
- Positives
  - Water dedicated to agriculture reduced by 98%
  - Need for fertilizer reduced by 95%
  - The need for pesticides is almost non-existent
  - Crop yield is 45%-75% higher compared to more traditional techniques

The Aeroponics System

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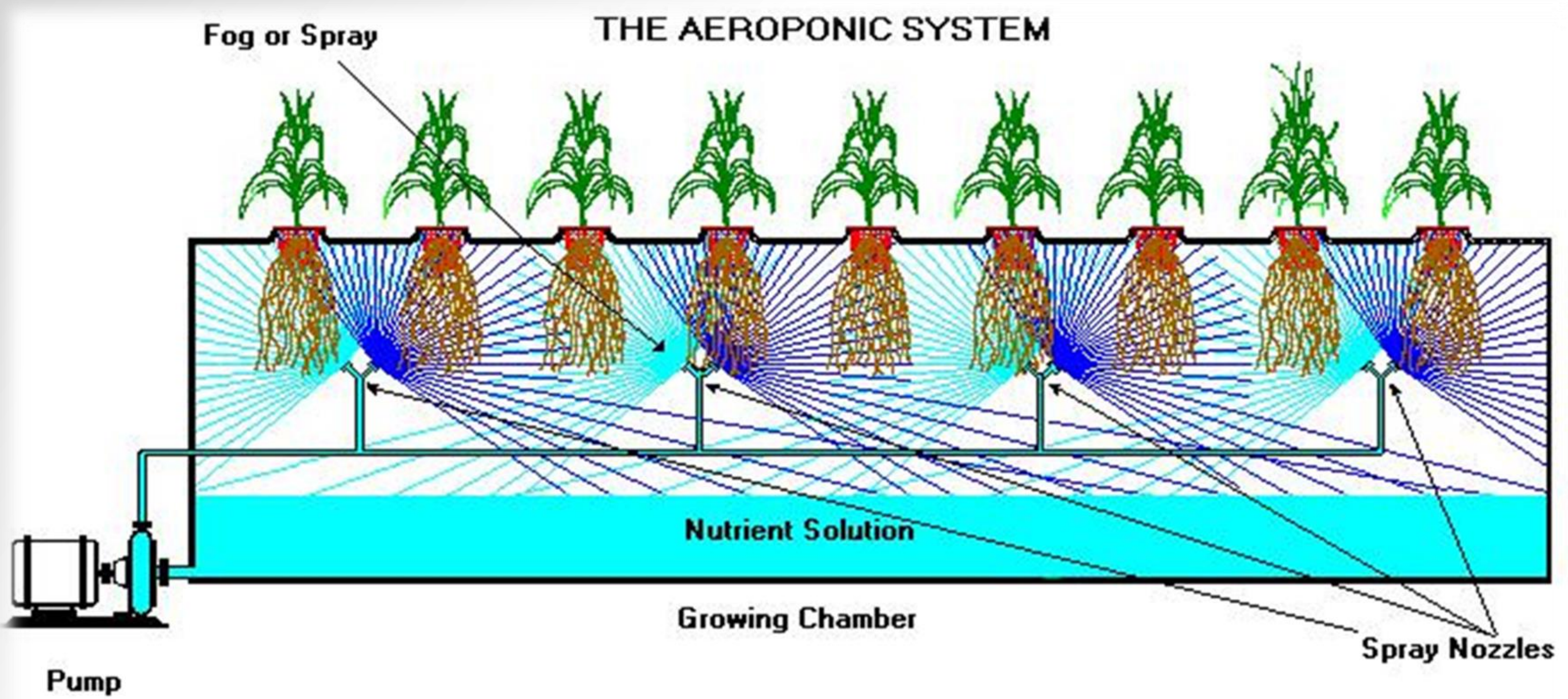

Conclusions

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- Project purpose
  - Meaningful senior design exercise
  - Is deep space exploration possible with today's technology?
- Utilized the Interplanetary Super Highway to define the trajectory
  - Savings in propellant and therefore mass
- Artificial gravity provided by spinning the Asteria at 3.5 rpm
  - Generating less than 1-g would improve adaptability and perhaps more acceptable
- Nuclear power is crucial to longevity and safety
- Radiation protection technology requires development
  - Students were not completely satisfied with their solution
  - However, technically the student's solution satisfied NASA's requirements
- On-board crop cultivation can realistically supplement pre-packaged food
- Regenerative life support will require development and improved reliability

Questions?

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