



ME 6135: Advanced Aerodynamics

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Introduction

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Aerodynamics

Aerodynamics is the study of flow dynamics of air around and within a moving object and its interaction with the atmosphere.

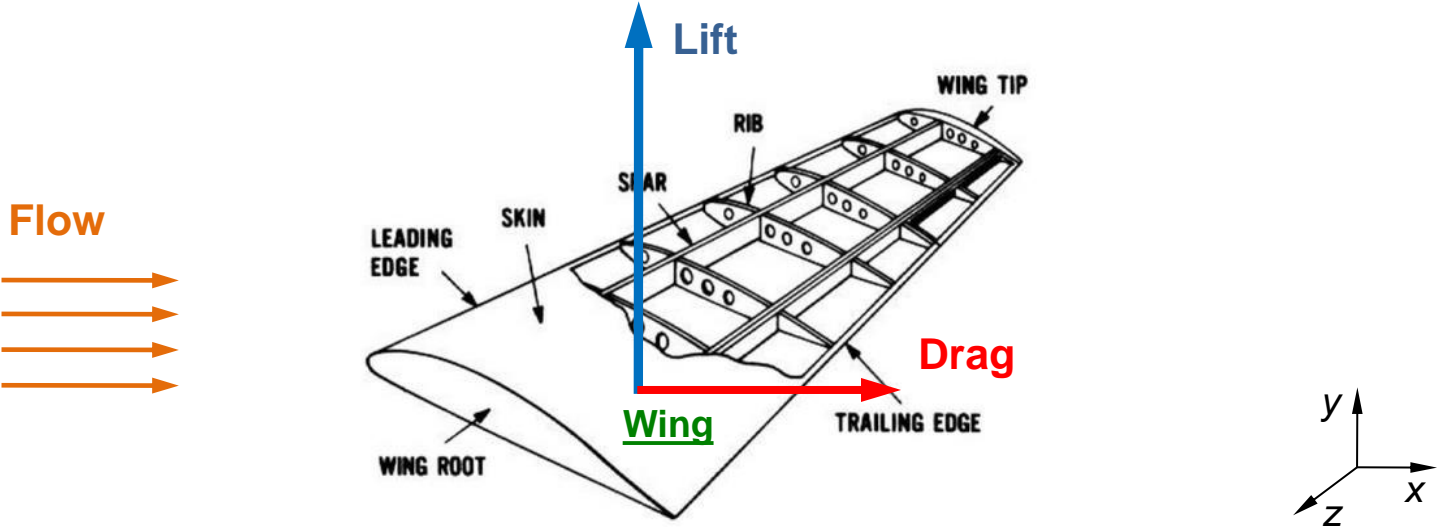
This field of engineering deals with the aerodynamic forces; namely - **lift** (L) and **drag** (D) and **moments** and the heat transfer rates acting on a vehicle in flight.

These mechanical parameter greatly depends on the pattern of flow around the vehicle. And the resultant flow pattern depends on:

- the geometry of the vehicle (mostly the shape of the airfoil: NACA, NASA SC, RAE, ONERA, BGK, NLR, DLR, OAT, Eppler, etc.)
- its orientation with respect to undisturbed free-stream (**angle of attack - AOA**)
- flight speed (**Mach No.**) and
- flight altitude (**density**) at which the vehicle is moving.



Lift (L) and Drag (D)



Wing consists of series of airfoils placed along the spanwise direction (z-axis)

Three airfoil types are shown with flow arrows pointing right and a 2D coordinate system (x, y) to the right.

- Symmetrical airfoil**: A simple, balanced airfoil shape. **NACA 0012 airfoil** (National Advisory Committee for Aeronautics)
- Asymmetric airfoil**: An airfoil with a curved leading edge and a flat trailing edge. **RAE 2822 airfoil** (Royal Aircraft Establishment, UK)
- NASA multiement airfoil**: An airfoil with a leading edge slat, a main element, and a trailing edge flap. **NASA multiement airfoil** (National Aeronautics and Space Administration)



