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EDITORIAL

Dear Readers,

A warm welcome to you all as the summer approaches and you look forward to your issues of *JBIS* dropping through the letter box. I have mentioned this in the past but I want to do so again, to remind you that *JBIS* does receive letters from readers pertaining to past published papers. I feel this is important as it continues the peer review process and ensures effective scrutiny of people's research, whilst also opening up promising new lines of thought. So, please feel free to drop us a technical letter. Whilst on the subject of reminders, please do also have a look at the *JBIS* web site (www.jbis.org.uk). It has come a long way since it first launched and you can now download papers for a small fee. Currently, we are also working on an online editorial system. We are also looking at the possibility of receiving LaTeX submissions. None of this will happen overnight, but we are gradually making progress to improve the oldest astronautical journal in the world.

Now for this issue which contains a mix of papers, as an interlude to the 100YSS papers we have been publishing recently. First is a paper by Duncan Forgan on the possibility of detecting class A stellar engines using exoplanet transit curves. Next we have a paper by Graham Paterson and colleagues which explores the potential for asteroid control and resource utilization. The authors argue that asteroids are materials rich small solar system bodies which are candidates for rendezvous and mining. The authors examine the scenario of asteroid capturing in detail. Matthew Cross and associates write about the application of commercially available off the shelf components for Martian surface exploration.

Neil Gilhooney has written an intriguing paper discussing in-orbit construction with helical seam pipe mill. This approach is meant to be a novel way to address the construction of large structures in space and in particular a torus habitat. In another paper from Duncan Forgan and colleagues, he explores the effect of probe dynamics on galactic exploration timescales. The authors present multiple realisations of single probes exploring a small patch of the Milky Way. Chris MacLeod examines innovative approaches to fuel-air mixing and combustion in airbreathing hypersonic engines. Finally, we have a thought provoking submission from Joseph Breedon, exploring the possibility of interstellar travel with Binary Asteroids. By selecting the correct chaotic trajectory the author calculates the velocity that may be achieved if this mission can be made plausible.

We have several other special issues in the planning, including a paper dedicated to the research of Dr Les Shepherd, papers from the 2013 Tennessee Valley Interstellar Workshop. We also have papers pending from a recent Chinese/Soviet symposium and a symposium discussing the philosophy of the starship. Recently, we in the *JBIS* team put together a feedback form so we can see how we are doing. You can find this form in this issue (middle pages) or online at www.surveymonkey.com/s/Q5XTT7M. Please complete it if you get time and let us know how we are doing. Please enjoy the latest issue of your journal.

Kelvin F. Long, Editor *JBIS*

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ON THE POSSIBILITY OF DETECTING CLASS A STELLAR ENGINES USING EXOPLANET TRANSIT CURVES

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The Class A stellar engine (also known as a Shkadov thruster) is a spherical arc mirror, designed to use the impulse from a star's radiation pressure to generate a thrust force, perturbing the star's motion. If this mirror obstructs part of the stellar disc during the transit of an exoplanet, then this may be detected by studying the shape of the transit light curve, presenting another potential means by which the action of extraterrestrial intelligence (ETI) can be discerned. We model the light curves produced by exoplanets transiting a star which possesses a Shkadov thruster, and show how the parameters of the planet and the properties of the thruster can be disentangled provided that radial velocity follow-up measurements are possible, and that other obscuring phenomena typical to exoplanet transit curves (such as the presence of starspots or intrinsic stellar noise) do not dominate. These difficulties aside, we estimate the *a priori* probability of detecting a Shkadov thruster during an exoplanet transit, which even given optimistic assumptions remains stubbornly low. Despite this, many exoplanet transit surveys designed for radial velocity follow-up are on the horizon, so we argue that this remains a useful serendipitous SETI technique. At worst, this technique will place an upper limit on the number of Class A stellar engines in the Solar neighbourhood; at best, this could help identify unusual transiting exoplanet systems as candidates for further investigation with other SETI methods.

Keywords: SETI, exoplanet, transits, megastructures

1. INTRODUCTION

For much of its sixty-year history, the Search for Extraterrestrial Intelligence (SETI) has relied heavily upon the detection of artificial radio signals emitted in the frequency range often referred to as the "Water Hole" or terrestrial microwave window [1], a band of frequencies where the Earth's atmosphere is transparent and interference from Galactic and cosmic background radiation is minimal. This band also happens to contain the 21 cm (or 1.42 GHz) spectral line emitted by neutral hydrogen atoms when the alignment of proton-electron spins "flip" from parallel to anti-parallel. As hydrogen is the most abundant element in the Universe, it is often argued that extraterrestrial intelligences (ETIs) with radio technology will be scanning frequencies near to the 21 cm line, and may even choose to emit signals at frequencies related to it (e.g. 21π cm or $21/\pi$ cm). This would suggest that Earth-like intelligent species could be detected by searching frequencies in the Water Hole for narrowband transmissions or broadband pulses [2].

