Revolutionary Propulsion & Power for the Next Century of Space Flight

Von Braun Symposium, October 2009

Introductory Briefing

Harold White, Ph.D.

Introduction

- Imagine if it were possible to utilize the very vacuum of space as a source of propellant such that a spacecraft need only provide power, and not carry propellant – what would be the possibilities?
  - A spacecraft equipped with such a propulsion system would have, mathematically, an infinite Specific Impulse[1] (I_{SP}) - the limiting design parameter would then be power density.
  - Reference missions could entail multiple destinations, and orbits.
  - Transit time could be drastically reduced.

- In order to enable bold exploration missions to Mars, the outer solar system, and beyond, we must engage in advanced propulsion research with the goal of developing point solutions that are orders of magnitude more effective than the current arsenal of propulsion technologies.

- While it is true that advanced propulsion research provides critical enabling technologies for exploration, I intend to show that this research will clearly have an immediate beneficial impact to the local Commercial/Civil/Defense Satellite Sector.

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1. Specific Impulse, or I_{SP}, mathematically said is how many seconds can 1lb of fuel provide 1lb of force. In conceptual terms, I_{SP} is the efficiency with which a rocket can convert chemical energy to kinetic energy. In terrestrial terms, I_{SP} can be thought of as a form of “miles per gallon” for a rocket motor.

Outline

- Identify **Pinnacle Objectives** that frame the need for Advanced Propulsion and Power Research.
- Discuss the **Challenge** of exploration and identify the deficiencies with the current propulsion paradigm.
- Identify an **Alternative**, and use this point solution as a Case Study to show that while advanced propulsion research might appear to only be relevant to deep space exploration, breakthroughs in this area can lead to propulsion systems that will have immediate impacts back home.
- Stepping back from the point solution, an **Advanced Propulsion Research** organization will be discussed.
- The presentation will close with
  - status from Ad Astra on their VASIMR technology development,
  - brief synopsis of noteworthy historical advanced propulsion research,
  - some pointers to some organizations that serve as portals to others that are actively pursuing advanced propulsion research.

1. Specific Impulse, or I_{SP}, mathematically said is how many seconds can 1lb of fuel provide 1lb of force. In conceptual terms, I_{SP} is the efficiency with which a rocket can convert chemical energy to kinetic energy. In terrestrial terms, I_{SP} can be thought of as a form of “miles per gallon” for a rocket motor.

Pinnacle Objectives

- Humanity should explore and colonize the Solar System in the next fifty years, while making human-crewed and robotic interstellar flights a real possibility by the end of the 21st Century.
- To that end, many dedicated teams and individuals are actively working to research and develop both the science and technology (propulsion and power) required to accomplish these goals.

***Propulsion** and **Power** are the keys to exploration and utilization of the Solar System and beyond.*

The Challenge

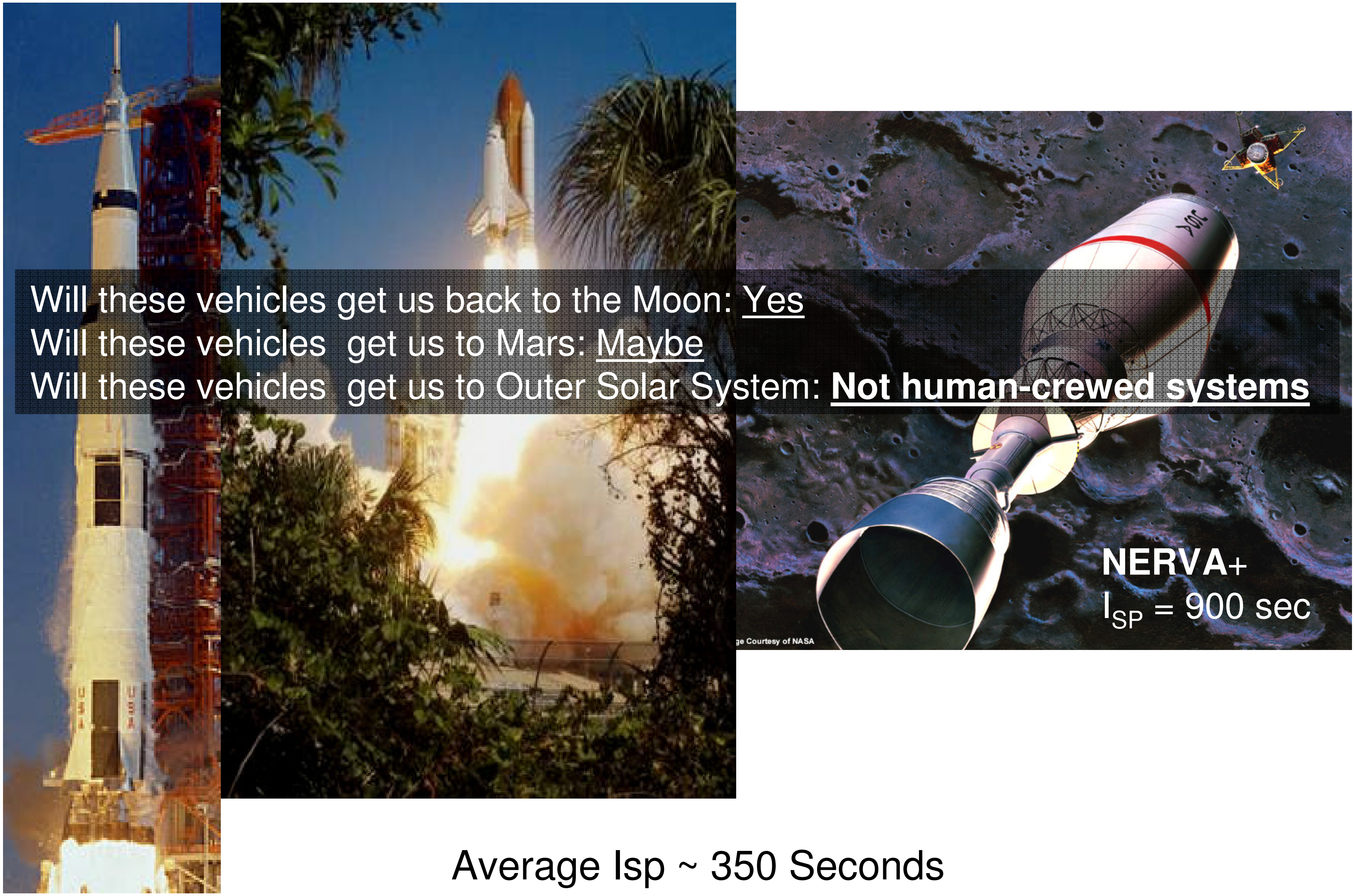
Why Is Propulsion Research Critical?

- Expanded human-crewed operational capabilities in space will only come from new developments in propulsion and power generation technologies that will decrease transit times, increase safety, and lower operational costs.
- Conventional liquid fuel chemical rockets have reached their practicable zenith in the expression of the Russian RD-170 / RD-180 LOX/Kerosene engines and the LOX/Hydrogen Space Shuttle Main Engine (SSME).
- Significantly higher performance engines with an order of magnitude increase in specific impulse or higher will require much larger energy sources than chemical reactions can provide. And for interstellar flights, even nuclear power in the form of anti-matter reactions will not suffice.
- The next few charts illustrate the deficiencies of the current paradigm.

Chemical Rockets: Transit Times and Costs

- Transit Times:
  - Moon: 3 days one-way
  - Mars: 6-to-8 months one-way
  - Jupiter & outer solar system: years
  - Interstellar: Millennia
- Costs:
  - LEO: \$1.6k-to-\$10k per lb_m to orbit
  - Lunar: \$195k-to-\$215k per lb_m delivered to surface
  - Mars: \$30k to orbit, \$1,200k per lb_m delivered to surface
  - Interstellar: \$???
- Problems with chemical rocket solutions?
  - Slow transit times are compounded by adverse physiological effects from long-term exposure to microgravity and ionizing radiation, our relatively short lifetimes, and the colossal costs and complexities of using chemical (or even nuclear) rockets for these applications.

Past, Present & Future Rockets to Low Earth Orbit, the Moon, & Mars



Will these vehicles get us back to the Moon: Yes
Will these vehicles get us to Mars: Maybe
Will these vehicles get us to Outer Solar System: **Not human-crewed systems**

NERVA+
I_{SP} = 900 sec

ge Courtesy of NASA

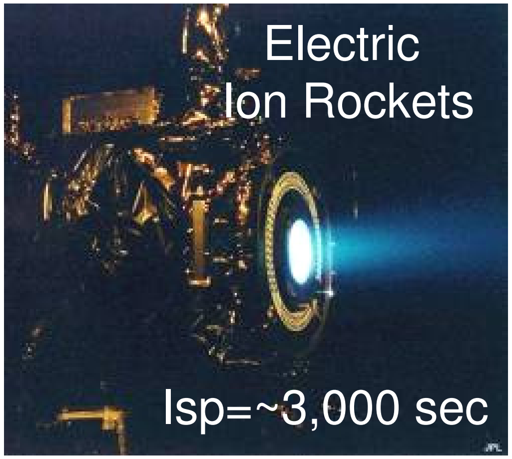
Average Isp ~ 350 Seconds

Current Options for Mars and beyond


NERVA

Fission Nuclear Thermal Rocket

$Isp=\sim 900$ sec


Electric Ion Rockets

$Isp=\sim 3{,}000$ sec


Project Orion Nuclear Bomb Rocket

$Isp=10k+$ sec

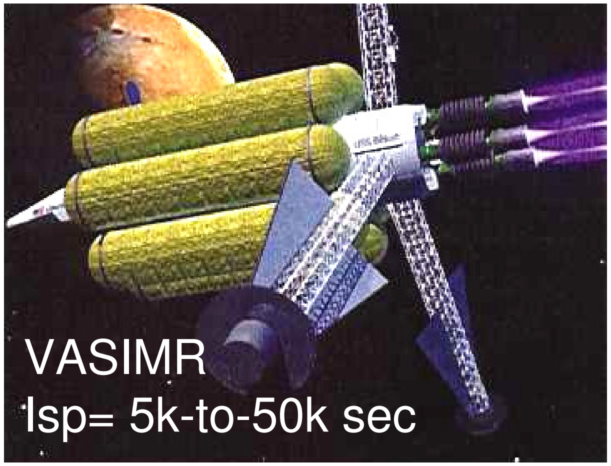
Higher I_{SP}

This chart shows a collection of higher I_{SP} propulsion systems that could be employed for Mars and beyond missions.


