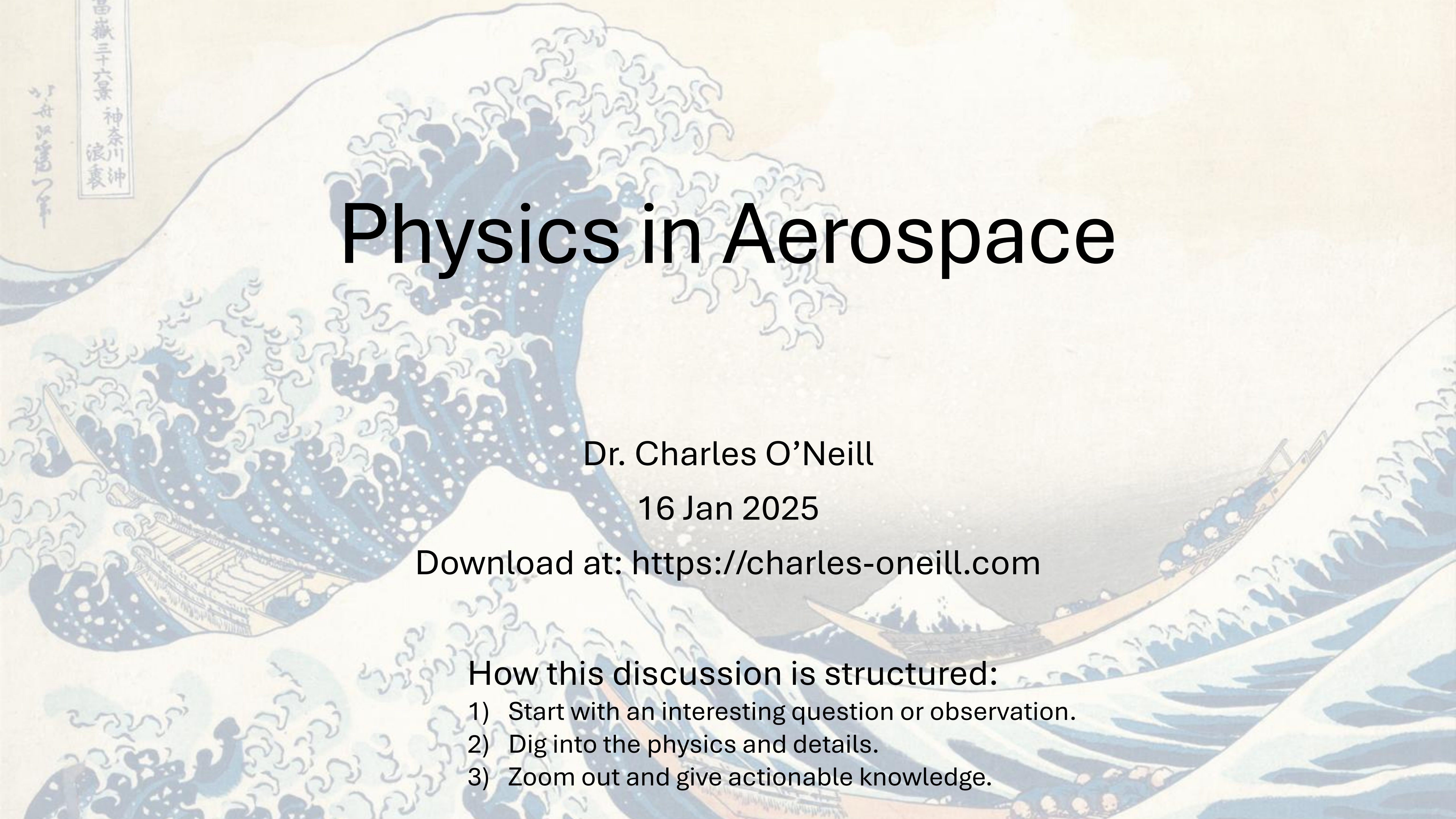


Physics in Aerospace

Dr. Charles O’Neill

16 Jan 2025

Download at: https://charles-oneill.com

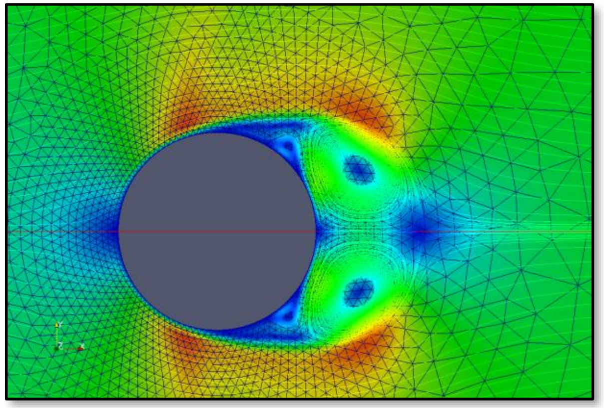
How this discussion is structured:

1) Start with an interesting question or observation.
2) Dig into the physics and details.
3) Zoom out and give actionable knowledge.

