72nd International Astronautical Congress 2021 The Interstellar Papers

edited by John I Davies

In this second of two pieces likely to be of special interest to Principium readers we again cover explicitly interstellar topics and others important in contributing to our interstellar goal. See also *A brief on IAC2021: Inspire, Innovate and Discover For the Benefit of Humankind* by i4is Contributing Editor Samar AbdelFattah elsewhere in this issue.

Reports are by - Adam Hibberd, Paul Campbell, Michel Lamontagne, Cassidy Cobbs, Angelo Genovese, Alan Cranston, Robert W Swinney, Patrick Mahon & John I Davies. Please contact john.davies@i4is.org if you have comments, find discrepancies or have additional items to suggest.

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In these reports you will find -
Code - the unique IAC code and a link to the Abstract
Paper title, Speaker, Institutional Affiliation, Country, Reporter
And Links to papers and videos on the IAF website (login required) and to open publication (where found) with each Report on the paper.

IAC-21-C4-9-10-x61782	The Comet Interceptor Mission — Making a Case for Solar Electric Propulsion	Mr Henrique Costa	GMV Innovating Solutions	Portugal/Spain

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IAF cited presentation video: none
Open paper: none found
Reported by: Adam Hibberd

Most readers I'm sure will be aware of the planned ESA Comet-Interceptor mission which will launch towards the end of this decade and will spend up to three years waiting at the Sun/Earth Lagrange 2 point for a suitable dynamically new comet (a comet new to the inner solar system and in pristine, un-eroded condition). It will then be sent on an intercept trajectory to study it.

By necessity, the intercept point will coincide with either the comet's Descending or Ascending Node, the two points at which the comet's path intercept with the ecliptic plane. 'By necessity' because the Sun Earth L2 point rotates around the sun in the ecliptic plane, hence all the spacecraft's velocity will lie in this plane and any applied thrust out of this plane will amount to wasted effort.

The baseline system will employ Chemical Propulsion (CP) implying high thrust, and which can be approximated by assuming an impulsive initial application of ΔV (velocity increment). The mass of propellant required for this burn is given by:

$M_p = M_I - M_f = M_I (1-\exp(-\Delta V/g/I))$

The paper reviewed here is concerned with the investigation of an alternative propulsion system, Electric Propulsion (EP), which comes under the general category of 'low thrust propulsion'. For CP, the trajectory arcs can be treated as approximately ellipses, with the main influence from the sun's gravity and none from the CP system, excepting the impulse at dispatch.

In the case of EP, the probe's orbit is continuously being altered by what amounts to a consistent small perturbing acceleration generated by the EP system, leading to trajectories which deviate significantly from conic sections. For Solar Electric Propulsion (SEP), the mass of propellant is determined by the rate of mass ejection, dm/dt which is dependent on available wattage from the power supply, which in turn depends on the distance from the sun (if solar panels are used).

There are two approaches in the field of trajectory optimization – indirect and direct. The indirect method generally involves application of Pontryagin's Maximum Principle and a Hamiltonian formulation, the direct one involves parametrisation of the control variables (like pitch and yaw for

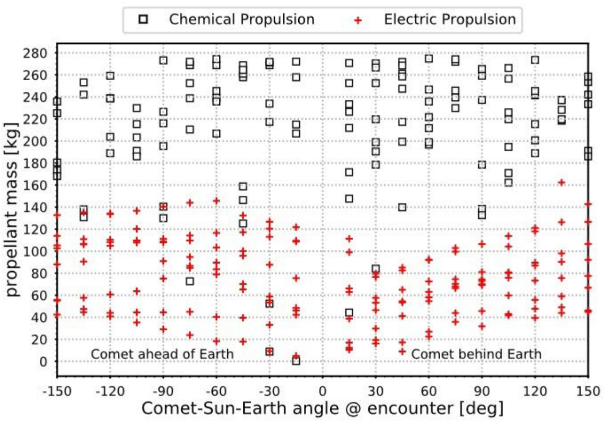

Fig. 4. Superimposed EP and CP m_p maps for minimum m_p trajectories

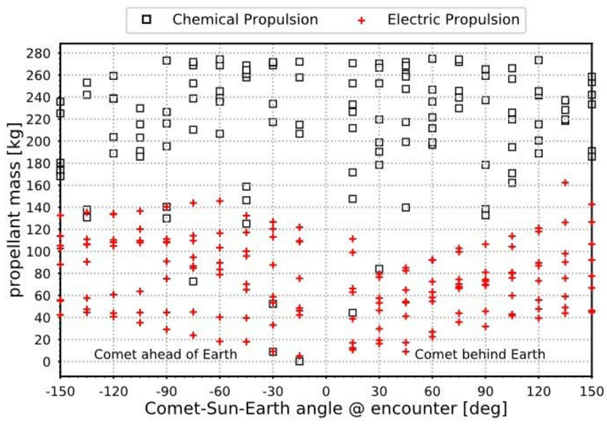

Fig. 5. Superimposed EP and CP m_p maps for minimum Δt trajectories

Electric propellant (EP) and chemical propellant (CP): Minimum propellant mass Mp (left) versus minimum transfer duration Δt (right).

Credit: Costa et al

example in rockets), and usually the application of a Non-Linear Programming (NLP) solver.
The approach here is the latter, direct method, but not only are the controls parameterised but the trajectory itself which is approximated by Chebyshev Polynomials, with the coefficients calculated to satisfy a) the initial position and velocity, b) the final position (the intercept point) and c) the equations of motion.
The problem is formulated as motion in the ecliptic plane with the initial position of the spacecraft located at distance R_{L2} from the Sun and with initial solar longitude $\theta = 0°$ with respect to Earth. Various target values of sun-radial intercept distance R_c and longitude θ_c were selected where $0.9 \leq R_c \leq 1.2$ and $-150° \leq \theta_c \leq 150°$. Values of θ_c near to 180° were neglected to avoid an intercept at conjunction. Furthermore multiple cycles around the sun were modelled where appropriate.
There were two optimization criteria (objective functions) for these trajectory calculations, i) minimum propellant mass, and ii) minimum time. (Reasoning this out and we find these routes are indeed not equivalent for SEP: a time minimum trajectory may use a route which is high wattage – closer to the sun – and therefore require more propellant mass.)

The results were that for SEP there were significant savings in propellant mass, for situation i) above - SEP required max160 kg as opposed to a CP of 280 kg max. In the case of ii) above, the difference is not quite so clear, SEP requiring 260 kg against CP of 280 kg.
Analysis was also performed on the back-up target which is the short period comet 73P/Schwassmann-Wachmann.
To conclude, the SEP system saves 125 kg of propellant mass for 50% of the comet encounter locations, and 75% of the encounter locations required no additional time-of-flight. For 73P/Schwassmann-Wachmann, SEP can reach it with only 16 kg of propellant.

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IAC-21,D4,1,14,x66313	Selection of Asteroids Which Are Suitable For Collision With Mars For The Purpose of Terraforming	Neelabh Menariaa, Aditya Balasubramania, Dhruthi Bhatc	Ramaiah Institute of Technology	India

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Open paper: None found
Reported by: Michel Lamontagne

The writers propose the use of asteroids as impactors for the Mars terraforming process. They propose the use of volatile rich asteroids such as C-complex asteroids from the main asteroid belt. Asteroid deflection methods are described but not calculated. They suggest a runaway greenhouse effect can be started with an artificial 4K rise of the martian atmosphere temperature created by the impact, requiring a 1/200 of the engineering effort for a full 55K rise as originally proposed by Zubrin*. This can be provided by 5-20% of the energy from the impact of a single C-type asteroid of sufficient dimension, somewhere between 150 m to 380 m in diameter ($1{,}9 \times 10^9$ kg to $2{,}96 \times 10^{10}$ kg).
Four candidates are proposed for this purpose, 259P/Garradd (P/2008 R1), P/2013 R3, 238P/READ and 101955 Bennu.

