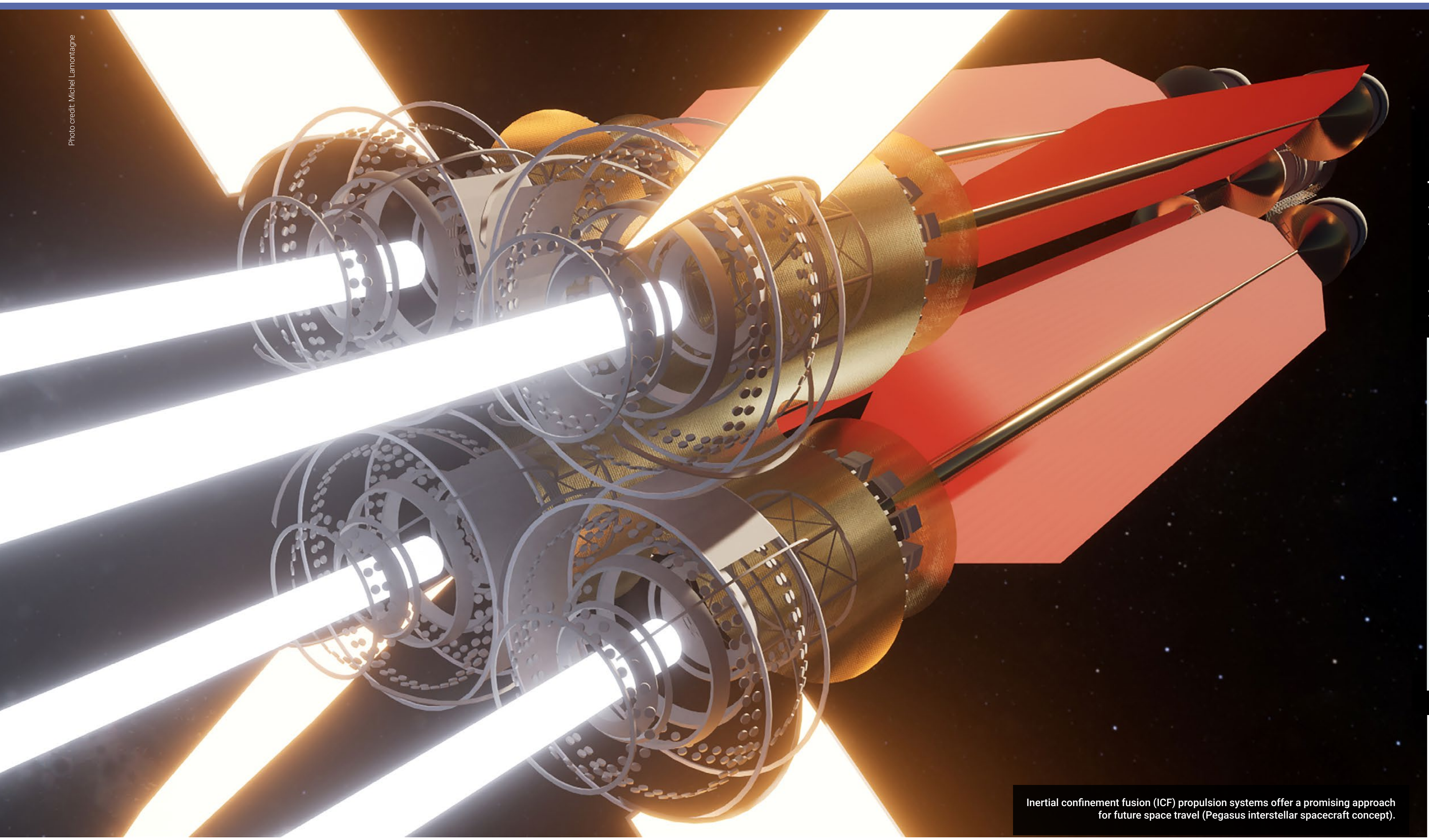

Inertial confinement fusion (ICF) propulsion systems offer a promising approach for future space travel (Pegasus interstellar spacecraft concept).

