ENGINEERING

# Flying with ionic wind

**Aeroplanes use propellers and turbines, and are typically powered by fossil-fuel combustion. An alternative method of propelling planes has been demonstrated that does not require moving parts or combustion.** SEE LETTER P.532

FRANCK PLOURABOUÉ

Small, lightweight devices called lifters can propel themselves into the air without combustion or moving parts, and have become a popular topic of discussion with technology buffs on social media in the past few years. And yet the physical mechanism behind lifters has been known for more than a century[1]. When charged molecules in the air are subjected to an electric field, they are accelerated. And when these charged molecules collide with neutral ones, they transfer part of their momentum, leading to air movement known as an ionic wind. On page 532, Xu *et al.*[2] demonstrate that an aeroplane with a 5-metre wingspan can sustain steady-level flight using ionic-wind propulsion. Improvements are required, but the authors' proof-of-concept demonstration could pave the way for the development of enhanced propulsion systems.

In Xu and colleagues' plane, an electric field is applied to the region that surrounds a fine wire called the emitter (Fig. 1a). The field is strong enough to induce a chain reaction: free electrons in the region collide heavily enough with air molecules to ionize them, producing more electrons that then ionize more molecules. These electron cascades give rise to charged air molecules in the vicinity of the emitter — a phenomenon called a corona discharge. Finally, the charged molecules drift away from the emitter and generate a propulsive ionic wind as they are accelerated by the electric field towards a device called the collector (Fig. 1b). This process occurs only in gases, and not in liquids, justifying the authors' use of the term 'electroaerodynamics'.

Previous experiments suggested that ionic-wind propulsion could enable the steady-level flight of an aircraft, but that the feasibility of achieving this lies at the limit of what is currently technologically possible[3]. Xu *et al.* therefore needed to systematically search through all of the possible aeroplane designs for a feasible option. They used a technique called geometric programming to find the optimum set of design variables that would also minimize the aircraft's wingspan and, in turn, its weight, electrical-power requirements and cost.

The optimization technique found a feasible design at a wingspan of 5 metres, with a mass of 2.5 kilograms, a flight velocity of 4.8 metres per second and a power requirement of 600 watts. The authors built a full-scale plane based on this design (see Fig. 1b of the paper[2]). They flew the aircraft ten times, and showed that it achieved steady-level flight.

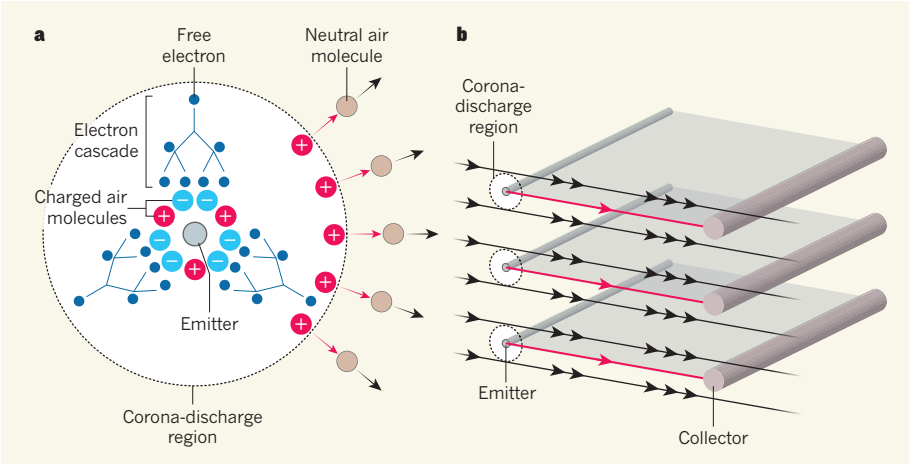


**Figure 1 | Ionic-wind propulsion.** Xu *et al.*[2] demonstrate that an aeroplane can sustain steady-level flight using air movement known as an ionic wind. **a**, In the authors' aircraft, an electric field (not shown) is applied to the region surrounding a fine wire called the emitter (shown in cross-section). The field induces electron cascades, whereby free electrons collide with air molecules (not shown in the cascades) and consequently free up more electrons. This process produces charged air molecules in the vicinity of the emitter — a corona discharge. Depending on the electric field, negatively or positively charged molecules drift away (red arrows) from the emitter. These molecules collide with neutral air molecules, generating an ionic wind (black arrows). **b**, The aircraft uses a series of emitters and devices called collectors, the longitudinal directions of which are perpendicular to the ionic wind. The flow of charged air molecules occurs mainly along the directions (red arrows) joining emitters and collectors. Consequently, the ionic wind is accelerated (black arrows) predominantly in these regions.

