What is NIAC?

NASA Innovative Advanced Concepts

A program to support early studies of innovative, yet credible, visionary concepts that could one day “change the possible” in aerospace.
Exploration Technology Today
An Analogy

Launch
Staging
Safely Home!
Exploration Technology Today
An Analogy

Launch
Staging
Burnout
Safely Home!
Exploration Technology Today
An Analogy

- Launch
- Staging
- Burnout
- Safely Home!

Why Would You Want To Explore Like This?
The ephemeral ‘advanced propulsion’

New technologies with the promise of more affordable, more efficient, and safer propulsion for space launch currently seem to be out of reach. That however, does not mean that we should stop searching.

“. . . . All in all, the near-to-medium prospects for applying ‘advanced propulsion’ to create a new era of space exploration are not very good.”

Because That’s The Best We Can Do Now
The ephemeral 'advanced propulsion'

New technologies with the promise of more affordable, more efficient, and safer propulsion for space launch currently seem to be out of reach. That however, does not mean that we should stop searching. . . . .

All in all, the near-to-medium prospects for applying ‘advanced propulsion’ to create a new era of space exploration are not very good. “

Spacecraft Impact:

- More Payload
- Faster Travel
- Unlimited Electrical Power
- Enhanced Astronaut Safety

A FISSION FRAGMENT ROCKET ENGINE:

Engine Attributes:

- Far Less Propellant Than Chemical Or Nuclear Thermal ($I_{sp} \sim 500,000s$)
- Far More Efficient Than Nuclear Electric (100X Thrust)
- Far Safer Than Nuclear Thermal (Charge Reactor In Orbit, Radiation Leaves Solar System At >1% Light Speed)
FFRE History

Original Spinning Brush FFRE
1986: George Chapline’s “Spinning Brush” FFRE: Uranium coated carbon fiber permits half the fission fragments to escape, providing thrust. The other half heats up so fibers rotated out of reactor to cool.

Dusty Plasma FFRE Creation
2005: Dr. Rod Clark creates “Dusty Plasma” FFRE: Fissioning uranium dust maximizes both fission fragment escape and radiative cooling, increasing efficiency and permitting reactor operation at Gigawatts of power.

Grassmere Dynamics, LLC
- Engineering & Consulting
- Specialty Modeling Skills:
  - Computational Fluid Dynamics (CFD)
  - Magneto Hydrodynamic Plasma (MHD)
  - Nuclear (Radiation, Reactor Design & Performance)
  - Optical

3D Simulation Of Tokomak Nuclear Fusion Reactor Magnetically Confined Plasma Using Grassmere Code
Study Approach

Organize:
- Study structure, goals, objectives
- Identify SMEs, allocate resources
- Identify study outputs & milestones

Notional Architecture
L1 Reqmts

FFRE Concept

Spacecraft Concept

Iterate to Close

Data Archival & Reporting

TRL Maturation Roadmap

Operations Concept

Test Methodology

Manufacture, Technology, Issues & Risks
Study Groundrules

Spacecraft and mission based on 2004 Human Outer Planet Exploration (HOPE) study
- 60 mT crewed payload on roundtrip mission to Callisto
- Propulsion was hypothetical nuclear electric magneto-plasma-dynamic thrusters (6 NEMPD engines, 33 MW each, providing ~22-lb thrust at 8,000 s delivered Isp using hydrogen as propellant)
- 1 FFRE substituted for 6 NEMPD engines
- All impacted spacecraft subsystems to be redesigned

- 60 mT Crewed P/L
- 3 m Truss
- Fwd RCS
- LH₂ Tanks (400 mT)
- Aft RCS
- Brayton Cycle Power System
- P/L Avionics & Radiators
- 243 m Long by 42 m Wide
- 522 m² Medium-temp Radiators
- 2,976 m² High-temp Radiators
- Radiation Shield w/6.5° Protection
- Hypothetical Solid-Core Reactor Magneto-Plasma-Dynamic Nuclear Electric Engine
Principles of FFRE

- Reactor Core Uses Submicron Uranium Dust Grains
- Fissioning Low-Density Dust Is Radiatively Cooled.
- Moderator Reflects Neutrons To Keep Dust Critical
- Carbon-Carbon Heat Shield Reflects IR Away From The Moderator.
- Superconducting Magnets Direct FFs Out Of Reactor.
- Electricity Is Generated From Heat Shield Coolant
- Reactor Hole Provides: Heat Escape, FF Escape At 1.7% Light-Speed
**Base FFRE Design**