HeliosX

A numerical modelling tool for designing fusion-powered spacecraft

- Spacecraft propelled by inertial confinement fusion could play a key role in future missions to the outer Solar System and beyond.
- Created by Kelvin F Long, Interstellar Research Centre, UK, HeliosX is a comprehensive, reliable tool for designing these spacecraft based on their propulsion performance.
- Using the program, Long has considered how fusion-powered spacecraft in hypothetical future missions could be designed to best achieve their scientific goals.

Before future spacecraft can traverse the vast distances of interplanetary space, engineers and mission planners will need to design entirely new propulsion systems, which stretch far beyond the capabilities of today's state-of-the-art technology.

In theory, this could be achieved by harnessing the power of nuclear fusion: where vast amounts of energy are released as low-mass atomic nuclei combine into different larger nuclei, and the mass difference in the reaction releases energy. For this to happen, nuclei need enough energy to overcome their mutually repulsive forces. If enough energy is supplied by the fusion reaction itself, the overall process can become self-sustaining. In 2022, a groundbreaking achievement was made in physics, in that the US National Ignition Facility achieved thermonuclear ignition in a laboratory environment using lasers.

Inertial confinement fusion

For spacecraft propulsion, it will be particularly crucial to control the amount of energy released in fusion reactions, and initiate them in compact, tightly controlled settings. Among the most promising approaches to this challenge is an emerging technique named 'inertial confinement fusion' (ICF).

Here, fusion reactions are triggered by loading hydrogen isotopes into a small capsule, then firing intense laser pulses onto the capsule's outer layer. This creates shockwaves which travel inwards towards the centre of the capsule: rapidly heating and compressing the hydrogen nuclei inside. Under just the right conditions of temperature, number density, and confinement time (known as the Lawson criteria), this should be enough for the hydrogen nuclei to overcome their repulsion, initiating a self-sustained fusion reaction.

HeliosX is a consistent and reliable design tool for calculating both propulsion performance and spacecraft mission profiles.

A lot of guesswork

When designing interplanetary spacecraft, it will be crucial for engineers to consider how the energy output of the ICF process is connected to unique mission requirements. By considering the mass taken up by propulsion systems (including engines, waste heat radiators, and power supply), for example, researchers can make more realistic estimates of the space available for systems vital to the mission's success (like scientific instruments, imaging telescopes, and communications).

So far, however, most hypothetical studies have involved a lot of guesswork about how spacecraft designs should be tailored to the unique parameters of ICF propulsion systems. For Kelvin F Long at the Interstellar Research Centre, UK, these limitations mean that many existing concepts for interplanetary spacecraft may ultimately prove to be completely unfeasible.

Introducing: HeliosX

Through his research, Long addresses this oversight through a rigorous system for modelling ICF-propelled spacecraft. Named HeliosX, he believes that the program is a consistent and reliable design tool for calculating both propulsion performance and spacecraft mission profiles (a comprehensive guide of the

Kelvin F Long, pictured with a scaled spacecraft Cassini, which left Earth in 1997 to journey to Saturn.

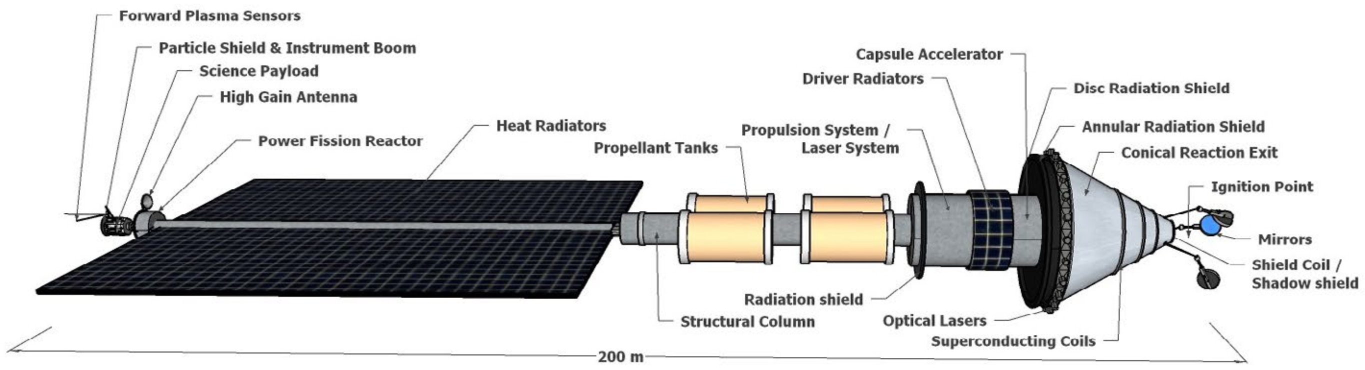

Figure 1. SunVoyager, an interstellar precursor probe (robotic flyby mission concept).

