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The Science of Flight and the Insight it Provides

June 6, 2022
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A Science, Not a Theory:

The science of flight is sufficiently straight forward that theories are not needed. This avoids falling into the traps of using faulty theories and heuristics that can cripple an industry (as is the case with today's aerospace industry).

Conservation equations (equations of continuity) are the science. Conservation equations are applied to the boundary of a control volume. The single most important tool used by chemical engineers is the conservation equations (conservation of mass and atomic balances).

The science of flight is based on the Conservation of Force applied at steady-state conditions on the surface of an aircraft. That force balance is then interpreted in vertical and horizontal dimensions to elucidate lift and drag as follows:

Lift -In the vertical dimension, the vertical component of the <u>surface integral</u> of pressure over the aircraft surface is the lift; and that lift is equal and opposite the aircraft weight.

Drag - In the horizontal dimension, the horizontal component of the <u>surface integral</u> of pressure over the aircraft surface is the drag; and that drag is equal and opposite the thrust of the engines at steady-state (constant speed and elevation).

Shear Force – The above analysis only considers the pressure force at the surface and neglects shear force. For smooth surfaces at low velocities, shear force is typically two orders of magnitude less than dynamic pressure force on a surface; however, it can become more significant at higher velocities. In this analysis, the impact of shear force is a qualitative correction as a final step.

A resulting ratio of lift to drag ("L:D") is the measure of flight efficiency where weight divided by L:D is the drag force that needs to be overcome by an aircraft's engines. The drag times velocity provides the power requirements, and power times flight time provides fuel consumption.

The Surface Integral:

In this analysis, the complexities and amount of information needed to perform a surface integral can be daunting

; however, the analysis of a flat surface provides significant insight. The analysis is an application of trigonometry. More specifically, D:L is the tangent of the pitch angle; therefore, L:D is the ARCTAN of the pitch angle. In the limit of small angles, the following equation becomes increasingly accurate as a trigometric approximation:

$$L:D = 57.3\ \theta$$

where θ is air's angle in degrees of attack (pitch angle) and 57.3 a conversion factor (180 / π) from radians to degrees. Hence, the performance of a flat plate airfoils is as illustrated by Figure 1.

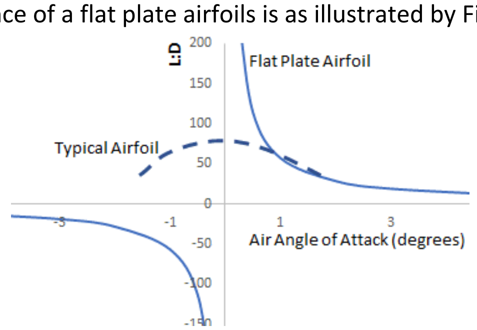

Figure 1. L:D of flat plate airfoil

Dynamic Pressure Generation:

During flight, the upper surface of a lifting body flat plate has a lower-than-ambient pressure; the lower surface has a higher-than-ambient pressure. The higher pressure is caused by the momentum of the air impact the surface.

The "no-slip boundary condition" is key to the generation of lower pressure on the upper surface. The no-slip condition causes air at the boundary to follow the surface. At distances further from the surface, the momentum of the air molecules provide a force to separate from the surface (due to its negative pitch). Combined, the no-slip boundary and the momentum of the air molecules cause air to expand in the "boundary layers". When working well, air flow in the boundary layers is laminar, which maximizes the expansion and decrease in pressure.

Lift begins to fail when turbulence replaces laminar flow. Basically, turbulence brings the ambient pressure closer to the surface and reduces the desirable dynamic pressure (which is a low pressure above the surface and a high pressure below the surface). Ice can cause the air next to the surface to "slip", creating turbulence with loss of lift. Repaid changes in the surface orientation can also cause turbulence and loss of lift.

Decreasing Drag with Increasing Velocity

Figure 2 illustrates a aircraft comprising a front tiltwing (delta wing) pulling two towed platforms.

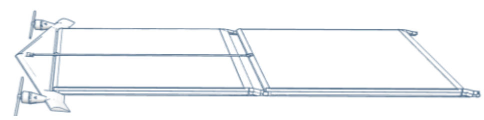

Figure 2. Aircraft with towed platforms.

It is to observe/prove that as you pull a sheet/plate through the air, the faster the plate is pulled the lower the θ. The lift component of force on the sheet is approximately constant which translates to a nearly constant ΔP (difference between surface and ambient pressure) on that surface. A lower θ and near-constant ΔP translates to a lower drag.

Yes, the <u>drag on a towed plate actually decreases with increasing velocity</u>. This is the basis for identifying that 24/7 towed platform aircraft are more-compatible with high speed transit versus contemporary counterparts. Also, this is in direct contrast to shear and form drag correlations that typically have drag increasing with the square of velocity.

Sum of Parts Analysis

The sum of parts analysis divides a complex object into multiple simpler objects. In this analysis, the flat plate airfoil can be considered a rod of lateral orientation as a rounded front edge and a flat sheet. The rod has drag increasing with velocity squared while the flat sheets have drag decreasing with increasing velocity. The result is a L:D versus air angle of attack that no longer has a singularity at 0° [air angle of attack].

In a broader sense, a flat plate airfoil has a minimum front profile at an air angle of attack near or at 0°; wherein, that minimum profile ultimately limits the maximum L:D like the rod. In comparing a flat plate versus a bent plate, the bent plate would have an increased profile, like the rod. This analogy identifies that maximum L:D is for the thin platform of an evenly distributed load and plate of constant thickness, such as a thin structural battery with photovoltaic cells on its upper surface.