Fusion/Electric Rocket

$Isp=\sim 20{,}000$ sec

To Mars


VASIMR

$Isp=$ 5k-to-50k sec


Anti-Matter Rocket

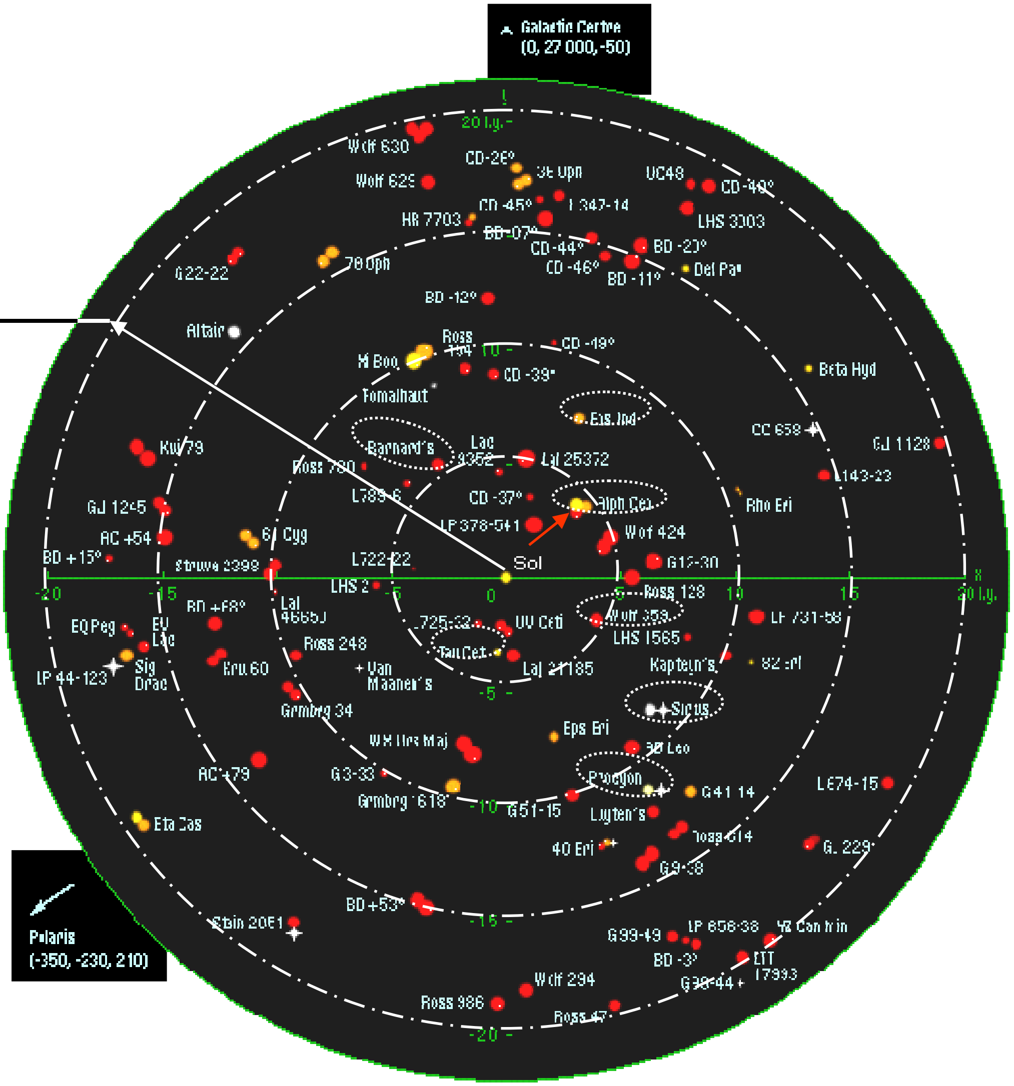
$Isp=\sim 1{,}000{,}000$ sec

Cost of Anti-Matter??

6-yr Interstellar Mission

This sphere's Radius is 20 Light Years or 117.6 Trillion miles (1 light year = 5.879×10^{12} miles)

20 Light Years



Proxima Centauri is 4.3 light years away.

To get there in 6 years Earth time with a Propellant Mass Ratio (PMR) of 0.5 would require an I_{SP} of 66.2×10^6 seconds. Please note that this is 2X higher than a photon rocket's performance.

This level of performance is not currently available.

Findings of the Current State of Technology

- For Low Earth Orbit (LEO) and lunar missions, chemical rockets can continue to be used successfully for crewed and robotic missions, but at non-trivial cost and complexity.
- For crewed missions to Mars and out to the rest of the solar system, chemical rockets could be used, but missions may have unacceptable costs and durations.
  - Dr. Franklin Chang Diaz's Variable Specific Impulse Magneto-plasma Rocket (VASIMR) is a more logical choice and can reduce transit times.
  - Nuclear rockets can also be used to possibly reduce transit times for Mars missions., but they introduce additional complexity and safety issues.
- For interstellar missions, neither chemical, nor electric, nor nuclear rockets are sufficient.

Is there another way?

An Alternative:
A Case-Study in Advanced Propulsion Research

NOTE: In actuality, there are a large diversity of advanced propulsion alternatives, many of which are actively being researched and investigated. This example is used to serve as a touchstone to establish the potential near-term and terrestrial benefits of advanced propulsion research in general.

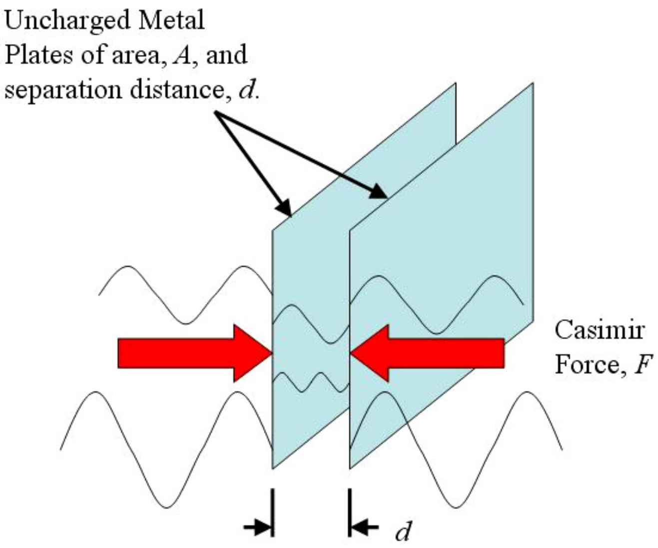
Ultra-high I_{SP} Solution

- In the executive summary, the question was posed: Imagine if it were possible to utilize the very vacuum of space as a source of propellant such that a spacecraft need only provide power, and not carry propellant – what would be the possibilities?
  - The physics community knows from experiments performed over the last 10 years that the vacuum is anything but empty, rather it is a sea of virtual particles (electron and positron pairs) that pop into and out of existence as they spontaneously create and annihilate, otherwise known as the quantum vacuum.
- The substantive question is, how, or can this be done? Based on theoretical models developed by members of the advanced propulsion community, it is mathematically possible to <u>augment</u> the available vacuum fluctuation density (squeezed vacuum) and utilize it as propellant reaction mass.
  - In this theoretical model, gravity is an emergent force, a long wavelength consequence of the quantum vacuum, rather than a fundamental force.
  - Beginning with the cosmological Friedmann equation, big-G from Newton's equation of gravitational force (and hence inertia) can be derived as a relativistic consequence of dark energy, or the quantum vacuum.

How Does It Work?

What are Quantum Vacuum Fluctuations?

- The idea of quantum vacuum fluctuations stems from the Heisenberg's uncertainty principle suggesting that empty space is never really *empty*…
  - Rather, empty space is filled with a sea of virtual particle pairs that pop into and out of existence over very short time periods.
  - The Dirac Sea approach (earlier vacuum model) predicted the existence of the electron's antiparticle, the positron in 1928, which was later confirmed in the lab by Carl Anderson in 1932.
- Another confirmation of quantum vacuum fluctuations was produced by way of measuring the Casimir Force; first measured in 1958 by Marcus Spaarnay, and subsequently measured more accurately in 1996 by Steven Lamoreaux.

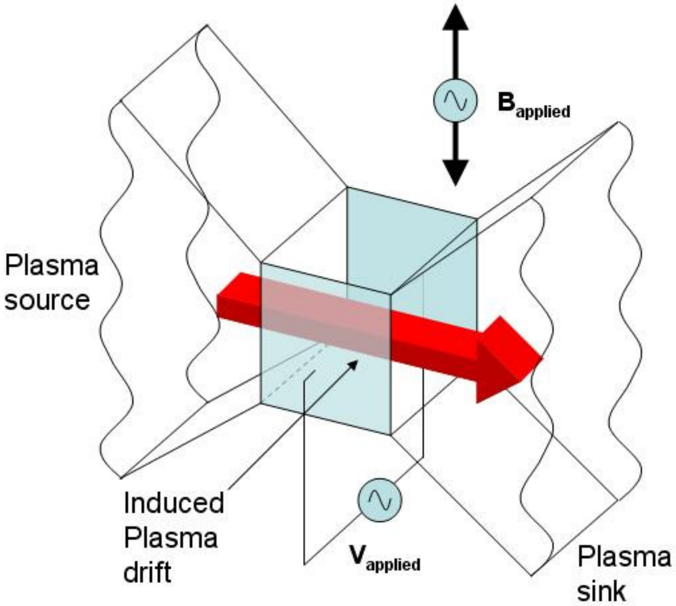


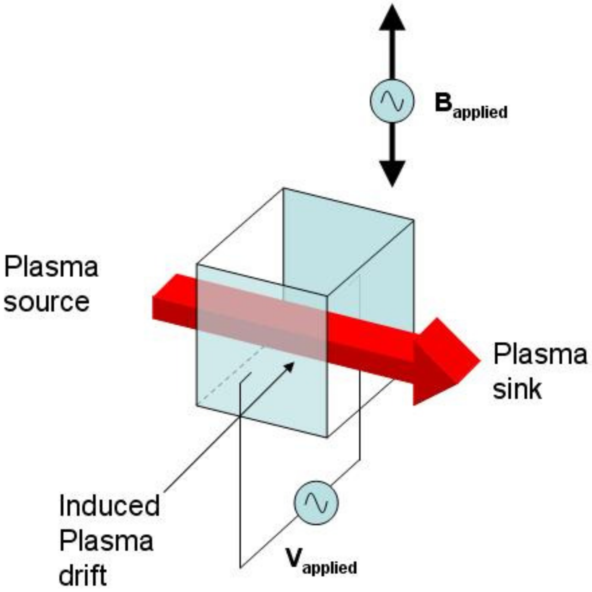
$$\frac{F}{A} = -\frac{\hbar c \pi^2}{240 d^4}$$

A historical, conventional analog to the idea behind the Casimir Force can be drawn considering training given to sailors of the tall-ship era who were instructed to not allow two ships to get too close to one another in choppy seas lest they be forced together by the surrounding waves requiring assistance to be pulled apart.

What is a Quantum Vacuum Plasma Thruster (QVPT)?

- A QVPT uses the same principles and equations of motion that a conventional plasma thruster would use, namely Magnetohydrodynamics (MHD), to predict propellant behavior.
  - The plasma is exposed to a crossed *E* and *B*-field which induces a plasma drift of the entire plasma in the *ExB* direction which is at right angles to the first two applied fields.
- The difference arises in the fact that a QVPT uses quantum vacuum fluctuations as the fuel source *eliminating* the need to carry propellant. This suggests much higher specific impulses are available for QVPT systems limited only by their power supply's energy storage densities.
  - *Historical test results provide for an equivalent* I_{SP} *of* ~$1x10^{12}$ *seconds.*

