IAC 2023: The Interstellar Presentations Part 2

Edited by John I Davies

The Programme

Here is the programme with IAF identifying codes for the symposium sessions.

A1	IAF/IAA SPACE LIFE SCIENCES SYMPOSIUM
A2	IAF MICROGRAVITY SCIENCES AND PROCESSES SYMPOSIUM
A3	IAF SPACE EXPLORATION SYMPOSIUM
A4	52nd IAA SYMPOSIUM ON THE SEARCH FOR EXTRATERRESTRIAL INTELLIGENCE (SETI) – The Next Steps
A5	26th IAA SYMPOSIUM ON HUMAN EXPLORATION OF THE SOLAR SYSTEM
A6	21st IAA SYMPOSIUM ON SPACE DEBRIS
A7	IAF SYMPOSIUM ON ONGOING AND NEAR FUTURE SPACE ASTRONOMY AND SOLAR- SYSTEM SCIENCE MISSIONS
B1	IAF EARTH OBSERVATION SYMPOSIUM
B2	IAF SPACE COMMUNICATIONS AND NAVIGATION SYMPOSIUM
B3	IAF HUMAN SPACEFLIGHT SYMPOSIUM
B4	30th IAA SYMPOSIUM ON SMALL SATELLITE MISSIONS
B5	IAF SYMPOSIUM ON INTEGRATED APPLICATIONS
B6	IAF SPACE OPERATIONS SYMPOSIUM
C1	IAF ASTRODYNAMICS SYMPOSIUM
C2	IAF MATERIALS AND STRUCTURES SYMPOSIUM
C3	IAF SPACE POWER SYMPOSIUM
C4	IAF SPACE PROPULSION SYMPOSIUM
D1	IAF SPACE SYSTEMS SYMPOSIUM
D2	IAF SPACE TRANSPORTATION SOLUTIONS AND INNOVATIONS SYMPOSIUM
D3	21st IAA SYMPOSIUM ON BUILDING BLOCKS FOR FUTURE SPACE EXPLORATION AND DEVELOPMENT
D4	21st IAA SYMPOSIUM ON VISIONS AND STRATEGIES FOR THE FUTURE
D5	56th IAA SYMPOSIUM ON SAFETY, QUALITY AND KNOWLEDGE MANAGEMENT IN SPACE ACTIVITIES
D6	IAF SYMPOSIUM ON COMMERCIAL SPACEFLIGHT SAFETY ISSUES
E1	IAF SPACE EDUCATION AND OUTREACH SYMPOSIUM
E2	51st IAF STUDENT CONFERENCE

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E3	36th IAA SYMPOSIUM ON SPACE POLICY, REGULATIONS AND ECONOMICS
E4	57th IAA HISTORY OF ASTRONAUTICS SYMPOSIUM
E5	34th IAA SYMPOSIUM ON SPACE AND SOCIETY
E6	IAF BUSINESSES AND INNOVATION SYMPOSIUM
E7	IISL COLLOQUIUM ON THE LAW OF OUTER SPACE
E8	IAA MULTILINGUAL ASTRONAUTICAL TERMINOLOGY SYMPOSIUM
E9	IAF SYMPOSIUM ON SECURITY, STABILITY AND SUSTAINABILITY OF SPACE ACTIVITIES
E10	IAF SYMPOSIUM ON PLANETARY DEFENSE AND NEAR-EARTH OBJECTS
GTS	GLOBAL TECHNICAL SYMPOSIUM

All of the programme items listed here are visible via iafastro.directory/iac/browse/IAC-23/.

Contents

These are the presentations and papers we report on in this issue - in order of IAC23 reference -

The Interstellar Programme Items

Access them all via iafastro.directory/iac/browse/IAC-23/. The reports include - Code - the unique IAC code, Paper title, Speaker, institutional Affiliation and Country plus links to the abstract, paper and video/ presentation on the IAF website (login required) and to open publication where found.