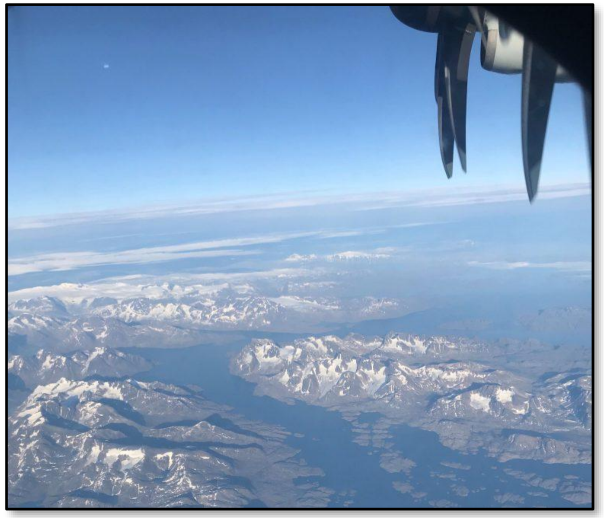
A brief history of my aerospace life.

Ancient History

Drones & RC Aircraft



Computational Fluid Dynamics



Remote Sensing

1st Solo Flight

Know your stuff; doors open!

Prototype Aircraft Design

Flight with My Family

What does it take to design this?

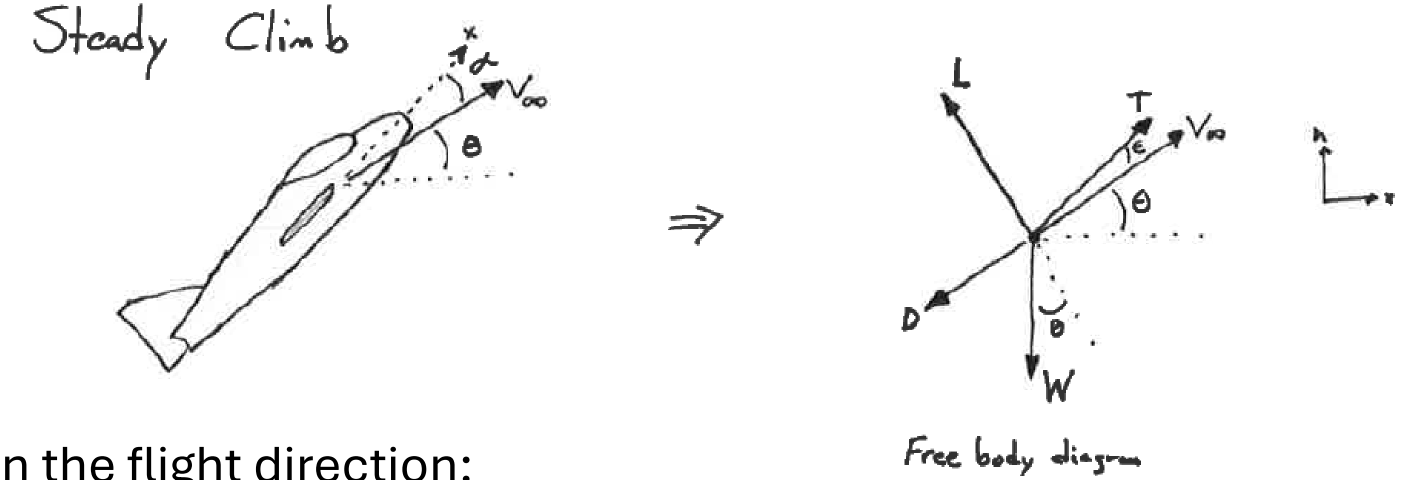
- Aerodynamics
- Structures
- Propulsion
- Flight Controls
- Avionics
- Mission Systems
- Environmental Control Systems
- Pilots & Pilot Systems

- $$$
- Leadership & Management
- Concept (!)
- Fabrication
- Testing facility & airspace

All models are wrong, but some are useful.

