Aeroplane wings and rotating disks
What's the difference?

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CARDIFF UNIVERSITY
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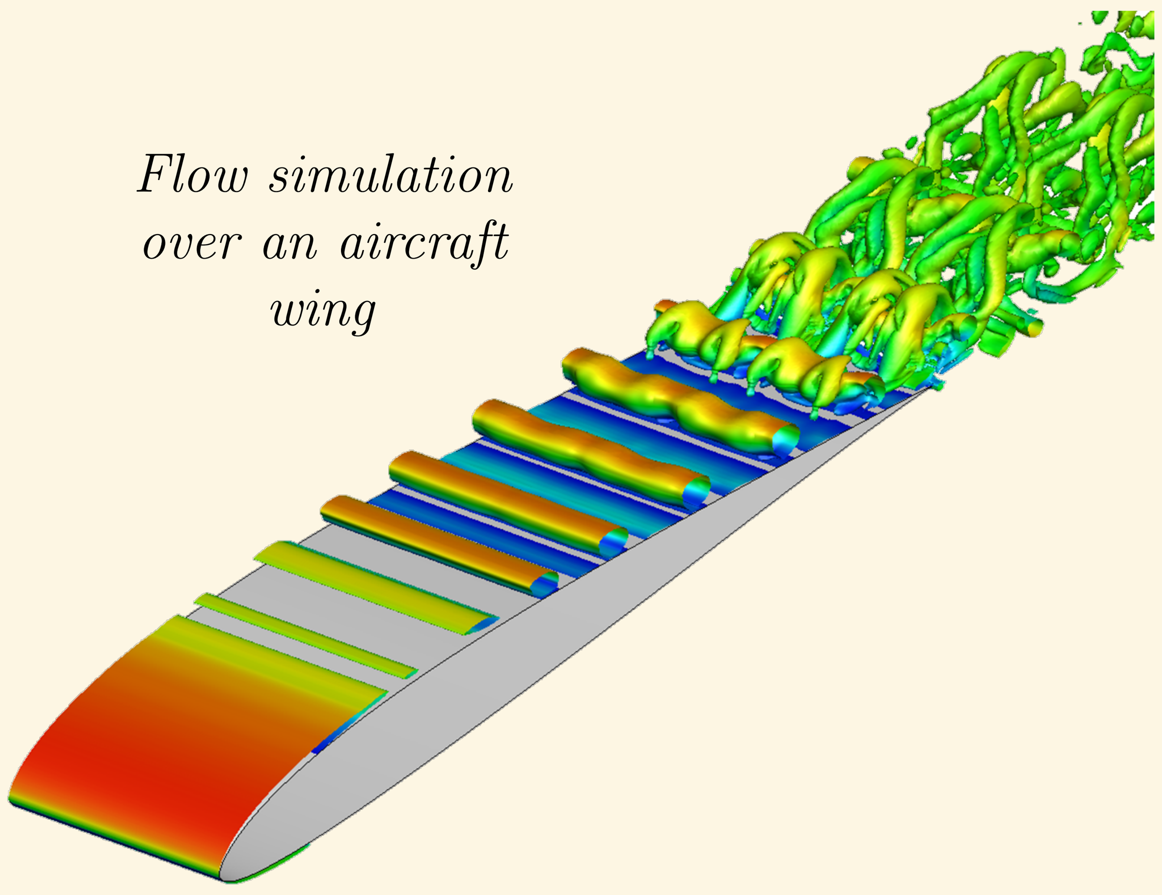
Scott Morgan — *MorganSN@cardiff.ac.uk* — *Supervised by: Dr. Christopher Davies*

The title is a simple question!

Aeroplane wings are nothing like rotating disks... Right?

But there's not a simple answer...

- Not for a mathematician!
- In fact, a disk rotating in air can help us understand many **complex properties** of the flow over an **aircraft wing**.



