Paths to Space Settlement

Space Tourism -- Space Solar Power
Planetary Defense -- Molecular Nanotechnology

"For me the single overarching goal of human space flight is the human settlement of the solar system, and eventually beyond. I can think of no lesser purpose sufficient to justify the difficulty of the enterprise, and no greater purpose is possible," -- Michael Griffin

Al Globus
San Jose State University, NASA Ames
Space Settlement

• Not just a place to go work or visit for a limited time
  - Not a space station like ISS
  - Not exploration

• A home in space
  - Hundreds or thousands of residents
  - Many space settlements (thousands)

• Some stay for life

• Some raise kids
Where? Orbit

- To raise children that can visit Earth requires 1g
  - Moon 1/6g  Mars 1/3g
  - Orbit any g, for 1g rotate at 2rpm = 250m radius

- Continuous solar energy

- Large-scale construction easier in 0g

- Short supply line to Earth (hours vs days/months)

- Orbital disadvantage: materials
  - Need millions of tons, mostly shielding and structure
  - Moon: metals, Si, O
  - Near Earth Objects (NEO): wide variety
Lewis One Exterior
Image: AI Globus, CSC
Software: Jeff Hultquist
Applied Research Branch, NASA
NASA Ames Research Center
3 April 1991
O’Neill Cylinder
Stanford Torus
Kalpana One

body mounted solar arrays and power rectenna

thermal rejection

200m

250m

550m

Shielding inside rotating hull
Hull 15 cm steel

transparent end caps

Population 5,000
Why
Growth

• Largest asteroid converted to orbital space settlements can produce 1g living area 100-1000 times the surface area of the Earth.
  - Reason: 3D object to 2D shells
  - Easily support trillions of people.
• New land
  • Build it yourself
  • Don’t take from others
Wealth and Power

• China’s Ming dynasty
  – 1400-1450 ocean exploration
  – Pulled back, was colonized

• English 100 Year War 1337-1453
  – Failed military expansion in known world
  – Established empire overseas
    • English merchant marine, 1485-1509
    • 1550s Irish colonization
    • American colonies 1600s

• 625 million x energy on Earth
  – Total solar energy available

• One smallish NEO, 3554 Amun, contains $20 trillion materials.
  – There are thousands of such asteroids
Nice Place to Live

- Great views
- Low/0-g recreation
  - Human powered flight
  - Cylindrical swimming pools
  - Dance, gymnastics
  - Sports: soccer
- Independence
  - Separate environment
  - Easy-to-control borders
What Do We Need?

- **Earth to Orbit transportation**
- **Build really big things in orbit**
  - Habitats, solar collectors, thermal rejection
  - Use local materials (ISRU)
    - Moon, NEOs
- **Stay alive**
  - Small semi-closed plant-based ecosystem
- **Pay for it**
  - Unlikely fiscal 2010 line item
  - Piggy-back on space tourism, SSP, planetary defense, molecular nanotechnology
    - Pay for themselves independent of settlement
Launch Problem

- Failure rate about one percent
- Thousands of dollars per kg
- Forces mass, power optimization
  - Leads to small margins requiring extensive analysis and testing
  - No repairman!
    - Redundancy expensive, particularly testing
- In man-hr/kg to orbit, Saturn V cheapest!
- **Cause: low volume** (55 launches in 2005)
  - Cheapest commercial vehicles are Russian, who have made, by far, the most launches
Tourism = Launch Volume

<table>
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<th>Price/ticket</th>
<th>Passengers/year</th>
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Tourism Path

- Sub-orbital -- book flights now
- Orbital
- Orbital hotels -- two tourists/yr now
- Low-g retirement
- Special group habitats
  - Pay a premium to separate from rest of humanity
- General space settlement
Sub-orbital Tourism

- Book flights today
  - Virgin Galactic ($200K)
  - XCOR ($95K)
- Started by $10 million Ansari X-Prize
- Two sub-orbital launches same vehicle within two weeks by end of 2004
- Won by Burt Rutan
  - $40 million of Paul Allen's money
    - Couple million painting Virgin on the tail
    - Lead to a $120 million contract with Virgin
  - Funded by insurance policy
    - All industry experts said it couldn’t be done by deadline. Oops.
Orbital Launch Proposal

• Pay to put people in orbit -- like X-Prize
• Pay for many launches
• Limit payout fraction to any one competitor
• Estimate $1 - 8 billion in prizes to get cost to $10,000/person
  - If fail, keep the prize money!
• Based on costs estimates by tSpace, SpaceDev
• Safety: key personnel on flights
## Launch Prize Schedule

