Systems Engineering and Near Term Commercial Space Infrastructure

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My Connection to Paul Kantor

- Keith Taggart: PhD-Physics (1970)
- Case-Western Reserve University
- Description
  - Paul's only Physics PhD student
  - Not an Academic: Couldn't deal with the politics
  - Learned a Trade: Problem Solving with a Supercomputer
  - Enduring interest in National Defense problems
  - Now Retired and trying to solve my own problems
  - Joke / Puzzle

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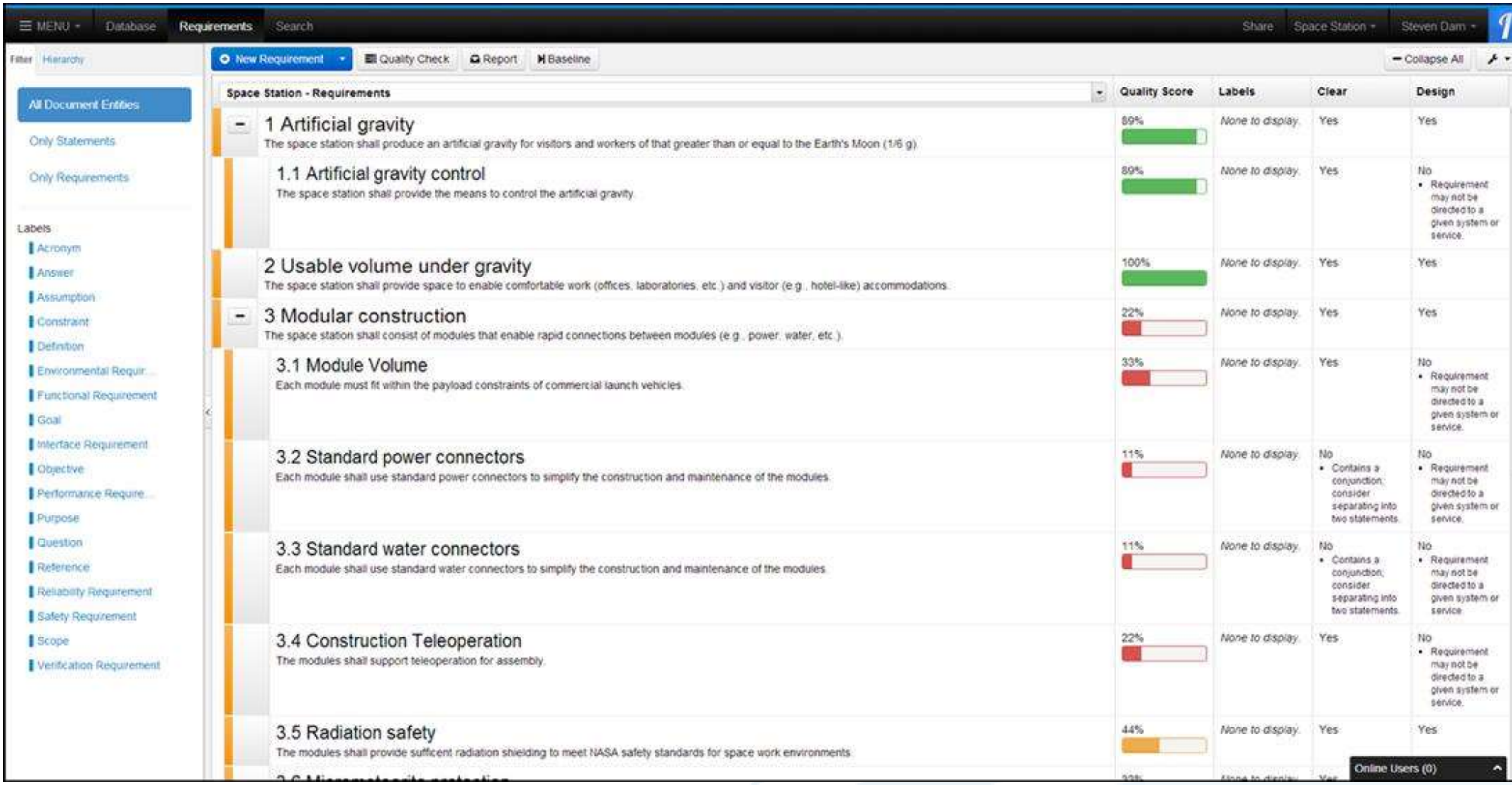
Systems Engineering

- Ordered Problem Solving
  - Concept
  - Initial Requirements
  - Initial Trades
  - Conceptual Design
  - Architecture
  - Refined Trades
  - Refined Design
  - Iterate as much and as often as money allows
- Model Based Systems Engineering Tool
  - **Innoslate**
  - Cloud Based Interface
  - Enforces and Aids "Ordered"
  - www.innoslate.com
- Example-Space Stations Conceptual Design