—G. Box

Example: Let's derive and explore the dynamics of a gliding aircraft (no propulsion).



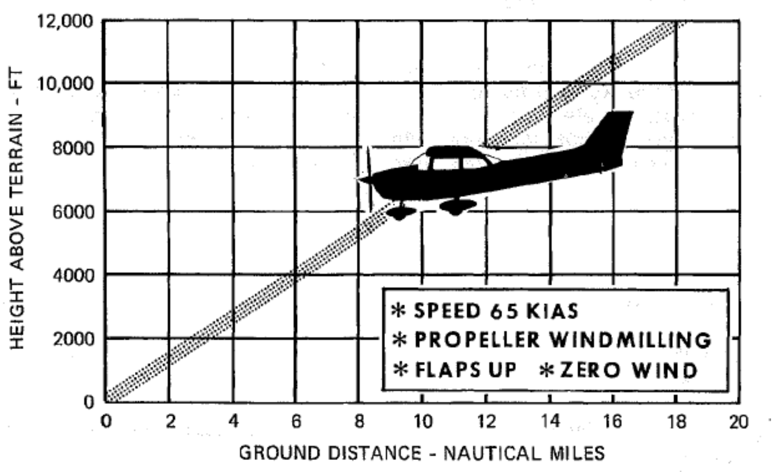


Figure 3-1. Maximum Glide

In the flight direction:

$$T - D - W \sin\theta = 0$$

Orthogonal to the flight direction:

$$\mathrm{L} - W \cos\theta = 0$$

Combine to form

$$\frac{D}{L} = -\frac{W \sin\theta}{W \cos\theta} = -\tan\theta$$

$$\theta_{glide} = \arctan\left(\frac{\mathrm{L}}{D}\right)^{-1}$$

For a Cessna 172 at 2400 lbs, the best glide is 65 knots with a glide ratio of 9:1 (6 deg down).

Question: Does weight influence the glide angle?

No! Weight canceled out!

Let's look at the glide velocity

The physics scale through non-dimensionalization of the fundamental fluid dynamics:

$$\text{Lift} = \frac{1}{2}\rho V^2 S C_L$$

Lift scales with density, wing area, configuration (i.e. C_L = f(AOA)), and the square of velocity.

At 1700 lbs, the glide velocity would be the ratio of mass and velocity squared:

$$\frac{1700}{2400} = \frac{V^2}{65^2\ kts} \Rightarrow V = \sqrt{\frac{1700}{2400}}65 = 54\ kts$$

Thus at 1700 lbs, the glide velocity slows to 54 kts and the angle remains the same.

Correct! Pilots vary aircraft operating speeds depending on the weight.

Broken Model: Where is the physics valid?

Let's look at the glide velocity again.

What is the theoretical glide velocity at 240,000 pounds?

$$\frac{240000}{2400} = \frac{V^2}{65^2\ kts} \quad \Rightarrow \quad V = 650\ kts$$

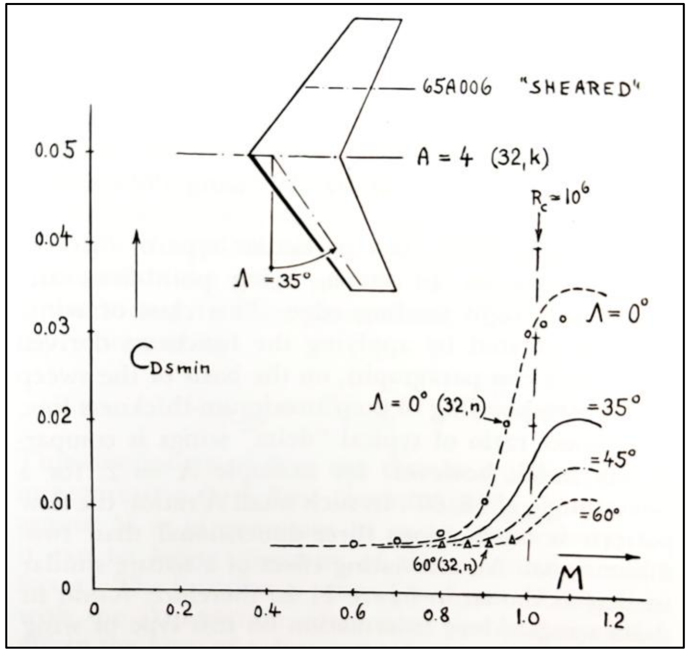
Wait! The speed of sound at sea level is 667 kts! Do you really think the aerodynamics will give a constant drag as Mach 1 is approached? Nope!

