An answer to NASA’s Big Idea Challenge

Odysseus

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Mission Goals

Develop a system architecture which will take cargo to the moon based on a cost effective architecture.

Develop a mission system to meet the BIG Idea Challenge.

Research current day technology and extrapolate an architecture which is advanced but based on an incremental leap forward.

Seek out industry feedback to mature our design.

Learn about relevant demonstration missions.
Key Drivers

Complete assembly of the tug will take no more than 60 days in orbit.

The tug must provide at least 200 kW of solar-produced power to its ion propulsion system.

The tug must withstand up to 0.4 g’s of acceleration.

The fundamental flexible body vibration mode will be at least 0.05 Hz.

The tug’s design will be able to be scaled up to the 500 kW power class.
Modularity

Like DARPA’s Dragonfly and Orbital Express, Odysseus will be a robotically assembled platform with the ability to replace and even upgrade each major component.

2 Levels of modularity:

• Tug – Multiple identical modules
• Subsystem – redundant hardware and multiples of specific subsystems
Spacecraft Versions

100 Kw Module

200 kW Earth Lunar Transport (ELT)

500 kW Earth Martian Transport (EMT)
CONOPS

PHASE 1: Launch
1. Launch of first module
2. First module in assembly orbit
3. Launch of second module
4. Second module in assembly orbit

PHASE 2: Assembly
1. Both modules approach each other
2. Both modules berthed, ELT complete

PHASE 3: Cargo Transport
1. Cargo is launched into orbit
2. ELT docks with the cargo
3. ELT and cargo begin transfer orbit
4. Cargo is dropped off in lunar orbit
5. ELT begins transfer orbit back to Earth
6. ELT reenters Low Earth Orbit

PHASE 4/5: Service/Repurpose
1. Three more 100kW modules are berthed to the ELT
2. The new 500kW EMT is ready for interplanetary travel
Phase 1

Launch

➢ 1 Launch per Module
  ○ 2 Launches for ELT
  ○ 5 Launches for EMT
➢ Falcon 9 Launch Vehicle
Phase 2

Assembly
Phase 3

Cargo Transfer

EMT

ELT
Phase 4 & 5

Service & Repurpose
Design Overview
Spacecraft Geometry

➢ Rough shape of an extruded octagon.
  ○ Space for robotic arm.
  ○ Room for solar panels and thrusters.
  ○ Increased volume efficiency.

➢ Each subsystem is compartmentalized into ‘wedges’ of the octagon.
EPS

➢ To reach 200 kW each module will produce 100 kW.
➢ Allocated 2kw for all other systems per module.
➢ Require 622 m^2 of solar panel area.
➢ Main bus voltage designed around 28 volt architecture.
➢ Propulsion system requires ~450 volts across each thruster
EPS

➢ Solar cells used: spectrolab XTJ Prime 30.7% efficiency
➢ Solar array design based off of:
  ○ ISS arrays
  ○ MMA’s R-HaWK
  ○ Fits into a volume of 6.7 x 1.66 x 0.24 m when stowed.

Solar arrays “fan out” from the support boom while the base of the boom rotates the solar array to always point toward the sun.
ADCS and RCS

➢ The attitude control system is reaction control wheels and the primary thruster bank.
  ○ Three reaction wheels per axis.
  ○ Each 1.25m in diameter due to volume constraints, but can be optimized.
➢ The reaction control system is eight cold-gas Xe thrusters.
  ○ Will be used for emergency attitude/orbital maneuvers.
C&DH

The two modules’ processors will act together in a primary-secondary relationship.

The two processors are connected to their own subsystems. They are also connected to each other through the docking port.
The left processor is also connected to the other module’s subsystems through the docking port for redundancy and protection from right processor failure.
The right processor is also connected to the other module’s subsystems through the docking port for redundancy and protection from left processor failure.
Propulsion

Hall effect thruster:
- Power = 20 kW (each)
- Thrust = 1.020 N (each)
- Isp = 2500s (each)
- Voltage = 450 V (each)
- 5 thrusters per module
- Clustered to improve performance

<table>
<thead>
<tr>
<th></th>
<th>Thrust (N)</th>
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<tbody>
<tr>
<td>Thruster</td>
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<tr>
<td>Module</td>
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</tr>
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<td>ELT</td>
<td>10.2</td>
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<tr>
<td>EMT</td>
<td>25.5</td>
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BRACE
Berthing and Rendezvous Arm Control Environment

➢ Assembly
➢ Cargo Rendezvous
➢ Refueling
Orbital

Continuous Burn Orbit Given a Mass of 15000 kg

Travel to lunar distance takes 86.2 days
As designed, tug can make 15 round trips to the moon in ten years assuming 30 days spent for orbital insertion and loiter.
Conclusion
Special Thanks