*Zubrin, Robert, and Christopher McKay. *Technological requirements for terraforming Mars* 29th Joint Propulsion Conference and Exhibit. 1993.

Authors:
Neelabh Menariaa, Aditya Balasubramania, Dhruthi Bhatc, all from the Ramaiah Institute of Technology

IAC-21-A1.6.1,x63282	Extended Habitable Zone of M-dwarf planets	Amri Wandel	The Hebrew University of Jerusalem	Israel

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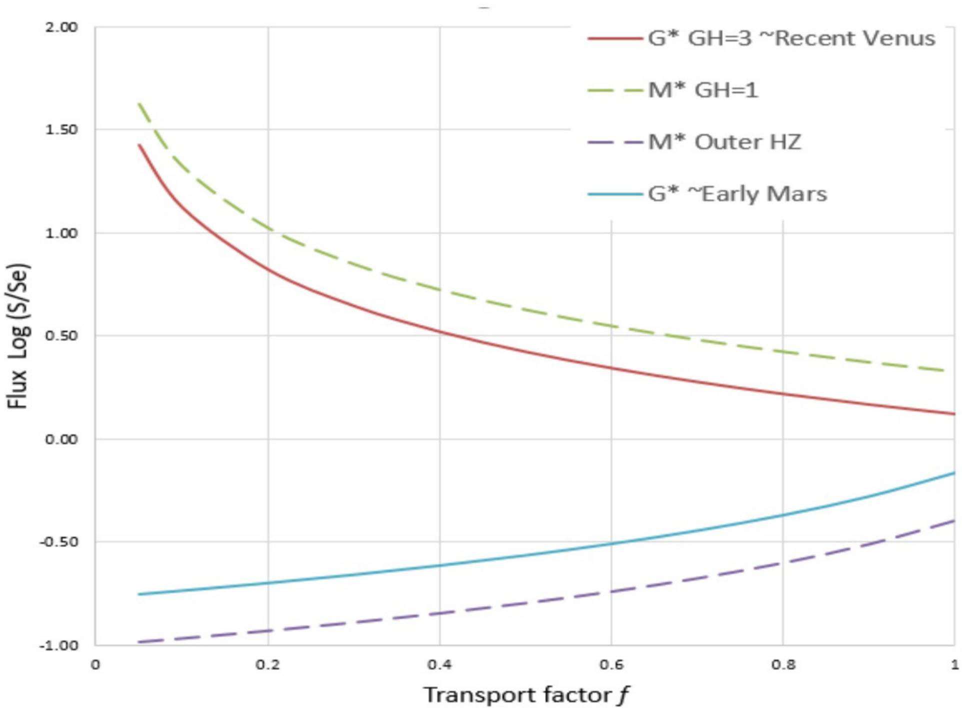
Open paper: none found
Reported by: Cassidy Cobbs

Wandel expands on the implications of previously reported models (Wandel, 2018 and Wandel and Gale, 2020) of atmospheric properties of planets which are locked, in synchronous orbit, or slowly rotating around M-type stars. This report shows that these atmospheric models, which reduce the surface temperature distribution estimations to a function of host star irradiation, heat transport/reflection, and greenhouse effects, imply a wider Habitable Zone around M-type stars than previously assumed.
Wandel identifies a "heating factor" by combining the Bond albedo, fraction of radiation reaching the planet's surface, greenhouse factor, and insolation (as defined by the host star's luminosity and its distance from the planet) relative to Earth. Thus, the minimum and maximum surface temperatures on a given planet with a defined heating factor can be plotted across latitudes to identify what percentage of the surface falls in the habitable range for temperature.
Further, Wandel plots potential sources of variability in the model, including horizontal heat transport, determined by the atmospheric conditions and rotation speed of the host planet; greenhouse heating; and atmospheric composition and density. This model demonstrates that the HZ for M-type stars may be broader than previously assumed, and that atmospheric conditions can lead to a wide range of estimated surface temperatures by latitude on closely orbiting planets of these stars.



Wandel Fig 4. Minimum and maximum flux values of locked planets as a function of the transport factor. Solid curves show the early Mars-recent Venus HZ of a G-type star, while the dashed curves show the inner (upper curves) and outer (lower curves) HZ-boundaries of an M-type star, for a locked or slowly-rotating planet. Credit: (image and caption) Amri Wandel

IAC-21,C4,6,7,x64788	Progress in Research and Development of Superconductor-Based Applied-Field Magnetoplasmadynamic Technology	Marcus Collier-Wright	NeutronStar Systems UG, Köln 50674	Germany

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IAF cited presentation video: none
Open paper: none found
Reported by: Angelo Genovese

The low thrust produced by current electric propulsion (EP) devices has created a large gap between the applications for which they are suited and those where chemical propulsion is more fitting. For example, crewed missions prioritise short travel times, and thus, the large thrust produced by chemical systems is needed even at the expense of payload mass. However, with more power, EP systems may produce enough thrust to break into this niche, while retaining the propellant efficiency characteristic of this class of propulsion. As a result, there is continuing research into scaling EP devices to higher power and exploring new concepts that may excel at > 100 kW.

MPDT (Magneto-Plasma-Dynamic Thruster) is a form of electromagnetic propulsion as it employs electromagnetic fields to accelerate a propellant and generate thrust. In an MPDT, a cylindrical anode is located concentric to a central cathode. An arc is struck between these electrodes, ionising the propellant and forming a plasma. This plasma conducts the current radially between the electrodes, inducing an azimuthal magnetic field. The combination of this magnetic field with the electric field generates a Lorentz force which accelerates the plasma out of the thruster to produce thrust.

There are two types of MPD Thruster: Applied-Field and Self-Field. In self-field designs, only the self-induced magnetic field contributes to the plasma acceleration. Applied-Field designs make use of a second, external magnetic field which is typically generated with either permanent magnets or electromagnets. This field is applied in the axial direction, resulting in an overall helical magnetic field configuration due to the interaction of the axial and azimuthal fields. The result is two additional acceleration mechanisms: a Hall-effect acceleration, and a swirl acceleration. As self-field designs require significantly higher currents to operate effectively, today MPDT research has mainly focused on Applied-Field designs (AF-MPDT).

The generation of the applied magnetic field can be achieved through applying a current on a copper coil. For the high field strengths required, this leads to extremely bulky and heavy electromagnets. High-Temperature Superconductor (HTS) technology provides a way of generating the required magnetic field using a much smaller and lighter coil, thereby solving a fundamental issue with conventional AF-MPDT.