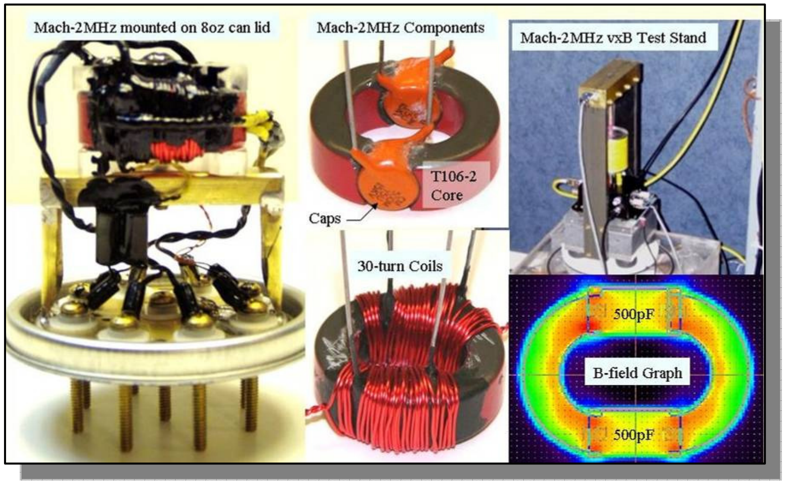


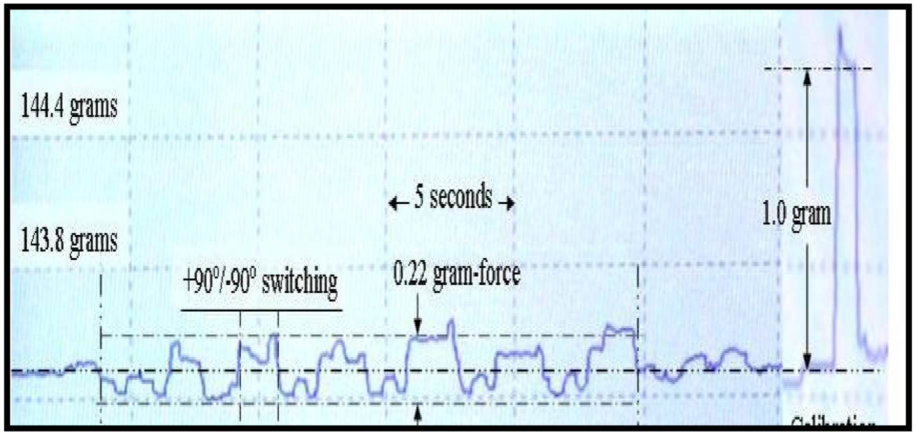


Experimental Effort

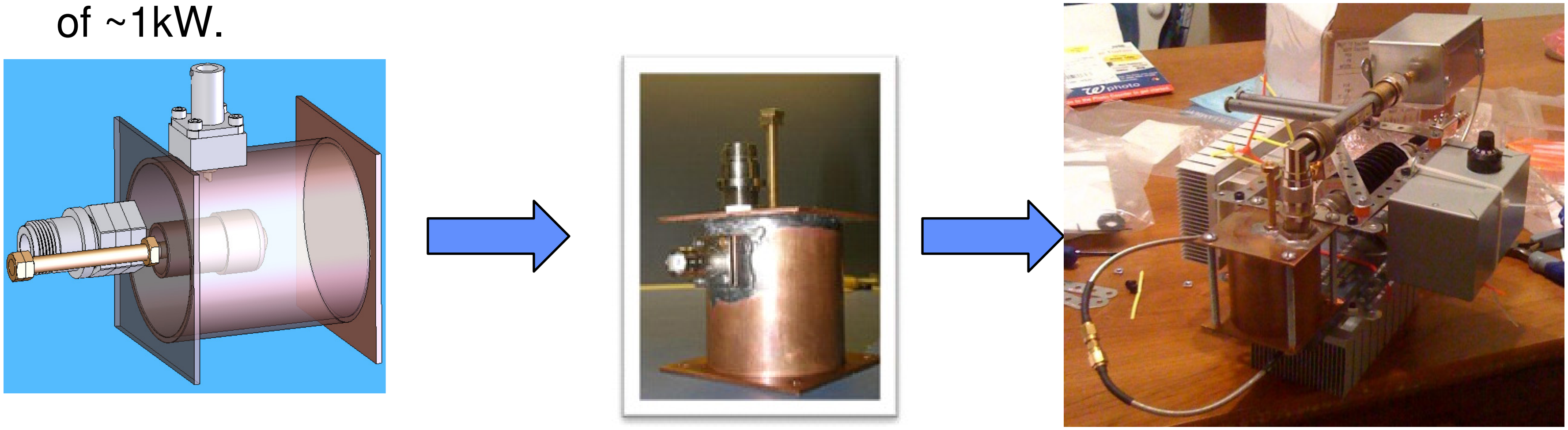
Strategic Objective

- To date, the investigation of QVPTs have generated a possible thrust signal in the thousands of micro-Newtons range.

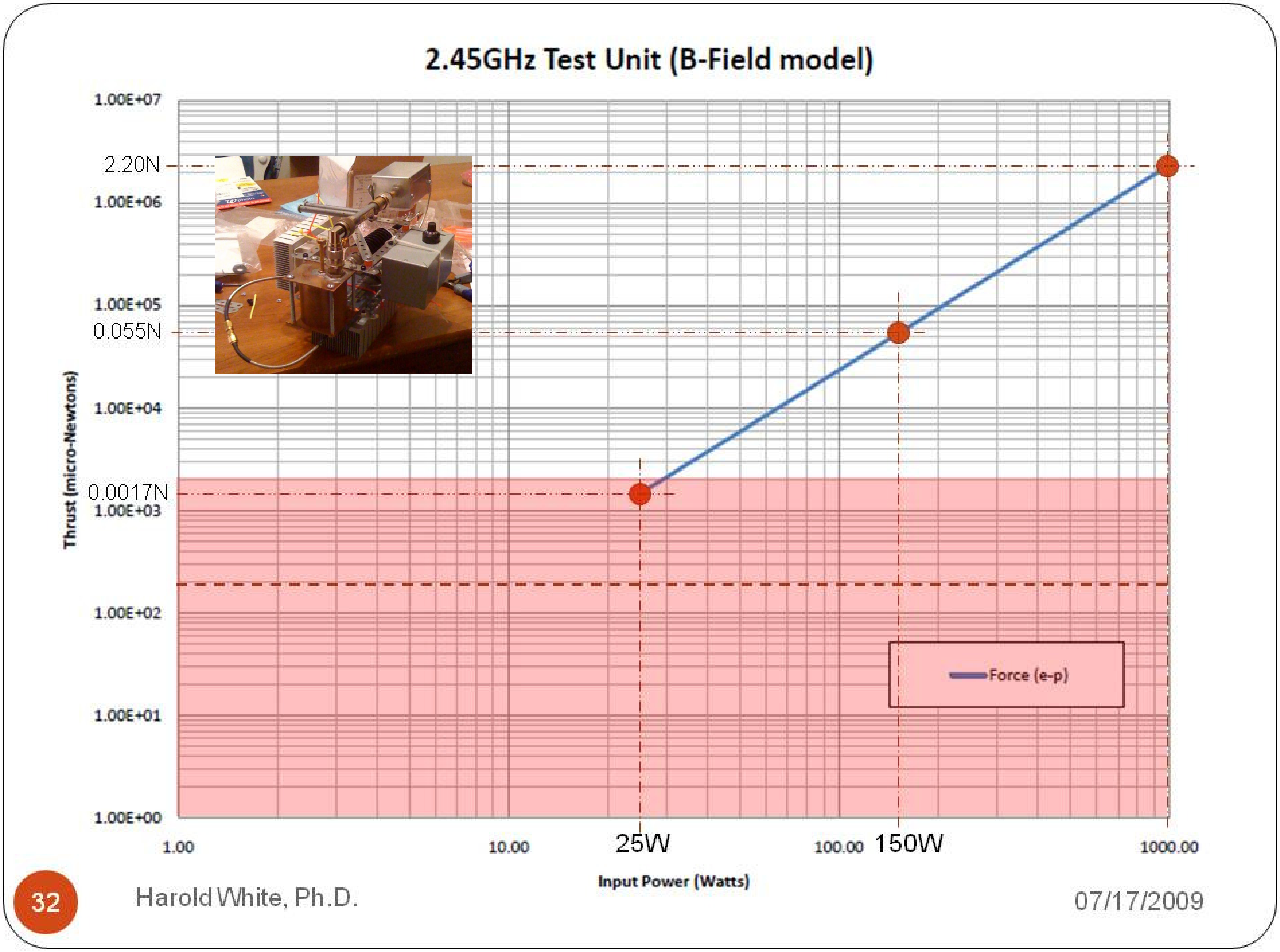




- To clearly establish the phenomenon, its scaling behavior, and make this technology relevant to the commercial satellite sector, the current test article was designed to produce a thrust in the 0.1-1 Newton thrust with an input power of ~1kW.



2.45 GHz QVPT Thrust Predictions



2.45GHz Test Unit (B-Field model)

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07/17/2009

Near-Term Benefits to Commercial/Civil/Defense Satellite Sector

- **If the thrust magnitude can be scaled to the 0.1 to 1 Newton range with an input power of ~0.1 to 1 kilo-Watt, this would establish the market entry-point for this technology.**

- **High power Hall-Effect Thrusters are used as station-keeping thrusters providing 0.5 to 1 Newton of thrust with 7 to 20 kilo-Watts of input power.**

- **Is there a business case that can adapt and employ the QVPTs to benefit the commercial satellite sector?**

Hypothetical Business Case (*highlights*)

- **Currently, there are 40-80 minisatellites (1000lbs) per year that could utilize QVPTs in this size and power budget** (Futron presentation, *If you build it, who will come*, to 22nd AIAA/USU Conference on Small Satellites)**.**
  - If the test article were to generate the desired thrust levels, it is estimated that it would take ~two years and approximately $10 million to design the first flight article.
  - By producing equivalent thrust at a lower input power requirement, this would allow satellite designers to reduce the size of solar panels and thermal management systems.
  - This translates into $$ savings for satellite designers based on an industry metric of ~$500 per Watt
  - The power budget for a 0.1N Hall-Effect thruster would be ~ 1500Watts, while an equivalent thrust level QVPT ~200Watts, yielding a net savings of 1300 Watts power for a QVPT-equipped satellite design.
  - This would result in a potential savings of ~$650k in the final design due to reduction in overall power level and reduced thermal management system.
  - Assume that the flight QVPT articles could be manufactured for ~$500k per copy, and sold for ~$750k.
    - Satellite designer saves the $650k in reduced thermal and power systems, and saves the cost of the equivalent Hall-effect thruster that was replaced by the QVPT, minus the $750k to purchase the QVPT – the net result is that the satellite manufacturer effectively gets a high performance engine for $100k.
  - With these rough metrics, the design can become profitable within ~40 sales, which is reasonable considering the annual market and cost savings for customers.

This simplified business case is employed to communicate a point: Advanced Propulsion Research can (and will) produce point solutions that enable bold exploration missions, while at the same time produce technology spin-offs that will greatly benefit us here at home.

Synopsis

- **Note that in the above *brief* business case, we did not make use of the ultra-high I_{SP} for the QVPTs, which will also result in the beneficial characteristics of the satellite system:**
  - Satellite can maintain position for life of hardware
  - Satellite mission can include servicing multiple orbits/inclinations which are precluded with other systems
    - Earth monitoring satellites and communications satellites could maintain a park position in GEO, and change to different altitudes and/or inclinations based on transient and unpredictable events.

- **Although this case study dealt with QVPTs, most forms of advanced propulsion research, can likewise be shown to have beneficial characteristics back here at home.**
- **While the mention of advanced propulsion may invoke pictures of plucky little probes or vast crewed-spaceships headed off into the great unknown, advanced propulsion research can produce technology that can be matured within the crucible of the terrestrial commercial/civil/defense satellite sector.**
- **Thus the argument can be made that advanced propulsion research will not produce myopic point solutions with little-to-no intrinsic domestic value, rather these solutions will greatly improve the abilities and robustness of local space assets, while at the same time producing mission-enabling technology.**

Segue

- Now that we have provided a touchstone to illustrate the local and near-term benefits from advanced propulsion research, we would now like to cast a broader vision.

- We would like to provide a high-level example of a logical organization that could be commissioned to pursue advanced propulsion research in a more general manner.