Flow simulation over an aircraft wing

One set of equations to rule them all

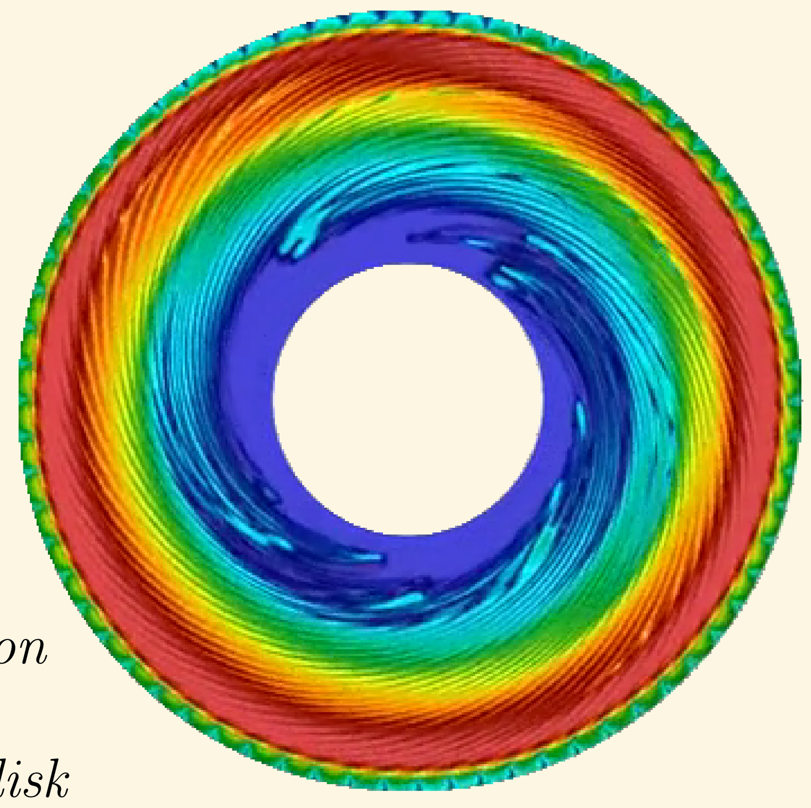
The Navier-Stokes Equations

$$\frac{\partial \mathbf{u}}{\partial t} + (\mathbf{u} \cdot \nabla)\,\mathbf{u} = -\nabla p + \frac{1}{R}\nabla^2 \mathbf{u}$$
$$\nabla \cdot \mathbf{u} = 0$$

- Fundamental equations governing fluid flow.
- Very **poorly understood** in general.
- The **Clay Mathematics Institute** offers a **\$1 million** prize for:

  "...making substantial progress toward a mathematical theory which will unlock the secrets hidden in the Navier-Stokes equations."

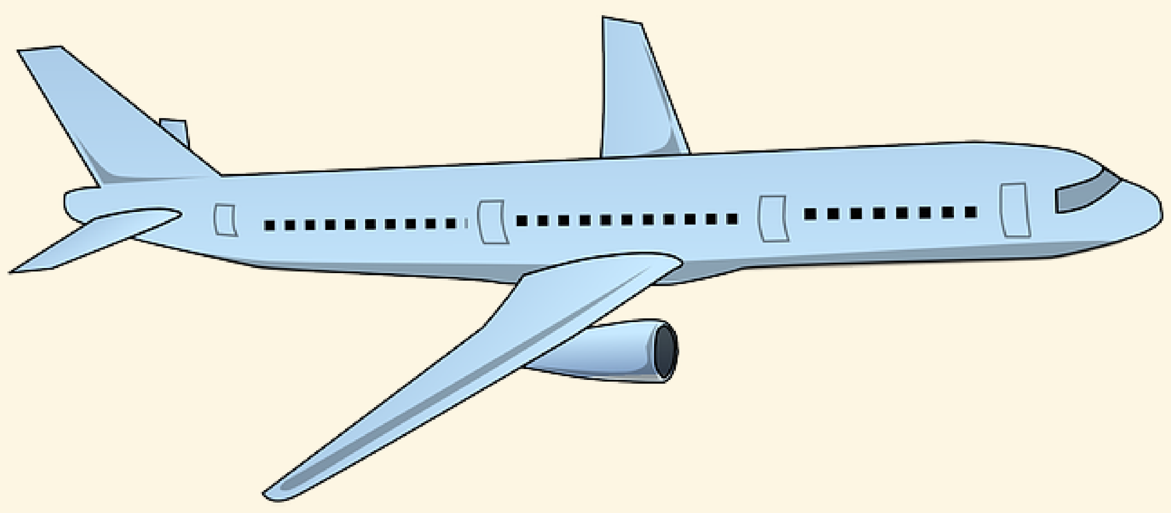
- Understanding these equations will shed light on **turbulence**, **weather patterns**, **ocean currents**, **blood flow** and many other **physical**, **biological** and **chemical** phenomena.



Flow simulation over a rotating disk

Rotating disk flows are cool...