This motivation has inspired many radio SETI surveys carried out to date, placing constraints on the number of civilisations emitting in the surveyed bands in the Solar neighbourhood. Most recently, a SETI survey of 86 stars in the Kepler field known to host transiting exoplanets estimates that less than 1% of the targets host civilisations that emit in the 1-2 GHz band, at strengths comparable to those producible by humankind [3]. Recent SETI searches using Very Long Baseline Interferometry (VLBI [4]) show that the next generation of telescope arrays such as the Square Kilometre Array (SKA) will be able to survey the local neighbourhood to even higher fidelity, while efficiently discriminating potential signals from human radio frequency interference (see also [5]).

Equally, SETI scientists have recognised that searching in a limited region of the electromagnetic spectrum may be counter-productive to the overall goal of detection. Even at the beginning of radio SETI, some argued for searches in the optical [6], noting that technology akin to the then recently-invented laser would be a highly efficient means of interstellar communication, both in its potential to traverse much larger distances at the same energy cost, and the ability to encode more information per unit time due to their higher carrier frequency. While extinction by interstellar dust could destroy or mask a signal, ETIs can strike a balance by reducing the carrier frequency and emitting in the near infrared [7]. Recent searches for laser pulses in the spectra of local main sequence stars (e.g. [8, 9]) are also yet to bear fruitful detections.

While both radio and optical SETI have their orthogonal advantages and disadvantages, they share a weakness common to all transient astrophysics - repeatability of detection. The few cases where SETI searches uncovered a potential signal (e.g. the "Wow!" signal of 1977 [10, 11]), the candidate signal was not rediscovered. In the most memorable case where an apparently artificial signal was detected repeatedly, it was soon shown to be a previously undiscovered natural phenomenon - the pulsar [12, 13]. As pulsing transmitters are generally more energy efficient, there is a strong element of serendipity in detecting intentional transmissions, and as such surveys must be carefully designed [14, 15]. While it is possible that ETIs may deliberately repeat their signals to make their acquisition easier, they are under no compulsion to do so.

If the goal is to detect unintentional transmissions, then this obstacle can be avoided, as these transmissions are expected to

ASTEROID CONTROL AND RESOURCE UTILIZATION

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Asteroids are materials rich small solar system bodies which are prime candidates for rendezvous and mining. Up until now much attention has been focused on methods of destroying or deflecting potentially hazardous asteroids from colliding with the Earth. Recently however the concept of asteroid capture has been suggested whereby the asteroid is returned to an orbit close to the Earth before mining can begin. This paper aims to provide a comprehensive introduction to the field for new researchers and to put forward a number of novel strategies for asteroid control.

Keywords: Asteroid control, asteroid resources, smart asteroid membranes, surface operations, asteroid mining

1. INTRODUCTION

There are severe problems facing humankind which will have to be tackled this century. Prominent among these are the scarcity of non-renewable resources [1] and global climate change [2]. It is possible that space utilization may provide significant partial answers to these problems. As one example solar power satellites could collect endless supplies of solar energy with no associated pollution cost before beaming the energy back to Earth [3]. To make this a reality space industrialization will be needed on a scale an order of magnitude higher than today's. This will demand a steep increase in construction resources having to be brought up the deep gravity well of the Earth, which at today's launch costs will be prohibitively expensive. A potential solution is to utilize the enormous resources that exist in the thousands of asteroids which orbit throughout the solar system. It is possible to rendezvous with a suitable asteroid and mine its resources, sending them back to Earth for exploitation [1]. Recently it has also been suggested that the asteroid orbit itself be altered, much like asteroid deflection scenarios for Earth defence, effectively shepherding it back to a position closer to the Earth [4]. Once in such an accessible orbit the asteroid can be more easily mined for its resources [5, 6]. The present paper will review the options available for making this possibility a reality.

2. ASTEROID LOCATIONS, COMPOSITION AND SHAPE

Asteroids are small rocky bodies, too small to be classed as planets or planetoids, orbiting the Sun. They are thought to be remnants of the early formation of the solar system. The three largest asteroids currently identified are Ceres (diameter 960 km), Pallas (570 km), and Vesta (530 km). The asteroids do not all orbit in the same location of the solar system, nor do they all have identical masses and compositions. The Main Asteroid Belt is between the orbits of Jupiter and Mars, between 2 AU and 3.5 AU from the Sun. More than 100,000 are known, with less than 5000 being larger than 10 km. Closer to the Earth there is a class of asteroids which holds the most promise of exploitation in the medium term, as well as potentially the largest threat to life on Earth itself – the Near Earth Asteroids [1]. These are defined to be asteroids with a perihelion q less than 1.3 AU. The proximity of these objects to Earth makes them obvious targets for rendezvous and exploitation.