Cost
Schedule
Performance
You can have any 2

Requirements Analysis



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Key Usability Requirements

- 35 m radius at 3 rpm gives .35 g
  - Result of trade between gravity, coriolis force, and size/cost/construction time
- Total volume under gravity 3300 m^3 or 117,000 cubic feet
- Total floor space under gravity about 7200 square feet
  - One Module is about 300 square feet
  - A nice hotel room or office or lab
- These stations could support:

- Closed Environment Research
- Space Tourism
- Space Based Manufacturing
- Space Based Power
  - Assembly
  - Testing
- Research for Radiation Mitigation
- Research for Impact Mitigation
- Low Gravity Research (not micro gravity)
  - Control of Spinning Habitats
  - Long Term Effects on Humans
  - Long Term Effects on animals and plants
- Lunar/Asteroid/Martian
  - Exploration
  - Resource Exploitation
- Debris Collection
- Satellite Repair

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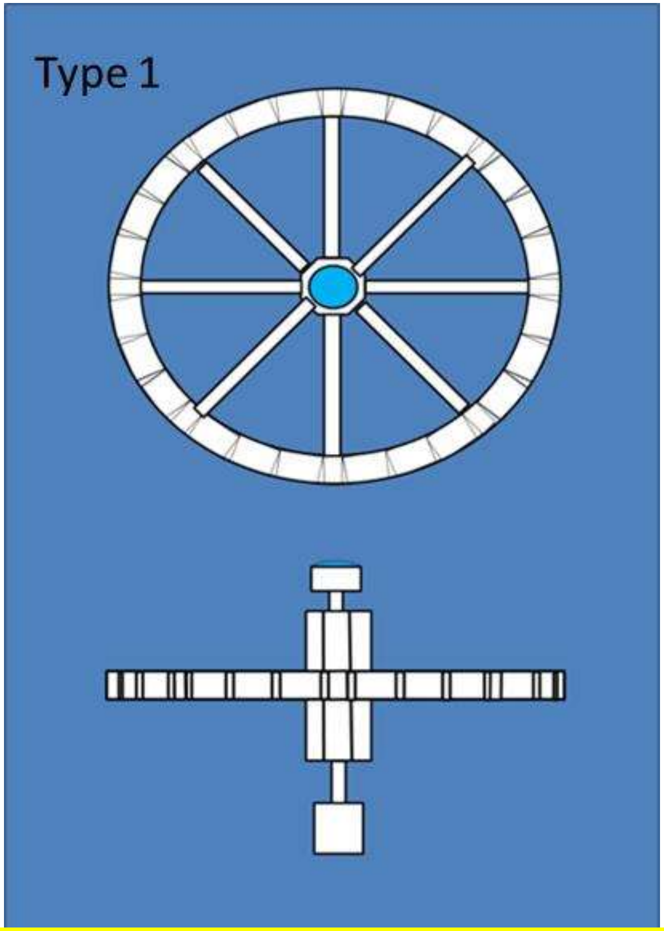
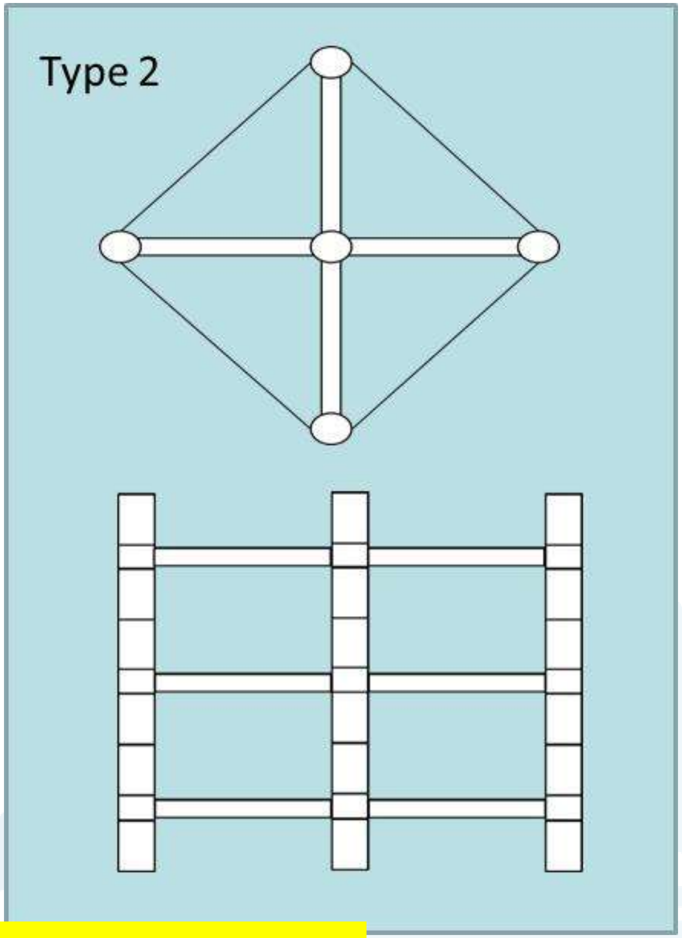
Two Space Station Concepts