Eagleworks Laboratories (Hudson Model)

- **Description – research organization is analogous to a mini Bell Labs**
  - **Organization equipped with comprehensive spectrum of hardware/infrastructure necessary to pursue innovative advanced propulsion research**
  - **Core team of extremely qualified scientists, engineers, technicians, and workflow personnel that are able to envision and implement revolutionary propulsion research concepts to a proof-of principle level, producing intellectual property and patents that can be easily licensed to the market to generate future revenues to facilitate continued research. .**
  - **scalable architecture**
- **Business Organization – research organization can be government institution (DARPA, AFRL, NASA, etc.), fully commercial (Skunkworks model), or a hybrid (e.g. Sandia's GOCO model)**
- **Research Approach**
  - **Core Research - team(s) pursue development of revolutionary propulsion concepts peer-reviewed and nominated by governing steering committee**
  - **Venture Research (cost-sharing) - organization can also host guest investigators (nominated by steering committee) and their team to make use of lab equipment/infrastructure and lab personnel to pursue research (analogous to particle physics research)**
  - **Lab can provide consultation to external research teams.**
  - **Special Tiger-teams can be assembled to facilitate integration of innovated technologies into follow-on flight hardware projects sponsored by government/academia/industry (market-entry)**

Brief update on status of some advanced propulsion research

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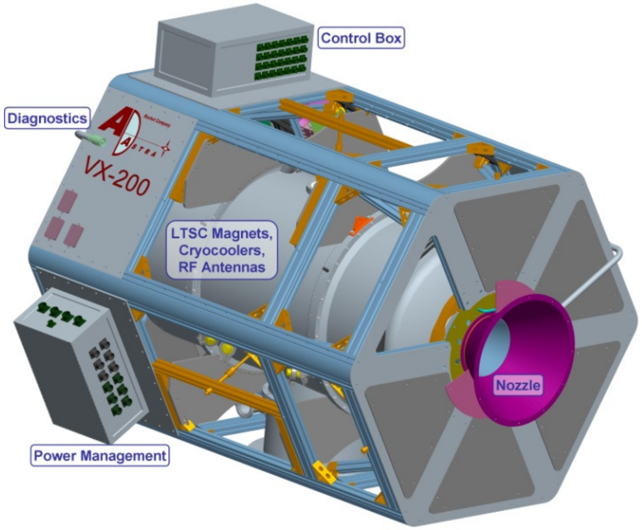
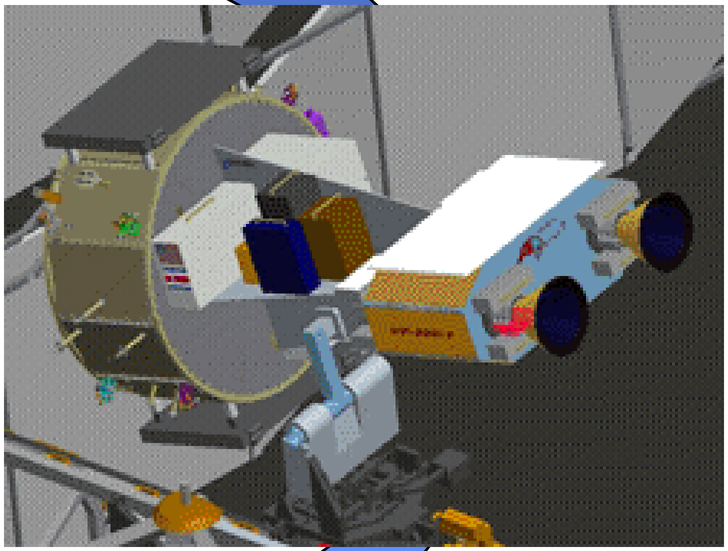
Ad Astra Hardware Development Spiral 1



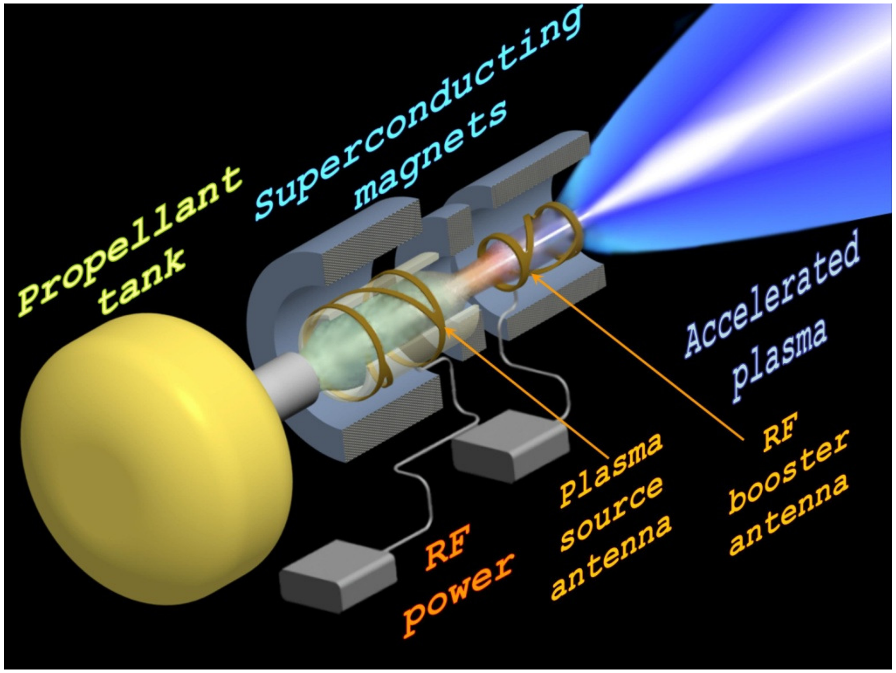
VX-200 Integrated System Technology Demonstrator

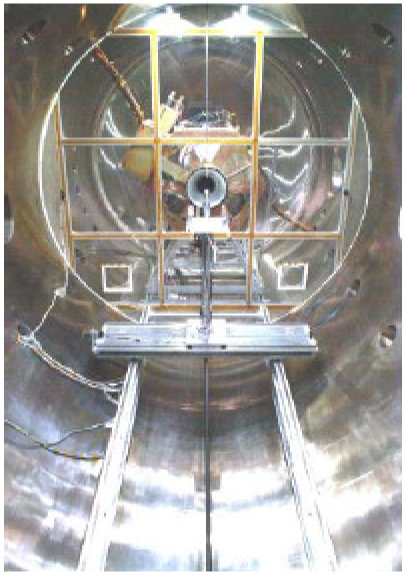


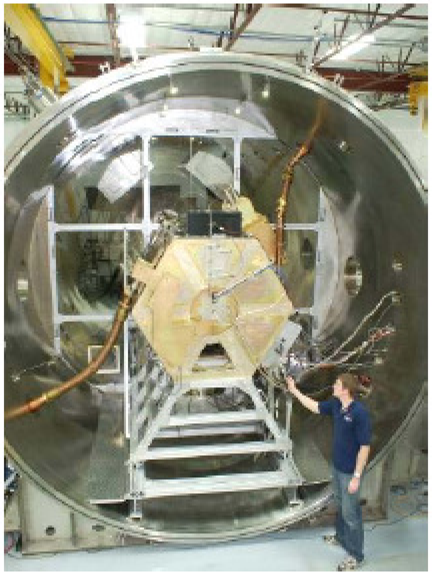
VF-200 First Flight Unit on ISS

Lunar Tug with 2MW Solar Powered VASIMR

Ad Astra Accomplishments & Near-Term Tactical Objectives







2009 Accomplishments

- VX200 has undergone initial testing in new vacuum facility and successfully operated with a low-temperature superconducting magnet.
- First stage (helicon section) has been operated at full power with maximum magnetic field
- Booster stage has been operated at 149.2kW at reduced magnetic field strength.
- Ion flux measurements have been gathered over a range of flow-rates to evaluate efficiency.

2009-2010 Tactical Objectives

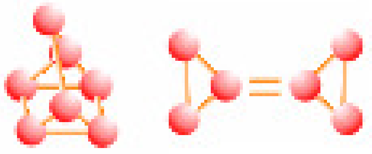
- Operate first stage and booster stage concurrently at full power with maximum magnetic field (ACCOMPLISHED!).
- Continue to characterize plasma using RPAs, multiple flux probes, force targets, and magnetic field probes.
- Continue design and requirements development for the VF-200 system for use in ISS. (develop list of long-lead items)
- Continue Lunar Tug early design trade studies.

Advanced Propulsion Research: Some History, Organizations, and Reference Material

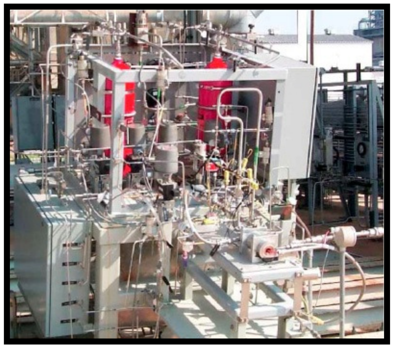
Some Advanced Propulsion Research
by NASA Marshall, Glenn, JPL and Colleagues (1996 – 2006)

Advanced Propellants and Engines

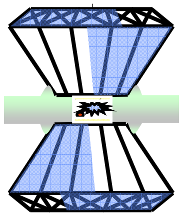
- Strained ring hydrocarbons
- Ionic liquids
- Metallic hydrogen
- Pulse detonation rocket engines
- Solar thermal engines



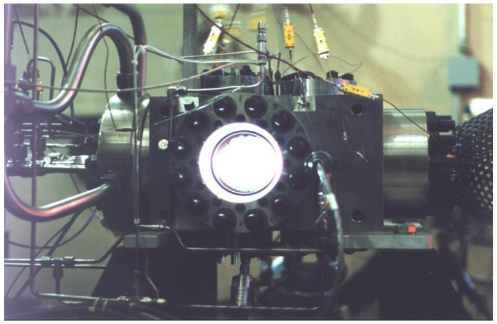
Strained Ring Hydrocarbons



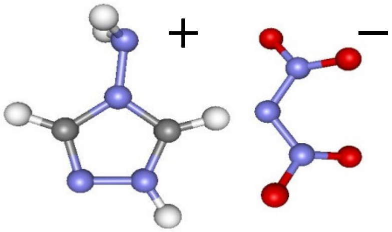
Advanced Fuels Rocket Test Rig



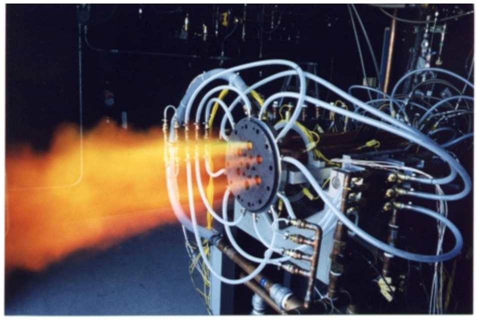
Diamond Anvil for Metallic Hydrogen



Windowed Combustor



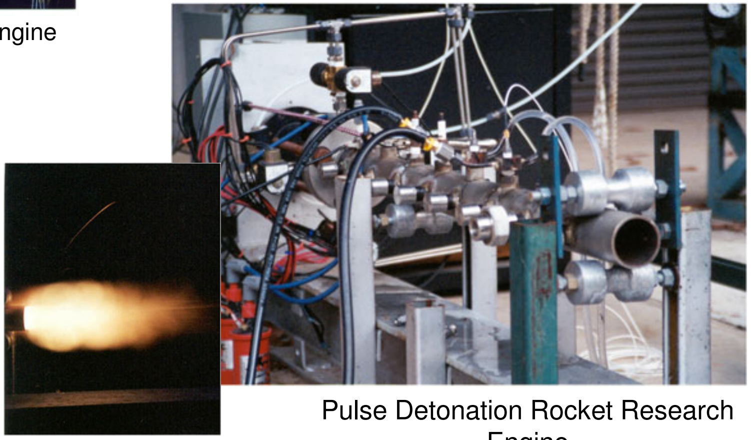
4ATDN, an ionic liquid



6 Tube Pulse Detonation Rocket Engine

Deployable Mirror

Solar Thermal Test Facility



Pulse Detonation Rocket Research Engine

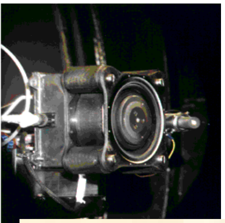
Some Advanced Propulsion Research by NASA Marshall, Glenn, JPL and Colleagues (1996 – 2006)