The small size means that asteroid gravity fields are also exceedingly weak. Consequently, using gravity to remain attached to an asteroid is not feasible, as even slight reaction forces may cause detachment and escape. On the other hand the low gravity means that materials will be much lighter and also the intriguing prospect exists of using other forces to control surface dynamics, such as using electromagnetic forces to control orbits and influence the motion of dust clouds. Many space engineers have noted that the low gravity will almost certainly mean that a large asteroid bag will be needed to collect particles which have been knocked loose during the mining process [7].

There are also various classifications of asteroids according to composition. One of the most useful and prevalent in the literature is a subset of Tholen's taxonomy. One simple but widely used version of this characterises asteroids as C type, S type or M type. The C type carbonaceous asteroids are water rich and dark, making up the majority of asteroids. By contrast S type Silicon asteroids are based on iron, nickel and silicates, and are less common. Rarer still are M type metallic asteroids, which have high radar reflectivity based on a metallic nature.

According to current theories, heavy metals would sink to the core of a planet when it formed, a phenomenon known as differentiation, which is one reason geologists believe that large concentrations of iron and nickel exist close to the Earth's core. However on most asteroids it is likely that differentiation did not occur due to the low gravity, meaning that metal ores are likely to be more accessible in asteroids than on Earth. Studies of meteorites and spectral/photometric studies of asteroids have indicated that they are made of diverse but very valuable materials [1].

The surfaces of asteroids are extremely diverse, consisting

APPLICATION OF COTS COMPONENTS FOR MARTIAN SURFACE EXPLORATION

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This paper details the motivation behind COTS component testing, the results, and their application for a low-cost, sample and fetch scout rover to accompany large scientific exploration rovers. Carleton University's Space Exploration Engineering Group proposed using Maxon motors and controllers for the wheel and mechanism assemblies on a micro-rover development platform called *Kapvik*. These components were subjected to extensive environment tests to determine their operability at sub-rated temperatures. The results showed the motors and controllers will perform at temperatures experienced at equatorial Mars.

Keywords: Mars rovers, COTS components

1. INTRODUCTION

Kapvik is a 30 kg micro-rover analogue designed as a tool for further developing Canada's planetary exploration capabilities. *Kapvik* was funded by the Exploration Surface Mobility (ESM) project of the Canadian Space Agency (CSA) and administered by MPB Communications Inc. This prototype is designed with a view to flight qualification and to help asess potential exploration missions to which Canada may contribute. It was designed for temperatures associated with summer in the high arctic. Its trial operations will be in an unknown environment - likely in the Canadian Arctic - analogous to the Martian equatorial surface.

The Space Exploration Engineering Group (SEEG) at Carleton University was responsible for the design and development of the chassis, motor control, and additional instrumentation mechanisms for *Kapvik*. *Kapvik's* chassis comprises of six wheels in a rocker-boogie system each individually driven by a Maxon motor. The rover must be able to operate in temperatures of -20 °C to 40°C for evaluation purposes. In addition, the entire rover was designed in a way that provides a "path to flight", i.e. it uses components that have a suitable space qualified counterpart, or demonstrate suitability for space application. The chosen motor controllers have a rated operating temperature between -10°C and 45°C. This is a narrow window when compared to the overall required temperature range for the rover. *Kapvik* has a limited power budget of 30 W due to the constraints of being a micro-rover. This is the motivation behind a passive thermal control system. The motor and controller pair's performance was characterized in an effort to determine how tolerant the motor control would be at sub-rated temperatures.

2. THE *KAPVIK* ROVER

Kapvik (Fig. 1) has an instrumented six-wheeled rocker-bogie system with differential drive similar to NASA's fleet of exploration rovers: *Sojourner* [1], *Spirit* [2] and *Opportunity* [3], and *Curiosity* [4]. The rocker-bogie allows all six wheels to maintain ground contact to enhance mobility while allowing the rover to climb over rocks [5, 6]. Each of the six rigid wheels have 24 grousers. The grousers extend 5 mm from the base of the 145 mm diameter wheel giving the wheel an average diameter of 150 mm. *Kapvik* contains a suite of instruments for localization including a laser range finder, stereo vision camera, inertial measurement unit (IMU) and sun sensor. A robotic arm comes equipped with a scoop for collecting soil samples. Solar panels are mounted on top of the cab to provide unregulated power at 24 V. Inside the cab, the avionics system includes the motor controllers, on-board computing and power electronics. When fully operational, *Kapvik* is capable of semi-autonomous navigation using localization and path planning.