Please contact john.davies@i4is.org if you have comments, find discrepancies or have additional items we may have missed at the Congress. Details of each report are as follows -

IAC23 ref	Title	Presenter	Institution	Country
C4,10- C3.5 ,10,x76665	System Design Optimization for a Centrifugal Nuclear Thermal Rocket	Mr Mitchell Schroll	Propulsion Research Center University of Alabama in Huntsville	United States

IAF Abstract: iafastro.directory/iac/proceedings/IAC-23/data/abstract.pdf/IAC-23,C4,10-C3.5,10,x76665.brief.pdf

IAF Cited Paper: iafastro.directory/iac/proceedings/IAC-23/IAC-23/C4/10-C3.5/manuscripts/IAC-23,C4,10-C3.5,10,x76665.pdf

IAF Cited Presentation/Video: iafastro.directory/iac/proceedings/IAC-23/IAC-23/C4/10-C3.5/presentations/IAC-23,C4,10-C3.5,10,x76665.show.pptx

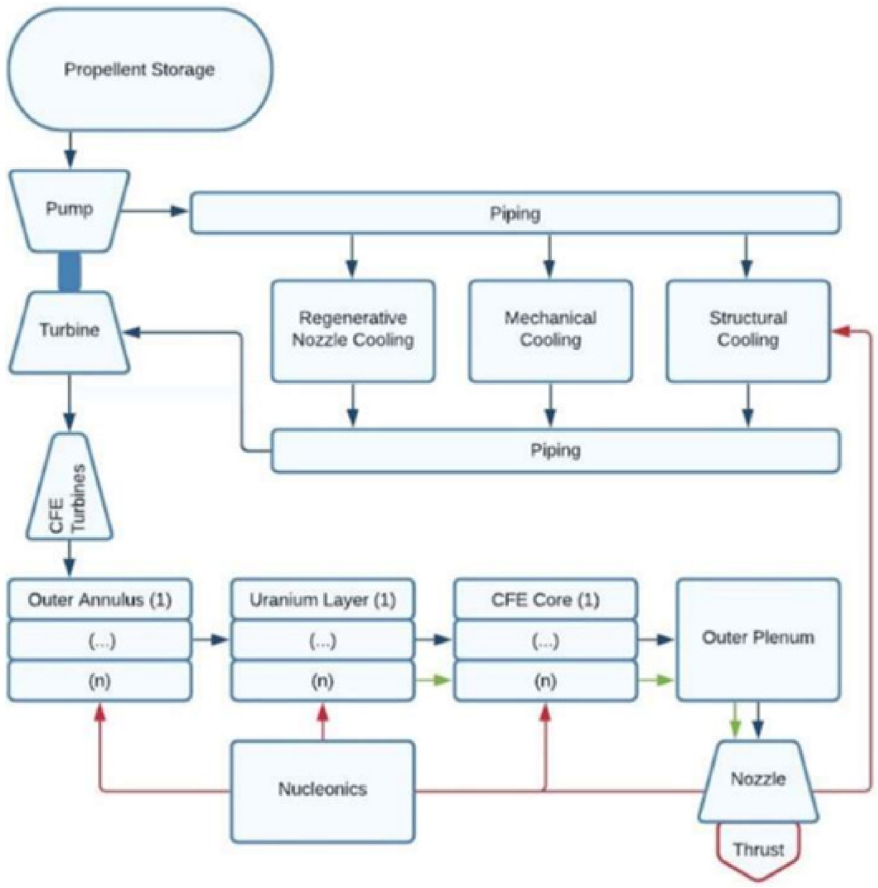
Open Paper: None found

Reported By: Parnika Singh

A Centrifugal Nuclear Thermal Rocket (CNTR) is a high-performance engine concept utilizing a liquid uranium fuel to achieve a theoretical specific impulse of 1,800 seconds. The design is a modification of traditional Nuclear Thermal Propulsion (NTP) in that it utilizes a high energy density uranium reactor to heat a propellant gas, eliminating the need for mass-hungry oxidizers. Preliminary studies suggest a CNTR could reach theoretical specific impulses in the range of 1,800 seconds, twice that of traditional NTP and nearly four times that of a chemical engine such as the RS-25.

This paper by Mr Mitchell Schroll develops a comprehensive model of CNTR technology, to allow for a more comprehensive investigation of its capabilities.

The idea of a CNTR is not new. The paper discusses the history of this technology – from its birth during the ROVER/NERVA programs of the 1950s, to the recent reinterest by NASA. However, despite this lengthy history, no comprehensive systems model has been created, which this paper changes. The paper uses a power balance approach as the main modelling method and MATLAB Simulink as the programming environment.