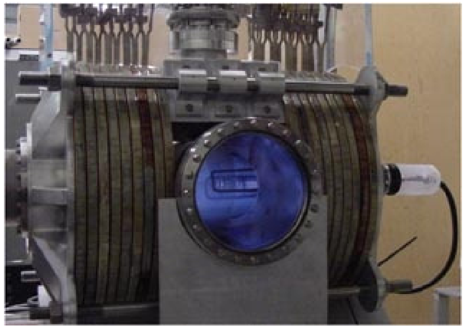
Electric Propulsion

- **High power MPD thrusters**
- **Plasma engines**
- **EM launch assist**
- **MHD thrust augmentation**

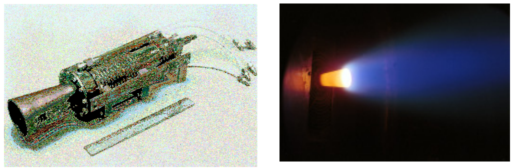
Beamed Energy

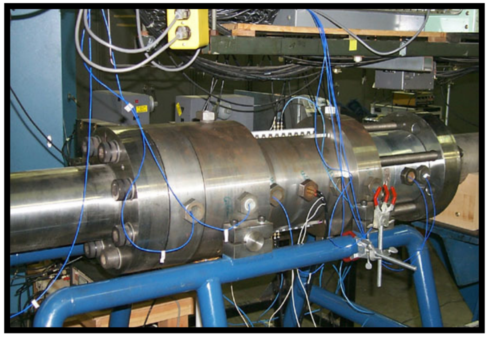
- **Laser propulsion**
- **Microwave propulsion**
- **Laser sails**


Bismuth Anode Layer Thruster


Helicon Plasma Thruster

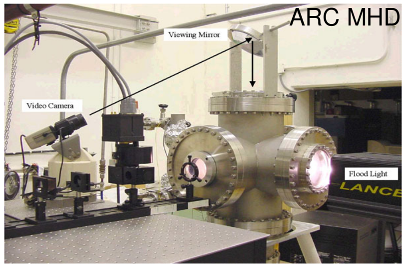

Electromagnetic Launch Assist


Lithium-Fed Lorentz Force Accelerator

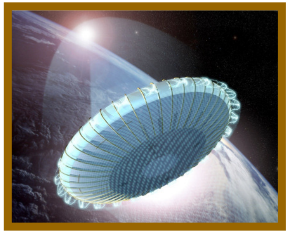

ARC MHD Accelerator Assembly


Laser Vehicle Concept


Laser Vehicle Test



Laser Photon Sail Impulse Tests

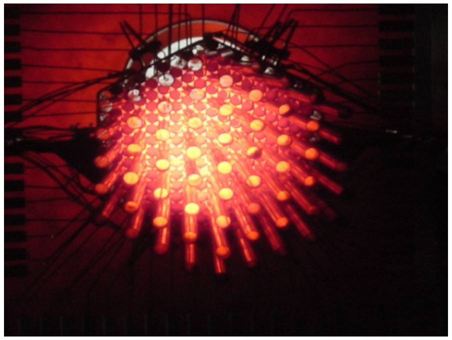

Microwave Vehicle Concept

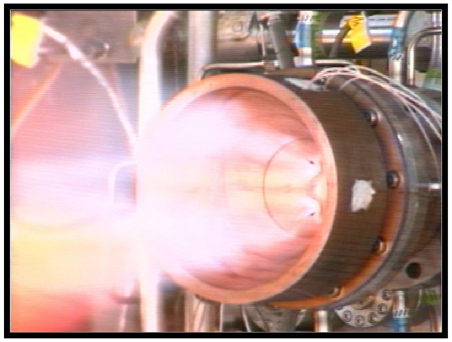

Microwave /Rectenna Test

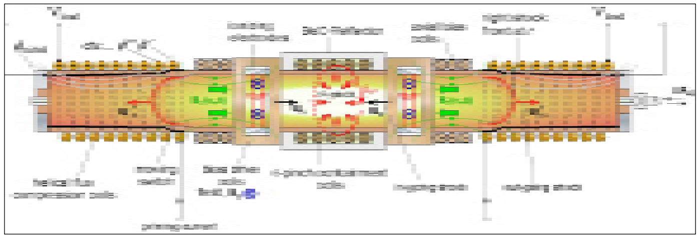
Some Advanced Propulsion Research by NASA Marshall, Glenn, JPL and Colleagues (1996 – 2006)

Nuclear Fission

- **Non-Nuclear simulator**
- **LOX augmented nuclear thermal**
- **MHD pulsed gas core**

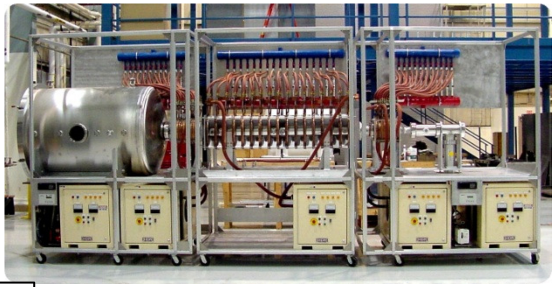

Nuclear Reactor Simulator

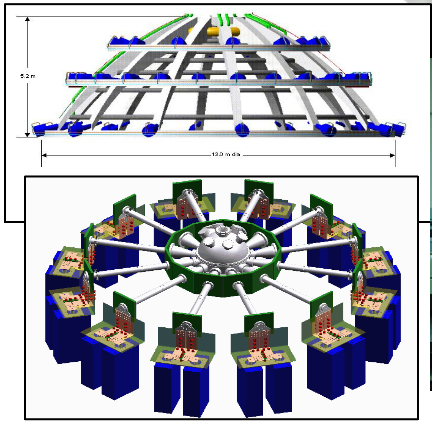

LOX Augmented


MHD pulsed gas core reactor concept

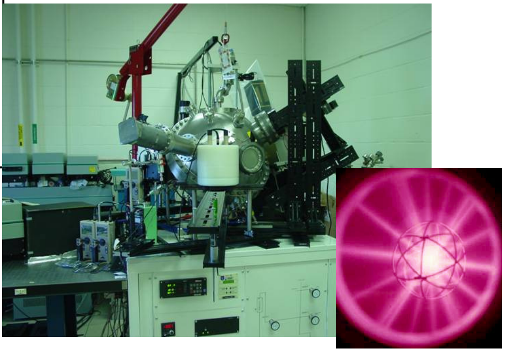
Fusion

- **Gas dynamic mirror**
- **Magnetized target fusion**
- **Electrostatic confinement**


Gas Dynamic Mirror Fusion



Magnetized Target Fusion


Electrostatic Confinement Fusion

Antimatter

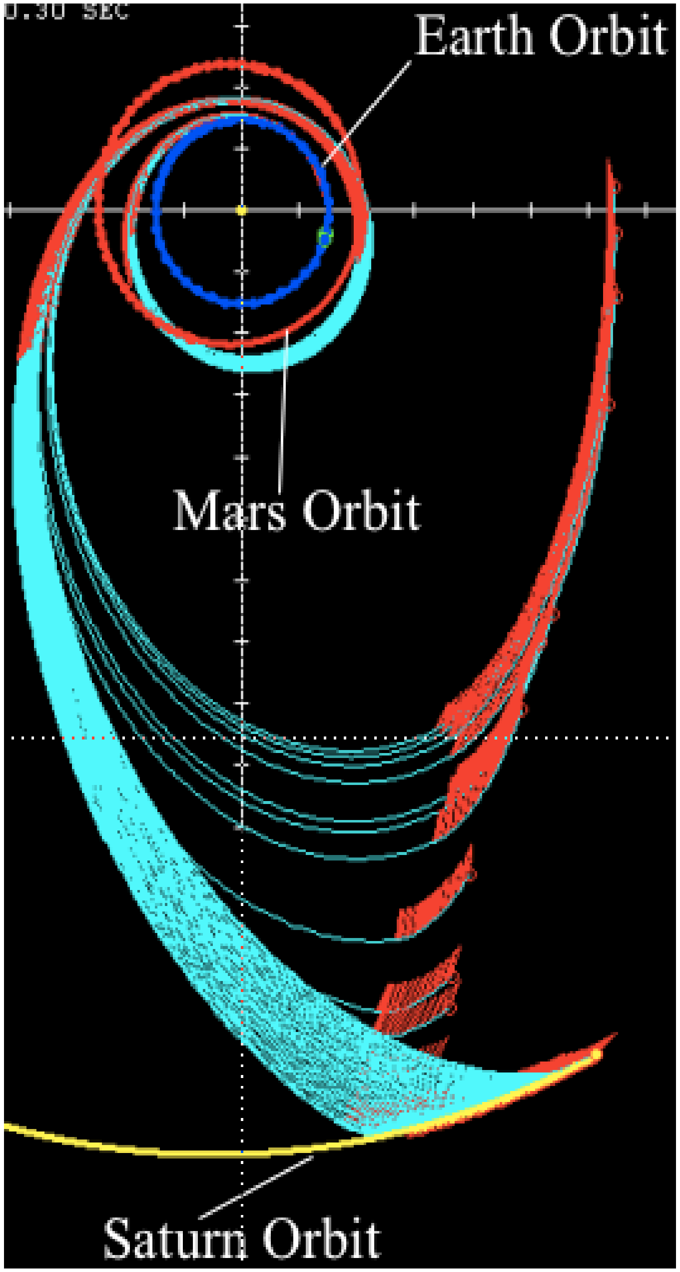

Antimatter Trap

MSFC-Managed In-Space Propulsion Technology Project Successes

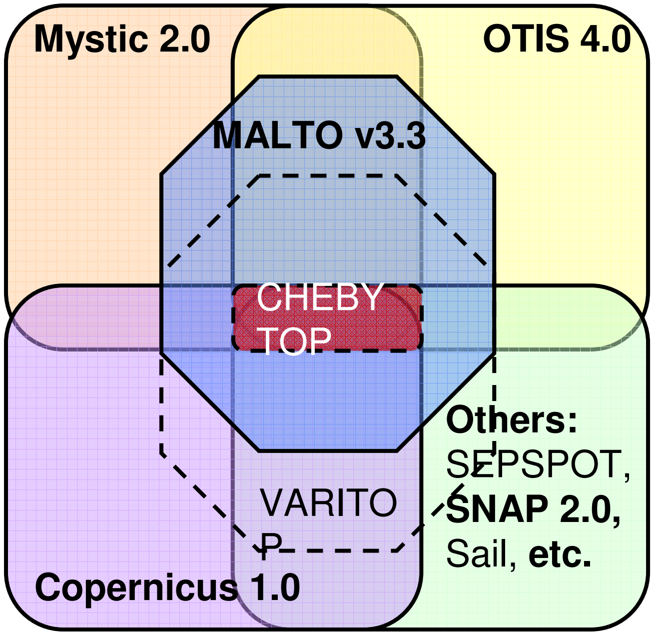
- **Aerocapture**
  - Matured aerocapture technology to the point that it is ready for flight validation (TRL-5)
  - Applications include robotic and human Mars missions; Titan sample return

- **Solar Sail Propulsion**
  - Designed, built, delivered, and safely tested in a ground environment two 400-m^2 solar sail systems (TRL-5)
  - Applications include multiple solar physics missions; Earth pole sitters; near-term Interstellar Probe

MSFC-Managed In-Space Propulsion Technology Project Successes, Continued



- **Systems Analysis**
  - Updated and standardized a complete set of Low Thrust Trajectory Tools for use across NASA for mission planning (with SEP, NEP or solar sails)