- Nozzle Beam Straightening Coils
- Moderator Heat Shield
- Reacting Dusty Plasma Cloud
- Superconducting Magnets

**Revised FFRE Designs**

**Generation 1**

- **Attributes:**
  - Ellipsoid Moderator
  - Ring Magnets

- **Assessment:**
  - Reduced heat load so less Spacecraft radiator mass
  - Complex Shape Moderator
  - Thrust & \( I_{sp} \) unchanged

**Generation 2**

- **Attributes:**
  - Dual Paraboloid Moderator
  - Ring Magnets

- **Assessment:**
  - Reduced heat load so less Spacecraft radiator mass
  - Complex shape moderator, difficult to support & cool, weighs more
  - Thrust: 2X (86 N, 19 lbf)
  - \( I_{sp} \) unchanged (527,000 s)

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**Master Equip List Mass incl 30% MGA**

<table>
<thead>
<tr>
<th>FFRE System Total, mT</th>
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<tr>
<td>Nozzle</td>
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<tr>
<td>Shadow Shield</td>
<td>7.8</td>
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</tbody>
</table>

**Distribution (MW)**

- Total Reactor Power 1,000
- Neutrons (30% to FFRE) 24.2
- Gammas (5% to FFRE) 95.6
- Other 70.2
- Thermal (IR) 699
- Jet Power 111

**Performance**

- Thrust 43 N (9.7 lbf)
- Exit Velocity 5170 km/s
- Specific Impulse 527,000 s
- Mass Flow 0.008 gm/s
Payload Packaging, hypothetical 12m shroud and >120mT capacity

FFRE & Braytons
Crew & Avionics
Structure Backbone
Radiator
Radiators
Spacecraft Performance
(First FFRE / Spacecraft Assessment)

ffre:
43N Thrust, 527,000 sec Specific Impulse

Adding an “afterburner” to FFRE boosts thrust, shortens trip, but adds propellant weight:
Example: 430N / 52,700 sec

Earth Escape From L1
Lunar Orbit
Jupiter

Outbound Trajectory Results
Segment Time (Days) Thrust Time (Days) CUM Nuclear Prop (Kg)

Earth Spiral — Out 55 55 40
Interplanetary 2,106 2,161 1,553
Jupiter Spiral — In 503 2,665 1,915

Stay Time at Callisto: ~330 Days
Total Elapsed Mission Time 5,850 Days (16.0 Years)
Total Nuclear Fuel Used 4 mT
Spacecraft Comparison

What Is Learned So Far

- A FFRE is credible – ordinary engineering, ordinary physics. NO MIRACLES.
- A FFRE-propelled spacecraft is game changing to travel in space. A spacecraft with a heavy payload can depart for and return from many solar system destinations. NO REASSEMBLY REQUIRED.
- Our first constructs of a FFRE are grossly inefficient. We are like a Ford Model T engine. Only a few ways of improving performance of the FFRE and spacecraft have been considered.

**THERE’S MUCH WORK TO DO.**
Performance Trades

**Effect on Mission Of 2nd Generation FFRE Design**

**FFRE**
- Thrust: 2X (86N)
- $I_{sp}$: 527,000s

**Spacecraft**
- Assumed no change (conservative)

**Mission**
- ~8 years round trip
- Spiral out and in times halved
- Small coast period in interplanetary flight
- Propellant: ~4 mT nuclear

**Effect on Mission Of Adding an “Afterburner“ to FFRE Design**

**FFRE**
- Fission fragments accelerate an inert gas added to nozzle via friction, adding thrust & decreasing specific impulse
- Thrust: 430N, $I_{sp}$: 52,700s (notional)

**Spacecraft**
- Added “propellant” and tankage

**Mission**
- ~6 years round trip
- From Earth: 4 days, Into Jupiter: 40 days
- Interplanetary Coast: 950days
- Propellant: 0.3mT nuclear, 22mT gas
The Next Step:

Lighting The Afterburner On A Fission Fragment Rocket Engine

FY 13 Center Innovation Fund Study Award