Royal College of Science Union Science Challenge 2021

[redacted]

2021

Question by judge Letizia Diamente:

“*You have one billion pounds to spend on research: how will you use them?*”

"On the benefits, limitations, and research of ion propulsion technology to be used in aviation."

I. Introduction

II. What is ion propulsion and how does it work?

III. What are the benefits of ion propulsion?

IV. How has ion propulsion been limited and why does it require research?

V. Concluding notes

I. Introduction

Despite the Covid-19 pandemic, global travel rates are increasing even more than predicted just a few decades ago, with the ICAO predicting 10 billion aeroplane passengers per year in just 2 decades [1]. Alongside the rise in air travel, the effects of climate change are simultaneously rapidly accelerating, as humanity drives dangerously close to an irreversible climate crisis.[2] With gridlock in the developments of greener energy and an inability to electrify modern aeroplanes; a revolutionary, completely new method of providing thrust is ripe for development, and MIT may have provided just that in 2018 – the ion plane, a form of air travel with no moving parts.[3] This remarkable feat in physics and chemistry has been described as a 'Wright brothers moment' and may be a crucial piece on the puzzle of saving Earth. However, it has a long way to go until it hits the market and requires desperate research.

II. What is ion propulsion and how does it work?

An ion is an atom that has been charged, for example by the addition or subtraction of an electron. This charge on the atom gives it a value and presence in the electric field, which can be exploited through the laws of electromagnetism. The fundamental process of ion propulsion is accelerating atoms between an anode and cathode, creating 'ionic wind' – which in turn accelerates the vehicle. [4] On the MIT plane, multiple 'ion drives' in 4 rows below the wing were utilised. These ion drives consisted of a positive anode in the form of a small steel wire (to minimise drag – a key area of research needed within ion propulsion), and a negative cathode in the form of foam aerofoils covered in aluminium, specifically designed to provide lift. Lithium-polymer batteries provide a potential difference of 40,000 volts between the anode and the cathode, and therefore the surrounding air molecules are ionised, their electrons are removed, leaving behind relatively heavy positive ions. It is the acceleration of these molecules towards the negative aerofoils due to the electrostatic force which provides the thrust to the plane. [5]

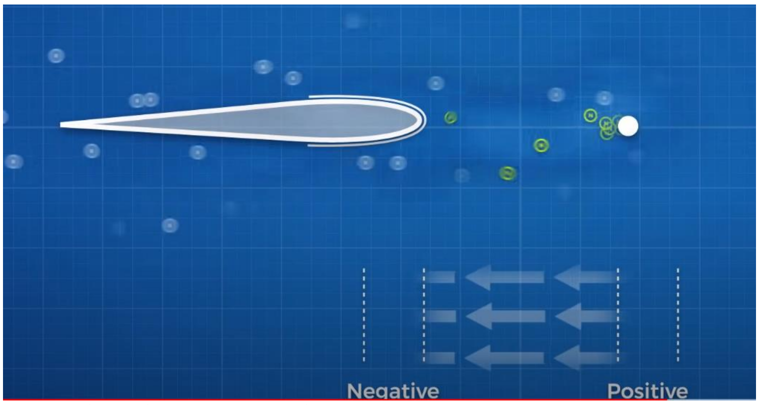

Figure 1 Ionic wind | Note the flow of charged atoms from the positive to negative end and the subsequent interaction with neutral atmospheric particles. Also, note the shape of the foam glider, maximising lift provided. | Courtesy: Real Engineering

III. What are the benefits of ion propulsion?

A multitude of benefits inevitably come with such revolutionary engineering. The first and foremost being the fact that the ion plane has no carbon emissions when operating, potentially saving over a billion tonnes of carbon being emitted every year, if implemented into the aviation industry. [6] This will not only benefit the climate but will also lead to more improvements that a lack of emissions in the atmosphere can bring: higher quality of life for those suffering from respiratory disease, higher visibility, cleaner water, and others. Another advantage which may, at first, seem inconsequential, is the lack of noise; ion planes are silent. This is a great characteristic as it is an advantage and incentive for military contractors to use this technology, as silent air forces would be of great value – this could lead to further investment in this and even more research, and is a way of bringing ion propulsion to governmental attention. [7]

IV. Issues regarding ion propulsion and why it requires research

Ion propulsion is clearly an exciting new prospect for humanity, potentially fixing many modern-day problems we face – but there is still a long way to go, which is why I would invest in research in this field. Outlined are some problems with this technology, and how the £1bn can be used to research solutions.