Mystic 2.0

OTIS 4.0

MALTO v3.3

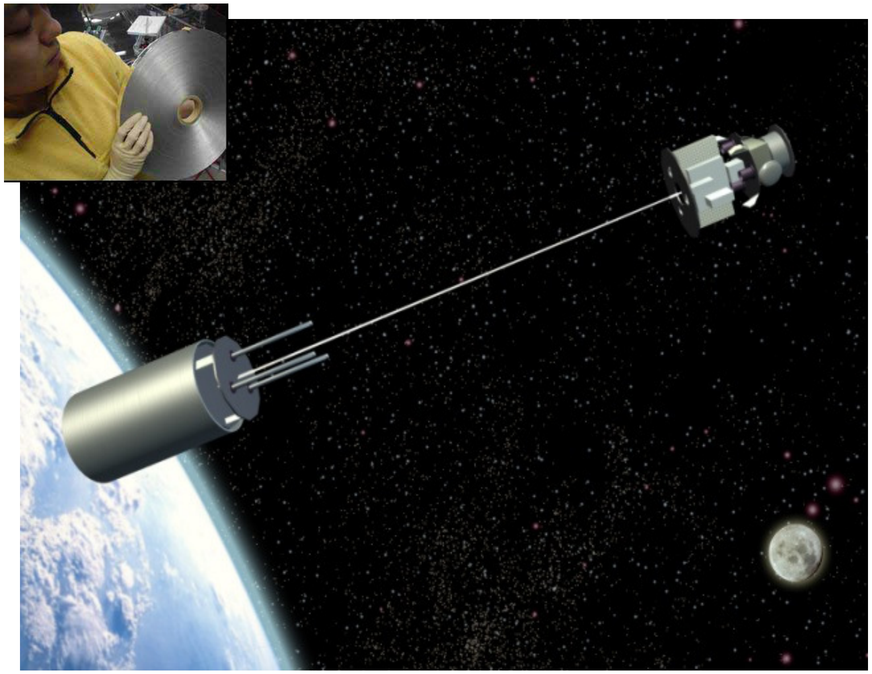
CHEBYTOP

VARITOP

Copernicus 1.0

Others: SEPSPOT, **SNAP 2.0,** Sail, **etc.**

Tether Propulsion

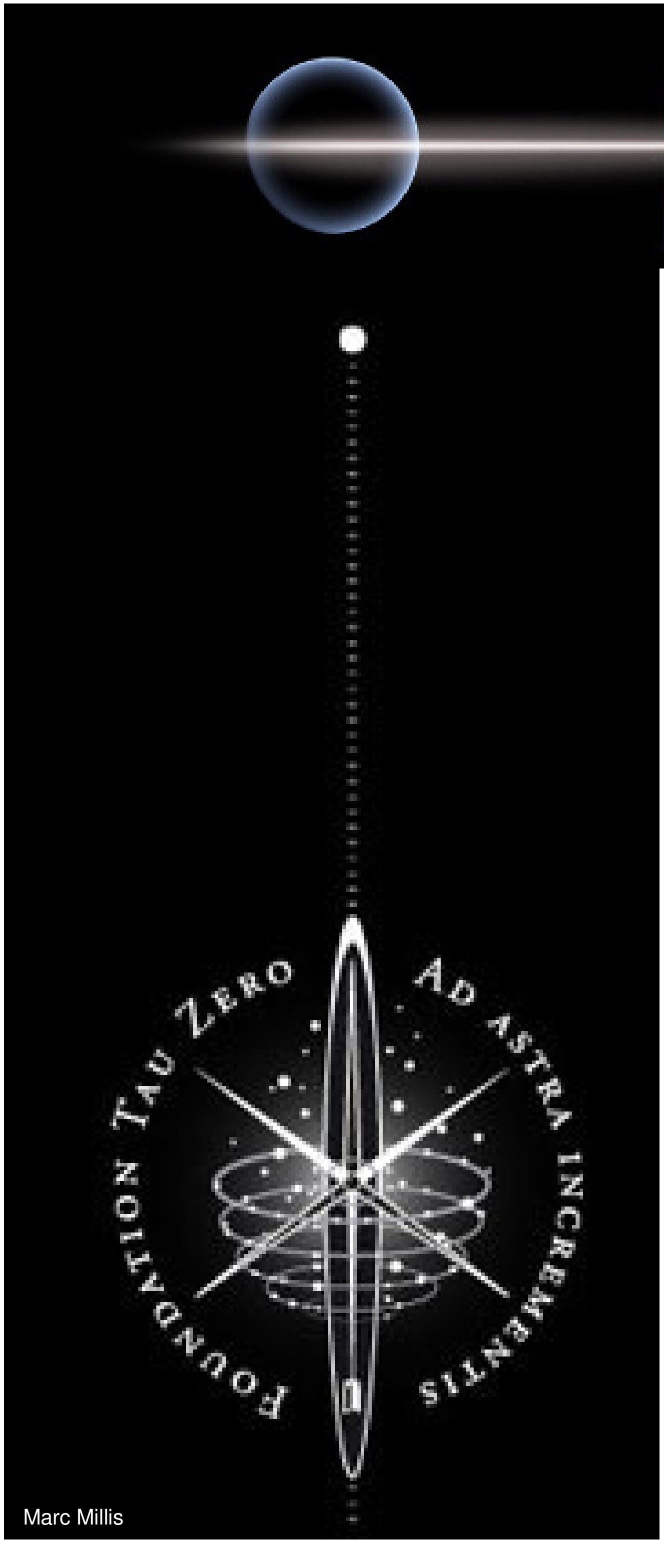


- **T-Rex Space Experiment**
  - JAXA/NASA experiment to validate current collection models for application to electrodynamic tether propulsion systems
  - Planned for late 2009 launch

- **Momentum Exchange Electrodynamic Reboost Tether Systems**
  - Reusable, propellantless Earth-orbiting transfer station for high-impulse interplanetary missions

AFRL-Advanced Concepts Office, Edwards, AFB, CA Research conducted from 2002 to 2006

- 2001 - 2006: *Laser-Propelled 'Lightcraft' Vehicle System*
  H. D. Froning & E. W. Davis, Principle Investigators
  - Laser Lightcraft Propulsion, Applications, System Performance, & Cost
- 2004 - 2006: *Military Aerospace Vehicles: Breakthrough Capabilities & Features in 2050*
  E. W. Davis, Principle Investigator
  - Antigravity via General Relativistic Gravitomagnetic Forces & Negative Quantum Vacuum Energy
  - Wormhole-Stargates
  - Stargates Induced by Polarizable Quantum Vacuum Fluctuations
  - Modifying Gravity/Inertia via EM Fields
- 2003 - 2004: *Advanced Propulsion Study*
  E. W. Davis, Principle Investigator
  - Blast-Wave Accelerators
  - Laser Lightcraft & Microwave Lightcraft
  - Nuclear DC-X (a.k.a. LANTR Nuclear Rocket)
  - Miley's Inertial Electrostatic Confinement Fusion Propulsion
  - Engineering the Vacuum & Spacetime: Inertia/Gravity Modification for Propulsion
- 2003: *Generation of Gravitons via Quantization of Coupled Maxwell-Einstein Fields*
  E. W. Davis, Principle Investigator
  - Physics of Graviton Rockets



Marc Millis

Tau Zero Foundation

- **Tau Zero Foundation is volunteer group of scientists, engineers, entrepreneurs, and writers who have agreed to work together toward practical interstellar flight and to use this quest to teach about science, technology, and our place in the universe.**
  - By posting the latest developments and unfinished advancements here, TZF gives students the starting materials to begin their own discoveries.
  - By showing both how daunting and incredible this challenge is, TZF hopes to increase attention on protecting the habitability of Earth while planning journeys into the galaxy.
- **Using the dream of reaching other worlds as both a long-range goal and a catalyst for near-term progress, the Tau Zero Foundation supports incremental advancements in science, technology, and education.**
  - As a private nonprofit (501c3) corporation, supported mainly through philanthropic donations, the Foundation seeks out and directs support to the best practitioners who can make credible progress toward this incredible goal and educate the public during this journey of discovery.

Symposium on New Frontiers in the Space Propulsion Sciences

- **This Symposium pertains to advancements in space propulsion sciences from current technologies to emerging concepts and theories. The symposium is broken into Five Topic Areas**
  - Advances in Contemporary Propulsion Sciences
  - Advanced Technologies, Concepts, and Techniques for Space Application
  - Frontiers in Propulsion Science
  - Toward New Directions in Astrophysics/Particle Physics with application to Propulsion, Power or Communications
  - Far Term Space Transport/Environment Models and Theories
- **This symposium was held within the Space Technology Application & International Forum (STAIF) from 2004 through 2008 (five years) and in the Space, Propulsion & Energy Sciences International Forum (SPESIF) in 2009.**
- **This symposium will also be held in the SPESIF 2010 Conference at the Johns Hopkins University in Baltimore, Maryland.**
- **All conference proceedings are published by, and available from the American Institute of Physics.**

Contact Information: Glen A. Robertson, gar@ias-spes.org

NEW BOOK:
Frontiers of Propulsion Science (AIAA 2009)

- **First rigorous book about**
  - Gravity control propulsion
  - Faster-than-light travel
  - Related energy conversion
  - Managing such research
- **Editors**
  - **Marc Millis**: Propulsion Physicist led NASA's Breakthrough Propulsion Physics Project & created Tau Zero Foundation
  - **Eric Davis**: Physicist specializing in General Relativity of space-warping, USAF study contracts
- **Lead Author Affiliations**
  - 40% NASA
  - 13% Other US Government Labs
  - 30% Private Industry/Consultants
  - 10% University
  - 7% Foreign

18 Lead Authors, 27 Total Authors, 22 Chapters, 739 pages, ~3 years in the making

Godspeed!

(Questions?)

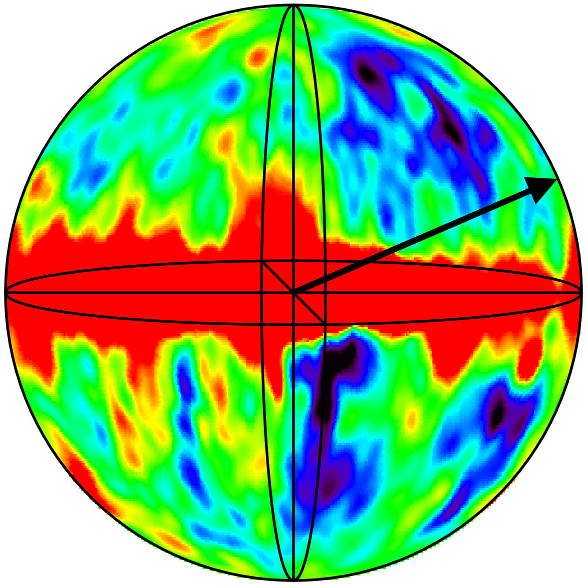
Special Thanks to Gary Hudson and
Paul March for help with core content
of presentation.