Nomenclature

CAN	Controller Area Network
COTS	Commercially Available Off-The-Shelf
CSA	Canadian Space Agency
ESM	Exploration Surface Mobility
IMU	Inertial Measurement Unit
MER	Mars Exploration Rover
MFEX	Pathfinder Microrover Flight Experiment
SEEG	Space Exploration Engineering Group

2.1 Instrumented Mobility System

An instrumented chassis and individually throttled motors were early design objectives for *Kapvik*'s mobility system. The instrumented chassis allows for the mobility system to adapt to changing terrain conditions. Each motor can be individually throttled to allow for traction control on Martian rovers [7, 8].

Each of the six wheels is driven by a Maxon Motor RE25 motor with planetary gearing and harmonic drive. The wheel motor assemblies include planetary gearing and a harmonic drive for a gear ratio of 1400:1, and are contained at the wheel base inside an enclosure to protect against weathering and dust. Wheel odometry is provided by incremental encoders attached to each motor. Single axis load cells are mounted on top of each wheel to measure the vertical force. Potentiometers provide the

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IN-ORBIT CONSTRUCTION WITH A HELICAL SEAM PIPE MILL

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The challenges of building large structures in space, and in particular a torus habitat, require novel processes. One potential method is to manufacture helical seam (also called spiral) pipe in orbit using a pipe mill. These machines turn rolls of steel or alloy into fully formed, welded and inspected pipe, pressure vessels and silos of various diameters. Pipe mills are highly automated and efficient in a factory environment and are increasingly being used for in-situ repair. By constructing in-orbit (on-orbit assembly) the launch vehicle can supply full payloads of compact, robust rolls of material; and the installation design is less restricted by fairing constraints and modular limitations. The use of a pipe mill is discussed as a possible construction method, for comparison an example design envelope is shown and further pipe mill products are considered.

Keywords: In-orbit construction, pipe mill, habitat, torus, rotating wheel space station

1. INTRODUCTION

Significant decisions in space exploration to date have been taken over direct versus indirect modes [1], with the former proposing a single launch vehicle powerful enough for the task and the latter advocating some level of assembly in orbit from multiple launches.

The vast majority of installations in space have been lifted in single launches. With the space stations of the Salyut programme, Mir, and culminating in the International Space Station (ISS), far larger installations have been assembled in orbit using modules from multiple launches. However it is still the case that each individual module is limited to the capabilities of the launch vehicle, whilst adding the complexity of in-orbit assembly.

These long missions have allowed us to study the potentially debilitating effects on man of prolonged microgravity. High equipment failure rates have also been experienced from lack of heat convection [2]. In the decades preceding manned missions, many designs intended to mitigate these effects with a rotating wheel habitat to create artificial gravity by reaction to centripetal acceleration [3]. For an interplanetary mission, such as a voyage to Mars, it would be advantageous to provide artificial gravity for the health and wellbeing of the crew.

Without doubt a torus is more difficult to assemble than a monolithic structure, asking the question: how to sub-divide, strengthen and squeeze such an installation through the launch vehicle conduit from earth to orbit? Wernher von Braun sought to address this with several collapsible modules [4]. By the late 1950's his attitude to space station design (e.g. Fig. 1) was "Let's envision a space station and what [it] is made up of, what it can perform and not worry too much about how we would get it up there" [5]. Yet the construction method is key to the feasibility of such a space station, and this challenge requires the development of tools, subject to risk-benefit analysis, of absolute reliability and severe mass limitations. In this discourse an in-orbit construction method is considered to address both monolithic (tubular) and rotating wheel (toroidal) structures.

2. HELICAL SEAM PIPE MILLS

A very successful automatic manufacturing technique in terrestrial applications is the helical seam pipe mill, also called a spiral pipe mill. Two-thirds of steel tube production is by welded tube mills [6]. A tool of this efficiency, with high production standards and limited human intervention, is a strong candidate for in-orbit construction. Such a mill could manufacture tubular and toroidal structures from alloy and composites, with dimensions largely independent of the launch vehicle fairing size.

Helical seam pipe mills use rolled steel or alloy that is uncoiled, aligned and rolled by one internal, and a cage of external rollers to create a tube, welded internally and externally and then inspected (ultrasound and X-ray) as part of a continuous process. When one roll is finished another is welded on without interruption and sections may be automatically cut to length. The pipe may also be corrugated.

The pipe dimensions are produced according to:

$$\sin\alpha = \frac{W}{\pi d}$$

Where α is the skelp (strip) feed angle, *W* is the skelp width and *d* the tube diameter (minor axis for a torus) as per Fig. 2 [6].