mission's key stages and activities) HeliosX comes into its own because it combines ICF physics with space propulsion in-line with the mission performance.'

To achieve this, the HeliosX predicts how fusion will be initiated in different capsule designs: accounting for factors including the properties of the laser ICF pulses, and the resulting pressure inside the capsule and ultimately the expected burn-up fraction of the fuel. With his modelling tool, Long aims to achieve three particular goals: firstly, to provide detailed assessments of the ICF assumptions used in engineers' propulsion calculations; and secondly, to give reliable assessments of the capsule's performance, and how this should influence spacecraft designs.

Finally, HeliosX aims to enable suitable analysis of ICF-propelled spacecraft concepts from previous studies – helping researchers to determine whether or not their proposals are really feasible. Altogether, Long hopes that his program will enable engineers and mission planners to confirm that their assumptions about ICF propulsion are both reliable and accurate. In parallel with developing the modelling tool he has also been deriving the foundational physics equations which govern laser driven ICF propulsion.

Long's research may prove to be the first steps towards scientific missions to star systems beyond our own.

SunVoyager

To explore HeliosX's potential in more detail, Long has conceived a hypothetical interstellar precursor mission named 'SunVoyager' (Figure 1). So far, missions sent to explore the outer Solar System (such as the Voyager 1 and 2 probes) have relied on gravitational assists from giant planets to reach their destinations. This approach is slow and painstaking, however – and ultimately means that despite the monumental achievements of these missions, they still take decades to gain any meaningful results.

Propelled by ICF, the SunVoyager probe, together with a 100-tonne scientific payload, could reach speeds of over 700 kilometres per second. Travelling this fast, the spacecraft could complete a journey up to 1,000 times longer than the distance between the Earth and the Sun (Astronomical Units to astronomers) in just over 3 years.

In his research, Long exhaustively considered the parameters of one specific design for an ICF propulsion system, which could be achievable by the end of the 21st century. Using HeliosX, he set out a feasible design for a spacecraft built specially for a specific set of scientific goals: including a flypast of a dwarf planet, and taking images of interstellar asteroids.

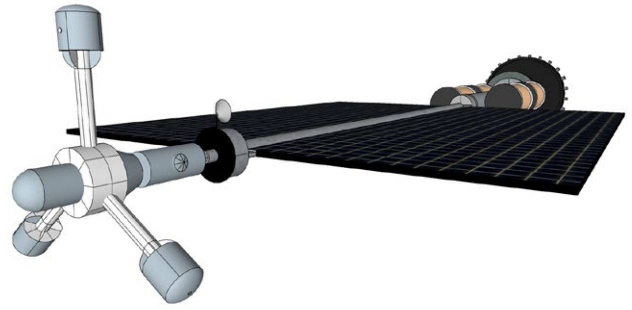

Figure 2. Discovery III, a crewed mission concept to Jupiter/Saturn.

Photo credit: Michel Lamontagne

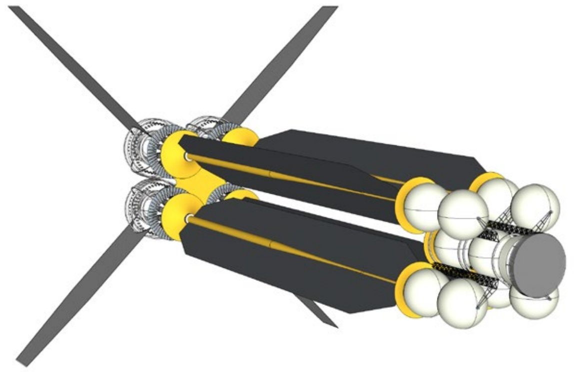

Figure 3. Pegasus 4.5 light years interstellar probe (robotic rendezvous mission).