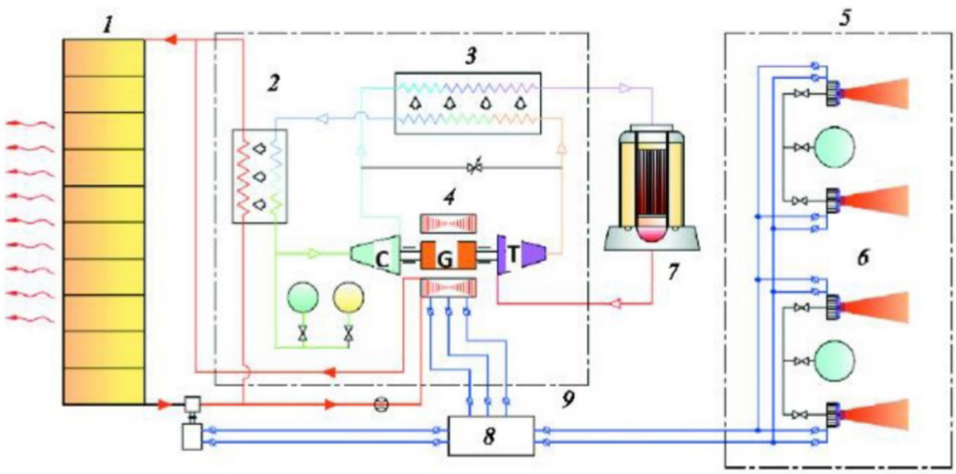
CNTR System Model
- Power Balance Approach
- Propellant State Engine
- Detailed Subsystems Models
  - Propellant Storage
  - Turbomachinery
  - Pipe Losses
  - Regenerative Nozzle Cooling
  - Structural Cooling
  - CFE Turbine
  - Cooling Loops
  - Core Model
  - Nucleonics
  - Core CFD
  - Nozzle Performance

Credit (image and caption): Schroll.

Because of the highly coupled nature of several of the sub-systems it was decided to model each component and avoid using "black box" methods to improve fidelity. The subsystems chosen for simulation are shown in the figure. The subsystems communicate through the master program which tracks the propellant properties across each state points in the engine. The individual methods used for each subsystem are detailed in subsections of the paper, with their equations and calculations included. The paper proceeds to optimize the CNTR model and compare it directly to conventional NTP. It finds that while CNTR technology is more powerful than convention NTP technology, it falls short of theorized maximum performance levels. Thus, the paper concludes that greater development of CNTR technology is needed before it becomes a feasible option for interstellar missions.

C3,5-C4.10,4,x75360	Application of Nuclear Power and Propulsion Systems of High Power Level for Space Transportation	Dr Vladimir Koshlakov	Keldych Research Centre	Russian Federation

IAF Abstract: iafastro.directory/iac/proceedings/IAC-23/data/abstract.pdf/IAC-23,C3,5-C4.10,4,x75360.brief.pdf
IAF Cited Paper: iafastro.directory/iac/proceedings/IAC-23/IAC-23/C3/5-C4.10/manuscripts/IAC-23,C3,5-C4.10,4,x75360.pdf
IAF Cited Presentation/Video: None found
Open Paper: None found
Reported By: Parnika Singh
This paper by Dr Vladimir Koshlakov deals with the application of spacecraft with power propulsion systems of a high-power level to perform various missions in outer space. The paper first discusses the various propulsion options currently feasible – namely solar sails, nuclear propulsion, and ion propulsion. It concludes that nuclear propulsion technology is the most promising option as it allows for very high specific impulses. The paper specifically singles out megawatt-class nuclear power and propulsion systems (NPPS). It explains the basic structure of an NPPS, which includes a nuclear reactor as a heat source and a system for converting thermal power into an electrical one in the closed gas turbine cycle (the Brayton cycle). A turbo compressor-generator is the major element of the gas and turbine system in the power conversion of nuclear energy into useful electrical energy. AC electrical power, generated by the power conversion system, with the help of the equipment of the electrical power conversion and distribution system, is transformed into DC electrical power of the required voltage ratings, which is used for electrical operations.
The paper then discusses how NPPS technology would be applied to space missions. It presents a variety of possible missions, such as Mars, Jupiter's moons, or even more distant targets. The paper develops a model for the flight duration for sample missions depending upon the payload mass. Missions to Europa, for example, range anywhere from 3.2 to 7.4 years. The paper also notes the various tweaks and specifications that would be required for each specific mission. From this, it also discusses the outstanding challenges of NPPS technology, such as the fact that missions to distant targets would require more Xenon than is currently annually produced. In order to avoid some of these issues, the paper proposes that NPPS technology be combined with electric propulsion technologies such as ion engines which would reduce the amount of fuel needed.