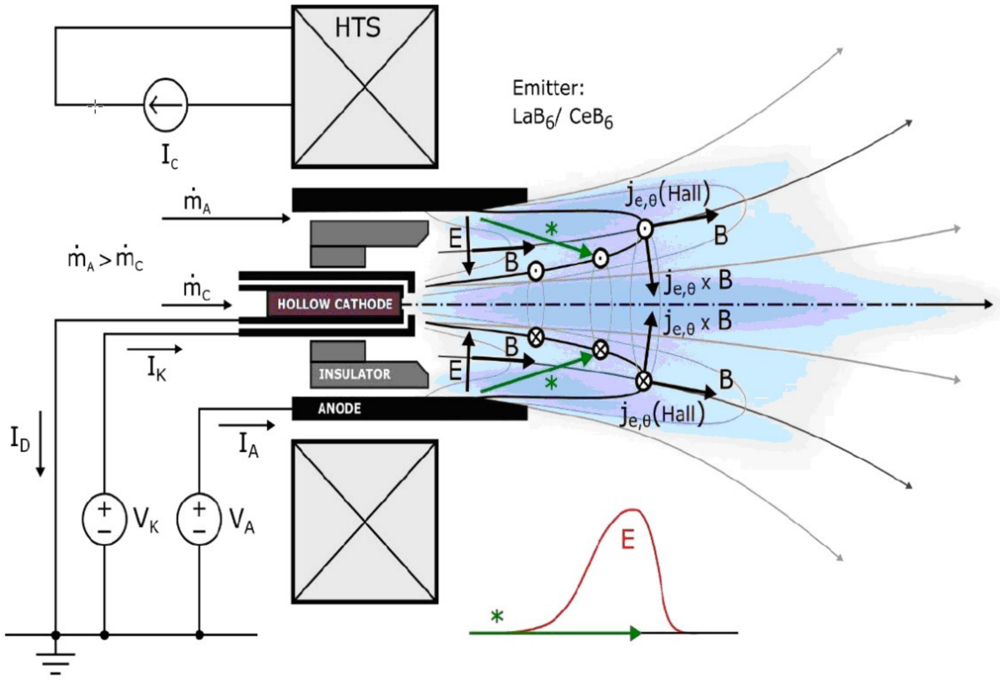
This paper reviews the latest advances in AF-MPDT and HTS developments and presents the SUPREME design concept, an effort to commercialize HTS-based AF-MPD technology currently underway in Germany, led by Neutron Star Systems (NSS) and the University of Stuttgart.

The 100 kW SX3 AF-MPDT developed by the Institute of Space Systems (IRS) of the University of Stuttgart has shown gradual improvements in efficiency up to 62%, a thrust of 2.75 N and a specific impulse close to 4700 s using Argon as propellant. This high performance and high thrust density are very attractive for high-power interplanetary missions, but there are still formidable technical challenges to be solved.

The main challenge is the present poor lifetime, which makes MPDT not competitive against other more mature EP technologies.

The HTS electromagnetic coils which are needed to increase the flight feasibility of this technology present a number of engineering challenges which NSS is currently addressing.

Furthermore, MPDT performance is poor at power levels <100 kW. Hence, any high-performance MPDT design is currently impractical due to the lack of in-space >100 kW power systems. NSS is addressing this issue with the SUPREME concept; it is defined by an operating mode which considers voltage regulation and high voltage operation, alongside with very strong HTS applied magnetic fields, in order to maximize the Applied-Field acceleration mechanisms, namely the Hall and Swirl accelerations.



Operating principles of AF-MPDT Thll1sters.

Credit: Collier-Wright et al

Operating principles of AF-MPDT Thrusters.

The authors note that the AF-MPDT topic has seen an increased traction worldwide with strong national funding, in particular in Russia and China in order to develop high-power EP systems for their joint Lunar and Martian programs. It is then essential to support research efforts in Europe and USA in order not to lose ground with respect to these antagonist space superpowers.

Authors: Marcus Collier-Wright (marcus@neutronstar.systems), Elias Bögel, Manuel La Rosa Betancourt, NeutronStar Systems marcus@neutronstar.systems.

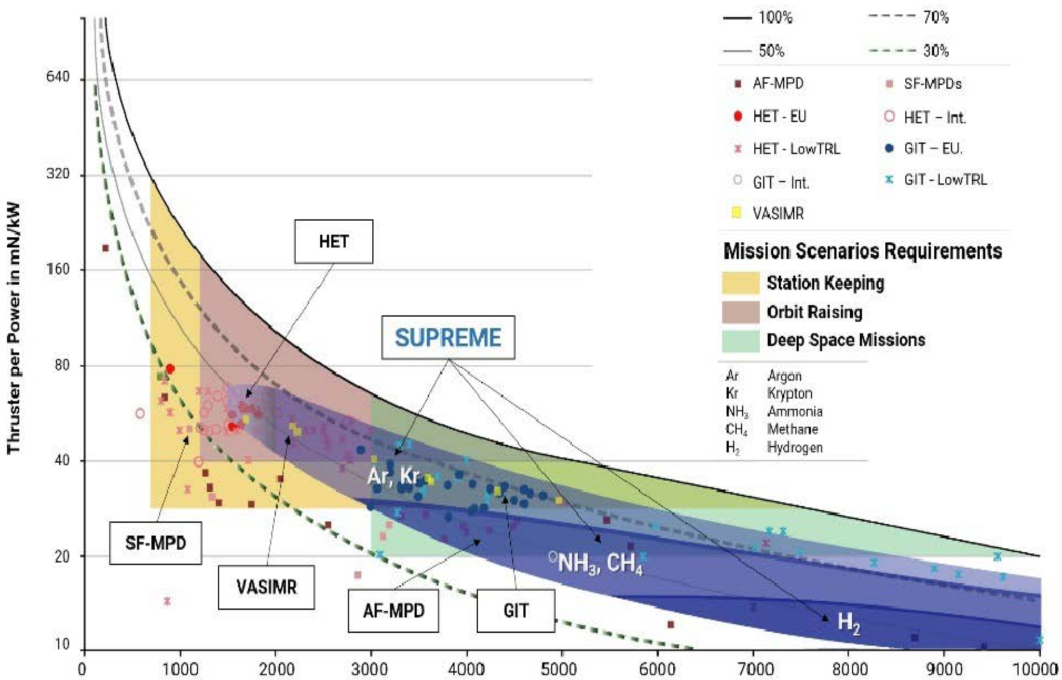


Fig 1. Comparison of Thrust-to-Power ratio and Specific Impulse of different EP technologies.

Credit (image and caption): Collier-Wright et al / M Peukert and B Wollenhaupt [1])

[1] M Peukert and B Wollenhaupt, "OHB-System's View on Electric Propulsion Needs," in EPIC Workshop Brussels, Brussels, 2014. (www.researchgate.net/profile/Markus-Peukert/publication/330082426_OHB-System's_View_on_Electric_Propulsion_Needs/links/5c2c89fe92851c22a3547bc7/OHB-Systems-View-on-Electric-Propulsion-Needs.pdf)

IAC-21, A4,2,10,x65430	Benedict XVI and SETI	Dr Paolo Musso	University of Insubria	Italy

AF cited paper: iafastro.directory/iac/proceedings/IAC-21/IAC-21/A4/2/manuscripts/IAC-21,A4,2,10,x65430.pdf
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IAF cited presentation video: none
Open paper: none found
Reported by: Alan Cranston

The encounter between Pope Benedict XVI and Dr Paolo Musso in 2015, after their exchange of letters.

Credit: Musso

What does the Pope think about extraterrestrial life? Well, you could always ask him, and that is exactly what Paulo Musso did. As he says, "the discovery of other civilisations in the universe would clearly have deep religious implications." So he wrote to Pope Benedict XVI (then Pope Emeritus) with some questions: and got some answers. His paper discusses what the Pope had to say.