The fundamental physics and flow mathematics change form above Mach 1. **The mathematics become a different type of equation**. Instead of decaying spherical pressure waves, we see conical shock waves!

Shock waves create "wave drag" as a shock is not 100% efficient at changing velocity to pressure.

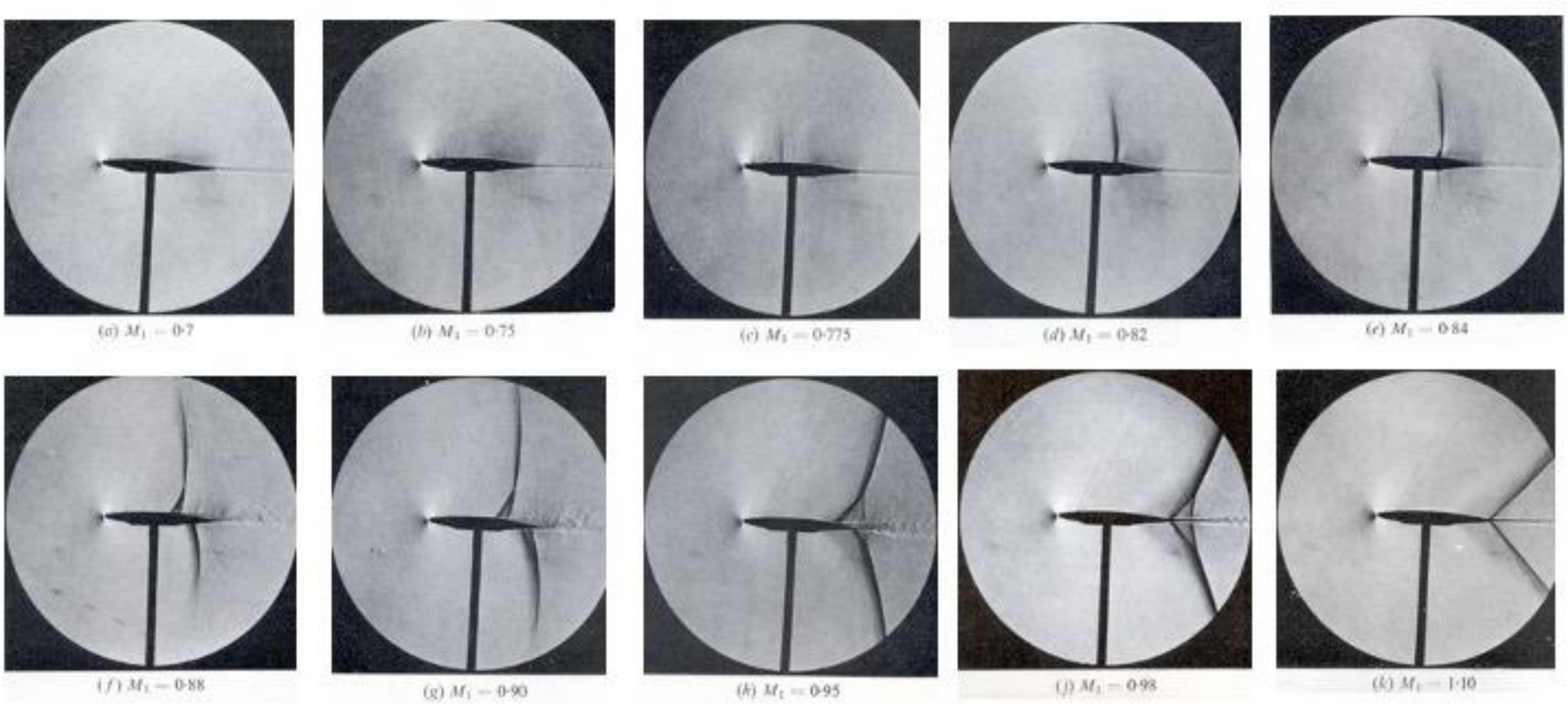
Aircraft drag goes up 5x – 10x near Mach 1.

The constant L/D glide model is broken. So is the structure!



Drag, Hoerner

Shocks and Airfoils



Mechanics of Fluids, Duncan, Thom, and Young.

Attention to Details Matter: F-86 vs MiG-15

The USAF F-86 had a lower maximum altitude, lower thrust, higher weight, smaller armaments, and a politically constrained operating environment. Yet, the F-86 had an 8 to 1 advantage over the MiG-15 in Korea.