Silos of large diameters, up to 25 m, can currently be manufactured in situ with lightweight equipment. There are also growing developments of construction and repair in demanding environments by helically wrapping pipelines; and internally installing liners underground, such as [7], a technique that might have applications in Martian lava tubes.

3. IN-ORBIT CONSTRUCTION

3.1 Tubular Products

The simplest form that the helical seam pipe mill can

THE EFFECT OF PROBE DYNAMICS ON GALACTIC EXPLORATION TIMESCALES

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The travel time required for one civilisation to explore the Milky Way using probes is a crucial component of Fermi's Paradox. Previous attempts to estimate this travel time have assumed that the probe's motion is simple, moving at a constant maximum velocity, with powered flight producing the necessary change in velocity required at each star to complete its chosen trajectory. This approach ignores lessons learned from interplanetary exploration, where orbital slingshot maneouvres can provide significant velocity boosts at little to no fuel cost. It is plausible that any attempt to explore the Galaxy would utilise such economising techniques, despite there being an upper limit to these velocity boosts, related to the escape velocity of the object being used to provide the slingshot. In order to investigate the effects of these techniques, we present multiple realisations of single probes exploring a small patch of the Milky Way. We investigate 3 separate scenarios, studying the slingshot effect on trajectories defined by simple heuristics. These scenarios are: i) standard powered flight to the nearest unvisited star without using slingshot techniques; ii) flight to the nearest unvisited star using slingshot techniques, and iii) flight to the next unvisited star which provides the maximal velocity boost under a slingshot trajectory. We find that adding slingshot velocity boosts can decrease the travel time by up to two orders of magnitude over simple powered flight. In the third case, selecting a route which maximises velocity boosts also reduces the travel time relative to powered flight, but by a much reduced factor. From these simulations, we suggest that adding realistic probe trajectories tends to strengthen Fermi's Paradox.

Keywords: Fermi Paradox, SETI, interstellar exploration, probe dynamics

1. INTRODUCTION

Fermi's Paradox remains an important cornerstone of modern thinking on extraterrestrial intelligence (ETI). It taxes most, if not all attempts to formulate an optimistic perspective on the frequency of alien civilisations in the Galaxy both in space and time.

Detailed reviews of the Paradox can be found in [1, 2 and 3]. The Paradox rests on the current absence of ETI in the Solar System (what [4] refers to as "Fact A"). This absence runs counter to estimated timescales for intelligent species to colonise of the Galaxy - what [3] (and references within) refers to as the Fermi-Hart timescale (see e.g. [4, 5]):

$$t_{FH} = 10^6 - 10^8 \text{ yr} \tag{1}$$

This is compounded by the fact that the age of the Earth is at least an order of magnitude higher, and the median age of terrestrial exoplanets is estimated to be a further 1 Gyr older than the Earth [6]. It appears the inexorable conclusion one must draw is that ETIs do not exist, otherwise we would have detected their presence in the Solar System.

It is common for attempts to resolve the Paradox to speculate on the motivation or sociological make-up of ETIs - for example, one solution suggests that the Earth has attained a protected status and must not be disturbed, often known as the Zoo Hypothesis (e.g. [7]). While flaws can be exposed in these types of hypothesis (see e.g. [8]), there are many solutions that are simply unfalsifiable, and while they cannot be ruled out, they cannot be currently considered as scientifically meritorious. Until conclusive data is compiled on something as esoteric as extraterrestrial sociology, it is more worthwhile to focus on potential physical constraints for extraterrestrial contact.

Weaker formulations of the Paradox merely rest on ETIs practising interstellar communication rather than interstellar colonisation (e.g. [9]) - stronger formulations use self-replicating Von Neumann probes to explore the galaxy at an exponential rate. It is this process of self-replication (or colonies carrying out subsequent autonomous colonisation) that allows t_{FH} to be small enough for the Paradox to be robust. While there have been many arguments for and against the use of self-replicating probes (e.g. [5, 10, 11, 12]), we wish to focus instead on a more fundamental aspect of probe exploration that has not been addressed fully.

The Paradox leans heavily on the dynamics of interstellar flight, and the motivations of the extraterrestrial intelligences (or ETIs) that drive the exploration. Sagan [13] expounds a framework for a cadre of civilisations visiting star systems using relativistic interstellar flight. Under these assumptions, the visiting rate for main sequence stars could be as high as once per ten thousand years (although it makes relatively optimistic assumptions about the number of civilisations forming the cadre). The associated problems of population growth and carrying capacity are also important drivers for continual exploration, as was explored by Newman *et al*. [14] using nonlinear diffusion equations. The stipulation that ETIs practise zero population growth can alter t_{FH} by several orders of magnitude.