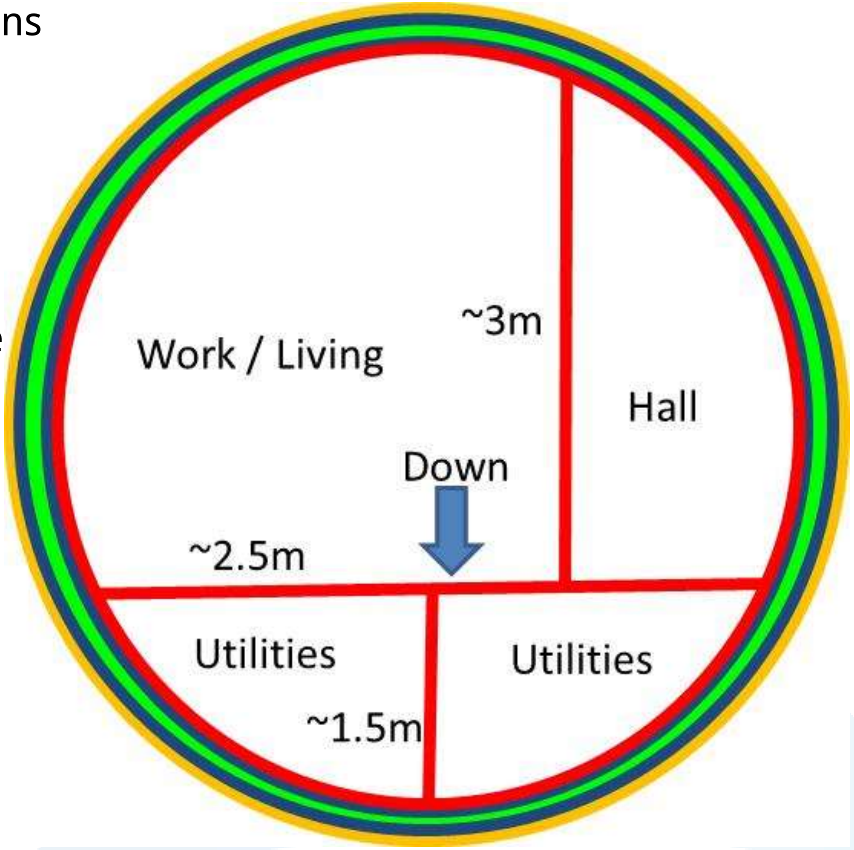




Coriolis Force F_c=-2mΩ x V

Conceptual Module Construction

Module Structure Mass M=(3.1+5.9+4.2+2.0) metric tons
  – M=15.2 metric tons
- Available Launch Mass
  – M=40 metric tons
- Five Layer Shell
  – Insulation / Impact - Orange
    - 1cm Mylar and Kevlar Layers, white surface
    - M=220x.01x1.4=3.1 metric tons
  – Pressure - Blue
    - 2x0.5 cm Aluminum
    - M=2x220x.005x2.7=5.9 metric tons
  – Sealant - Green
    - 1 cm Seals small holes
    - M=220x.01x2.0=4..2 metric tons
  – Interior - Red
    - .5 cm Structural Plastic, Foamed Core
    - M=(220+60)x.005x1.4=2.0 metric tons



Falcon Heavy Provides 160% Launch Margin

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“Back of the Envelope” Cost Estimates

Launch Costs

- 35 Falcon Heavy Launches
  - 35x40 metric tons=1400 metric tons to about 300 km
  - 35x120 M$ per launch = 4.200 B$
- 12 Falcon 9 Launches
  - 4 x 6 Construction Crew
  - 8 x 10 = 40 Metric tons of supplies
  - 12 x 56 M$ per launch = .67 B$
- Total Launch Costs to Construct
  - 4.9 B$

Construction Costs (Much Less Precise)

- 30 Modules at 100 M$ each equals 3.0 B$
- Crew Cost
  - 18 person years x 8760 hours per year x $1000 per hour equals
  - Equipment and Supply Cost 200 M$
  - Ground Support 200 M$
  - Fudge Factor 400 M$
- Total Construction Cost about 4.0 B$