Perhaps I should start by saying that I am pretty much an atheist whereas I think Dr Musso makes clear in the paper that he is a believer. That might make him more interested in a detailed exegesis of the Pope's view than I am, but we can all recognise the importance of the question as about more than just religious doctrine. It is about human culture and belief systems, which we all have whether we recognise it or not. The discovery of other civilisations in the universe would surely have a profound effect on how most people, whether religious or not, see humanity's place in the universe. It's probably part of the job description for Pope to have thought deeply about these matters or to be willing to do so.

So what did the Pope have to say? On the main question, Benedict suggests that the implications of extraterrestrial life can't seriously be discussed until there is actual evidence of it. Dr Musso recognises that we might be disappointed by this answer (and to be honest I am) but he explains its importance as not dismissing the idea as heresy, as remaining open-minded. It is not only prudent not to speculate, he argues, but scientific. I am more convinced by the former than the latter, but it is surely a psychological truth that most people find it easier to contemplate matters when they are in some sense real to them rather than theoretical constructs. (Anyone who has watched the film 'Don't Look Up' will understand that to many people the comet only became real when they could see it.)

Dr Musso's other questions to the Pope were about how the existence of extraterrestrial life might bear on three aspects of Christian belief: the origins of humankind (Adam and Eve), original sin, and redemption via Jesus Christ. I didn't find the paper very clear on how the existence (or otherwise) of extraterrestrial life bears on the first two of these. However Benedict seems clear that "the triumph of Christ embraces the whole cosmos". In this context, that seems to me to be an extraordinarily forceful view. Christ was born to save all of the beings of the universe, not just the inhabitants of planet Earth. So were we to achieve communication, should we send missionaries? It's interesting that, in an interview quoted at the end of the paper, Pope Francis (Benedict's successor) seems to differ "I am sure that Jesus Christ died on the Cross to *save us human beings* from sin, and resurrected by overcoming death". (I've abbreviated and the italics are mine.) That seems more like a view that Christianity is for humans and stands in a particular relationship to the human condition. But an omnipotent God would still have a view on the whole universe, so there are perhaps conflicts in Francis's view that Benedict avoids. If God thought that extraterrestrials needed the offer of redemption, would he have sent a Christ figure to them too? Perhaps the Church's stance of not having a view until it is needed is the right one.

I found this an interesting paper raising some interesting questions. But for myself I found Dr Musso wanting to dive deeper into specifically Catholic theology than I wanted to go, and I would have valued more discussion about views of other faith systems on these profound matters.

IAC-21-E2.2.9.x65326	A first step towards interstellar fusion propulsion	Mewantha Aurelio Kaluthantrige Don	Department of Mechanical and Aerospace Engineering, University of Strathclyde	UK

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Open paper: None found
Reported by: Robert W Swinney

Over recent years many theoretical options for fusion propulsion have been proposed. Fusion is often seen as one of the few candidate technologies that might meet the extreme requirements of interstellar travel using rockets. The lack of definitive experimental evidence has kept the field wide open for a multitude of potential alternatives and it has been difficult to conclude which might win out.

Don highlights the Inertial Electrostatic Confinement (IEC) method which among many others was first studied in the 1960s [eg ref 3] and now being given new life in the intensifying race for fusion power and propulsion. He describes some first practical steps for physically modelling the 'non-fusing' behaviour of IEC along with mathematical modelling.

IEC uses strong electrical fields to confine a plasma in a concentric configuration that accelerates the ions toward the centre of the system. It is conceived that at high enough electrical potentials, eventually, the kinetic energy obtained by ions drawn to the centre will cause fusion by collision of the nuclei. With manipulation of the electrical fields the fusion products could be ejected for thrust akin to current electrostatic propulsion systems.

This paper in reality describes initial attempts to build non-fusing IEC plasma-type drives, noting recent attempts at the Institute of Space Systems [13] and also Kentucky University [15]; Don's test programme is based on a Farnsworth-Hirsch fusor [16] placed in a vacuum bell.

Although the lab results were fairly inconclusive due to leaks and other issues, along with the analytical work it seems that there is potential for a small-scale plasma confining propulsion system that Don considers could even conceivably be applied to a 6U CubeSat. At the range of potential of the anode, the specific impulse of the IEC type devices described varies from 1,000 to 12,000 sec. As he alludes, it is just a first step to building a fusing IEC on a much larger scale.

The work was undertaken at NASA Ames in the Technological and Educational Nanosatellite department under the direction of Marcus Murbach of the Space Technology division.

References (numbers as given in original paper):
[3] Hirsch, R L, 1967. Inertial-Electrostatic Confinement of Ionized Fusion Gases. Journal of Applied Physics, 38 (11).
[13] Chan, Y-A and Herdrich, G, 2018a. Breakthrough of Inertial Electrostatic Confinement Concept for Advanced Space Propulsion. 69th International Astronautical Congress.
[15] Winter, M and Koch, H, 2017. Inertial Electrostatic Confinement Plasma Devices - Potential thruster technology for very accurate attitude. 35th International Electric Propulsion Conference, pp.1–17.
[16] Makezine, 2016. nuker_diagram, i1.wp.com/makezine.com/wp-content/uploads/2013/10/nuker_diagram_v4.jpg?w=1200&ssl=1, (accessed 20.08.21)

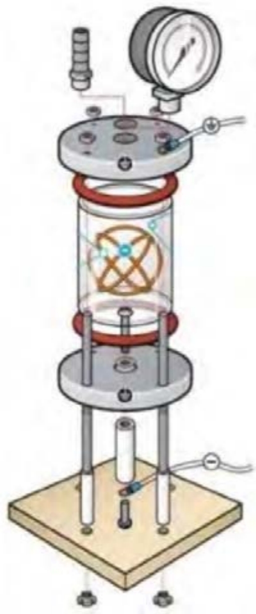

Figure 1. Farnsworth-Hirsch fusor [16] Credit: [16]

IAC-21,A3,3A,10,x66846	Colonizing Mars: In-Situ Resource Utilization of Martian Moons	Vipul Mani	Energy Acres, Uttarakhand	India

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Open paper: None found
Reported by: John I Davies

Phobos is 27 km across at its widest point. Deimos is even smaller. This paper discusses a possible Mars colony via In-Situ Resource Utilization (ISRU) of these moons. It identifies the overall requirements for such an enterprise, identifies additional research required to better characterise the moons, discusses possible landing sites and identifies the project risks.
Authors: Vipul Mani (M.Sc. Space Engineering, TU Berlin), Harshit Goel, Lawanya Awasthi, Dushyant Singh, Adwait Sidhana (all Department of Aerospace Engineering, Energy Acres)

C4,10-C3.5,5,x66797	Overview of the High Performance Centrifugal Nuclear Thermal Propulsion System	Jimmy Allen	Dynetics	USA

IAF cited paper: none available
IAF cited presentation: none available
Open paper: local.ans.org/ne/wp-content/uploads/2021/02/OverviewCNTR-ANS-Winter-2020-summary-paper.pdf (note this link may be insecure)
Reported by: John I Davies

