Project Icarus: Son of Daedalus – flying closer to another star.

K F Long
Contents

- Motivation
- Project Daedalus
- Fusion Propulsion
- Project Icarus
- Conclusions
Motivation: Robotic Pioneers
Motivation: Robotic Pioneers
Motivation: Technology Readiness Levels

What is the TRL of fusion based propulsion schemes?
The Challenge of the Spaceship

“We can take it for granted that eventually nuclear power, in some form or other, will be harnessed for the purposes of space flight....The short-lived Uranium age will see the dawn of space flight; the succeeding era of fusion power will witness its fulfilment”. Arthur C Clarke, 1961.
Inertial Confinement Fusion

\[ n \tau T \geq 10^{21} m^{-3} s KeV \]

1. Laser MegaJoule
2. JET & ITER
3. HiPER
4. NIF

Fuel
- \( \rho \sim 10^2 g/cm^3 \)
- \( \rho r \sim 0.3 g/cm^2 \)

Hotspot
- \( \rho \sim 10^3 g/cm^3 \)
- \( \rho r \sim 1 g/cm^2 \)

This is the NIF baseline target
Project Vista (1986-1987)

- ICF DT fuel, 5MJ laser driver energy.
- Fast ignition for high gain >1000. Isp~$10^4$s.
- Round trip to Mars ~6months; any planet in solar system ~7years.

- Design study to reach Alpha Centauri in ~100 years.
- ~300kW nuclear fission reactor powers lasers for ICF propulsion using D/He3 fuel.
- Isp~$10^6$s.
Project Daedalus (1973-1978), BIS

- Design study for interstellar flyby probe to Barnard’s Star, 5.9ly away.

- Three guidelines:
  - [1] The spacecraft must use current or near-future technology.
  - [3] The spacecraft must be designed to allow for a variety of target stars.

David Hardy
D/He3 ICF using electron beams.
Ignite ~250 capsules/s, magnetic nozzle.

- Electromagnetic gun accelerates capsule, via superconducting shell around capsule.
- Electron beams target capsule
- Implose to ignition.
Daedalus (Capsule design)

- Diameter $\sim 3.9\text{cm}$ (1st stage) $\sim 1.8\text{cm}$ (2nd stage)
- Require $\sim 3 \times 10^{10}$ capsules.
- If production was for 1 year, would need to make $\sim 1000$ capsules/s.
- Neutrons per pulse:
  - $6 \times 10^{21}$ (1st stage)
  - $4.5 \times 10^{20}$ (2nd stage)
- Neutron production rate:
  - $1.5 \times 10^{24}\text{n/s}$ (1st stage)
  - $1.1 \times 10^{23}\text{n/s}$ (2nd stage).

British Interplanetary Society
What is Project Icarus?

- Tau Zero Foundation (TZF) initiative in collaboration with The British Interplanetary Society (BIS).

- **Greek mythology**: Icarus flew too close to the sun melting the wax on his wings. He fell into the sea and died after having ‘touched’ the sky. *Project Icarus aims to ‘touch’ the stars and escape from the bounds of mother Earth.*

- Daedalus study report: “*it is hoped that these 'cunningly wrought' designs of Daedalus will be tested by modern day equivalents of Icarus, who will hopefully survive to suggest better methods and techniques which will work where those of Daedalus may fail, and that the results of this study will bring the day when mankind will reach out to the stars a step nearer*.”
Project Icarus Logo
What is the Purpose of Project Icarus?

- To design a credible interstellar probe that is a concept design for a potential mission in the coming centuries.
- To allow a direct technology comparison with Daedalus and provide an assessment of the maturity of fusion based space propulsion for future precursor missions.
- To generate greater interest in the real term prospects for interstellar precursor missions that are based on credible science.
- To motivate a new generation of scientists to be interested in designing space missions that go beyond our solar system.

**Mission Range (light years)**

\[ D(ly) = \left( \frac{v}{c} \right) \times t(y) \]

**Mission Duration (years)**

- Alpha Centauri ~4.3ly
- Barnard’s star ~5.9ly
- Epsilon Eridani ~10.7ly
- Tau Ceti ~11.9ly
What are the terms of reference?