Backups

Quantum Vacuum Fluctuations and Big-G

Gedanken Experiment

- Imagine being an inertial observer in deep space…
- The longest path a quantum vacuum fluctuation can travel for any inertial observer is the radius of the observable universe, or more simply, the radius of the “COBE Sphere” at ~13.7 billion light years.
- The vacuum energy density has been measured to be approximately 72% +/-3% of the critical density, or rather 0.72 * 1x10^{-26} kg/m^{3,} based on the apparent brightness of supernovae at red shifts of z ~ 1.
- If we integrate the vacuum energy density over the surface area of the COBE sphere, we arrive at a startling conclusion…



“COBE Sphere”

$$\underbrace{\boxed{\rho_{vac} c^2}}_{\text{Vacuum Energy Density}} \overbrace{4\pi c^2 \underbrace{T_0^{\,2}}_{\text{Square of Light radius of COBE sphere}}}^{\text{Inner-surface area of COBE sphere}} = \overset{\text{we obtain the Plank Force.}}{\boxed{\frac{c^4}{G}}}$$

Quantum Vacuum Fluctuations and Big-G

Formal Proof

- **Formal derivation: This discussion will start with the Friedmann Equation (also derived by Lemaitre), and through some manipulation, the gravitational coupling constant, G, will be shown to be a time-independent function of the dark energy density integrated over the spherical light horizon (the co-moving coordinate facilitates the requirement that G be constant over all time). Recall the Friedmann Equation (1)**
- **The variables take on their familiar nomenclature: *R* is the co-moving coordinate; *t* is time; *G* is the gravitational constant; ρ_0 is the density; *k* is the curvature; and *c* is the speed of light. Assume a flat universe, *k=0*, and simplify to get (2)**
- **This can be solved for *R* to get the following familiar time-dependent function (t_H is the Hubble time, or rather the age of the universe) (3)**
- **Going back to equation 2, and set up the integrals again (4); This can be integrated to yield (5); Simplify and rearrange to get (6); *G* can be isolated to one side (7); Equation 3 can be used to substitute for the co-moving coordinate, *R*, to get (8); Cancelling terms and multiply both sides by *c4* (9)**
- **Here, I claim that equation 9 can be physically interpreted as a general relativistic origin of inertia. Consider the following. Let there be an inertial observer in flat space. This inertial observer can integrate the dark energy density over the surface area of his/her light horizon. This is the left side of equation 9. The right side is the Planck force. To be more explicit, equation 9 can be written in an alternate form (9b)**
- **The value of the gravitational coupling constant can be interpreted as a boundary constraint consequence of this general relativistic origin of inertia.**
- **There are two things that should be noted. First, the left side of equation 9 is the integral over the light horizon of 2/3 of the critical energy density of the universe. The 2/3 factor suggests that it is the dark energy that can be viewed as the portion responsible for the gravitational coupling constant, *G*. The latest estimates on dark energy are 72% +/- 3 % [1][2] putting the latest lower bound very close to the 2/3 factor. Second, although equation 9 has the Hubble time (current age of the universe) in it, t_H, it is not a function dependent on time and is constant for the duration of the cosmos as the variable time dependency cancelled in equation 8.**

(1) $$\left[\left(\frac{1}{R}\frac{dR}{dt}\right)^2 - \frac{8\pi G\rho_0}{3R^3}\right]R^2 = -kc^2$$

(2) $$\left(\frac{dR}{dt}\right)^2 - \frac{8\pi G\rho_0}{3R} = 0$$

(3) $$R = \left(\frac{3}{2}\right)^{2/3}\left(\frac{t}{t_H}\right)^{2/3}$$

(4) $$\int R^{1/2}dR = \int\sqrt{\frac{8\pi G\rho_0}{3}}dt$$

(5) $$\frac{2}{3}R^{3/2} = t\sqrt{\frac{8\pi G\rho_0}{3}}$$

(6) $$\frac{4}{9}R^3 = \frac{8\pi G\rho_0}{3}t^2$$

(7) $$\frac{9}{4}\cdot\frac{2}{3}\cdot\frac{4\pi\rho_0 t^2}{R^3} = \frac{1}{G}$$

(8) $$\frac{9}{4}\cdot\frac{2}{3}\cdot 4\pi\rho_0 t^2\left(\frac{2}{3}\right)^2\left(\frac{t_H}{t}\right)^2 = \frac{1}{G}$$

(9) $$4\pi c^2 {t_H}^2\cdot\frac{2}{3}\rho_0 c^2 = \frac{c^4}{G}$$

(9b) $$G = \left(4\pi\cdot {t_H}^2\cdot\frac{2}{3}\rho_0\right)^{-1}$$

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[1] WMAP mission results, Available at: http://map.gsfc.nasa.gov/news/index.html

[2] Dark Energy description, Available at http://nasascience.nasa.gov/astrophysics/what-is-dark-energy

QVPT Equivalent Specific Impulse (I_{SP})

- Chemical rocket engine efficiency is calculated by comparing its generated thrust to the amount of expelled propellant mass required to produce 1.0 lb_f for 1 second. This parameter is called the Specific Impulse (I_{SP}) with units of seconds.

- An equivalent I_{SP} is calculated for the QVPT by converting the engine's input energy per second into an equivalent mass flow rate by using Einstein's mass/energy equivalency equation of $E = m^*c^2$ to obtain the equivalent mass flow rate required to power the QVPT.

- A sample I_{SP} calculation for the Mach-2MHz test article is shown below:
  - Input Energy = 7.0W * 1.0 second = 7.0 Joules
  - Equivalent Mass (kg)/sec = $E / c^2 = 7.0J / 9.0x10^{16}$ m/sec = $7.778x10^{-17}$ kg/sec
  - or ($1.719x10^{-16}$ lb_m/sec)
  - Equivalent I_{SP} = Force / mass/sec = $2.205x10^{-4}$ lb_f / $1.719x10^{-16}$ lb_m/sec =
  - $1.282x10^{12}$ seconds or <u>1.282 tera-seconds</u>

Predictive Tools Data Correlation

- **The following charts show a historical test article that was run with two distinct sets of input parameters and was first reported on during the STAIF-2006 Conference.**

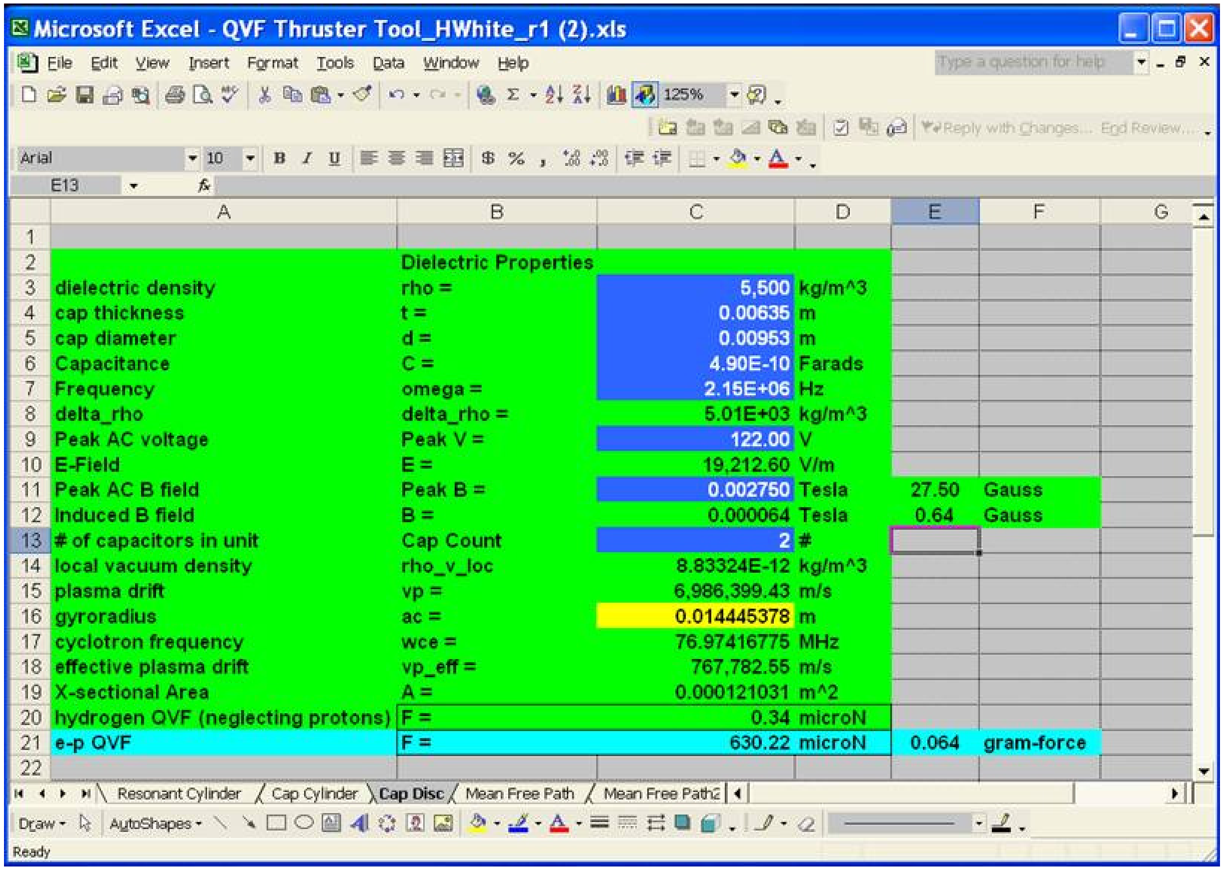
- **The test unit was run at 2.13 MHz, yielding an AC electric field of ~20kV/m, and an AC magnetic field of ~27 Gauss.**
  - Based on the input parameters, the QVPT thrust prediction was 0.064 gram-force.
  - The observed thrust was +/- 0.090 gram-force.

- **The test unit was run at 3.8 MHz yielding an AC electric field of ~20kV/m, and an AC magnetic field of ~48 Gauss.**
  - Based on the input parameters, the QVPT thrust prediction was 0.284 gram-force.
  - The observed thrust was +0.5 to -0.2 gram-force as measured via a 500 gram load cell.

- **As can be seen on the next chart, the thrust signal is very clear when the unit is excited.**

Historical Data Results (1)

- **Test Unit: 2.0 MHz 2-Cap resonance test unit run at 2.15MHz**
- **Observed Thrust:**
  ~0.11 gram-force - 0.020 gram force EMI Signal = 0.090 gram-force
- **Predicted Thrust:**
  e-p QVF prediction 0.064 gram-force

