A Review of Interstellar Starship Designs

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Overview

- Part 1: Brief Intro to Icarus Interstellar
- Part 2: The Physics of Interstellar Travel
- Part 3: Specific Starship Designs

Interstellar Precursor Probe, “Icarus Pathfinder”, designed by Project Icarus. Courtesy Adrian Mann
Part 1: Introduction to Icarus Interstellar

Icarus Interstellar was ‘born’ out of Project Icarus

Project Icarus has a fourfold purpose:

1. To motivate a new generation of scientists in designing space missions that can explore beyond our solar system.

2. To generate greater interest in the real term prospects for interstellar precursor missions that are based on credible science.

3. To design a credible interstellar probe that is a concept design for a potential mission in the coming centuries so as to allow a direct technology comparison with Daedalus and to provide an assessment of the maturity of fusion based space propulsion for future precursor missions.

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Icarus Interstellar is a nonprofit corporation.

Founded in March 2011

Mission Statement:

The mission of Icarus Interstellar is to realize interstellar flight before the year 2100.

We will accomplish this objective by researching and developing the science and the technologies that will make interstellar flight a reality, igniting the public's interest, and engaging with all those prepared to invest in interstellar exploration.
International Team

Designers:
1. R. Obousy, Ph.D (USA)
2. A. Tziolas, Ph.D (USA)
3. R. Adams, Ph.D (USA)
4. I. Crawford, Ph.D (UK)
5. A. Hale, Ph.D (USA)
6. J. Benford, Ph.D (USA)
7. S. Baxter, Ph.D (UK)
8. K. Long, (UK)
9. P. Galea, (UK)
10. R. Osborne, (UK)
11. R. Swinney, (UK)
12. P. Reiss, (Germany)
13. A. Hein, (Germany)
14. A. Mann, (Netherlands)
15. A. Crowl, (Australia)
16. J. French, (USA)
17. R. Freeland, (USA)
18. D. Homatas, (Greece)
19. M. Stanic, (Serbia)
20. B. Cress, (USA)
21. Kostas Konstantinidis, (Greece)

Student Designers:
1. B. Vernon, (USA)
2. T. Frierson, (USA)
3. D. Shankar, (India)

Friends of Icarus:
1. S. You, Ph.D (Cambodia)
2. J. Barrington-Cook, (UK)
3. H. Bright, (USA)
4. J. Winchester, (USA)
Part 2: The Physics of Interstellar Travel

Currently four US spacecraft are travelling in interstellar space. These are the *Voyager* and *Pioneer* probes, travelling at speeds of 2.2 and 3.5 AU/year respectively.

Voyager 1 is travelling at 17 km/s (38,000 mph) and is 116 AU from Earth.

One of our closest neighbors, $\alpha$-Centauri, is 272,000 AU from Earth.
This challenge becomes more apparent if we consider one of the simplest equations that governs spaceflight; the Tsiolkovsky rocket equation.

\[ R = \exp(\frac{\Delta v}{I_{sp} g_0}) \]

Plugging in the numbers relating to a chemical propellant fueled flyby of α-Centauri with a Δv of 10%c reveals that we would need more fuel than there exists mass in the known universe!
Classically, **chemical** reactions encompass changes that strictly involve the motion of electrons in the forming and breaking of chemical bonds.

Only 13.6 eV of energy is required to ionize a Hydrogen atom.

Contrast this with 200 MeV released from the fission of U-235, or the 17.6 MeV released during a DT fusion event.

<table>
<thead>
<tr>
<th>Reaction</th>
<th>Specific Energy (J/Kg)</th>
<th>Specific Impulse (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical</td>
<td>1.5 E7</td>
<td>~100</td>
</tr>
<tr>
<td>Fission</td>
<td>7.1 E13</td>
<td>~1000</td>
</tr>
<tr>
<td>Fusion</td>
<td>7.5 E14</td>
<td>10,000 - 1,000,000</td>
</tr>
<tr>
<td>Antimatter</td>
<td>9.0 E16</td>
<td>&gt; 1,000,000</td>
</tr>
</tbody>
</table>

*Energy Densities of Rocket Fuels*
**Solar Sails**

- Harness solar photon pressure
- Typically large, low density structures
- Can be utilized for missions outside the solar system if a solar ‘flyby’ maneuver is executed.
- Could exit the solar system at 10’s AU/Year

Japanese Ikaros probe. Image courtesy JAXA.
Beamed Energy

• Harness manmade photon pressure, typically laser or microwave.