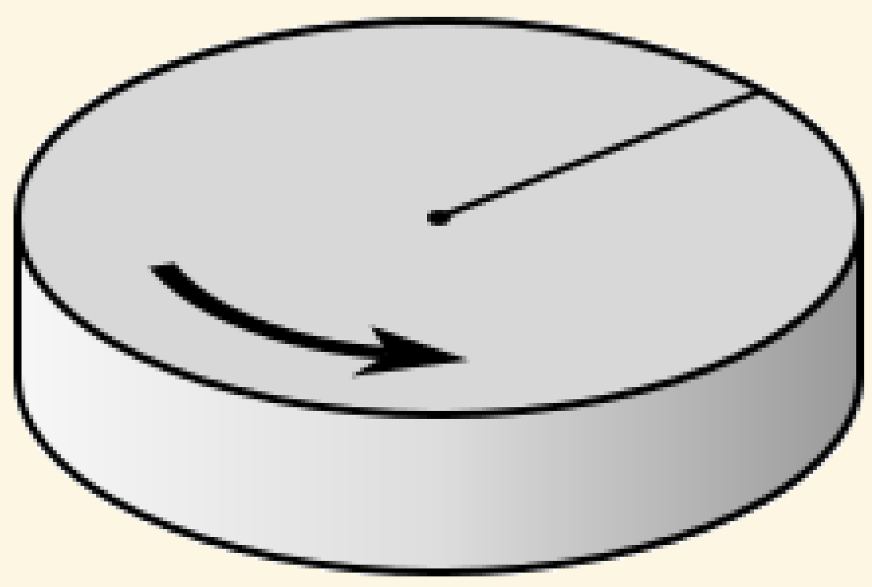
- The flow above a rotating disk contains three important flow components:
  - **Laminar** - neat & well-behaved.
  - **Transition** - getting messier...
  - **Turbulent** - totally chaotic & random.
- Importantly, all three can exist **at the same time** but at different **radial positions**.



The research question

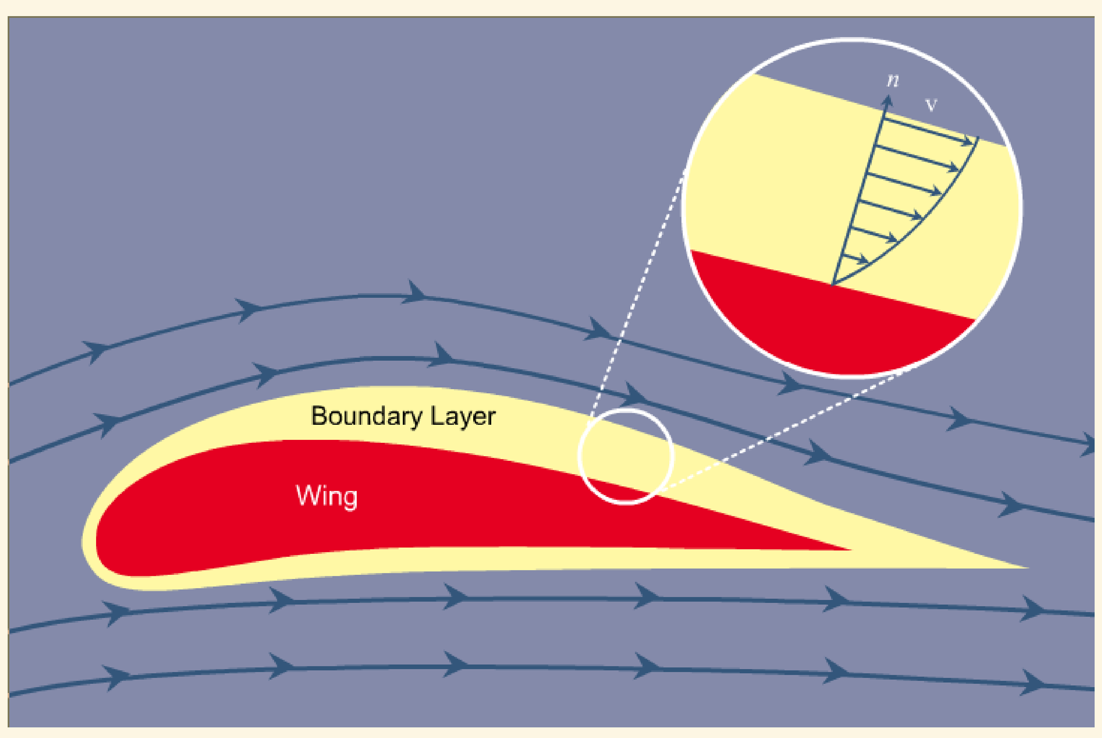
Does oscillating the surface have a ***stabilising effect*** *on disturbances in the rotating disk boundary layer?*

Yes!
Our research has shown that on a rotating disk, typical properties which contribute to ***turbulent breakdown*** *are alleviated for certain* ***frequencies*** *of oscillation.*



What is a boundary layer?

