The Enzmann Starship:

History & Engineering Appraisal

K.F. Long, A. Crowl, R. Obousy

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Acknowledgements

- Robert Duncan Enzmann
  - Jay Snyder
  - Michelle Snyder
- Rick Sternbach
- Don Davis
- David Hardy
- Greg Matloff
- Authors: A. Martin, A. Bond, G. Stine, M. Michaus, Thomas Schroeder, Ian Ridpath, Roy Gallant, Robert Bussard.
What is the Enzmann Starship?

- Well known about in the science fiction community.
- Not well known in the interstellar research community.
- We wanted to clarify its history, raise its profile and give a basic engineering assessment of its credibility.
History of the Enzmann Starship

- Although Robert Enzmann is the originator of the concept, as will be shown, Rick Sternbach and Don Davis must receive some credit for its ‘augmented lollypop’ configuration.
- G.Harry Stine’s Analog article did much to publicise the concept as well.
- 1984 ‘World Ship’ article in JBIS by Anthony Martin and Alan Bond claims Enzmann starship invented in mid 1960s. Referred to a ‘snowball’ design. 3-10 vehicles, 0.01c cruise speed, 200→2000 population increase.
Robert Duncan Enzmann
PhD, MIT Professor
Raytheon Corporation
Says he thought of concept August 6\textsuperscript{th} 1945 (day of first WW2 Japan bombing).
1940s seems too early, we think 1960s more likely based on discussions with Rick Sternbach.

(Robert Enzmann, 1949)
The Ship of Fools or ‘The Cruise & I’ (1972)

- S.S.Statendam, 24,000 gross tons, 196 m length, built 1957, 881 capacity, speed 16.5 knots.
- Later part of Regency Cruises fleet and renamed Regent star.
- But company went bankrupt.
- Ship scrapped in India 2004.
- December 1972 space conference to watch launch of Apollo 17.
- New York to Cape Canaveral.
- 4th Conference on Planetology and Space Mission Planning
- ‘The Ship of Fools’
This conference was probably the first (and only) public discussion by Enzmann of his Starship concept.
In 1972 Don Davis & Rick Sternbach worked with Robert Enzmann to develop the idea further. Several pieces of artwork were produced during this period.

(Don Davis, 1972)
Enzmann Starships (1972)

- This image first appeared in “Arthur C Clarke’s July 20, 2019, Life in the 21st Century”.
- Shows Enzmann taking off from an asteroid factory.
- Note the move from an 8 engine to a 24 engine design.
- Note there are two Enzmann’s.
- Modular sections also made so they could be split off from main vehicle.

Rick Sternbach, 1972, 2003
Flying Iceberg was from the idea that frozen deuterium could be kept frozen without a tank and be strong enough to be pushed around. Neither idea proved viable, thus the redesign with Rick Sternbach and Don Davis in 1972.

- Analog Science Fiction
- Gorgeous cover by Rick Sternbach
- Two Enzmann’s

(Rick Sternbach, 1973)
**Harry Stine Program for Star Flight (1973)**

- Mission part of full program rather than one-off mission.
- Three phases to roadmap
  - Identification of astronomical target
  - Launch of unmanned probes to destination
  - Launch of full expedition fleet to destination
- 10 starships, from 1990 at cost of $100 billion over ~2 decades. In 1973 money ~1/10th GNP USA.
- Each starship 12 million tonnes, assembled Earth orbit.
- 30% of light speed {not credible}
- Discussed use of absorbers to mitigate shocks and use of 8 engine design.
- Mentions artificial gravity for habitat spin.
Originally painted by Sternbach in 1972.
3 million tonnes fuel, super cold deuterium.
Use magnetic fields by ‘magnetic bottle’ for thrust generation.
Fuel sphere enclosed in metal shell and also serve as radiation shield for habitats.
20 decks per habitat.
100 rooms per level.
Some habitats rotate for artificial gravity.
Cruise at 0.09c and reach Alpha Centauri in 60 years.
Enzmann Starships at Jupiter (1974)

- Originally painted in 1974 as 35 mm slide, possibly for Readers Digest.
- Long commissions repainting in 2010.

(David A Hardy, 1974, 2010)
M.A.G. Michaus, March 1977 issue of JBIS.

“Spaceflight, Colonization & Independence”

Discussed Enzmann starship and Harry Stine Analog article.