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Stephen Sandford
Stinger Graffarian Technologies
HansPeter Schaub
Veronica Bierbaum
Example Control Flow-Down

```plaintext
while dockingSensor reads notDocked:
  readSensors:
    star sensor
    gyro
    magnetometer
    accelerometer
    proximity sensor
    partner orientation sensor
    docking

if dockingSensor reads docked:
  break

decideWhatToDo:
  - Accelerate toward partner
  - Decelerate w/ respect to partner
  - Rotate about axis
  - Docking

doIt:
  - Firing engine(s)
  - Use reaction wheels/RCS
  - Docking

continue
```
<table>
<thead>
<tr>
<th>System</th>
<th>Estimated Power Consumption (W)</th>
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<tr>
<td>CDH processor unit</td>
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<td>Reaction wheels</td>
<td>20</td>
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<td>Robotics</td>
<td>10</td>
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<tr>
<td>Solar array movement</td>
<td>200</td>
</tr>
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<td>Communication</td>
<td>50</td>
</tr>
<tr>
<td>Sensors</td>
<td>50</td>
</tr>
<tr>
<td>Thermal heat pumps</td>
<td>100</td>
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<tr>
<td>Propulsion</td>
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</tr>
<tr>
<td>Total</td>
<td>100,630</td>
</tr>
</tbody>
</table>
Graphic Reference

hdwallpapers

wallpaperscraft.com

wallpaperswide.com

Laboratoire LAPLACE

NASA
Appendix Slides
7075 Aluminum

5.1 N force applied in the -x direction

Solved for inertial relief
Solar Panel Vibration Mode straight configuration

<table>
<thead>
<tr>
<th>Mode No.</th>
<th>Freq (Hertz)</th>
<th>X direction (cm)</th>
<th>Y direction (cm)</th>
<th>Z direction (cm)</th>
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Assumptions:

Worst case analysis of the module as a single piece of 7075 Aluminum.

We chose a current technology that can mitigate some structural issues.
Solar Panel Vibration Mode offset configuration

<table>
<thead>
<tr>
<th>Mode No.</th>
<th>Freq (Hertz)</th>
<th>X direction (cm)</th>
<th>Y direction (cm)</th>
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<td>5.1197</td>
</tr>
</tbody>
</table>

Assumptions:

Worst case analysis of the module as a single piece of 7075 Aluminum.

We chose a current technology that can mitigate some structural issues.
Thermal

➢ Major thermal contributors include Propulsion system & solar radiation
➢ Active internal thermal control via heat pipes
➢ Larger radiator and power allotment for thermal subsystem required
➢ Potential use of solar panel thermoelectric generation technology, reducing heat input
Berthing

Berthing Modules Together

1. Both modules are in orbit ~100 m away from each other.
2. First (passive) module keeps solar array stowed and uses batteries to maintain orientation until docked.
3. Second (active) module deploys solar array and approaches passive module at ~1 m/s.
4. Once the two modules are within ~15 m, the active module deploys its arm and soft docks with the passive module.
5. Once both modules are stationary relative to each other the arm pulls the two modules together where clamps hard dock the two modules together.
6. If during any step something goes wrong, the passive module can use its RCS to quickly separate both modules to prevent collisions.

Berthing with the cargo

1. Tug and cargo are in orbit ~100 m away from each other.
2. Until docked, cargo will maintain orientation.
3. Tug approaches cargo at ~1 m/s.
4. Once they are within ~15 m, the tug deploys its arm and soft docks with the cargo.
5. Once they are stationary relative to each other the arm pulls the cargo against the tug where clamps hard dock the two together.
6. If during any step something goes wrong, the tug can use its RCS to quickly separate from the cargo to prevent collisions.
Mass

Roughly estimated to be 15,000 kg total
12,000 kg lower limit
16,500 kg upper limit

Distribution of mass
Propellant - 3,200 kg
Solar panels - 1,300 kg
Cargo - 10,000 kg
Additional Components - 500 kg
Communications

➢ Ideal Comms environment on the ground side
  ○ DSN readiness
  ○ High gain
  ○ Low Path loss

➢ 10 Watt omnidirectional antenna on each module
  ○ Able to hardlink in series
Testing & Production

➢ Neutral Buoyancy Tanks

➢ Small Satellite Dynamics Testbed

➢ Formation Control Testbed
  ○ T.R.L. level 7

➢ Universal, Simple and modular design:
  ○ optimal for efficient production of multiple tugs
All key technologies have a TRL of 6 or higher.
Feasibility

Several missions and technology have demonstrated technical feasibility

- Orbital Express
- Hall Effect Thrusters
- Solar array deployment and efficiency