MIMPS-G

Green rocket propulsion for miniature satellites

Miniaturised satellites have brought about a new generation of space missions, allowing research groups to conduct affordable experiments and commercially operate in communications, reconnaissance, and imaging applications in Low Earth Orbit, as well as deep space missions. Yet so far, the propulsion systems required to manoeuvre these spacecraft have widely relied upon highly toxic propellants, which are likely to be legally regulated in the near future. To address this issue among others, a group of researchers from Italy (UniPi) and The Netherlands (TU Delft) have designed MIMPS-G: a miniaturised, modular green propulsion system which can manoeuvre these satellites efficiently, using environmentally sustainable green propellants.

MIMPS-G500mN - Green Propulsion Module for VLEO Imagery Satellites and Remote Sensing.

Since the earliest years of space travel, unmanned missions to Earth's orbit and beyond have been dominated by the use of large satellites and probes. Many of these spacecraft have carried extensive amounts of scientific equipment: for purposes ranging from the high-resolution monitoring of Earth's surface, to analyses of planets, moons, and asteroids in distant reaches of the solar system.

Yet more recently, missions have started to undergo a shift towards far smaller satellites, which can be launched into space with very little cost. Small satellites can be easily built using commercial off-the-shelf components, and can be easily loaded with delicate, high-precision scientific equipment to, for example, monitor Earth's surface and study environmental and climate changes with high resolution and accurate imaging and radar data.

Whereas the spacecraft used in most missions so far have been expensive, and required extensive teams of scientists and engineers to build and operate, CubeSats and similar technologies are now making space-based research accessible to research institutions, governments, and policy makers around the world. Yet inevitably, the operation of these groundbreaking satellites hasn't come without its own challenges.

MODULARITY, MINIATURISATION, AND HIGH-PERFORMANCE

To get into orbit, CubeSats are typically launched as the secondary payloads of rockets – which may also be launching larger satellites or probes, or delivering supplies to the International Space Station. This means that they won't have any further assistance once they reach orbit, and will often need to carry out a series of complex manoeuvres before they can carry out the scientific tasks they have been assigned.

Such operations could include orbit insertion; alterations to orbital altitude and inclination; assemblies into formations with other satellites; and obstacle avoidance which is becoming more important, especially due to the increasing presence of satellite constellations. To complete them, it is crucial for satellites to carry sufficient amounts of fuel, and to use it efficiently enough to perform responsively.

Researchers must also ensure that the costs and manufacturing times of their CubeSat propulsion systems remain low. To achieve this, they must adopt modular components and use state-of-the-art 3D metal printing and perhaps multi-material Additive Manufacturing (AM) techniques. In this way, the intended green propulsion system components can be rapidly fabricated, and then assembled into a high-performing final product.

HIGH-THRUST CAPABILITIES AND THE STARLINK 2022 CRASH

On 3rd February 2022, SpaceX launched a batch of 49 Starlink satellites to its global internet constellation. Due to a solar geomagnetic storm, the orbits of 40 satellites were destructively altered, falling back to Earth burning in the atmosphere. Starlink constellation satellites rely on a low-thrust Hall-Effect Thruster (HET) Electric Propulsion system (EPs), fuelled by krypton gas for orbital manoeuvres. Due to the already low altitude flight of the constellation, they were unable to deal with the geomagnetic storm impact. High-thrust impulsive propulsion would typically save the day for such unforeseen events, otherwise similar missions would need to launch the satellites to higher initial altitudes. It is worth noting that SpaceX has launched about 2,000 Starlink satellites to date and has permission to increase these to 12,000 satellites.

