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Journal articles

Lidia Caros, Oliver Buxton, Tsuyoshi Shigeta, Takayuki Nagata, Taku Nonomura, Keisuke Asai, and Peter Vincent, "Direct Numerical Simulation of Flow over a Triangular Airfoil Under Martian Conditions, " AIAAJ, Vol. 60, No. 7 (2022), pp. 3961-3972 doi: doi/abs/10.2514/1.J061454

Lidia Caros, Oliver Buxton, and Peter Vincent, "Optimization of Triangular Airfoils for Martian Helicopters Using Direct Numerical Simulations, " AIAAJ, Vol. 61, No. 11 (2023), pp. 4935-4945 doi: doi/abs/10.2514/1.J063164

www.cirrus.ac.uk

Engineering and Physical Sciences Research Council

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Optimization of rotor blades for Martian Helicopters

The NASA Mars helicopter, Ingenuity, successfully carried out the first ever powered flight on another planet. However, the unique conditions on Mars, including its very thin atmosphere (less than 1% of the density of Earth's), create challenges for the design of new aerial vehicles for further exploration of the planet. Researchers at Imperial College London have used Cirrus for aerodynamics simulations to help design new airfoils for such vehicles.

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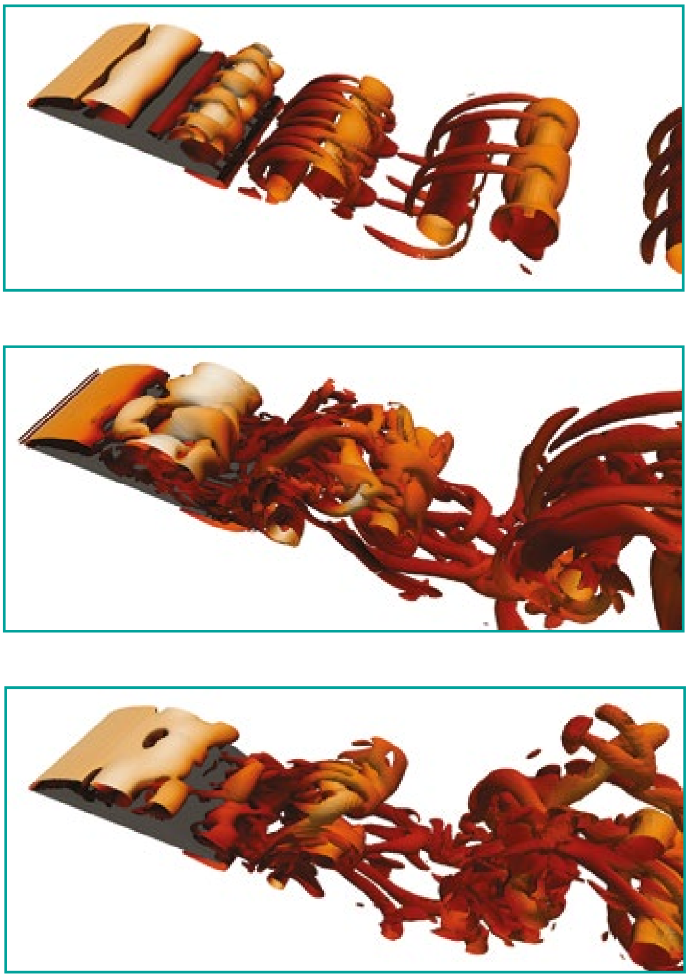
Illustration of NASA's Ingenuity Mars Helicopter flying on Mars with NASA's Perseverance rover in the background.

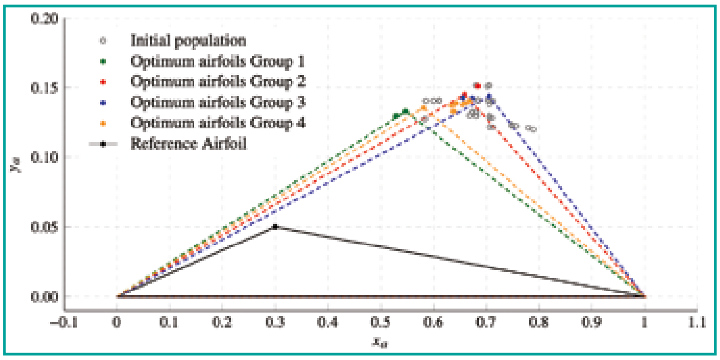
NASA's Ingenuity helicopter has set a new standard in extraplanetary aviation. Exceeding its expected lifespan and objectives, Ingenuity has impressively conducted over 60 flights on Mars since April 2021.

While Ingenuity is not equipped with scientific instruments or the capability to retrieve samples from Mars' more inaccessible terrains like craters or peaks, due to weight limitations, its success nevertheless marks a significant advancement in aerospace engineering. This achievement paves the way for the development of future Martian helicopters capable of longer, farther flights with the ability to carry scientific equipment, as envisioned by experts in the field.

The atmospheric conditions on Mars pose unique challenges for flight. The Martian atmosphere is characterized by lower pressure, a higher concentration of CO2, cooler air temperatures, and a slower speed of sound compared to Earth. This results in a significantly lower Reynolds number on Mars, akin to the flight dynamics of insects on Earth, and a higher Mach number due to the slower sound speed. Addressing these challenges requires innovative approaches in aerodynamic design.



Images from simulations of optimized airfoils showing the vortices being shed off the leading edge and apex of the airfoils that then break down into three-dimensional structures. (Images: L. Caros, O. Buxton and P. Vincent 2023)



Sets of optimized airfoil cross-section shapes (depicted in green, red, blue and yellow) compared with a reference airfoil (in black). (Image: L. Caros, O. Buxton and P. Vincent 2023)

The Martian atmosphere is characterized by lower pressure, a higher concentration of CO2, cooler air temperatures, and a slower speed of sound compared to Earth.

To tackle these issues, researchers at Imperial College have been conducting high-fidelity Computational Fluid Dynamic simulations using the Cirrus supercomputer, focusing on developing airfoil shapes optimized for Martian conditions. Drawing inspiration from the aerodynamics of dragonfly wings, which are effective in low Reynolds number environments, the researchers are investigating unconventional designs such as triangular and corrugated airfoils.

These new designs have also been explored through experiments in the Mars Wind Tunnel at Tohoku University in Japan, which simulates Martian atmospheric conditions. These studies have indicated that optimal airfoils for Mars might differ significantly in shape from those used on Earth, with a focus on designs that efficiently generate lift in Mars' unique atmospheric conditions.

We have employed the software PyFR (www.pyfr.org) to simulate the complex, unsteady vortex-dominated flows associated with these new airfoil designs. This software provides a more accurate representation of these flows compared to traditional flow simulation algorithms.

Through computational simulations and the use of genetic algorithms, we have developed a range of airfoil shapes, each optimized for a balance between lift generation and drag reduction.

Our simulations have revealed the mechanisms of lift generation in triangular airfoils, primarily through the formation of large vortices. The optimization process has also identified key design features that maximize lift while minimizing drag. This has led to the creation of a set of optimized airfoil shapes, each designed for specific aerodynamic efficiency.

This ongoing research is key to enhancing the capabilities of aerial vehicles suitable for Mars, furthering scientific exploration, and deepening our understanding of Martian aerodynamics and environmental conditions.

Images from simulations of the reference triangular airfoil in a virtual wind tunnel simulation to compare against the experiments performed at the Mars Wind Tunnel in Tohoku University, Japan. (Images: L. Caros, O. Buxton, T. Shigeta, T. Nagata, T. Nonomura, K. Asai and P. Vincent, 2022)