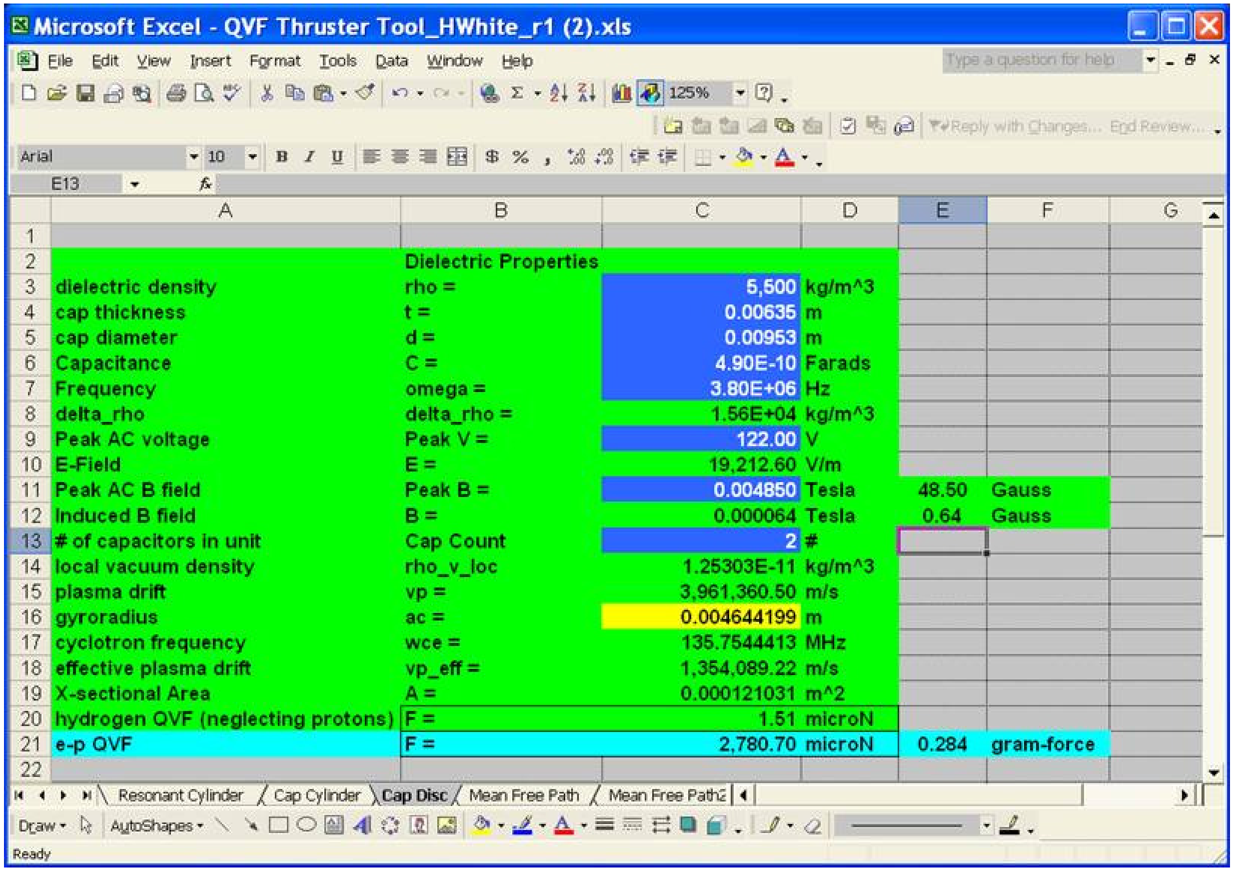


	A	B	C	D	E	F	G
1							
2		Dielectric Properties					
3	dielectric density	rho =	5,500	kg/m^3			
4	cap thickness	t =	0.00635	m			
5	cap diameter	d =	0.00953	m			
6	Capacitance	C =	4.90E-10	Farads			
7	Frequency	omega =	2.15E+06	Hz			
8	delta_rho	delta_rho =	5.01E+03	kg/m^3			
9	Peak AC voltage	Peak V =	122.00	V			
10	E-Field	E =	19,212.60	V/m			
11	Peak AC B field	Peak B =	0.002750	Tesla	27.50	Gauss	
12	Induced B field	B =	0.000064	Tesla	0.64	Gauss	
13	# of capacitors in unit	Cap Count	2	#			
14	local vacuum density	rho_v_loc	8.83324E-12	kg/m^3			
15	plasma drift	vp =	6,986,399.43	m/s			
16	gyroradius	ac =	0.014445378	m			
17	cyclotron frequency	wce =	76.97416775	MHz			
18	effective plasma drift	vp_eff =	767,782.55	m/s			
19	X-sectional Area	A =	0.000121031	m^2			
20	hydrogen QVF (neglecting protons)	F =	0.34	microN			
21	e-p QVF	F =	630.22	microN	0.064	gram-force	
22							

Harold White, Ph.D.
League City, TX

Historical Data Results (2)

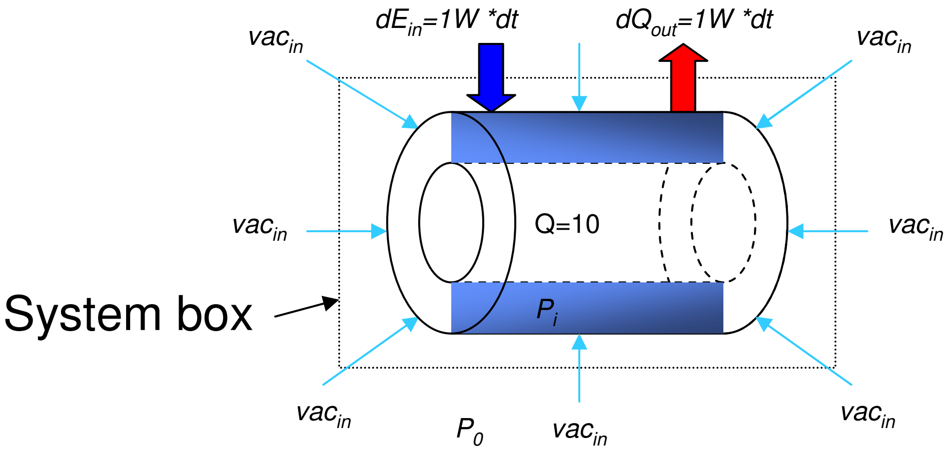
- **Test Unit: 2MHz 2-Cap resonance test unit run at 3.8MHz**
- **Observed Thrust:**
  +0.50- 0.02 = 0.48 / - 0.20 + 0.02 = - 0.18 gram-force, <F> ~ 0.32 gram-force
- **Predicted Thrust:**
  e-p QVF prediction 0.284 gram-force



Microsoft Excel - QVF Thruster Tool_HWhite_r1 (2).xls

	A	B	C	D	E	F	G
1							
2		Dielectric Properties					
3	dielectric density	rho =	5,500	kg/m^3			
4	cap thickness	t =	0.00635	m			
5	cap diameter	d =	0.00953	m			
6	Capacitance	C =	4.90E-10	Farads			
7	Frequency	omega =	3.80E+06	Hz			
8	delta_rho	delta_rho =	1.56E+04	kg/m^3			
9	Peak AC voltage	Peak V =	122.00	V			
10	E-Field	E =	19,212.60	V/m			
11	Peak AC B field	Peak B =	0.004850	Tesla	48.50	Gauss	
12	Induced B field	B =	0.000064	Tesla	0.64	Gauss	
13	# of capacitors in unit	Cap Count	2	#			
14	local vacuum density	rho_v_loc	1.25303E-11	kg/m^3			
15	plasma drift	vp =	3,961,360.50	m/s			
16	gyroradius	ac =	0.004644199	m			
17	cyclotron frequency	wce =	135.7544413	MHz			
18	effective plasma drift	vp_eff =	1,354,089.22	m/s			
19	X-sectional Area	A =	0.000121031	m^2			
20	hydrogen QVF (neglecting protons)	F =	1.51	microN			
21	e-p QVF	F =	2,780.70	microN	0.284	gram-force	
22							

QVPT Conservation Issues



$$\Delta P_{fv} = P_0 - P_i = 0 - {}^{-}10 = +10$$

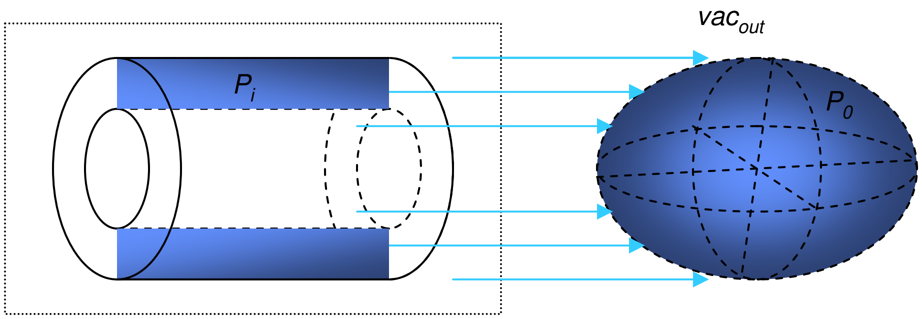
$$\Delta u_{fv} = -\Delta P_{fv} = -10$$

$$\Delta u_{fv} = -(u_0 - u_i)$$

$$u_0 \approx 0$$

$$u_i = -10$$

“Compressed” vacuum serves as potential energy source (like a compressed spring, hence “negative”)



$$\Delta P_{fv} = P_i - P_0 = -10 - 0 = -10$$

$$\Delta u_{fv} = -\Delta P_{fv} = +10$$

“expanding” the vacuum does work on the system which has the net effect of increasing system box’s kinetic energy

Vacuum Equation of State:

$$dP_{fv} = -du_{fv}$$

AFRL-Advanced Concepts Office, Edwards, AFB, CA
Research conducted from 2002 to 2006

- 2004 - 2006: *Laser-Propelled 'Lightcraft' Vehicle System*
  H. D. Froning & E. W. Davis
  (restricted report)

- 2004 - 2006: *Military Aerospace Vehicles: Breakthrough Capabilities & Features in 2050*
  E. W. Davis
  Final Report AFRL-PR-ED-TR-2004-0081 (unpublished)

- 2003 - 2004: *Advanced Propulsion Study*
  E. W. Davis
  Final Report AFRL-PR-ED-TR-2004-0024

- 2003: *Laboratory Generation of High Frequency Gravitons via Quantization of the Coupled Maxwell-Einstein Fields*
  E. W. Davis
  Paper HFGW-03-125
  DIA/NSSO: Int'l High-Frequency Gravitational Waves Conference, MITRE Corp., McLean, VA

Space Transportation Costs

Assumptions:

- Current 2009 market cost for commercial LEO services were used instead of total development cost vs flight rates.
- For the two-way manned Lunar surface missions the Saturn-V and Lunar Excursion Module (LEM) development costing adjusted for inflation from 1969 and total number flights (12 to Moon) were used to obtain the cost per flight to the surface of the Moon.
- For the Mars Mission, the Spirit & Opportunity Rover total development costs and the Delta-II Heavy launcher costs adjusted for inflation vs total number of rovers on the Martian surface (2) were used.

Calculations:

- The current Falcon-9 cost is $37 million per flight for a payload of 23,100 Lb payload for per pound cost of ~$1,600.00/lb
- Current 2009 LEO costs to 200km, 28 degree inclination orbit for the ULA/EELV Fleet (Atlas-V and Delta-IV) runs between $4,952/lb for the Atlas-V, Model-551 up to $6,117/lb for the Delta-IV Medium (29,900 lb payload) with 5m fairing. Average cost for all EELV models is $5,478/lb.
- Space Shuttle payload costs assuming $500 million per flight for incremental costs and a 50klb payload is $10,000/lb.
- Lunar surface payloads based on one Saturn-V per flight cost ($2.94 billion) & LEM cost ($294 million) for a on the lunar surface payload of 15,083 lb for a net cost on the ground for a two way trip, not including the Command and Service Module's development & mfg cost is $214,416/lb. If we just look at the per flight Saturn-V costs to the ground we get $194,921/lb, but that doesn't include the cost of the LEM's descent stage required to get on the lunar surface in one piece.
- For the Mars surface mission I've selected the Mars Spirit & Opportunity Rover missions using a Delta-II Heavy launcher. Cost for the Launcher is ~$70 million which delivers the 2,343 lb rover, cruise stage & Decent Capsule near Mars for ~$29,876/lb. However to get to the Martian surface we now have to include the total cost of the cruise/lander/rover combination which runs out to ~$400 million, which delivers a 408 lb rover on the surface of Mars for a cost of ~$1.152x10^6/lb for a one-way trip.
- For a human Mars Mission, let's use the most optimistic mission scenario cost figures pushed by Bob Zubrin and his two launcher Mars Direct project that would deliver a crew of six on the Martian surface in a 46 metric ton (mt) or (101,660 lb) lander and ascent stage for an estimated $55 Billon in 1993 dollars. Mars Direct required two Saturn-V class launchers. Correcting for inflation that comes out to $82.2 billion, which comes out to a cost of $808,570/lb on the Martian surface. However, NASA modified Zubrin's overly optimist plan and called it the Design Reference Mission, which added one more flight that added a redundant lander, power generation system and ground habitation module into the mix. This would boost the cost by at least 1/3 for the design and fabrication of these elements, so let's say the total cost for this NASA Mars Design Reference Mission would come out to 1.33 x $82.2B = ~$110.0 billion, which implies the cost for that 46 mt lander goes up to $1,082,000/lb delivered on the surface, which implies that a space suited astronaut's ticket to Mars and back to Earth using this all chemical approach is ~$325 million per person.