- There is a small region around a surface where the air velocity **reduces to zero** and **sticks** to it.
- The **vast majority** of the friction and drag forces come from this tiny layer.
- The boundary layer on a commercial plane wing can be as thin as **1mm!**

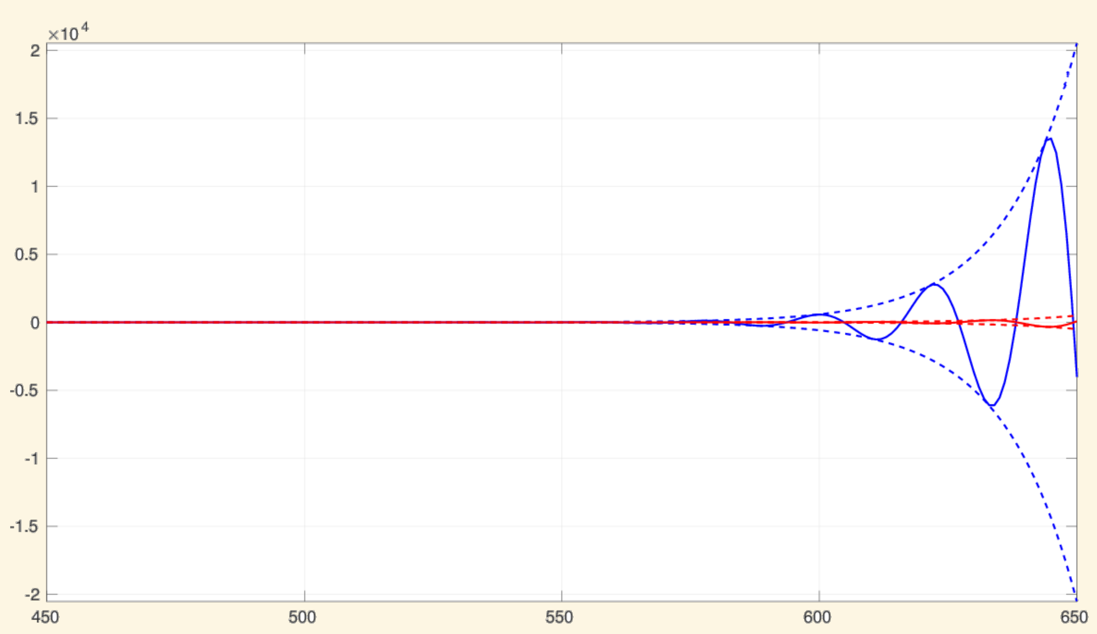


Why should I care?

- Turbulence is a major contributor to **drag**, which in turn greatly increases **fuel consumption**.
- This contributes to **carbon emissions**, a topic which needs no justification as to its **global implications**.

One illustrative result...

- Imagine you **hit** the disk at some point.
- You'll create a **disturbance** which travels along the surface (like ripples on a pond).
- We can **simulate** what will happen to these ripples for different flow configurations.



What is this picture?

- The blue line shows what happens to this disturbance when the disk rotates at a **steady** rate.
- The red line shows a case with added **oscillation**.
- The disturbance grows at a much **slower** rate, indicating **stabilisation**.
- This stabilisation will **delay** and **mitigate** the effects of turbulence, leading to **greater fuel economy** and **reduced emissions**.

So we're going to put disks on wings?

- Not exactly...
- Remember this is a first step. We have shown that **oscillation is stabilising** for a rotating disk boundary layer.
- We are now working with industrial partners to **translate** our findings across to an aircraft wing.
- The most likely application is small oscillatory sections of wings, which **actively** combat turbulence.

Scan the code for awesome videos...

Simulations courtesy of E. Appelquist (KTH)

References

Literature:

[1] Davies, C. & Carpenter, P. W. 2001 *J. Comput. Phys.* **172**, 119-165.
[2] Lingwood, R. J. 1995 *J. Fluid Mech.* **299**, 17-33.
[3] Thomas, C., Bassom, A., Blennerhassett, P. & Davies, C. 2010 *Proc. R. Soc.* **467**, 2643-2662.

Image Credits:

[1] Wing Simulation - *M. Riherd, APRG*
[2] Disk Simulation - *E. Appelquist, KTH*
[3] Boundary Layer - *Smithsonian National Air & Space Museum*