Airfoil flow dynamics

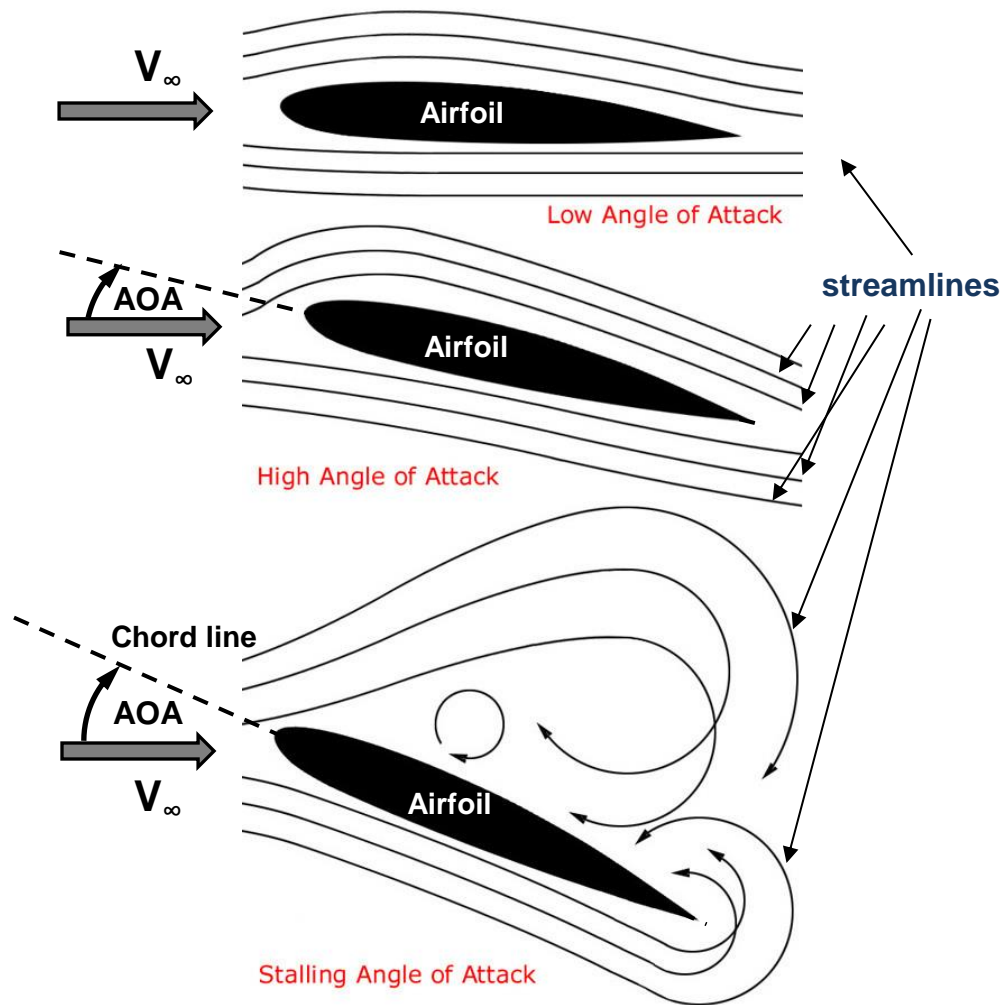


Fig. Flow past an airfoil

AOA= Angle of Attack

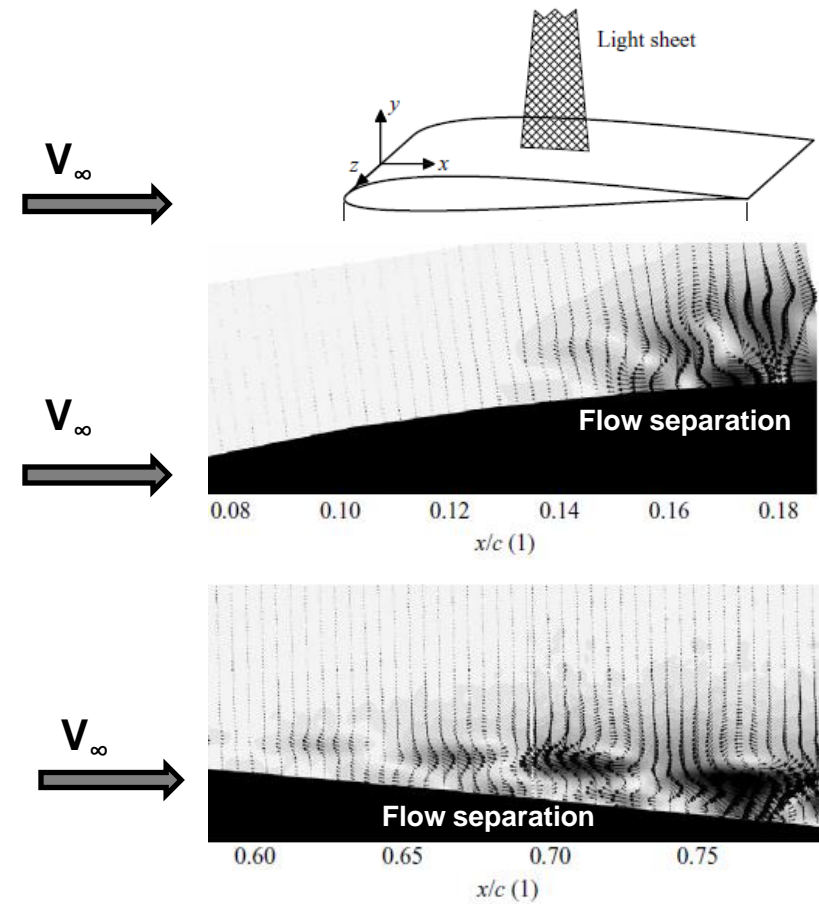


Fig. Separation bubble from SD7003 airfoil at $Re=66000$
Journal of Fluid Mechanics 2009; pp-129-153





The complete flight of a vehicle/object is mostly comprises of the following matters:

- Aerodynamics
- Propulsion and Power
- Structural mechanics/dynamics
- Stability and control

Aerodynamics is the fundamental of aerospace engineering (aeronautics).

A great scope is available for **propulsion technology (Jet propulsion and rocketry)** and **structural dynamics**.



Classification of Aerodynamics

Aerodynamics can be broadly classified to two groups-

1. External aerodynamics
2. Internal aerodynamics

External aerodynamics	Internal aerodynamics
<ol style="list-style-type: none">1. Helicopter2. Civil aircraft/passenger aircraft3. Cargo aircraft4. Military aircraft (most advanced)5. Rockets6. UAV7. Spaceships8. Wind turbine9. Racing car aerodynamics10. High speed train aerodynamics	<ol style="list-style-type: none">1. Rocket nozzle (C-D nozzle)2. Supersonic/hypersonic inlet3. Scramjet engine4. Compressor/turbine blade5. Fan blade6. Butterfly valve7. Cascade





Lockheed Martin F-22A Raptor



Avro Vulcan Bombar



A-10 Thunderbolt II

Military aircraft (s)
Flying faster than the speed of sound ($M > 1$)



Propulsion nozzles



Space Shuttle



JAXA spacecraft nozzle



Space Shuttle Main Engine (SSME)