• Thrust is generated by transmitting a collimated electromagnetic beam from a transmitter to the spacecraft.

• No power is lost as a function of distance.
Nuclear Rockets

- Wide range of fission/fusion propulsion ideas exist in the literature.

- Two general classes: *pulsed* propulsion and *continuous*.

- Solid Core fission rockets flight certified and relatively technologically mature.

- US NERVA program lead to flight certified fission rockets.
Antimatter Rockets

- Theoretical models for positron/electron and proton/antiproton propulsion engines exist in the literature.

- No known reaction yields more energy than matter antimatter annihilation.

- Main issues; creation and storage of antiparticles.

Antimatter concept craft created for Obousy courtesy of Adrian Mann.
Part 3: Specific Starship Designs

★ Orion

• Initiated in 1958 by Ted Taylor at General Atomics. Inspired by Stanislaw Ulam.

• Pulse units detonated and transfer thrust to the vehicle via the pusher plate.

• Original design utilized fission pulse units

• Ablation Space Ship is modified for interstellar.

Ablation Space Ship Specs

• Total mass of 400,000 tonnes.
• 300,000 pulse units comprising 60% of the total mass.
• 1 g acceleration for 10 days
• 10,000 km/s (3.3%c)
• α Centauri in 130 years.
Specific Starship Designs

Daedalus

- Detailed 5 year starship study initiated in 1973 by British Interplanetary Society.
- Internal/external hybrid fusion pulsed propulsion engine.
- Target: Barnard's star.
- Estimated top speed, 12%c
- Est. 10,000 man hours put into project.
- Deuterium Helium-3 fuel

Legend

- Charged Particle
- Neutron Power
- Thermal Radiation

Image Courtesy Adrian Mann
Specific Starship Designs

Daedalus Engine Components

- Propellant Storage
- Pellet Injection Gun
- Electron Beams
- Reaction Chamber
- Magnetic Nozzle Coils
Specific Starship Designs

**Propellant Storage**

- Stage 1: 46,000 tonnes of fuel
- Stage 2: 4,000 tonnes of fuel
- Storage Tanks Cooled to 3K and held at 0.812 atm.
Specific Starship Designs

**Pellet Injection Gun**

- Injected pellets at 250 per second using a magnetic wave.
- Field strength of 15T
- Pellet acceleration $3.83 \times 10^7 \text{ m/s}^2$ (1st stage) and $8.21 \times 10^7 \text{ m/s}^2$ (2nd stage).
- Massive capacitors (~30 tonnes)
- Massive cooling system (~40 tonnes)
**VISTA**

- Vehicle for Interplanetary Space Transport Application
- Manned Interplanetary Vehicle
- 12 T magnetic nozzle
- ~cm sized DT fuel pellets
- 30 HZ firing rate
- 5 MJ laser
- Capsules release 7,500 MJ energy
- ~9% of fusion energy (plasma) used for propulsion
- $I_{sp} = 27,200$
- $\Delta v = 100 \text{ km/s}$
Beamed Power Sail

- Does not carry its own fuel
- Interstellar rendezvous mission proposed by Forward, and adapted by Frisbee.
- 1μm laser beam
- Peak Laser Power = 73.24 TW
- Stage 1 Diameter = 102.05 km
- Stage 2 Diameter = 32.27 km
- Cruise velocity = 0.132c
- Total mass = 1GT
The Enzmann Starship

- Introduced by Robert Enzmann in 1960s
- Manned colonization ship
- Launch mass ~3M tonnes
- 6-24 fusion engines
- DD fusion
- Propulsion Orion style
- D sphere coated in metallic shell
- Claimed top speed 9%c
“All of this seems an incredible undertaking, but if we are to tackle the problem on the astronomical scale, then we must attempt to visualize solutions to suit.”

Dr. Anthony Martin, Project Daedalus