Total Costs About 9 B$

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Summary

- We have just begun to explore the utility of commercial space stations
- Applying Model Based Systems Engineering techniques during the architecture phase will enable more robust trade-offs
- Having a scalable, integrated tool cuts time, and therefore costs, that can then be applied to greater quality and profitability
- Puzzle Answer

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A Canticle for Kantor

- Paul Kantor is a Physicist!
- I claim him for the Brotherhood
- Proof of my claim:
  - The Italian connection
  - The American connection
  - Paul chooses family over career
  - Paul finally gets to be an academic
- Everything I needed to know I learned from Paul (and my mother).

Paul Kantor-Academic Genealogy(1)

- The Italian Branch of the Family
  - Francesco Rossetti: University of Padova (1857)
    - Researched Electrostatics, electrochemistry, and thermometry of flames.
  - Andrea Naccari: University of Padua (1862)
    - Studied the thermoelectric properties of metals
  - Angelo Battelli: University of Turin (1884)
    - Measured temperature and heats fusion of non-metals
  - Luigi Puccianti: University of Pisa (1898)
    - Studied infrared absorption spectra to determine molecular structure
  - Enrico Fermi: Scuola Normale Superiore (1922)
    - Nobel Prize in Physics for 1938
    - Manhattan Project Chicago Pile-1, the first artificial sustained nuclear reaction
    - Theory of the weak nuclear force.
    - Fermi-Dirac Statistics.
  - Sam Treiman: University of Chicago(1952)
    - He and his students credited with developing the Standard Model of Particle Physics
    - Major contributions to the fields of Cosmic Rays, Quantum Physics, Plasma Physics, and Gravity Physics
  - Paul Kantor: Princeton University(1963)
    - Thesis: "Nucleon Nucleon Scattering and the Meson resonances.

Average Length of a Generation 14.1 years

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Paul Kantor-Academic Genealogy(2)

- The American Branch of the Family
  - Owen Willans Richardson: University College (1904)
    - Won the Nobel Prize in Physics for 1928
  - Karl Taylor Compton: Princeton University (1912)
    - President MIT 1930-1948
    - Brother of Arthur Compton-Nobel Prize in Physics 1927
  - John Quincy Stewart: Princeton University (1919)
    - Chief instructor in the Army Engineering School in WWI
    - Co-authored “Astronomy: A Revision of Young’s Manual of Astronomy”-The standard Astronomy textbook for 20 years
  - Serge Alexander Korff: Princeton University (1931)
    - Pioneer in the observation of Cosmic Rays at high altitude
  - John Simpson: New York University (1943)
    - High Energy radiation detectors for the Manhattan Project and later for space experiments
  - Sam Treiman: University of Chicago (1952)
    - He and his students credited with developing the Standard Model
    - Major contributions to the fields of Cosmic Rays, Quantum Physics, Plasma Physics, and Gravity Physics
  - Paul Kantor: Princeton University (1963)
    - Nucleon Nucleon Scattering and the Meson Resonances

Average Length of a Generation 9.4 years

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Paul Chooses Family over Career

- Paul arrives at Case Institute (1967)
- Case Institute of Technology and Western Reserve University merge (1968)
- The Great Physics Department Debacle
  - Two Departments with ~ 50 Faculty
  - Room for only about 25
  - Particle Physics funding cut drastically (1969)
  - All without tenure not renewed (1970)
- Paul chooses family over career, works as a consultant, and stays in Cleveland Until 1991.

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Paul Moves to Rutgers

- Paul was meant to be an academic
- So after his family was secure he moved to Rutgers (1991)
- Where he became Distinguished Professor of Information Scientist
- Where he found a lot more PhD students
- Where he found a lot more friends.
- BUT…in his heart of hearts he remains a

PHYSICIST

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Everything I Needed to Know

- I learned from Paul
  - "Quantum Mechanics" by Albert Messiah (Mess-ee-ah).
  - Words don't mean the same thing in Physics.
  - Physics are fun and addictive, better than selling ice cream from an Uncle Marty's truck, and useful in all endeavors
  - If you work hard you might earn a PhD.
  - Family is more important than career.
  - Be Agile but be Honest.
  - Just because you got the same answer in two different ways doesn't mean it's right.
  - Algebra, even really cool relativistic tensor algebra, is not as important as thought and insight.
  - Laugh at yourself (and others) as appropriate.
  - Kindness to one's juniors helps more than you know.
  - Always recognize people for their contributions.
- (and my mother)
  - Don't let your sons grow up to be Physicists

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