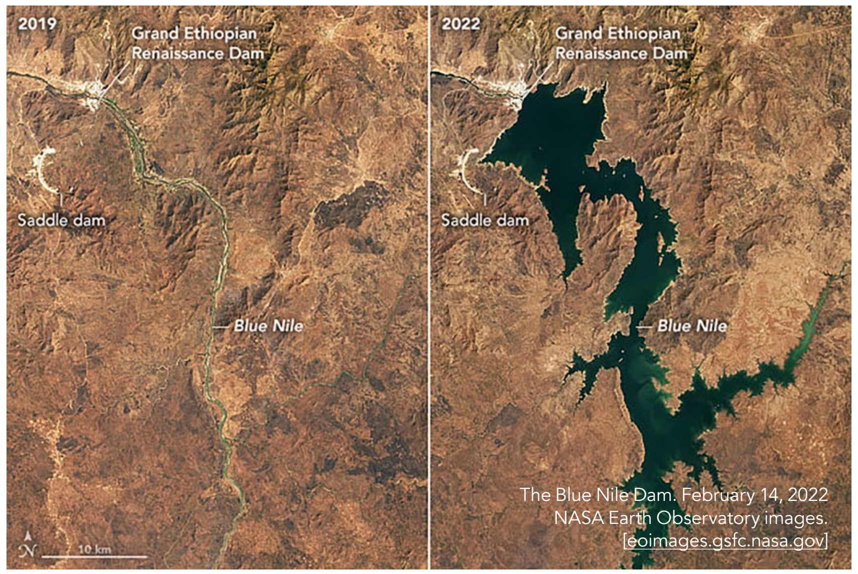
Likely Starlink space debris burning over Puerto Rico on Feb 7th, 2022 (Image credit: Eddie Irizarry/Sociedad de Astronomia del Caribe (SAC))

INTRODUCING SUSTAINABLE GREEN CHEMICAL PROPELLANTS

To reach these stringent requirements, many previous missions have relied on hydrazine and its derivatives as fuel for the high-thrust primary propulsion of the spacecraft. As global legal regulations look set to restrict the use of hydrazine fuels, there is now an increasingly pressing need for viable green alternatives – which are safe, stable, and easy to store, while maintaining the simple, high-performing designs of CubeSat propulsion systems. The search for effective green propellants has accelerated, and they have now been successfully demonstrated in a number of missions.

Among these are SkySat: a cluster of CubeSats launched by the US company, PlanetLab – which provided high-resolution images of the planet's surface from low-Earth orbit, between 2016 and 2020. The propellants have also been used in a number of NASA missions, including Mars Cube One. Here, a pair of CubeSats were used to provide a real-time communications link between Earth and the InSight lander, during its descent to the Martian surface. Another is the GPIM (Green Propellant Infusion Mission) launched in 2019.

SAR low-cost satellite constellations can help study climate and environmental changes with a great level of precision in the Nile Basin and the Red Sea regions.



The Blue Nile Dam. February 14, 2022
NASA Earth Observatory images.
(eoimages.gsfc.nasa.gov)

AF-M315E (or Air Force Monopropellant) was developed by the Air Force Research Laboratory and was recently renamed Advanced Space-Craft Energetic Non-Toxic (ASCENT) propellant and granted permission for commercialisation by DSSP Inc. This propellant produces an adiabatic flame temperature of around 2,100 K (far higher than that of hydrazine). It offers a 13% increase in specific impulse and 63% increase in density over hydrazine, which makes it superior when it comes to the miniaturisation of propulsion systems compared to other propellants.

HNP225 belongs to the Highly stable Non-detonating Propellant (HNP) green monopropellants family and has the lowest adiabatic flame temperature (around 1,000 K). The low temperature combustion gasses enabled IHI Aerospace Co, Ltd to develop low-cost 3D metal printed thrusters with lower heat-resistant materials – which means lower mass and costs. The HNP family of propellants were tested with newly developed catalysts and showed excellent response and combustion pressure stability compared to hydrazine with preheating temperatures starting from 200 °C for HNP225.

LMP-103S is the most mature of the ADN-based green propellants and was qualified by the European Space Agency (ESA) and demonstrated through the high-performance propulsion system on the Mango-PRISMA satellite, launched in June 2010. Advantages of LMP-103S over AF-M315E include a lower combustion temperature which permits the use of materials with a lower melting point and simpler designs for thruster development.

These green monopropellants show high promise for the future of miniaturised green propulsion systems, especially

14 February, 2022
Egyptian Red Sea and Nile from ISS

The affordability of such exquisite optical sensors in classes of green small-satellites have made this technology vital for the scientific research community.

HNP225, which is able to ignite effectively with low catalytic preheating abilities as well as the much lower adiabatic flame temperature, allowing for the use of the state-of-the-art 3D metal printed materials with high confidence. HNP225 propellant also shows high flexibility when exported from its country of origin to different parts of the world due to its non-detonating properties and safe transportability.

SCIENTIFIC AND COMMERCIAL APPLICATIONS

Microwave remote sensing has shown great potential in environmental monitoring and climate change studies on Earth. Synthetic-Aperture Radar (SAR) sensors are currently gaining a lot of attention in the aerospace, industrial and commercial realms due to their high benefit-to-cost ratio. SARs are used in small-satellite constellations for applications such as monitoring changing sea ice for maritime, flood monitoring, and tracking oils spills. SAR satellite constellations, due to their low-cost, can effectively facilitate the study of climate and environmental changes in developing countries such as in the highly-demanding Nile Basin and the Red Sea regions.