Referenced cruise speeds 0.9c (unmanned) and 0.3c (manned).
Astronomy Magazine “Slow Boat to Centauri” (1977)

(Thomas Schroeder & Mark Paternostro, 1977)

“Flying Iceberg”
Article claims 0.1c design but 0.3c design may be possible.
- 12 million tonnes fuel.
- The ‘snowball’ was to give added benefit of radiation protection for main vessel.
- The outer layers were comprised of bulk material to serve as radiation shielding for the inner decks.
- Bulk was main nuclear reactor, various store rooms, heat exchangers, airlocks, landing craft storage, observation areas and communications equipment.
- Carried several smaller craft.
Artist Syd Mead completes double page Daedalus/Enzmann picture for Roy A Gallant.
They always come in two’s.

(Syd Mead, 1980)
Boston Science Fiction Convention (1986)

- February 1986
- Front cover of Boskone XXIII, Regionary Science Fiction convention.
- Depicts two Enzmann Starships.

(Bob Eggleton, 1986)
In the 1980s Robert Enzmann began to experiment with his Starship design and consider alternative variations.
Modern Enzmann: Pulse Class Starship

- Pulse Class
- External Nuclear (fission) Pulse
- (original Enzmann type)
Modern Enzmann: Torch Class Starship

- Torch Class
- Continuous Fusion
- Likely magnetic
Modern Enzmann: Hyperon-Lance Class Starship

- Hyperon-Lance Class
- Interstellar Ramjet
- (Athodyd)
- Use lasers to ionize and direct ISM to fuel collector
- Enzmann apparently now favours this concept.
Engineering Appraisal of the
Enzmann Starship
Enzmann Starship: Engineering Layout

NUCLEAR PULSE ENGINES
HABITATION MODULES
DEUTERIUM PROPPELLANT

TITLE: ENZMANN SPACECRAFT CONCEPT
MAT: STEEL/DEUTERIUM
SCALE: 1:6,000

610 m
305 m
We now apply our own knowledge of spacecraft design to turn the Enzmann starship into a credible ‘concept’.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Original Concept (Enzmann)</th>
<th>Imagined Concept (Stine)</th>
<th>Altered Concept (Enzmann / Sternbach)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length (m)</td>
<td>610</td>
<td>610</td>
<td>610</td>
</tr>
<tr>
<td>Sphere Diameter (m)</td>
<td>305</td>
<td>305</td>
<td>305</td>
</tr>
<tr>
<td>Total Habitat Length (m)</td>
<td>273</td>
<td>273</td>
<td>273</td>
</tr>
<tr>
<td>Individual Habitat Length (m)</td>
<td>91</td>
<td>91</td>
<td>91</td>
</tr>
<tr>
<td>Habitat Diameter (m)</td>
<td>91</td>
<td>91</td>
<td>91</td>
</tr>
<tr>
<td>Core Diameter (m)</td>
<td>15</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>No.Habitats</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>No.Engines</td>
<td>8</td>
<td>8</td>
<td>24</td>
</tr>
<tr>
<td>Propellant</td>
<td>Deuterium</td>
<td>Deuterium</td>
<td>Deuterium</td>
</tr>
<tr>
<td>Exhaust Velocity (km/s)</td>
<td>Unspecified</td>
<td>Unspecified</td>
<td>Unspecified</td>
</tr>
<tr>
<td>Specific Impulse (s)</td>
<td>Unspecified</td>
<td>Unspecified</td>
<td>Unspecified</td>
</tr>
<tr>
<td>Structure Mass (tonnes)</td>
<td>Unspecified</td>
<td>Unspecified</td>
<td>Unspecified</td>
</tr>
<tr>
<td>Propellant Mass (tonnes)</td>
<td>3 million</td>
<td>12 million</td>
<td>3 million</td>
</tr>
<tr>
<td>Cruise Speed (km/s)</td>
<td>27,000 (0.69c)</td>
<td>90,000 (0.3c)</td>
<td>27,000 (0.9c)</td>
</tr>
<tr>
<td>Starting Colony</td>
<td>200</td>
<td>200</td>
<td>200</td>
</tr>
<tr>
<td>Final Colony</td>
<td>2,000</td>
<td>2,000</td>
<td>2,000</td>
</tr>
</tbody>
</table>
Project Orion proposed external nuclear pulse propulsion. Bombs exploded externally to a spacecraft.