The Centrifugal Nuclear Thermal Rocket (CNTR) is designed to enable advanced space exploration missions while minimizing engine development risk. This paper gives an overview of the concept, an initial design and an evaluation of its benefits with next steps to implementation. Differing from earlier Nuclear Thermal Propulsion (NTP) it uses liquid fuel, with the liquid contained in rotating cylinders by centrifugal force to deliver a specific impulse of 1,800 seconds using hydrogen propellant, and of 900 seconds using passively storable propellants such as ammonia, methane, or hydrazine. For comparison earlier NTP rockets delivered around 800-900 seconds using hydrogen propellant.
Hydrogen propellant passes through a neutron reflector, a regeneratively cooled section of the nozzle, neutron moderator, and into the main reactor keeping moderators and structural materials at a relatively low temperature (< 800 K). Propellant flows radially into each of 19 Rotating Fuel Elements (see schematic of 19 cylinder CNTR and cross-section of CNTR Rotating Fuel Element) via the porous rotating cylinder wall, passes radially through the molten uranium fuel and exits axially through a central channel into a

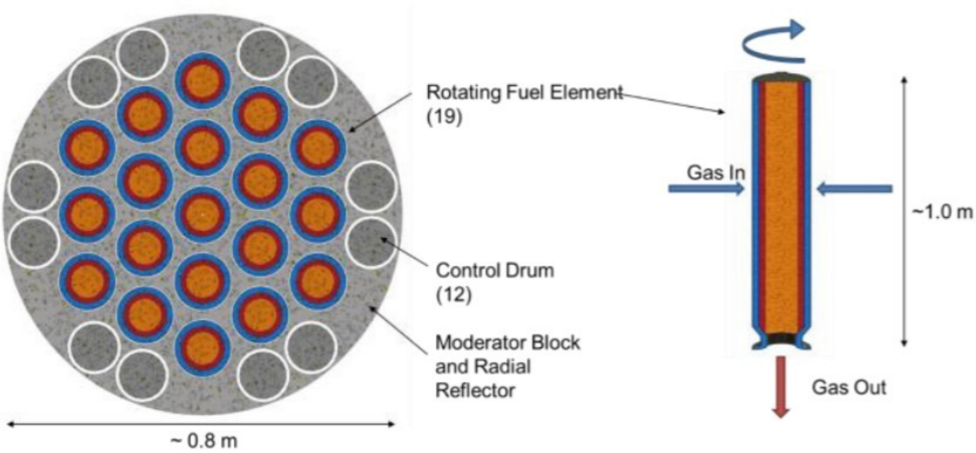


Fig. 1. Schematic of 19 cylinders CNTR

Credit: Allen et al

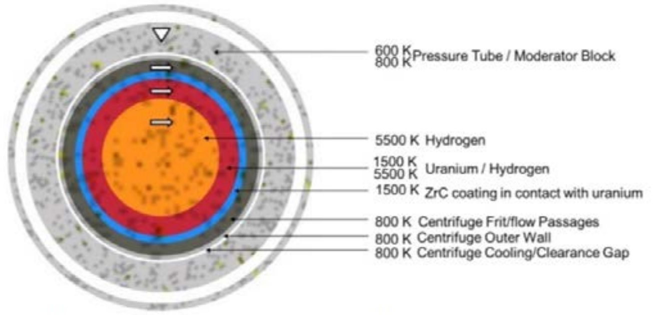


Fig. 2. Cross-section of CNTR Rotating Fuel Element

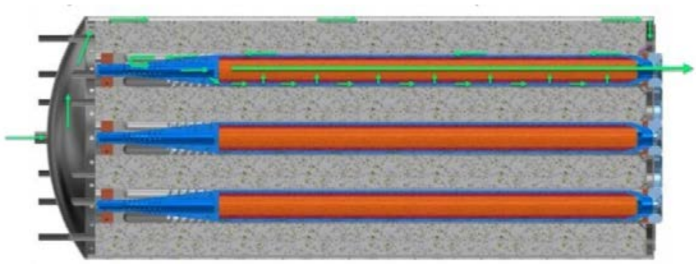


Fig. 3. Propellant Flow Path in the CNTR

Fig 2+3 Credit: Allen et al

common plenum prior to being accelerated through a converging/diverging nozzle. Liquid uranium only contacts the propellant and does not contact any structural material. The liquid uranium is kept under about 34 bar (atmospheres) pressure to prevent the uranium boiling.

The paper claims a number of potential advantages for the CNTR design -

- Only the metallic uranium fuel and a coating on the inside of the rotating cylinder wall exceeds 800 K.
- No thermal stresses in the fuel and no significant compatibility issues between fuel and propellant.
- Hydrogen gives highest specific impulse but propellant can be any volatile material.
- Metallic liquid uranium gives high uranium density using only Low Enriched Uranium while still maintaining acceptable system mass.
- Iodine-135, a fission product, can be exhausted during the engine burn, meaning Xenon-135 poisoning will not restrict engine restart.
- Other fission products exhausted during the engine burn would mitigate shutdown decay heat removal.
- High specific impulse (~1,800 s) at high thrust, which may enable round-trip times to Mars in around 420 days.
- A lower specific impulse storable propellant would enable long-term in-space storage.

The paper identifies a number of design risks and technologies and engineering approaches that are needed for the CNTR-

- Adequate heat transfer between the metallic liquid uranium and the propellant must be demonstrated.
- The porous rotating cylinder wall must allow propellant to flow into the cylinder while not allowing molten uranium to be forced out (by the centrifugal force) via the propellant flow.
- The porous wall must help ensure adequate mixing between the propellant and uranium.
- The coating for the inside of the rotating cylinder wall must be compatible with liquid uranium and any potential propellants at ~1,500 K.
- Rotating cylinder design and fabrication with transpiration and film cooling to avoid potential hot spots.
- Developing rotating cylinders at several thousand RPM with toleration of failure of individual cylinders.
- Methods for startup and shutdown must minimise loss of uranium and avoid vibrational instabilities
- The reactor and cylinder exit must keep the uranium (HALEU) loss rate acceptable, <0.01% of the propellant mass.
- Methods for replenishing HALEU.
- Optimised neutronic design of the core.
- Use experience from previous (lower temperature) liquid reactor development to ensure stable operation during startup, operation, and shutdown.
- Methods for incorporating the CNTR reactor into an NTP engine must be devised.
- A rapid, affordable CNTR development program is required including early proof of concept experiments.

The paper concludes that a high thrust propulsion system capable of providing 1,800 seconds specific impulse could enable 420-day round trip human Mars missions and other advanced space missions.

Authors: Jimmy Allen (Dynetics), Michael Johns & Mark Patterson (Southern Research, Birmingham, AL), Michael Houts (NASA Marshall), Florent Heidet (Argonne National Laboratory), Nicholas V Smith (Idaho National Laboratory), John E Foster (University of Michigan)

IAC-21,A4,1,10,x67003	From Dust to Technosignatures: Searching for Stellar Occulters with Machine Learning	Dr Daniel Giles	SETI Institute	USA

IAF Cited Paper: iafastro.directory/iac/paper/id/67003/abstract-pdf/IAC-21,A4,1,10,x67003.brief.pdf
IAF cited presentation: iafastro.directory/iac/proceedings/IAC-21/IAC-21/A4/1/presentations/IAC-21,A4,1,10,x67003.show.pptx
Open paper: none found
Reported by: Paul Campbell

Over the last decade the Kepler telescope and the Transiting Exoplanet Survey Satellite (TESS) have monitored millions of stars' cadences. These fading events have been hypothesised as being anything from artificial megastructures to transiting exocomets [1]. Utilising machine learning this work looks to identify more of these rare fading events in light curves from the TESS raw dataset to identify the most unusual for follow-up with ground-based observation.