In addition, multispectral imagery of the planet's surface is no longer new, though advancements in computing capabilities, optics, and onboard spacecraft processing abilities have provided unprecedented clarity and resolution in the past few years. The affordability of such exquisite sensors for green small-satellites will be vital for the scientific research community in the coming years, particularly for climate and environmental studies, either in academia or in the commercial sectors.

NOVEL GREEN PROPULSION

To develop their propulsion system, MIMPS-G, Ahmed Nosseir and the research group considered using state-of-the-art green monopropellants. As well as being environmentally sustainable, these chemical propellants offer numerous advantages over their toxic counterparts.

In their latest research, the research team introduced the MIMPS-G500mN: a green propulsion system designed to deliver thrust force of 0.5 Newtons. Modularity coupled with expandability of this system offers a particularly key advantage: depending on the size of the spacecraft, its required thrust level, and the total change in velocity it will undergo throughout its mission, operators can modify its propulsion by simply plugging in additional fuel tanks or thrusting units. This can be done with very few additional costs, and without diminishing the satellite's overall performance.

NEW DIRECTIONS FOR MANUFACTURING

In the development plan, the research group envisage that the MIMPS-G system could be manufactured using 3D-printed metal components. This would not only reduce the number of parts required by the system, and therefore its overall mass; it could also be used to optimise the designs of fuel tanks to maximise their efficiency.

Furthermore, while ASCENT is the most mature green propellant currently available, many other alternatives are undergoing continuous development, in particular the highly promising Japanese HNP225. These are offering a variety of advantages: including lower combustion temperatures, and a flexibility in using a wider variety of ignition techniques.

Through future research into different green propellants and additive manufacturing techniques, the researchers now hope to further improve upon the modularity and miniaturisation of CubeSat propulsion, by extending the capabilities of their MIMPS-G500mN system even further. These ongoing improvements could open vast expanses beyond Earth's atmosphere to research institutions which lack the colossal funding requirements and engineering expertise associated with traditional unmanned space missions.

At the same time, they could provide miniaturised spacecraft with the ability to navigate the hazardous environment of low-Earth orbit, which is becoming increasingly crowded with satellites, and the discarded remains of previous missions. In time, the research group ultimately hope that CubeSat missions may soon be visiting the Moon, and perhaps even more distant destinations.

Behind the Research

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Research Objectives

AES Nosseir and the research group under the supervision of A Cervone and A Pasini have designed MIMPS-G, a miniaturised, modular green propulsion system to be used in green space applications, and for studying environmental and climate changes, especially in developing countries and African regions.

Detail

Angelo Cervone (TU Delft)
Assistant Professor in the Aerospace Engineering Faculty at Delft University of Technology. His main research areas are micro-propulsion, small satellites, systems engineering, green propellants, cavitation and flow instabilities in liquid rocket engine turbopumps. He is chairperson of the Space Propulsion Technical Committee of the International Astronautical Federation, and serves as chairman for several international conferences related to space propulsion.

Angelo Pasini (UniPi)
Assistant Professor of Space Propulsion at Pisa University. His fields of research are turbomachinery, cavitation, rotordynamics and flow instabilities in space rockets turbopumps, high speed hybrid bearings, non-toxic propellants and catalytic beds for hydrogen peroxide decomposition.

Ahmed E S Nosseir (UniPi x TU Delft)
Carried out his postgrad studies in the field of aerospace engineering and astronautics between the University of Pisa, Italy and Delft University of Technology, The Netherlands. He is a Masters of Science holder with 110 Cum Laude. Current research activities: green space propulsion, green propellants, space systems. Ahmed is a licensed mechanical engineer since 2015 after graduating from the Faculty of Engineering and Materials Science, majoring in mechatronic systems engineering from the German University in Cairo, Egypt.

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Personal Response

What further challenges could arise for CubeSat missions to the Moon?

" Missions to the Moon using this type of satellite are usually aimed at the far side and the poles of the Moon, locations that are not accessible by visuals from Earth. Due to the long distance and typically the long duration of such missions, the main challenge is the high ΔV requirements for the spacecraft in order to secure stable orbital operations and therefore successful scientific missions – capable propulsion systems are key players in overcoming several related challenges in CubeSat missions to the Moon, and beyond. "

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