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<th>Passenger</th>
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<th>Cost($M)</th>
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</table>
Floating to Orbit

- Airships (JP Aerospace)
  - Experimentalists
  - Vehicles
    - Ground to 120,000 ft
    - Floating base at 120,000 ft
    - Orbital vehicle constructed at base
      - Km scale
      - Floats to 180,000 ft
      - Low thrust engines
      - 1-5 days to get to orbit
      - High drag return
        » SpaceShipOne too
Orbital Hotels

• ISS six guests @ $20-30
  - Russian Soyuz
  - First two-tourist flight advertised
  - May end after 2009 to accommodate 6 person crew

• Bigelow inflatable
  - Two small pressurized spacecraft currently in orbit
  - Habitable version 2010?
  - Market: inexpensive national human spaceflight programs
Low-g Retirement

• No wheelchairs needed.
• No bed sores.
• Never fall and break hip.
• Much easier to get around.
• Grandchildren will love to visit
  - 0g play
• Need good medical facilities.
  - Telemedicine
• Probably can’t return to Earth.
Space Solar Power

• Gather solar energy in space
• Wireless transmission to Earth
• Convert to electricity
• Vast quantities
  - 24/7 (no night, clouds)
• Extremely green
  - No CO2 emissions
• Depose King Oil
  - Requires electric cars
SSP = Launch Volume, ISRU

- Today’s energy market 18 TW
  - $8Tr/yr @ $0.05/kw-hr
    - US Military will pay $1/kw-hr remote regions
  - Tomorrow’s market much larger
  - 18 Mtons sat @ 1kg/kw
    - 100,000 Ares V launches

- ISRU
  - Lunar Si and metals supply most mass
  - Extremely green
    - Most work done thousands of km from biosphere
SSP Transportation

• Sea Dragon for launch
  - Big, dumb booster
  - Early 60s design
  - 150m tall, 23m diameter
  - First stage reusable
  - Pressure-fed engines
  - 8mm steel tankage
  - Ocean launch, shipyard construction
  - 500 ton to LEO @ $242/kg
  - 0.5 GW sat per launch
  - $27B development cost

• Solar-electric orbital transfer vehicle
Assembly and Maintenance

• Teleoperated cooperating robots
  - Weightless operations
  - Lighting, power, thermal constraints
  - Handle thin flexible mirrors, wires

• Major man/machine integration issues
  - MACS-like simulator essential
    • Simulate robots, video feeds, data limitations
  - Displays
  - Autonomy issues
  - Input device(s)
Planetary Defense

- Thousands of NEOs
- Large fraction impact Earth
  - Eventually, may be awhile
- NEO detection identifies potential materials sources
- Deflection technology may be adapted for retrieval
  - Small NEOs (10-50m) for safety
Three Pillars of Molecular Nanotechnology

• Atomically precise control of matter
• Molecular machines
• Programmable matter

Our favorite molecules:
carbon Nanotubes
Atomically Precise Control of Matter


[Dekker 1999]
Molecular Machines

[Cassell 1999]
Programmable Matter

- Numerical Machine Tools

- Fabbers

- DNA, RNA, Polypeptide sequencers

Programmed Molecules for Sale
What Can you Get?

• Diamondoid materials with great strength, thermal properties, stiffness.
• Existing design diamondoid SSTO $153-412/kg to orbit vs $16,000-59,000/kg for titanium [McKendree 95]
• Three-ton four-person clean sheet diamondoid SSTO vehicle [Drexler 1992]
• May enable space elevator
Space Programs

- Constitutional (promote the general Welfare)
  - Earth observation
  - Launch
  - Planetary defense
  - Aeronautics
  - SSP
  - Science

- Space Settlement
  - Launch
  - Lunar/NEO mine
  - Material transport
  - In-orbit materials processing and manufacture
  - SSP
  - Large construction
  - Life support
Life Support 'Easy'

- Consider Biosphere II
- Six people in closed environment for over one year on first try
  - We know it was closed, ran out of oxygen
- Scientific failure hid engineering success
- Lots of species
  - Survival of the fittest
  - Make sure most are edible
Conclusion

The settlement of the solar system could be the next great adventure for humanity. There is nothing but rock and radiation in space, no living things, no people. The solar system is waiting to be brought to life by humanity's touch.