The approach taken is based around anomaly detection. First the TESS dataset is filtered retaining only the most significant outlying light curves to reduce the size of the dataset for the next stages using a user defined threshold relative to the mean. The outlying light curves are then scored using a machine learning model based on 60 dimensions (a dimension in machine learning is an individual property of an input). The output of this is a score relative to how similar each light curve is to the others.

Having scored the individual light curves the research group are using the model to identify the most anomalous curves. Their future work will focus on investigating any dips in the most anomalous curves to identify occulters' similar to Boyajian's Star.

The scored dataset will also be made available to others for further research based into anomalous light curves.

[1] Boyajian T S, et al., 2016, Monthly Notices of the Royal Astronomical Society, 457, 3988

Authors: Daniel K Giles (Carl Sagan Center, SETI Institute), Ann Marie Cody (SETIwTESS Collaboration - Organized by the Breakthrough Listen group at UC Berkeley).

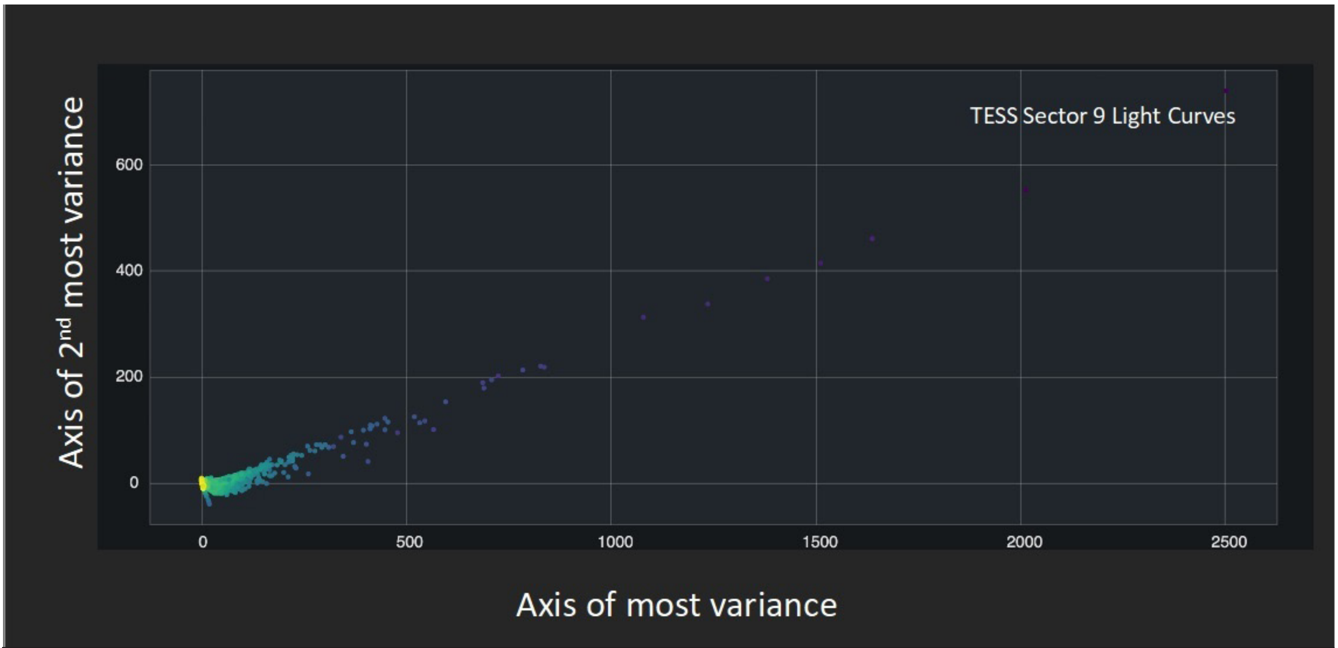


Chart showing two dimensions but, with additional dimensions the model is shown in 3D space. Credit: Giles/Cody

IAC-21,A4,1,1,x65248	Breakthrough Listen: Green Bank Telescope Observations, Analysis, and Public Data	Steve Croft	University California Berkeley	USA

IAF Cited Paper: not available
IAF cited presentation: iafastro.directory/iac/proceedings/IAC-21/IAC-21/A4/1/presentations/IAC-21,A4,1,1,x65248.show.pptx
IAF cited paper: IAC-21,A4,1,1,x65248.pdf
IAF cited presentation video: none found
Open paper: Not found
(background: http://seti.berkeley.edu/listen/)
Reported by: Patrick Mahon

Green Bank telescope *Credit: Croft*

In this presentation, Steve Croft outlines recent progress on the Breakthrough Listen-funded SETI work at the 100-metre diameter Green Bank steerable radio telescope in West Virginia, USA.

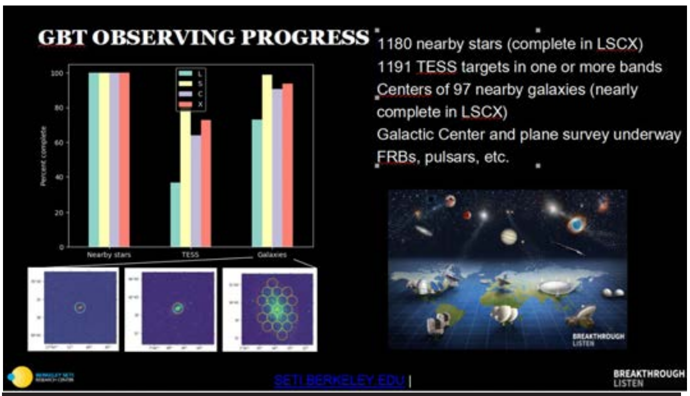
A summary of their previous work, based on Croft's presentation at IAC 2020, can be found in Principium issue 32, page 82.

They are now using the telescope for five hours a day for SETI work, which leads to them capturing hundreds of Terabytes of raw data each day, so data storage capacity is a major issue.

The Green Bank Telescope continues to have three main SETI targets: 1,180 nearby stars, 1,191 targets selected from the Transiting Exoplanet Survey Satellite (TESS) catalogue of 'Targets of Interest' (stars with potential exoplanets orbiting them), and the centres of 97 nearby galaxies.

The survey of nearby stars is now complete, and the survey of nearby galaxies is over four-fifths complete, while the TESS candidate survey is around half-completed. To date, they have found no technosignatures.

They are also undertaking a survey of the centre of our own Milky Way galaxy, recognising that the density of stars is relatively high there, providing more targets to observe per square degree of sky. They have now surveyed it comprehensively across a bandwidth of 1-93 GHz, and found no transients within their limits of detectability.



Progress at Green Bank / *Credit: Croft / Breakthrough Listen*

Finally, Croft provides an update on their use of machine learning techniques to automate the analysis of their massive datasets, looking to find new features that may be missed otherwise. This includes working with the 'Kaggle' data science and machine learning online community to run a competition with a $15,000 prize for the team that develops the best machine learning algorithm for detecting anomalous signals in the Breakthrough Listen datasets.

Galactic Centre Summary *Credit:* Gajjar, Perez, et al (2021)

For anyone who is interested in using this data to do citizen science, there is over 2 Petabytes of public data available to interrogate at seti.berkeley.edu/opendata.

Authors: Dr Steve Croft, Dr Andrew Siemion
Berkeley SETI Research Center.