[1] To design an unmanned probe that is capable of delivering useful scientific data about the target star, associated planetary bodies and solar environment.

[2] The spacecraft must use current or near future technology and be designed to be launched as soon as is credibly determined.

[3] The spacecraft must reach its stellar destination within as fast a time as possible, not exceeding 60 years and ideally much sooner.

[4] The spacecraft must be designed to allow for a variety of target stars.

[5] The spacecraft propulsion must be mainly fusion based (i.e. Daedalus).

[6] The spacecraft mission must be designed so as to allow a modification to the trajectory with minimum fuel for a second target destination.

Watchwords: CREDIBLE- PRACTICAL- SCIENTIFIC- NEAR FUTURE.
Why ‘Mainly Fusion Propulsion’?

- Daedalus one of only two comprehensive interstellar studies (i.e. Orion).
- Want to improve on Daedalus design.
- Fusion propulsion credible scheme for interstellar missions (i.e. high Isp).
- Build upon public interest in Daedalus, strong support based from BIS & TZF.
- Focussed design study to illustrate key stepping stones (forms project scope).
- Link propulsion studies into current fusion programmes.
- Overlap with other interests (i.e. ICF research) to justify time commitment.
- Capability to calculate ICF propulsion performance using physics codes.
# Project Icarus Scope

<table>
<thead>
<tr>
<th>Project Icarus System Research Modules</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0 Astronomical Target</td>
<td>11.0 Computing &amp; Data Management</td>
</tr>
<tr>
<td>2.0 Mission Analysis &amp; Performance</td>
<td>12.0 Environment Control</td>
</tr>
<tr>
<td>3.0 Vehicle Configuration</td>
<td>13.0 Ground Station &amp; Monitoring</td>
</tr>
<tr>
<td>4.0 Primary Propulsion</td>
<td>14.0 Science</td>
</tr>
<tr>
<td>5.0 Secondary Propulsion</td>
<td>15.0 Instruments &amp; Payload</td>
</tr>
<tr>
<td>6.0 Fuel &amp; Fuel Acquisition</td>
<td>16.0 Mechanisms</td>
</tr>
<tr>
<td>7.0 Structure &amp; Materials</td>
<td>17.0 Vehicle Assembly</td>
</tr>
<tr>
<td>8.0 Power Systems</td>
<td>18.0 Vehicle Risk &amp; Repair</td>
</tr>
<tr>
<td>9.0 Communications &amp; Telemetry</td>
<td>19.0 Design Realisation &amp;</td>
</tr>
<tr>
<td></td>
<td>Technological Maturity</td>
</tr>
<tr>
<td>10.0 Navigation &amp; Guidance Control</td>
<td>20.0 Design Certification</td>
</tr>
</tbody>
</table>

- **Fuel**: D/D, D/T, D/He3, Li/p, B/p...
- **Fuel acquisition**: Jupiter, solar wind, moon...
- **Capsule**: ICF, MCF, antimatter initiation...
- **Driver**: Laser, electron, ion...
- **Target star**: Barnards star, Epsilon Eridani, Tau Ceti, Alpha Centauri...
- **Exo-planet observations** critical to choice of destination, supported by numerical simulations.
Mining He\textsuperscript{3} from Jupiter

- Process 680kg/s of Jovian atmosphere. Produce 1.15g/s (He\textsuperscript{3}) 0.77g/s (D), 3.67g/s (H)

- Alternatives
  - Solar wind
  - Asteroids
  - Comets
  - Accelerator
  - The Moon
  - Other planets or moons

<table>
<thead>
<tr>
<th>Planet</th>
<th>Jupiter</th>
<th>Saturn</th>
<th>Uranus</th>
<th>Neptune</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance (AU)</td>
<td>5.2</td>
<td>9.5</td>
<td>19.2</td>
<td>30.1</td>
</tr>
<tr>
<td>$V_{\text{escape}}$ (km/s)</td>
<td>59.5</td>
<td>35.5</td>
<td>21.3</td>
<td>23.5</td>
</tr>
<tr>
<td>Atmosphere *</td>
<td>89%H, 10%He</td>
<td>95%H, 3%He</td>
<td>83%H, 15%He</td>
<td>80%H, 19%He</td>
</tr>
</tbody>
</table>

* + methane, ammonia, ethane…
Icarus – A Science Driven Mission

PRIMARY OBJECTIVES
(Exploration of the target system, in descending order of priority).