Why?

The F-86 was a pilot's airplane with attention to detail: Excellent visibility, radar guided gunsights, a wider flight envelope, and superior flight controls.

Perfect? Definitely not by modern standards.

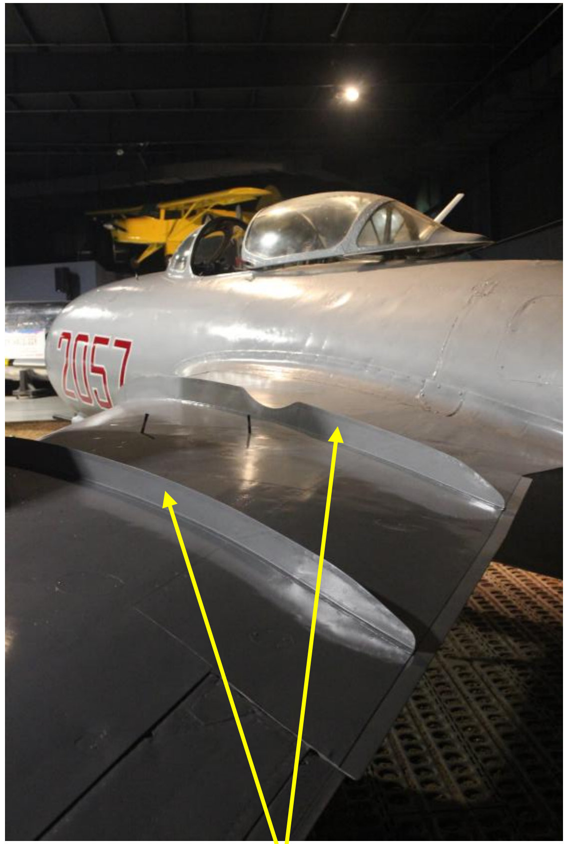
Secret Aerodynamics & Controls Advantage.

The entire F-86 stabilizer pivots! New technology in 1950.

MiG-15 stabilizer is fixed with a movable elevator surface. Old tech.

The USAF F-86 has a superior flight control system with a secret technology. The movable horizontal stabilizer that keeps the aircraft controllable at low and high speeds. The MiG-15 became unstable above Mach 0.92.

Life isn't perfect: Applied Physics & Engineering uses a bag of tricks to fix specific bad behaviors.

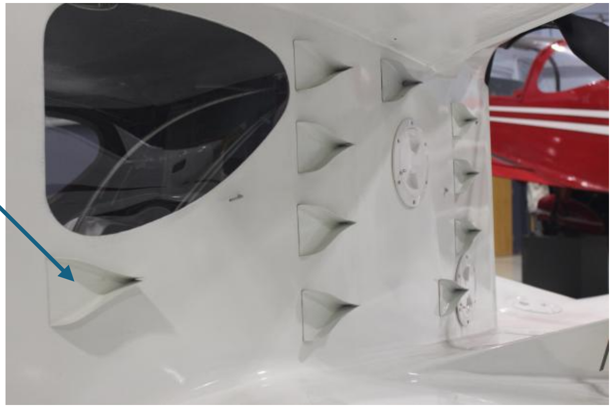


Unwanted spanwise flow causing loss of control? Add a fence or two!

To meet the FAA's stall requirements to certify an aircraft, an imperfection "stall strip" is often specifically added to the leading edge. Placement is an art! Engineers work with pilots.

Inlet diverters remove BL

Unwanted flow separation? Use vortex generators. The drag goes up slightly but the flow vibration goes down significantly.



Fluid Motion Occurs at Wide Ranges of Scale.

"When I meet God, I am going to ask him two questions: Why relativity? And why turbulence? I really believe he will have an answer for the first."

— Werner Heisenberg

"Big whirls have little whirls,
That feed on their velocity;
And little whirls have lesser whirls,
And so on to viscosity."