IV i. Low thrust density

Thrust density is a measure of the area over which a thrust force is applied, measured in Nm^{-2}. A conventional jet engine can provide 10,000 Nm^{-2} of thrust density, however, the MIT plane only managed around 3 Nm^{-2}. This low thrust density means that the MIT design, the only successful design, is not sustainable – it cannot be scaled up for conventional use with current technology means. This is because the power needed for flight increases with the square (x^2) of the mass, as given by the equation:

$$P_{lift} = \frac{M_{plane}^{2} \times g^{2}}{\rho_{air} \times L^{2} \times V_{flight}} \qquad P_{drag} = \frac{1}{2} C_D \rho_{air} V_{flight}^{3} A$$

Figure 2 Equation for power needed for lift of a fixed wing aircraft. The power needed increases with the mass of the plane square, so increases exponentially with a larger plane | Courtesy: Real Engineering

If the mass of the plane is doubled, the power needed for flight is quadrupled. Considering the wingspan of the MIT plane is only 5m, compared to a wingspan of a Boeing 787-8 Dreamliner being 60m [8], breakthroughs are needed to maximise thrust provided by the ion drives to get them to today's standards of aeroplane size.

The technology is only in its infancy - the solution to the thrust density problem, the largest hurdle for ion propulsion, may be a while away, but with investments in companies like Accion Systems, research can be accelerated. As of 2018, Accion Systems' total funding is only $12.9m, so with just a quarter of the money allocated within the question, £250m, Accion Systems could make great leaps. [9] It is of utmost importance to be using any amount of funds available to invest in such revolutionising technology.

IV ii. Atmospheric limitations

Ion thrust has been used for decades in another industry to aviation: space exploration. NASA has been making significant progress in creating engines that provide more force. There is one key distinction between ion engines in the atmosphere, and those in space: drag. In space, engines can gradually accelerate, no matter how small the acceleration, as there is no resistance. For example, their revolutionary new engine, the NASA Evolutionary Xenon Thruster (NEXT) only has an acceleration of about 0.00003 ms^{-2}, but in 6 years (usual timescales in space), can reach speeds of Mach 130. [10]

Despite these innovations, they are not possible on Earth due to air resistance. There are too many molecules in the atmosphere to allow velocity to build up from such small acceleration. A solution lies within the aerodynamic design of ion planes to reduce drag – an aspect of flight MIT have not endeavoured greatly into with their design:

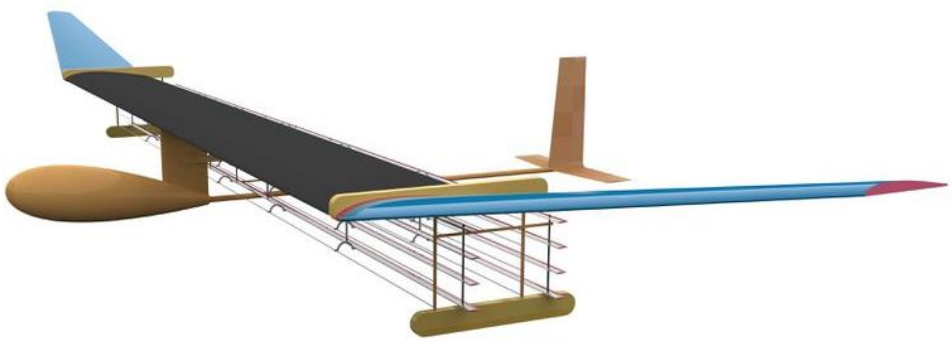

Figure 3 The MIT Ion Plane | Courtesy: Massachusetts Institute of Technology

Winglets, a key feature of aerodynamic design, are implemented, but more work can be done in terms of design to minimise the thrust needed for lift. Investment in aerodynamic design can enhance this.

Coupled with research in increasing thrust density, a more aerodynamic design can make other issues with ion propulsion easier to combat.

V. Concluding notes

In conclusion, ion propulsion is clearly an upcoming new horizon for humanity to strive in and can solve many issues faced in the 21st Century, however, investment is needed to resolve the key issues which face the technology. There are inevitably a myriad of other logistical and technical problems regarding ion thrust, but if a £1bn research investment opportunity like the one outlined in the question were to come to fruition, it could be the greatest invention by humankind.

(1189 words)

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