The NPPS diagram with a gas and turbine system of power conversion, and with a nuclear reactor: 1-heat radiator; 2-heat exchanger; 3-heat exchanger-recuperator; 4-turbo compressor-generator; 5-attitude control EP thrusters; 6-main EP; 7-nuclear reactor; 8-power management and distribution system; 9-power conversion system.
Credit (image and caption): Koshlakov Fig 2.

D4,4,1,x80088	Communications receiver designs for interstellar probe missions	Prof Philip Mauskopf	Arizona State University	United States

IAF abstract: iafastro.directory/iac/proceedings/IAC-23/data/abstract.pdf/IAC-23,C3,5-C4.10,4,x75360.brief.pdf
IAF cited paper: iafastro.directory/iac/proceedings/IAC-23/IAC-23/D4/4/manuscripts/IAC-23,D4,4,1,x80088.pdf
IAF cited presentation/video: none
Open paper: none found
Reported by: John I Davies

Prof Mauskopf emphasises the scale of the interstellar downlink by comparison with missions in or near our Solar System such as New Horizons to Pluto and the Kuiper belt [1]. With current deep space missions already using laser based downlinks their advantages for interstellar missions are clear. He introduces four concepts for large area optical receivers:

i) an array of 1 metre diameter low cost incoherently combined reflecting apertures,
ii) an array of 1 metre diameter low cost reflecting apertures coherently combined into 50 meter diameter optical receivers,
iii) a space-based collecting aperture based on low mass nanophotonic reflectors similar to the Breakthrough Starshot lightsail design,
iv) a crowd sourced citizen science initiative to produce small receivers for "backyard" collection of communications signals.

The target downlink data volume is approximately 100 kbytes per probe (recall that the Starshot mission would involve thousands of probes). As previously reported in Principium, Starshot chooses sparse pulse position modulation of the optical baseband. In a fixed length frame information is encoded by a single pulse in just one of the M slots in the frame. Each frame therefore carries $\log_2 M$ bits of information (eg for 2 slots this would be one bit, for four slots this would be two bits - and so on). The target receiver aperture is very large, 0.1 - 1 square kilometres.

Prof Mauskopf cites a paper that we summarised in our last issue *Interstellar flyby scientific data downlink design* in Principium 42, August 2023 i4is.org/principium-42 [2] and an open-source interactive communications model at www.wolframcloud.com/obj/messer/Published/Starshot%20parameter%20exploration%20v1.2.nb which includes four examples ranging from the most conservative, taking values that might readily be implementable in current technology to the most optimistic, assuming considerable advances in technology. A major input to this thinking is NASA's Deep Space Optical Communications (DSOC), a communications experiment flying with the Psyche spacecraft, as reported in Interstellar News in our August 2023 issue, P43 (page 21).

Prof Mauskopf notes that current laser communications systems typically use 1,550 nm wavelength sources but that shorter wavelengths have advantages for Starshot and typical values are 400-500 nm. This corresponds to transmit at 432 nm and receive, Doppler shifted, at 539 nm wavelengths in the paper by the i4is team reported in Principium 41, May 2023, *i4is delivers Communications Study to Breakthrough Starshot*, i4is.org/principium-41. The i4is team paper is *Swarming Proxima Centauri: Optical Communication Over Interstellar Distances* (arxiv.org/abs/2309.07061).

Other factors considered by Prof Mauskopf include receiver total collecting area, receiver individual aperture area, transmit aperture, transmit average power, transmit peak to average ratio (crucial in pulse position modulation - PPM), filter bandwidth for detection (data rate versus unwanted signal rejection), number of PPM slots (data rate versus power demand) and noise power.

He analyses the transmit component, an optical beamforming transmitter, comprising -

• Signal generation - a pulsed peak power of at least 5 W with a pulse width of less than 0.5 milliseconds.
• Signal distribution - over a diameter >10 cm.
• Phase control - to achieve a diffraction limited beam width and pointing accuracy.

Gallium-Arsenide (GaAs) lasers have already demonstrated close to the required power with masses less than 0.02 grams. Phased arrays are common at microwave frequencies but are a more recent challenge at optical wavelengths. Despite the title of the paper the receiver is treated only briefly.

[1] Basics of this see *The Interstellar Downlink: Principles and Current Work* in Principium 31 Nov 2020 i4is.org/principium-31/
[2] *Interstellar flyby scientific data downlink design*, David Messerschmitt, Philip Lubin and Ian Morrison arxiv.org/abs/2306.13550