In the 1960s, various studies[4,5] seemed to sound the death knell for propulsion based on ionic wind. They demonstrated that only about 1% of the input electrical energy was used in propulsion — not far from the 2.6% reported by Xu and colleagues. However, at least three factors make the approach appealing for aircraft.

First, it is now known that the energy efficiency improves substantially when the aircraft velocity is increased. For example, if the velocity reaches 300 m $s^{-1}$, the efficiency[2,6] can be as high as 50%. Second, many studies have shown that ionic wind can enhance the aerodynamics of plane wings[7]. Third, the technique could facilitate what is known as distributed propulsion[8], which is considered a major direction for improvement in aviation.

Aircraft propulsion is quantified by the freestream mass-flow rate — the total mass of air that passes through a given area in a given time. This rate is directly proportional to the cross-sectional area of the propulsion system, and to the increase in air velocity provided by the system. In distributed propulsion, an array of propulsion systems is spread along the length of the aircraft. This increases the total cross-sectional area and, in turn, the freestream mass-flow rate. But it also enhances the aerodynamic drag (the frictional force between the aircraft and the air). Using fine wires as the propulsion system, as Xu *et al.* did, could allow the total cross-sectional area to be greatly increased, while having almost no impact on the aerodynamic drag.

The scalability of the authors' propulsion system remains to be seen. Can ionic-wind propulsion fly an aircraft of several tonnes? This practical issue is still open, but predictions suggest that aircraft such as the solar-powered plane Solar Impulse 2 could sustain steady-level flight using only ionic wind[9]. An advantage of

ionic-wind propulsion systems, as opposed to propellers, is that they can be interfaced directly with batteries — the energy-storage devices of future planes — without affecting the rate of energy conversion. In the decades to come, drones or aircraft that use ionic wind might include secondary ionic-wind propulsion systems dedicated to energy saving and potentially coupled with solar panels.

These technological developments should provide a better understanding of the coupled physics of charged-molecule production and the resulting ionic wind that is central to such propulsion systems. The force generated by ionic wind is directly proportional to the electric current that flows in the system[2,10]. Because this current is strongly dependent on the configuration of emitters and collectors, research into the conception and optimization of ionic-wind propulsion can now begin, thanks to the breakthrough by Xu and colleagues. ■

**Franck Plouraboué** *is at the Institute of Fluid Mechanics of Toulouse, Toulouse University, CNRS, INPT, UPS, 31400 Toulouse, France.*
*e-mail: franck.plouraboue@imft.fr*

1. Chattock, A. P. *Phil. Mag.* **48**, 401–420 (1899).
2. Xu, H. *et al. Nature* **563**, 532–535 (2018).
3. Gilmore, C. K. & Barrett, S. R. H. *Proc. R. Soc. Lond. A* **471**, 20140912 (2015).
4. Robinson, R. *Am. Inst. Elect. Engineers Pt I* **80**, 143–150 (1961).
5. Stuetzer, O. M. *Phys. Fluids* **5**, 534–544 (1962).
6. Bondar, H. & Bastien, F. *J. Phys. D* **19**, 1657–1663 (2000).
7. Kriegseis, J., Simon, B. & Grundmann, S. *Appl. Mech. Rev.* **68**, 020802 (2016).
8. Sehra, A. K. & Whitlow, W. *Prog. Aerosp. Sci.* **40**, 199–235 (2004).
9. Monrolin, N., Plouraboué, F. & Praud, O. *AIAA J.* **55**, 4296–4305 (2017).
10. Monrolin, N., Praud, O. & Plouraboué, F. *Phys. Rev. Fluids* **3**, 063701 (2018).

NEURODEGENERATION

# Disease protein muscles out of the nucleus

**Protein aggregation is a characteristic of several neurodegenerative diseases. But disease-associated aggregates of the protein TDP-43 have now been shown to have a beneficial role in healthy muscle.** SEE ARTICLE P.508

LINDSAY A. BECKER & AARON D. GITLER

Most neurodegenerative disorders are characterized by the build-up of clumps of proteins in the brain[1]. A prevailing view in the field is that these large protein assemblies are inherently abnormal and are toxic to cells. Vogler *et al.*[2] challenge this canon by reporting on page 508 that muscle cells can contain physiological, reversible protein aggregates that have features similar to the aggregates seen in neurodegenerative disease, but that actually seem to be beneficial.