Enzmann proposes to detonated Orion type bombs internal to the vehicle. Claimed this is more efficient than Orion and cruise speeds 0.3c are possible.

The engine described as "Orion pulse drives" is more a place-keeper than a specific engine choice. Making working, high-Isp deuterium fusion pulse units needs something more akin to "Daedalus" for ignition than "Orion".
**Fusion Reactions**

DT:  \[ H^2 + H^3 \rightarrow He^4 (3.52\text{MeV}) + n(14.06\text{MeV}) \Rightarrow 17.58\text{MeV} / \text{reaction} \]

DHe\(^3\):  \[ H^2 + He^3 \rightarrow He^4 (3.67\text{MeV}) + p(14.67\text{MeV}) \Rightarrow 18.34\text{MeV} / \text{reaction} \]

DD:  \[ H_i^2 + H_i^2 \rightarrow H^3 (1.01\text{MeV}) + p(3.03\text{MeV}) \Rightarrow 4.04\text{MeV} / \text{reaction} \]

DD:  \[ H_i^2 + H_i^2 \rightarrow He^3 (0.82\text{MeV}) + n(2.45\text{MeV}) \Rightarrow 3.27\text{MeV} / \text{reaction} \]

\[ n \tau T \geq 5 \times 10^{21} \text{ m}^{-3} \text{skeV} \]

\[ V_e = \left( \frac{2E_{\text{kin}}}{m} \right)^{1/2} \]

<table>
<thead>
<tr>
<th>Propellant</th>
<th>Reaction products</th>
<th>Maximum Theoretical Exhaust velocity (km/s)</th>
<th>Specific impulse (million s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DT</td>
<td>He(^4) + n</td>
<td>26,400 (8.67%c)</td>
<td>2.64</td>
</tr>
<tr>
<td>DHe(^3)</td>
<td>He(^4) + p</td>
<td>26,500 (8.85%c)</td>
<td>2.65</td>
</tr>
<tr>
<td>DD</td>
<td>T + p</td>
<td>13,920 (4.64%c)</td>
<td>1.39</td>
</tr>
<tr>
<td>DD</td>
<td>He(^3) + n</td>
<td>12,510 (4.17%c)</td>
<td>1.25</td>
</tr>
</tbody>
</table>
Project Daedalus: Internal/External Pulse Hybrid

- Nuclear Pulse Propulsion.
- ICF pellets.
Enzmann assumed solid Deuterium which has density $= 180 \text{ kg/m}^3$ @ STP (0°C, 01.325 kPa)
But can assume slush Deuterium, mix of half liquid (170 kg/m$^3$) and half ice (205 kg/m$^3$)
We assume density $= 190 \text{ kg/m}^3$.
For 3 million tonnes propellant leads to revised geometry.
Radius $= 155.63 \text{ m}$; Diameter $= 311.26 \text{ m}$
- It may be necessary to surround the spherical Deuterium with a shell of material.
- Titanium alloy
- 1.3 mm thick (inc.50% SF for maximum stress)
- Reflective plastic insulation blanket mass ~200 tonnes & ~0.00001 m thick, in 50 layers with bulk density 1400 kg/m³ and areal density 0.7 kg/m².
If UDD is successfully made in-bulk and it can enable D+D ---> 4He reactions, then think Enzmann starships more feasible.

- For Enzmann we anticipate habitat thickness of order < m.
- But this is work in progress.
*Excluding 3 million tonnes Deuterium sphere mass*
Materials

- Sphere = Deuterium
- 1 inch Shell = Titanium
- Central column = Titanium
- Pulse Chambers = Molybdenum
- Habitats = Titanium/Aluminium
- Collars = Titanium
- Shoulder = Titanium
- Nose = Aluminium/Beryllium

Strength and density important parameters. ➔ metals.
Artificial Gravity

- For a ~45 m radii cylinder get 0.2 g for 2RPM (> lunar gravity) and get 0.05g for 1RPM (~1/2 lunar gravity)
- Therefore choose 1RPM.

\[ g = \frac{\frac{\pi \times \text{rpm}^2}{30}}{9.81} \]
Sternbach reports that the habitats can be removed.
In case one damaged.
Or to conduct exploration of target solar system.
Additional ‘Big Thinking’ for the Enzmann Starship
Slow Boat – Slow Ship – World Ship