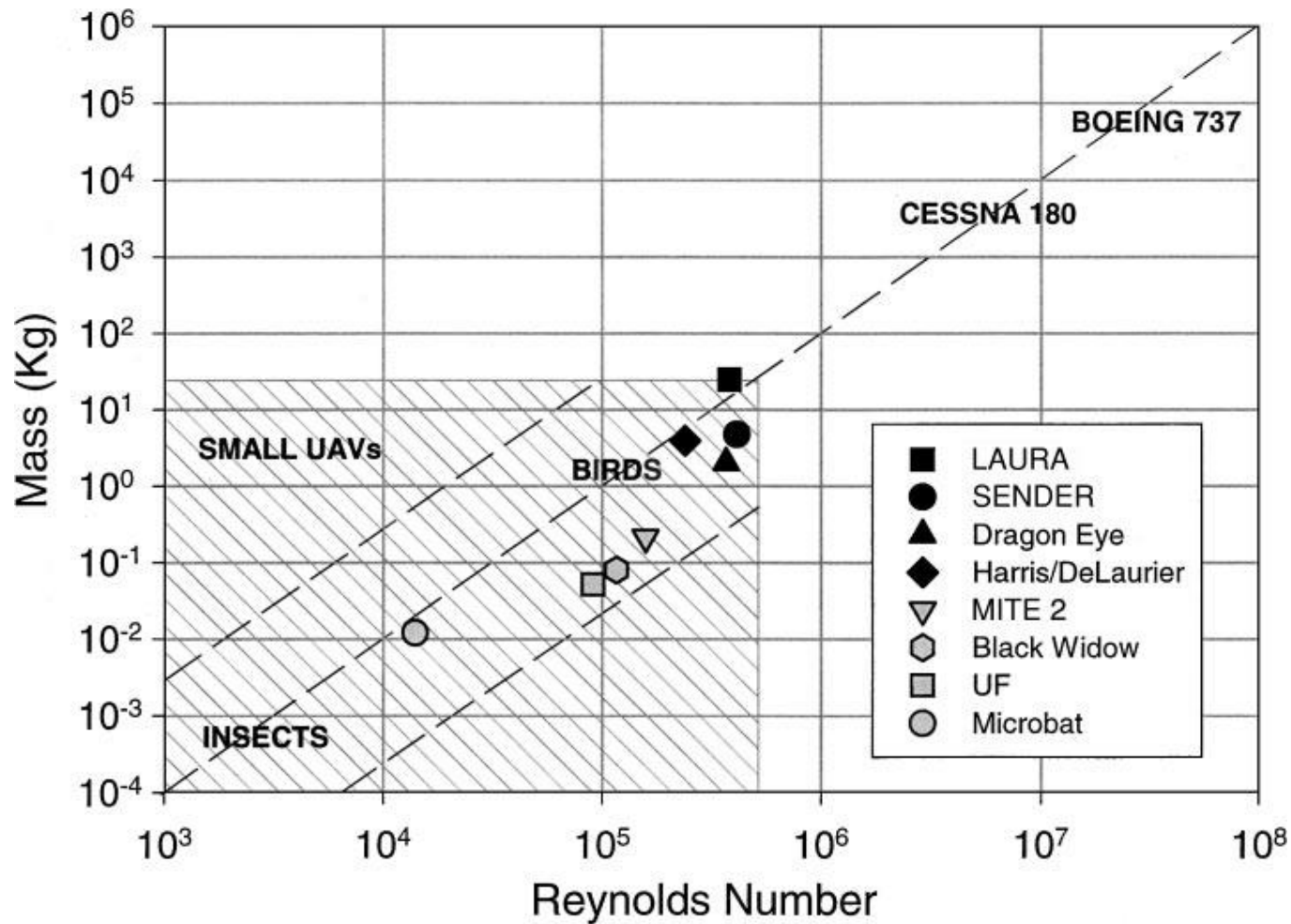
Vehicles with wing spans less than approximately 6 m and masses less than 25 kg are usually considered as UAV (Unmanned air vehicle).

UAV are either remotely piloted or autonomous with artificial intelligence. Requirements for a typical low-altitude small UAV include

- Long flight duration at speeds between 20 and 100 km/h
- Cruise altitude 3 to 300 m
- Light weight
- All-weather capabilities

Because of recent availability of very small sensors, video camera, and control hardware, systems as small as 15 cm with mass of 80 g, referred to as micro-air vehicle (MAV), are now possible for limited missions.





$$Re = \frac{\rho VL}{\mu}$$

Fig. Reynolds number range for flight vehicles*

The most important parameter in fluid dynamics/aerodynamics is the Reynolds number, **Re** which is the ratio of inertia force to viscous force.

* <http://www.annualreviews.org/doi/pdf/10.1146/annurev.fluid.35.101101.161102>





The physics of aerodynamics can be learnt from:

- **Theoretical aerodynamics** (governing equations, simplification, theoretical modeling etc.)
- **Experimental aerodynamics** (wind tunnel, flow visualization - PIV, LIF, Schlieren, instrumentation, measurements etc.). **ME, BUET has subsonic and supersonic (M~2.1) wind tunnels.**
- **Computational aerodynamics** (governing equations, numerical techniques, computational resources, CFD)

Since the powerful computers are available now-a-days, aerodynamic problems are conveniently solved using CFD software, such as

- ANSYS FLUENT (ME, BUET has license)
- ANSYS CFX
- FASTRAN
- STAR CCM+
- OpenFOAM (free GPL)

This course (ME 6135) will cover the basics of aerodynamics based on theoretical approach (theoretical aerodynamics).