1. Terrestrial planets.
2. Giant planets.
3. The star.
4. Minor objects.
5. Dust.

SECONDARY OBJECTIVES
(Observations or activities to be carried out in the boost or cruise phase, in no particular order).

1. Observations of solar system outer bodies.
2. Measurements of heliopause/ISM.
3. Measurements addressing gravitational issues.
4. Experience of autonomy, dormancy, and reliability of spacecraft components during long duration mission.

<table>
<thead>
<tr>
<th>No.</th>
<th>Theme</th>
<th>Science goal</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Gravitation</td>
<td>What is the nature of the pioneer anomaly?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>What sources of gravitational waves can be detected?</td>
</tr>
<tr>
<td>2</td>
<td>Heliosphere</td>
<td>What is the extent of the solar wind and its interaction with the solar</td>
</tr>
<tr>
<td></td>
<td></td>
<td>heliosphere?</td>
</tr>
<tr>
<td>3</td>
<td>Planetary formation</td>
<td>What are the conditions for planet formation?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>What is the extent of the habitable zone?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>How do other solar systems differ from ours?</td>
</tr>
<tr>
<td>4</td>
<td>Stellar physics</td>
<td>What is the accuracy of long distance measurements to the stars?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>What is the origin of low-frequency heliospheric radio emissions?</td>
</tr>
<tr>
<td>5</td>
<td>colonisation</td>
<td>Is human colonisation of the galaxy feasible?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Can a technological species outlive its parent star?</td>
</tr>
<tr>
<td>6</td>
<td>Life</td>
<td>Is their life on other planets around other stars?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>How long can life survive in deep space?</td>
</tr>
<tr>
<td>7</td>
<td>Interstellar space</td>
<td>What is the mass function of objects in the Kuiper belt or Oort cloud?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>What are the properties of the interstellar medium?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>What is the abundance of Interstellar nuclides?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>What is the cosmic ray background in interstellar space?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>What is the dust population resulting from collisions of Edgeworth-Kuiper</td>
</tr>
<tr>
<td></td>
<td></td>
<td>belt bodies?</td>
</tr>
<tr>
<td>8</td>
<td>Solar system</td>
<td>Is our solar system typical in structure and metal content to others in the</td>
</tr>
<tr>
<td></td>
<td></td>
<td>galaxy?</td>
</tr>
<tr>
<td>9</td>
<td>Galactic</td>
<td>What is the age of the galaxy?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>What is the nature of dark matter?</td>
</tr>
<tr>
<td>10</td>
<td>Spacecraft</td>
<td>What is the long time survivability of a spacecraft structure and electronics</td>
</tr>
<tr>
<td></td>
<td></td>
<td>on long duration deep space missions?</td>
</tr>
</tbody>
</table>
Icarus – A Science Driven Mission

**PRIMARY OBJECTIVES** (Exploration of the target system, in descending order of priority).

1. Terrestrial planets.
2. Giant planets.
3. The star.
4. Minor objects.
5. Dust.

**SECONDARY OBJECTIVES** (Observations or activities to be carried out in the boost or cruise phase, in no particular order).