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INNOVATIVE APPROACHES TO FUEL-AIR MIXING AND COMBUSTION IN AIRBREATHING HYPERSONIC ENGINES

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This paper describes some innovative methods for achieving enhanced fuel-air mixing and combustion in Scramjet-like spaceplane engines. A multimodal approach to the problem is discussed; this involves using several concurrent methods of forced mixing. The paper concentrates on Electromagnetic Activation (EMA) and Electrostatic Attraction as suitable techniques for this purpose - although several other potential methods are also discussed. Previously published empirical data is used to draw conclusions about the likely effectiveness of the system and possible engine topologies are outlined.

Keywords: Scramjet, mixing, EMA, controlled compression mixing, flow driven fuel system

1. INTRODUCTION

It is now around sixty years since the first serious attempts to produce a Scramjet engine. The progress made during the intervening time has been intermittent. Although new techniques like Computational Fluid Dynamics (CFD) mean that more is known about some of the detailed questions of aerodynamics, the current designs are little different to those suggested two generations ago. In recent years, programmes like HyShot, HyCause and the X-43A have again added to our knowledge but, despite optimistic claims from vested interests, extended flight under Scramjet power remains almost just as elusive as in the past.

There are several reasons why this is the case, some are due to the difficulty of designing the inlet and exhaust topologies for the extended flight envelope and similar mechanical-engineering concerns. However, although such issues are demanding, they have proved soluble in other aerospace applications and the most challenging aspect of Scramjet technology lies in fuel mixing and combustion.

In the high-drag and high-temperature regime where Scramjets operate, it is difficult to add further kinetic energy to an already excited flow-stream. This means that the engine is operating in a finely balanced region in terms of its thrust and drag and good conversion of the fuel's chemical energy into usable flow-energy is essential. However, at hypersonic speeds, air passes through the engine in around a millisecond, meaning that the fuel must mix with the air, burn and release its energy in a few tens of microseconds [1]. To achieve maximum extraction of energy, the fuel must be mixed stoichiometrically with air, at the molecular level, during this time. These operations should be performed in a way which does not disrupt the flow enough to cause an increase in drag. The resulting mixture has also to be burnt without the aid of the flameholding structures used at lower speeds - as projections into the duct would cause form-drag. Such considerations make it obvious why the technology is on the edge of practicality [2].

This paper builds on previous work [3, 4], published in *JBIS*, to suggest some engine topologies which might be used as a basis for experimentation or simulation into overcoming the mixing problem. For reasons discussed in the paragraphs below, these are not final design solutions, but are meant as a basis for discussion on Scramjet topologies and related issues.

In the work presented here, it is suggested that the answer to the mixing problem might lie in a multimodal system – that is, a system in which several different and complementary techniques are employed in order to achieve the mixing goal. In particular, the paper outlines how previous work on Electro-Magnetic Activation (EMA) and Electrostatic Attraction could be used to enhance and control the mixing and ignition process. Other potential methods that might be used in a multimodal system, including a new "flow-driven" concept, are also discussed.

The fuel-air mixing system in a scramjet engine is difficult to simulate accurately using techniques like CFD. Some of the physical phenomena present are hard to study - because of the speeds and temperatures involved, and are therefore rather poorly understood. Others, because they represent elements of both non-continuum (free molecular) and continuum (Navier-Stokes) flow or complex systems of interacting flows, are not readily amenable to standard modelling equations or simulation techniques. This is particularly true of the methods outlined in this paper, because they themselves are innovative in their approach and use unusual topologies and techniques to address the mixing problem.

Although modelling and simulation are difficult for the reasons outlined above, quite a number of authors have published their observations on applicable systems and these can be used to build useful conclusions. Therefore, the approach taken here is to base some of the discussion on previously published empirical and experimental results. It is for this reason, as already mentioned, that the suggestions presented are not final design solutions, but are meant to stimulate ideas for discussion. However, it is hoped that they can form the basis of future experiments or simulations to establish their credibility.

The paper deals with the dynamics of the fuel-air mixing

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GRAVITATIONAL ASSIST VIA NEAR-SUN CHAOTIC TRAJECTORIES OF BINARY OBJECTS

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Using a process similar to the creation of hypervelocity stars, this paper proposes the use of binary objects (binary asteroid, spaceship + asteroid, etc.) for interstellar travel. Previous research has shown that binary star - single star interactions can cause high-velocity ejection of one member of the inbound binary. By selecting the correct chaotic trajectory, the same may be attainable for ejecting the chosen member of a binary object targeted as near to the sun as is survivable by electronics and/or crew. This paper will outline the basic process and compute the velocity that can be achieved under various orbital parameters via a conservation of energy calculation. It is shown via analogy to previously published calculations involving binary star - black hole interactions that trajectories may exist to achieve useful energy gain.