IAC-21,C4,5,2,x63347	A Superconducting EmDrive Thruster: Design, Performance and Application	Roger Shawyer	Satellite Propulsion Research Ltd	UK

IAF Cited Paper: iafastro.directory/iac/proceedings/IAC-21/IAC-21/C4/5/manuscripts/IAC-21,C4,5,2,x63347.pdf
Presentation video: vimeo.com/641220207
Open paper: www.emdrive.com/IAC20212Gpaper.pdf
Reported by: Patrick Mahon

The EmDrive is a widely reported concept for an electrically-powered spacecraft thruster which appears to enable propulsion without the use of reaction fuel. Many observers are sceptical about the entire concept, since at first glance it appears to violate the principles of conservation of energy and momentum [1].

The basic design of the EmDrive is shown in Figure 1. It is a cavity in the shape of a truncated cone, into which microwaves are injected. At the resonant frequency (eg where the length of the cavity is equal to precisely 1.5 times the wavelength of the radiation) a standing wave is set up. The microwave beam transfers momentum to each of the end plates, but because one is larger than the other, and because the beam velocity varies across the cavity, there is a net thrust.

The inventor of the EmDrive, Roger Shawyer, insists that it is consistent with the laws of physics, and continues to develop the EmDrive design. Last year, he presented a paper at the virtual IAC 2020 which set out detailed design specifications for an EmDrive thruster suitable for use on a CubeSat, purportedly enabling a flight time from Low Earth Orbit to Mars in 8 months, or to Pluto in 4.3 years.

In this latest paper, he describes experiments aimed at significantly increasing the level of thrust produced from the CubeSat EmDrive [2] by coating the internal surface of the microwave cavity with a superconducting thin film. This is done because the thrust generated by the device is predicted by Shawyer's theory to be proportional to the 'Q-factor', or Quality factor, a standard feature of resonant cavities defined as the ratio between the energy stored in the cavity and the energy lost.

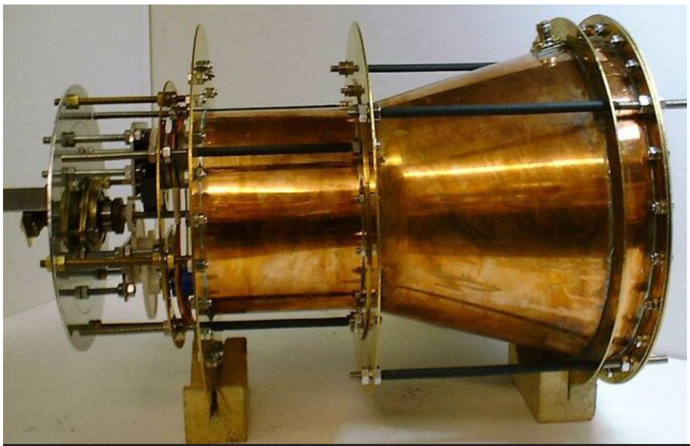
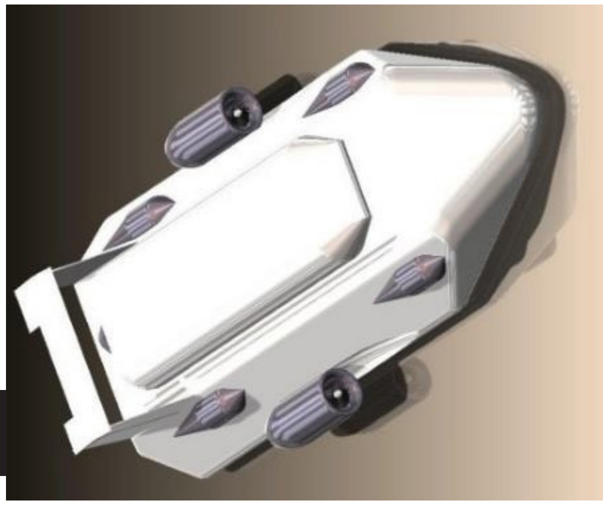


Figure 1. EmDrive / *Credit* - www.emdrive.com/

In his experiments, when the thin-film superconductor (made from Yttrium Barium Copper Oxide, which becomes superconducting below around 93 Kelvin) is cooled to 77 Kelvin with liquid Nitrogen, the Q factor and thus the available thrust increases by two orders of magnitude. Another two orders of magnitude improvement in thrust is predicted from cooling the equipment down to 20 Kelvin with liquid Hydrogen.

Using liquid Nitrogen, a specific thrust of 12.3 Newtons per kilowatt has been achieved in the experimental set-up. If reproduced at an operational scale, Shawyer suggests that such thrust levels could enable rapid missions to the outer planets, or even interstellar precursor missions.



Shawyer has wider ambitions - Hybrid Spaceplane Concept / *Credit:* Shawyer *[3]*

[1] P Sutter (2021), In a comprehensive new test, the EmDrive fails to generate any thrust. phys.org/news/2021-04-comprehensive-emdrive.html
[2] R Shawyer (2020), An EmDrive thruster for CubeSats, paper C4.6.9, IAC 2020. Open paper: www.em rive.com/IAC20paper.pdf
[3] The impact of EmDrive Propulsion on the launch costs for Solar Power Satellites - IAC-21,C3,1,5,x62540
Roger Shawyer www.emdrive.com/IAC2021spspaper.pdf

IAC-21, C4.10-C3.5.11,x65142	Toward the Engineering Feasibility of the Centrifugal Nuclear Thermal Rocket	Dale Thomas	University of Alabama in Huntsville	USA

IAF Cited Paper: iafastro.directory/iac/proceedings/IAC-21/IAC-21/C4/10-C3.5/manuscripts/IAC-21,C4,10-C3.5,11,x65142.pdf

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Related open paper: local.ans.org/ne/wp-content/uploads/2021/02/OverviewCNTR-ANS-Winter-2020-summary-paper.pdf (note this link may be insecure)

Reported by: Patrick Mahon

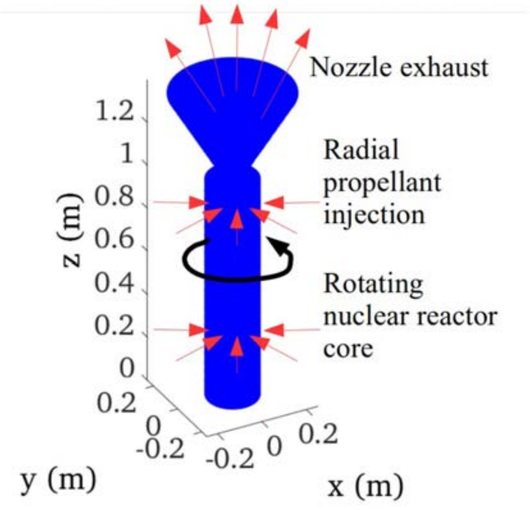
If we want to be able to reach the stars in a reasonable timeframe, we need to develop advanced propulsion systems that will enable our spacecraft to reach much higher velocities.

Amongst the many different technologies under investigation, Nuclear Thermal Propulsion (NTP) is one that seems closer to reality than most, having been studied since NASA's Nuclear Engine for Rocket Vehicle Application (NERVA) programme in the 1960s.