The protein TDP-43 forms aggregates in nerve cells in nearly all cases of the neurodegenerative disorder amyotrophic lateral sclerosis (ALS, also known as motor neuron disease)[3]. TDP-43 aggregation is also seen in other diseases, including frontotemporal dementia (FTD)[4] and inclusion body myopathy (IBM)[5], in which neurons and muscle cells, respectively, degenerate. FTD and IBM share genetic risk factors with ALS, indicating that the three have common disease mechanisms. In each disease, aggregates of TDP-43 are specifically found in the cytoplasm of dying cells. TDP-43 also has a normal job in the nucleus of healthy cells, where it acts as an RNA-binding protein[4].

Vogler *et al.* set out to investigate the behaviour of TDP-43 in healthy muscle. In doing so, they made a surprising observation. As expected, TDP-43 was located in the nucleus of muscle stem cells. But when the authors coaxed these cells to differentiate into young muscle fibres called myotubes, or if they used a chemical to injure a mouse's leg muscle to stimulate muscle regeneration, TDP-43 accumulated in the cytoplasm. There, it formed transient granular structures, which the researchers dubbed myo-granules, before moving back to the nucleus a few days later, as the myotubes became mature muscle fibres (Fig. 1). These data suggest that cytoplasmic TDP-43 myo-granules could have a role in muscle formation and regeneration.

Do myo-granules resemble the TDP-43 aggregates associated with neurodegenerative diseases? Disease aggregates are typically held together by strong bonds that are resistant to even heavy-duty detergents. Likewise, Vogler and colleagues found that TDP-43 myo-granules were resistant to such detergents. Another key feature of many neurodegenerative-disease proteins (although not all disease-associated TDP-43 aggregates) is that they can adopt a specific conformation, known as amyloid. Amyloids are long fibres made up of building blocks of the misfolded disease proteins arranged in a highly organized manner[6]. Using an array of analytical methods — including an antibody to specifically detect amyloid-like material, and high-resolution microscopy and X-ray diffraction techniques to enable examination of the myo-granule's structure — the authors demonstrated that TDP-43 myo-granules have amyloid-like properties.

Next, Vogler *et al.* investigated differences between TDP-43 in cytoplasmic myo-granules and in the nucleus, by examining the RNAs to which the protein binds in the two settings. They found that the types of messenger RNA that bind to TDP-43 changed markedly as muscle precursors differentiated into muscles. The mRNAs found associated with aggregated TDP-43 included those that encode proteins associated with the sarcomere — a unit of muscle structure that causes muscle contraction. These data suggest that TDP-43 myo-granules might control the development of sarcomeres.

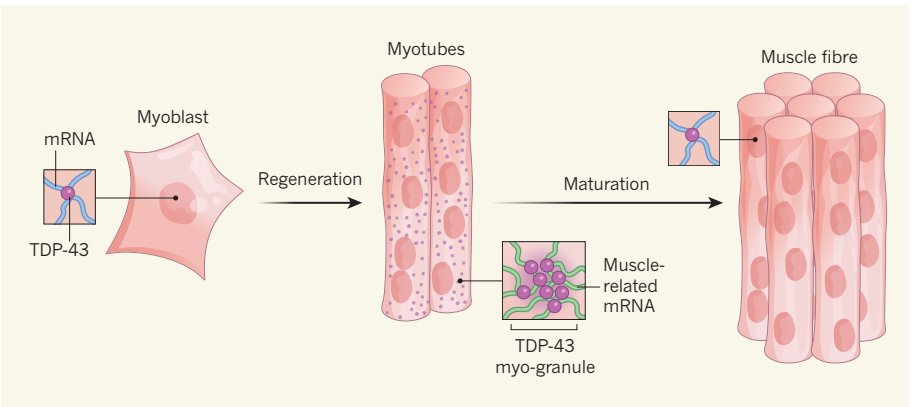


**Figure 1 | A functional aggregate forms during muscle regeneration.** In muscle precursor cells called myoblasts, the protein TDP-43, which binds messenger RNA, is located in the nucleus. Following muscle injury, myoblasts fuse into multi-nucleated fibres called myotubes that mature into muscle. Vogler *et al.*[2] show that TDP-43 transiently leaves the nucleus and assembles into large aggregate structures dubbed myo-granules, in which the protein binds to, and so might regulate, a distinct set of mRNA molecules involved in muscle formation. After recovery from injury, as the muscle matures, the myo-granules disassemble and TDP-43 returns to the nucleus.