Keywords: Interstellar Travel, Chaos Theory, Binary Asteroids, Hypervelocity Stars

1. INTRODUCTION

Gravitational assist is well known in spaceflight [1]. Simple gravitational assist from close approaches to moving bodies, typically planets, is used extensively for current unmanned space probes. These trajectories usually include an Oberth manoeuvre [2] to increase the acceleration during gravitational assist by firing engines at closest approach. This paper discusses the possibility of another kind of gravitational assist achieved when two objects in mutual orbit make a close approach to a massive body.

The interaction between binary stars and single objects has been shown to allow for the ejection of one of the incoming objects at high velocity [3, 4]. The high stellar density of globular star clusters causes binary star - single star interactions to occur at a comparatively high rate. This interaction has been shown to cause the diameter of the core of globular star clusters to oscillate [5], sometimes chaotically [6], because of the ejection of stars as a heating source for the cluster.

Similarly, hypervelocity stars have been detected in the Milky Way galaxy [7]. Sixteen such stars are known to date. These are stars traveling at galactic escape velocities. The best explanation for these extreme velocities appears to be the interaction of a stellar binary with the Milky Way's central black hole [8].

This process is also suggested for how Triton was captured by Neptune [9]. An inbound binary object was tidally disrupted, capturing one element of the binary and ejecting the other. The same process has been proposed as a general mechanism for how planets can capture moons [10].

The question addressed here is whether binary objects can be used in a similar way for astronautics. By appropriately targeting a binary object toward a massive body, such as the Sun, the goal is to eject one of those objects with a significant gain in velocity while leaving the other object in a close captured orbit. This paper computes the energy that can be transferred to one of the objects in the binary via a close approach to the Sun, and the resulting velocity obtained. This process leverages the intrinsically chaotic nature of a three-body system, so desirable trajectories should be rare, if present. Leveraging the study by Hills [8] it is shown that trajectories resulting in ejection may, in fact, exist. However, this paper cannot address yet whether such trajectories are survivable.

2. THE BASIC TRAJECTORY

The key to the binary object gravitational assist manoeuvre is having a disposable object of significant mass. For purposes of discussion, assume that an asteroid in near-Earth-orbit (NEA) is employed. As of September 2011, 8,121 NEAs are known [11] with 828 of those having diameters of 1 km or greater. A recent discovery has shown that such objects exist in "Trojan" orbits [12] near the Earth, inhabiting the Earth-Sun Lagrangian points L4 and L5, just as happens with the gas giant planets. The first such object was found at roughly +60° relative to the Earth sharing roughly the same orbit [13].

Using such an NEO as in Fig. 1, imagine that some part of the object is hollowed out and used as the interstellar space ship as proposed by D. Cole in the 1960s while the remainder is to be discarded. The NEO's orbit would have to be modified to achieve a close encounter with the sun.

En route to the Sun, the object would be split into a binary, presumably by destroying a "waist" that was created earlier in the object. Upon close approach to the Sun, assuming just the right trajectory, the expendable part would be captured into solar orbit and the "spaceship" would be ejected at high velocity.

The following results would also follow from assuming that a man-made spaceship enters orbit about an appropriately sized object, such as an asteroid or sun-grazing comet, and travels as a binary to near-Sun interaction.

BIS Lectures and Meetings

Sampling the Mysteries of Space by Sample Return of Comets and Asteroids

Natalie Starkey

31 July 2013, 7 - 8.30 pm

Comets and asteroids act as time travel capsules, having captured and preserved the earliest Solar System material that formed 4.6 billion years ago. Here on Earth we are fortunate to receive free samples of comets and asteroids that arrive naturally as meteorites and dust particles at the Earth's surface. However, sampling the rocky, icy surfaces of comets and asteroids in space allows for the collected material to be understood in context, and provides pristine samples for analysis. In this talk I will discuss the many sample return space missions past, present and future that are pushing technological boundaries to return comet and asteroid samples to Earth. I will discuss the importance these missions have had on the science of the Solar System, and what new scientific developments and discoveries have been made.

68th Annual General Meeting

7 September 2013, 1 pm

The 68th Annual General Meeting of the Society will be held at the BIS HQ, 27/29 South Lambeth Road, London SW8 1SZ on Saturday 7 September 2012 at 1 pm followed by refreshments.

Admission to the AGM is open to Fellows only but all Members are welcome to join the discussion after the formalities of the AGM around 1.30 pm. Please advise in advance if you wish to attend.