Missions to Jupiter and Saturn

In the nearer term, Long is also considering how ICF-propelled spacecraft could be used to explore Jupiter and Saturn (Figure 2). These giant planets can be found at distances ranging from 5 to 10 Astronomical Units – so that if a probe were travelling at the same speed as Discovery-III (the Jupiter/Saturn mission designs), it could reach them in well under a year.

Again using HeliosX, Long has calculated unique sets of parameters for ICF-propelled spacecraft which would be best suited for these voyages. By following the modelling tool's recommendations, he hopes his approach could help to vastly improve astronomers' access to this part of the solar system: paving the way for a new flood of scientific research, and perhaps even the possibility of crewed missions to the outer planets and deep space in the not-too-distant future.

Beyond the Solar System?

The potential for HeliosX's models could stretch far beyond our own Solar System. By adapting his program further, Long has already started to consider how ICF-propelled spacecraft could be designed to endure voyages of lightyears across interstellar space. Indeed, ICF propulsion is well suited for interstellar missions due to the high velocity achievable from the fusion reactions. Ultimately, his research may prove to be the first steps towards scientific missions to star systems beyond our own.

Personal response

What are the advantages of ICF over other types of fusion when used in spacecraft propulsion?

This is unclear since there have not been sufficient comparison studies to come to any strong conclusions. Indeed, this is an issue for space propulsion in general in that there is a lack of studies where one technology is compared against another for the same payload mass and mission. That said, my own calculations suggest that ICF propulsion may be competitive to magnetic confinement fusion propulsion, in terms of requiring less fusion fuel, perhaps half, for any given mission. But this is preliminary and needs more research. That said, if ICF propulsion could be made to work then there is the potential to achieve very high gain through methods such as fast ignition and shock assisted ignition, which go beyond just the hot spot ignition method by separating the compression and ignition phase. In principle a gain of order 1,000 may be possible in terms of the ratio of fusion energy produced to input energy from the lasers.

How do you hope to expand the use of HeliosX among mission planners?

The application of ICF in space propulsion is about a future capability rather than current, in terms of delivering high energy capability missions and with high payload masses. So it's more related to the vision of space exploration and what may be possible if we continue to work towards it. It's clear that ICF propulsion will open up the solar system to human spaceflight as well as robotic so we can eventually expand our population outwards. Yet planning space missions takes years, and human colony missions may be decades in the planning. Knowing we have a reliable propulsion system to ferry cargo back and forth, say between Earth and Mars or the outer planets, at high speed will greatly simplify the space architecture requirements.

How long do you think it will be before interstellar spacecraft propelled by ICF could become a reality?

It's entirely possible that it may be realisable in the second half of this century if not sooner. But this really depends on the continued investment in this technology in order to better understand the physics of ICF, and then to implement it first as a part of a commercial power grid on Earth. Currently this is only being pursued by government agencies and it needs commercial interest to move it forward. But we cannot underestimate the difficulty of laser driven ICF and it has taken decades to get to the point of ignition with the US National Ignition Facility, and yet we have achieved it. Next comes a reactor which delivers electricity to a national grid, but after that we can consider space applications of this technology. While interplanetary exploration and colonisation should be our immediate focus, I have personally been working towards the realisation of an interstellar flight capability by the year 2100 and this is the mission of the interstellar research centre. I may never live to see the first launch, but my children will and then the stars become a part of our plausible future to include any habitable exoplanets we may choose to settle. As Carl Sagan said, 'imagination will often carry us to worlds that never were. But without it we go nowhere.'

Voyager 1 is the first spacecraft to travel beyond the solar system and reach interstellar space.

Details

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Bio

Kelvin F Long is an Aerospace Engineer and Chartered Physicist and a Fellow of the British Interplanetary Society. He is the Director of the Interstellar Research Centre, a division of Stellar Engines Ltd and has published numerous peer reviewed papers and books on deep space exploration and advanced space propulsion.

Funding

• Limitless Space Institute
• Stellar Engines Ltd

Further reading

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