- Scale up spacecraft dry mass by 10 from assumed 30,000 start.
- Scale up population by 10 from assumed 200 start.
- Fixed total mission durations at 60, 150 and 350 years.
- Assumed 0.09c cruise from initial Enzmann.
- Then calculated mass ratio.
- Calculated exhaust velocity.
  - \( V_{ex} = V_c / \ln(R) \)
- Worked out acceleration and thrust profile.
- Assume ‘dry world ships’ only
NASA space colony studies, ~65 tonnes/person

** Russian Long duration CELSS system 15-65 tonnes/person
### Enzmann Slow Boat

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry spacecraft mass (tonnes)</td>
<td>30,000</td>
</tr>
<tr>
<td>Propellant mass (tonnes)</td>
<td>3 x 10^6</td>
</tr>
<tr>
<td>Start population</td>
<td>200</td>
</tr>
<tr>
<td>End population</td>
<td>2,000</td>
</tr>
<tr>
<td>Total Mass Ratio</td>
<td>101</td>
</tr>
<tr>
<td>Mass Ratio</td>
<td>10.05</td>
</tr>
<tr>
<td>Exhaust Velocity (km/s)</td>
<td>11,700</td>
</tr>
<tr>
<td>Total Delta.V (km/s)</td>
<td>54,000 (0.18c)</td>
</tr>
<tr>
<td>Cruise Velocity (km/s)</td>
<td>27,000 (0.09c)</td>
</tr>
<tr>
<td>Total acceleration time (years)</td>
<td>18.95</td>
</tr>
<tr>
<td>Total Cruise time (years)</td>
<td>41.05</td>
</tr>
<tr>
<td>Total Mission time (years)</td>
<td>60</td>
</tr>
<tr>
<td>Mass Flow Rate (kg/s)</td>
<td>5.02</td>
</tr>
<tr>
<td>Start Acceleration (m/s²)</td>
<td>0.019 (0.002g)</td>
</tr>
<tr>
<td>Thrust (kN)</td>
<td>58,730</td>
</tr>
</tbody>
</table>

\[ a = \frac{\frac{dm}{dt} v_e}{M_{\text{prop, tot}}} \]

\[ T = V_{\text{ex}} \frac{dm}{dt} \quad \text{Mpell} = \frac{M_{\text{prop}}}{(tb.fHz)} \]

- **PULSE FREQUENCY**
  - 1 Hz; ~5000 grams
  - 10 Hz; ~500 grams
  - 50 Hz; ~100 grams
  - 100 Hz; ~50 grams
  - 250 Hz; ~20 grams

But for 8 or 24 engine design pellet masses can be reduced further still.
<table>
<thead>
<tr>
<th>Dry spacecraft mass (tonnes)</th>
<th>300,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Propellant mass (tonnes)</td>
<td>3×10^6</td>
</tr>
<tr>
<td>Start population</td>
<td>2,000</td>
</tr>
<tr>
<td>End population</td>
<td>20,000</td>
</tr>
<tr>
<td>Total Mass Ratio</td>
<td>11</td>
</tr>
<tr>
<td>Mass Ratio</td>
<td>3.32</td>
</tr>
<tr>
<td>Exhaust Velocity (km/s)</td>
<td>11,260</td>
</tr>
<tr>
<td>Total Delta.V (km/s)</td>
<td>27,000 (0.09c)</td>
</tr>
<tr>
<td>Cruise Velocity (km/s)</td>
<td>13,500 (0.045c)</td>
</tr>
<tr>
<td>Total acceleration time (years)</td>
<td>98.67</td>
</tr>
<tr>
<td>Total Cruise time (years)</td>
<td>51.33</td>
</tr>
<tr>
<td>Total Mission time (years)</td>
<td>150</td>
</tr>
<tr>
<td>Mass Flow Rate (kg/s)</td>
<td>0.96</td>
</tr>
<tr>
<td>Start Acceleration (m/s2)</td>
<td>0.003 (0.0004g)</td>
</tr>
<tr>
<td>Thrust (kN)</td>
<td>10,810</td>
</tr>
</tbody>
</table>

- **Pulse Frequency**
  - 1 Hz; ~1000 grams
  - 10 Hz; ~100 grams
  - 50 Hz; ~20 grams
  - 100 Hz; ~10 grams
  - 250 Hz; ~5 grams
Enzmann World Ship