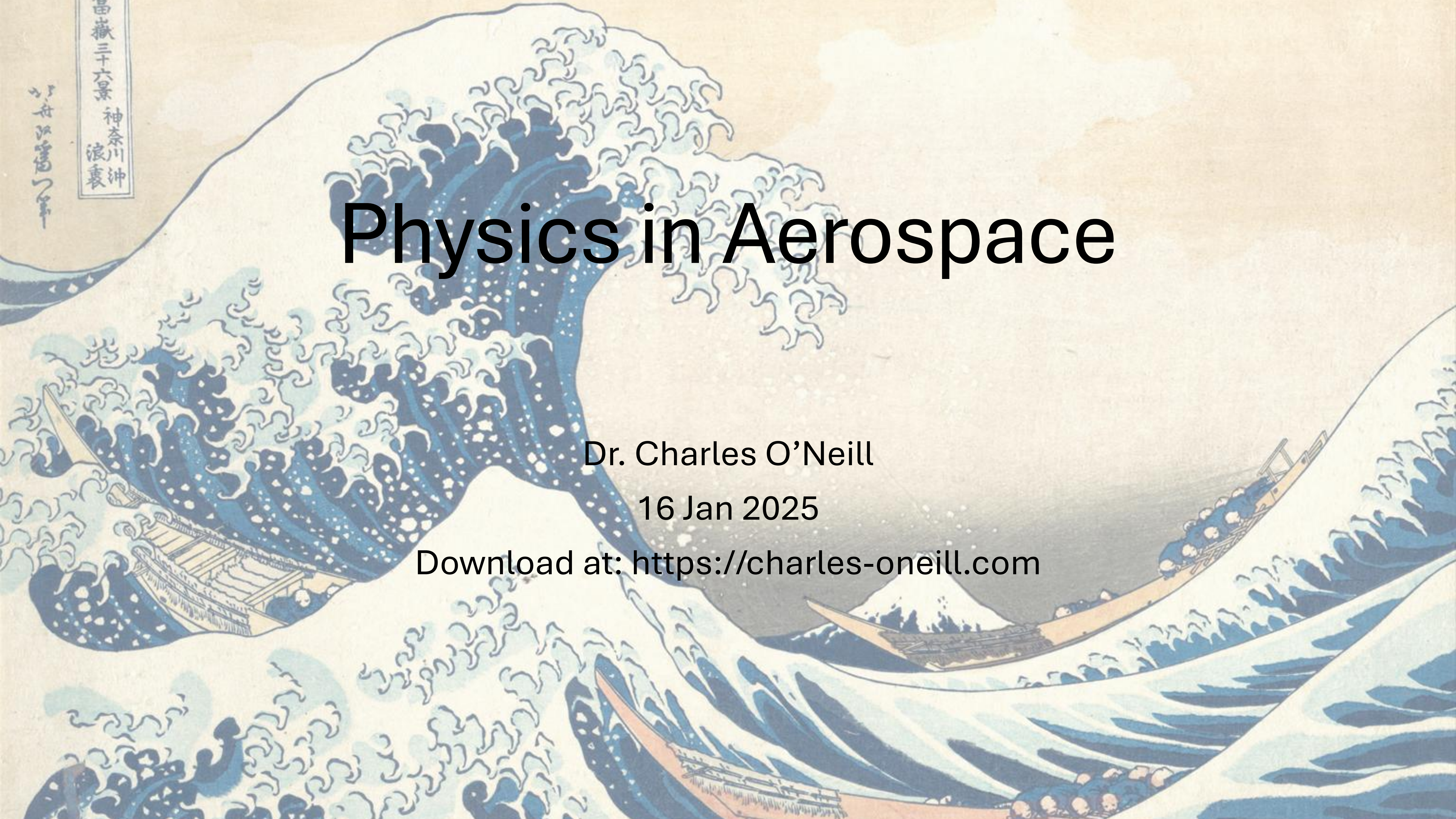
— Lewis Fry Richardson

Tips for Physics and Engineering

Level 0: Equations & Concepts
Level 1: Solving problems correctly
Level 2: Knowing which problem to solve. What accuracy?
Level 3: Observing the actual needs and physics concepts
Level 4: Integrating, planning, and fielding coupled solutions

A few more tips:

- Know how to effectively communicate and sell.
- Know how to sketch and draw. You will drive the design cycle. A sketch can get you out of a bind; if in doubt, draw a free body diagram.
- Use the right tools at the right time. Detailed computer simulations are amazing tools, but not appropriate for initial concept designs.
- Ethics matters, even if it costs you money and friends. The alternative is worse.
- Prototypes beat paper. The act of making teaches.
- Take Action: Get flying lessons; get a Part 107 drone license; make things.



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Misc Slides

Warning! I'm an Aerospace Engineer.

- We will discuss selected ideas and observations that may assist you in your journey.
- This discussion may contain simplifications or errors that are not appropriate or safe. In the immortal words of Gary Larson from the Far Side:

"Say … what's a mountain goat doing way up here in a cloud bank?"

N60HF, O'Neill