JUpiter ICy moons Explorer (JUICE): The First Large ESA Cosmic Vision Mission

Athena Coustenis

12 September 2013, 7 - 8.30 pm

The Jupiter Icy Moons Explorer (JUICE) mission selected by ESA as the first large mission within the Cosmic Vision 2015-2025 plan, is being developed to address questions regarding the Jupiter system and its satellites, with a focus on the largest moon, Ganymede. The over-arching theme for JUICE is the emergence of habitable worlds around gas giants taking into account the requirements involving the presence of organic compounds, trace elements, water, energy sources and a relative stability of the environment over time.

For Europa, two targeted flybys are planned, with a focus on the chemistry essential to life, including organic molecules, and on understanding the formation of surface features and the composition of the non water-ice material, leading to the identification and characterisation of candidate sites for future in situ exploration.

The JUICE mission is planned to be launched in mid-2022, with a backup opportunity in August 2023. It will arrive at Jupiter in January 2030 after 7.6-years using an Earth-Venus-Earth-Earth gravity assist sequence and is foreseen to last for 3 and a half years.

From Imagination to Reality 2

14 September 2013, 9 am - 6 pm

An all-day Space Event.

Built on the BIS motto, From Imagination To Reality, looks at the ideas that first took hold in 'the imagination' – books, paintings, film and television, and sees how they have become 'the reality' – maybe not at the current time, but could very well happen in the future – even if it is the far future?

Based on the success of the first such event last year – From Imagination To Reality 2, examines the commercialisation of space, borrowing it's alternative title from a quote by that most famous of visionaries, and founder member of the BIS, Sir Arthur C. Clarke.

From Imagination To Reality 2 will include features on what certainly has come about, communications satellites; what is soon to come about, the first steps with space tourism; what should come about, the totally re-usable shuttle; what could potentially come about – mining the vast resources of the asteroids; what will eventually come about, 'Life on Mars'; and, perhaps the most grandiose of all, what if the fledgling ideas of space colonies or world-ships finally comes about? Could we – at some point – all be living in self-contained artificial worlds, on our way to the stars – as envisioned in so much fiction? From Imagination To Realty 2 examines the possibilities…space exploration and settlement. It will bring together scientists, policy makers, sociologists and political philosophers.

You can register online at www.bis-space.com or by requesting a registration form.

Man in the Solar System: A Very British Approach

Alan Bond

2 October 2013, 7.30 pm

Venue: Bath Royal Literary and Scientific Institute, Bath, BA1 2HN

In the 1980s a promising new propulsion concept was investigated in the UK leading to a 2-1/2 year intensive study of a single stage to orbit reusable space launch vehicle called HOTOL. HOTOL was studied by British Aerospace and Rolls-Royce but abandoned because of lack of Government support at the end of the 1980s.

The project was not abandoned however by its inventors and in 1989 Alan Bond, Richard Varvill and John Scott created Reaction Engines Ltd to continue to pursue the concept. The result has been the SKYLON Spaceplane and its SABRE powerplant. In studying the requirements for the Spaceplane a number of additional studies have been conducted into space transport infrastructure and missions to Mars. This talk will describe these studies and the experimental development which has taken place to date to bring SKYLON to fruition.

The Nervous System of a Starship

Pat Galea

17 October 2013, 7.30 pm

Venue: Bath Royal Literary and Scientific Institute, Bath, BA1 2HN

Sending a ship to the stars has many daunting technical challenges. Discussion often focuses on propulsion but control and communication over the vast distances and timescales involved is also a formidable challenge.

This lecture will discuss how advanced computation and communication technologies such as machine learning and gravitational lensing can be used to build ships which can work reliably and autonomously over centuries, and communicate their status and their data to Earth.

Readers are reminded that these Notices contain only a reduced description of the event. Full details can be found on the website at www.bis-space.com, where any updates are also carried.

Non-BIS Events

Starship Congress 2013

15-18 August 2013

Venue: Hilton Anatole, Dallas, Texas

www.icarusinterstellar.org/congress-announcement/

Lectures

Venue: Lectures will be held at BIS HQ, 27/29 South Lambeth Road, London, SW8 1SZ, unless otherwise stated.

Members can attend free of charge. Places must be booked in advance, online or by post. Each member may also obtain a free ticket for one guest subject to availability of space.

Non-Members are able to attend the Society's lectures for a fee. You can order a ticket online or by post (please make cheques payable to the British Interplanetary Society). If oversubscribed Society Members will be given priority.

If applying by post please send an sae. If applying via our website the confirmation receipt is your entry ticket.

If, for reasons outside its control, the Society is required to change the date or topic of a meeting, every effort will be made to avoid inconvenience to attendees either by notice of change in ***Spaceflight/JBIS***, on our website or by special advice to each participant.

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