In a standard NTP rocket, a liquid propellant such as hydrogen is pumped through the core of a nuclear reactor, conceptually similar to the type used in nuclear power stations worldwide. The reactor generates huge amounts of heat through the fission of uranium atoms, and this heats up the hydrogen propellant, turning it into a gas which is expelled at high velocity through the exhaust nozzle to produce thrust. Such a rocket is predicted to be roughly twice as efficient as the best chemical rockets in turning propellant into thrust, as measured by the specific impulse: around 450 seconds for the Space Shuttle Main Engine, versus around 900 seconds for standard NTP [1].

In an effort to develop even more thrust per unit of propellant, researchers are investigating more complex types of NTP design, such as the one explored in this paper. The Centrifugal Nuclear Thermal Rocket (CNTR) differs from more standard NTP designs in that it uses liquid reactor fuel, rather than the solid uranium fuel rods found in a normal nuclear reactor. This enables the propellant to be directly heated to the extremely high temperature of the molten fuel, doubling the specific impulse once more, up to 1,800 seconds for hydrogen. This would, for example, enable a crewed mission to Mars in a round trip duration of 420 days, significantly reducing the travel time and thus the crew's exposure to cosmic radiation.

In order to keep the propellant as close as possible to the nuclear fuel, a further innovation in this design is that both are held in rotating cylinders, using centrifugal force to keep them together (see C4,10-C3.5,5,x66797, *Overview of the High Performance Centrifugal Nuclear Thermal Propulsion System* - earlier in this IAC21 report).



Notional elements of a 3D centrifugal nuclear thermal propulsion simulation.
Credit: Thomas Fig 7

While the fundamental physics is well understood, there are several major engineering challenges to be overcome before the CNTR concept can become a reality. These include optimising the heat transfer between the metallic liquid uranium fuel and the hydrogen propellant, designing the porous wall of the rotating cylinders so that the propellant can get in without the uranium fuel getting out, designing and manufacturing the rotating cylinders themselves, and minimising the loss rate of the uranium fuel to an acceptable level. Another six challenges are listed in the paper.

The early-stage research to address these challenges (analysis, modelling and experimentation) is being undertaken at five institutions in parallel: University of Alabama in Huntsville, MIT, University of Michigan, Penn State and NASA Marshall. While they admit to being some considerable way from developing a prototype CNTR engine, their research programme will take them towards that destination.

[1] Office of Nuclear Energy (2021), 6 Things You Should Know About Nuclear Thermal Propulsion. www.energy.gov/ne/articles/6-things-you-should-know-about-nuclear-thermal-propulsion

C4,10-C3.5,1,x63502	Thrust Measurements of Microwave-, Superconducting- and Laser-Type EMDrives	Oliver Neunzig, Marcel Weikert, Martin Tajmar	Technische Universität Dresden	Germany

IAF cited paper: iafastro.directory/iac/proceedings/IAC-21/IAC-21/C4/10-C3.5/manuscripts/IAC-21,C4,10-C3.5,1,x63502.pdf
IAF cited presentation video: none available
Open paper: none found
Reported by: Dan Fries, PhD

Using thrust measurements capable of nanoNewton resolution, Neunzig, Weikert and Tajmar assess the thrust generating capabilities of different EMDrive, or propellantless cavity-based, propulsion concepts. The EMDrive concepts encompass the classical microwave setup, an infrared laser type setup, and a superconducting configuration. The research is part of ongoing efforts to develop and test advanced space propulsion systems at the Institute of Aerospace Engineering at TU Dresden. Past tests had not shown any real thrust being produced by EMDrive devices. The current study re-assesses these results after implementing a range of external suggestions, increasing the reliability of the performed measurements. The most important developments for the new thrust measurements are summarized as follows:

• Environmental influences on thrust measurements were minimised and noise levels lowered to that of photon pressure thrust measurements.
• Ability to cryogenically cool the thrust balance setup for superconducting propulsion devices.
• The figure of merit is a thrust value exceeding the photon pressure of equivalent power, for a propulsion device to be of interest.
• The thrust balance developed is an inverted counterbalanced double-pendulum configuration.
• Deflections of the balance are measured with an optical interferometer. Thus, thrusts as low as 1.67 nanoNewton from a 0.5 W continuous laser can be measured with a signal-to-noise ratio of 10.

In the case of the classical microwave EMDrive, no measurements exceeded the noise floor nor the equivalent photon pressure at a given operating power. Neither predicted force values nor operating conditions were reached by the device. The superconducting EMDrive measurements presented challenges due to nitrogen boil-off and temperature variations, increasing the noise floor. Testing of this device in different orientations led to the conclusion that thrust measurements, while present, are most likely experimental artifacts. Finally, thrust measurements for optical cavity concepts, in all cases, resulted in pure photon thrust or balance noise only, with no enhancement as predicted by a certain theory of quantised inertia. Thus, the results reported in this study confirm previous findings, ie none of the EMDrive devices represent a "breakthrough in space propulsion". Nonetheless, the impressive sensitivities and capabilities of the developed thrust measurement approach will be useful in future studies.

Authors: Oliver Neunzig, Marcel Weikert, Martin Tajmar, all Technische Universität Dresden ■

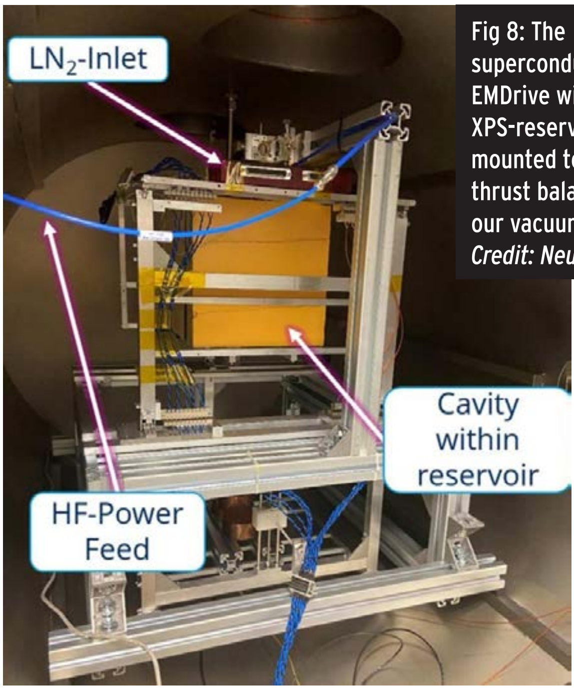


Fig 8: The superconducting EMDrive within the XPS-reservoir mounted to the thrust balance inside our vacuum chamber. *Credit: Neunzig et al*

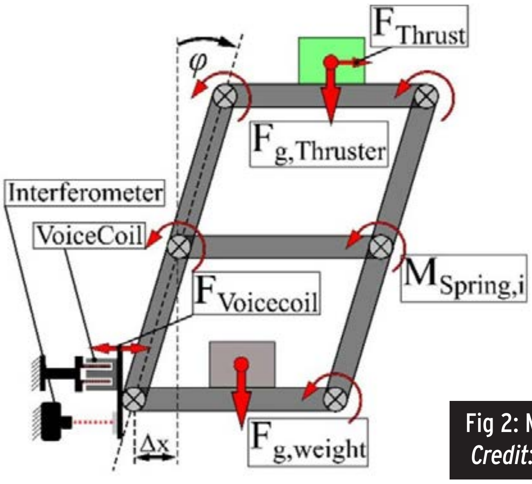


Fig 2: Measurement principle of the inverted double-pendulum thrust balance. *Credit: Neunzig et al*