- **PULSE FREQUENCY**
- 1 Hz; ~1,100 grams
- 10 Hz; ~100 grams
- 50 Hz; ~20 grams
- 100 Hz; ~10 grams
- 250 Hz; ~5 grams

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry spacecraft mass (tonnes)</td>
<td>3000,000</td>
</tr>
<tr>
<td>Propellant mass (tonnes)</td>
<td>$3 \times 10^6$</td>
</tr>
<tr>
<td>Start population</td>
<td>20,000</td>
</tr>
<tr>
<td>End population</td>
<td>200,000</td>
</tr>
<tr>
<td>Total Mass Ratio</td>
<td>2</td>
</tr>
<tr>
<td>Mass Ratio</td>
<td>1.41</td>
</tr>
<tr>
<td>Exhaust Velocity (km/s)</td>
<td>12,119</td>
</tr>
<tr>
<td>Total Delta.V (km/s)</td>
<td>8,400 (0.028c)</td>
</tr>
<tr>
<td>Cruise Velocity (km/s)</td>
<td>4,200 (0.014c)</td>
</tr>
<tr>
<td>Total acceleration time (years)</td>
<td>84.9</td>
</tr>
<tr>
<td>Total Cruise time (years)</td>
<td>265.1</td>
</tr>
<tr>
<td>Total Mission time (years)</td>
<td>350</td>
</tr>
<tr>
<td>Mass Flow Rate (kg/s)</td>
<td>1.12</td>
</tr>
<tr>
<td>Start Acceleration (m/s²)</td>
<td>0.004 (0.0005g)</td>
</tr>
<tr>
<td>Thrust (kN)</td>
<td>13,573</td>
</tr>
</tbody>
</table>
Slow Boat – Slow Ship – World Ship

Enzmann Slow Boat
(620 m, 200 → 2000)

Enzmann Slow Ship
(979 m, 2000 → 20,000)

Enzmann World Ship
(1752 m, 20,000 → 200,000)

Martin/Bond World Ships
Even ‘Bigger Thinking’ for the Enzmann Starship
Once the D fuel is used up, instead of replenishing the starship could remain at the destination and form a permanent colony station.
Habitats could then be mated together to form large colonies.
Enzmann Rings

- Several colony ships could then be mated together to form very large space structures.
- Enzmann Rings.
- Equivalent population of large town.
- These would be in permanent orbit around a planetary object.
- Need considerable thought to movable sections and individual spins.
- Need consider effect of system torques and gravity fields on structure and other objects if in planetary orbit.
Each cell could then be mated to other Rings to form large cells structures equivalent to the population of a small city.

An entire artificial world could be constructed, Enzmann Spheres, with a population the size of many cities or a small moon.
## Enzmann Starship-Rings-Cells-Spheres

<table>
<thead>
<tr>
<th></th>
<th>Size (km)</th>
<th>Mass (tonnes)</th>
<th>Population</th>
<th>Equivalent Size</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Enzmann Vessels</strong></td>
<td>Length 0.61</td>
<td><strong>Tens of thousands</strong></td>
<td>Tens of thousands</td>
<td>Town</td>
</tr>
<tr>
<td></td>
<td>Diameter 0.091</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Enzmann Rings</strong></td>
<td>Perimeter 10.4</td>
<td><strong>Hundreds of thousands</strong></td>
<td>Hundreds of thousands</td>
<td>City</td>
</tr>
<tr>
<td></td>
<td>Diameter 3.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Enzmann Cells</strong></td>
<td>Perimeter 10.4</td>
<td><strong>millions</strong></td>
<td>Millions</td>
<td>Asteroid</td>
</tr>
<tr>
<td></td>
<td>Diameter 9.4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Enzmann Spheres</strong></td>
<td>Perimeter 125</td>
<td><strong>billions</strong></td>
<td>billions</td>
<td>Moon</td>
</tr>
<tr>
<td></td>
<td>Diameter 40</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Based upon original Enzmann concept only (mass and population size)
We have conducted extensive research into the history and origins of the Enzmann Starship. This has now been clarified.
We have also conducted a *basic* engineering assessment of the concept as well as exploring variations on the theme. We conclude that the Enzmann Starship as originally proposed by Robert Duncan Enzmann would work in principle.
This work is dedicated to Robert Enzmann, who now takes his rightful place among the other interstellar Bobs:
(Forward, Bussard, Frisbee, Enzmann).