1. Observations of solar system outer bodies.
2. Measurements of heliopause/ISM.
3. Measurements addressing gravitational issues.
4. Experience of autonomy, dormancy, and reliability of spacecraft components during long duration mission.
Team Icarus: Brainstorming

- Informal discussions to date includes:
- Why fusion?
- Mission duration.
- ‘2050’ issue.
- He-3 acquisition (e.g. Jupiter, Uranus)
- Why minimal electron beam research in ICF community.
- Use of robotic manipulator arm for Icarus.
- Design of interstellar probe
- Potential for Magsail braking.
- Launch & assembly
Initial Trade Studies (examples)

- (1). Projected solar systems observatories in ~2050 compared to Icarus vehicle sensors – *Is flyby useful?*

- (2). Next, a trade study on Decelerating flyby probes compared to decelerating entire spacecraft bus with the main propulsion system and then launching probes – *What communications system is required for Icarus-Earth transmit?*

- (3). Examine history of solar system exploration to explore our own star (The Sun) – Galileo, Voyager, Cassin - *What type of science probes required for Icarus spacecraft?*

- (4) planetary acquisition of He-3 compared to accelerator generated He-3 (i.e. Deuteron → Deuterium target) – *What is the cost difference?*
Design team also has own private working web site
# Team Icarus (international activity)

<table>
<thead>
<tr>
<th>Name</th>
<th>Responsibilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kelvin Long</td>
<td>ICF capsule physics/design, Laser driver design, He-3 acquisition, Science instruments/payload</td>
</tr>
<tr>
<td>Martyn Fogg</td>
<td>Target destination, Astrophysics/planetary science</td>
</tr>
<tr>
<td>Richard Obousy</td>
<td>Primary/secondary propulsion, Antimatter catalysed fusion, Science instruments/payload</td>
</tr>
<tr>
<td>Andreas Tziolas</td>
<td>Primary/secondary propulsion, Computing/data management, Ground station &amp; monitoring, Risk &amp; repair</td>
</tr>
<tr>
<td>Richard Osborne</td>
<td>Systems engineering, Mission architecture, Vehicle assembly, Interstellar probe design</td>
</tr>
<tr>
<td>Adrian Mann</td>
<td>MagSail design, Layout &amp; 2D/3D visualisation graphics</td>
</tr>
<tr>
<td>Andy Presby</td>
<td>Power systems, Nuclear reactor design, Radiation shielding</td>
</tr>
<tr>
<td>Consultants</td>
<td>Marc Millis, Greg Matloff, Paul Gilster, Tibor Pacher</td>
</tr>
</tbody>
</table>

- **Stage 1** - Establish initial members of team + complete terms of reference (by Sept 09).
- **Stage 2** - Fully assemble team, decide on work programme (Sept - Dec 09).
- **Stage 3** - Team Icarus officially begin work (Jan 2010).
Daedalus (with improved calculations)
Daedalus (with minor subsystem changes)
Daedalus (with major system changes)
New Design (with major system attributes to Daedalus)
New Design (with minor subsystem attributes to Daedalus)
New Design (radically different)

Barnards star flyby
2-stage/54k tons
Fusion engine/ICF
D/He3 - Jupiter
Nuclear ion
Metal alloys
reactor + loop

1.0  2.0  3.0  4.0  5.0  6.0
Comparison of different design options:

1. **Daedalus** (with improved calculations)
2. **Daedalus** (with minor subsystem changes)
3. **Daedalus** (with major system changes)
4. **New Design** (with minor subsystem attributes to Daedalus)
5. **New Design** (with major system attributes to Daedalus)
6. **New Design** (radically different)

Options include:
- Fusion engine/ICF
- D/He3 - Jupiter
- Nuclear ion
- 2-stage/54k tons
- Metal alloys
- Reactor + loop
- Barnards star flyby

Down Select to chosen design.
Time Scale for Project Delivery
Deliverables
Conclusions

- Project Icarus has officially begun.
- ‘message in a bottle’
  - PI Club Interstellar (Tibor Pacher)
- Aim to demonstrate
  - Technology maturity measure of fusion based propulsion.
  - Improved design from Daedalus.
  - Create new generation of capable designers.
- Should inspire future generations to continue the aspiration for human interstellar travel, to the stars – Clarke’s vision.
- Team Icarus is looking for ‘suitably qualified’ volunteers to join the design effort.
FLYING CLOSER TO ANOTHER STAR

PROJECT I CARUS

SON OF DAEDALUS

Tau Zero Foundation
The British Interplanetary Society