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Project 3: Estimation of Incompressible Drag Coefficient for an Airplane

In this experiment we intend to determine the parasitic drag coefficient for an airplane. The complete drag polar for an airplane has a parabolic form,

$$C_D = C_{Dp} + C_L^2 / (\pi e AR) \quad - (1)$$

where, C_D is the drag coefficient.

C_{Dp} is the profile drag coefficient.

C_L is the lift coefficient.

e is the airplane efficiency factor.

AR is the wing aspect ratio.

In this project we intend to determine the C_{Dp} of the airplane of choice. This is the portion of the drag coefficient independent of lift, and is called the parasitic drag coefficient. The parasitic drag varying with lift is accounted for in the airplane efficiency factor e . To determine the C_{Dp} we use the formula,

$$C_D = \sum_0^n \frac{K_i C_{f_i} S_{wet_i}}{S_{ref}} \quad - (2)$$

Where 'i' represents the different parts of the airplane i.e. the wing, fuselage, nacelles, empennage, pylons, etc. In this formula,

C_f = skin friction coefficient.

S_{wet} = wetted area of surface in actual contact with air.

K = form factor obtained graphically.

S_{ref} = reference planform area of the wing.

The airplane of choice for this project is the Boeing 777-300. A schematic showing the dimensions of the airplane follows (on the right),

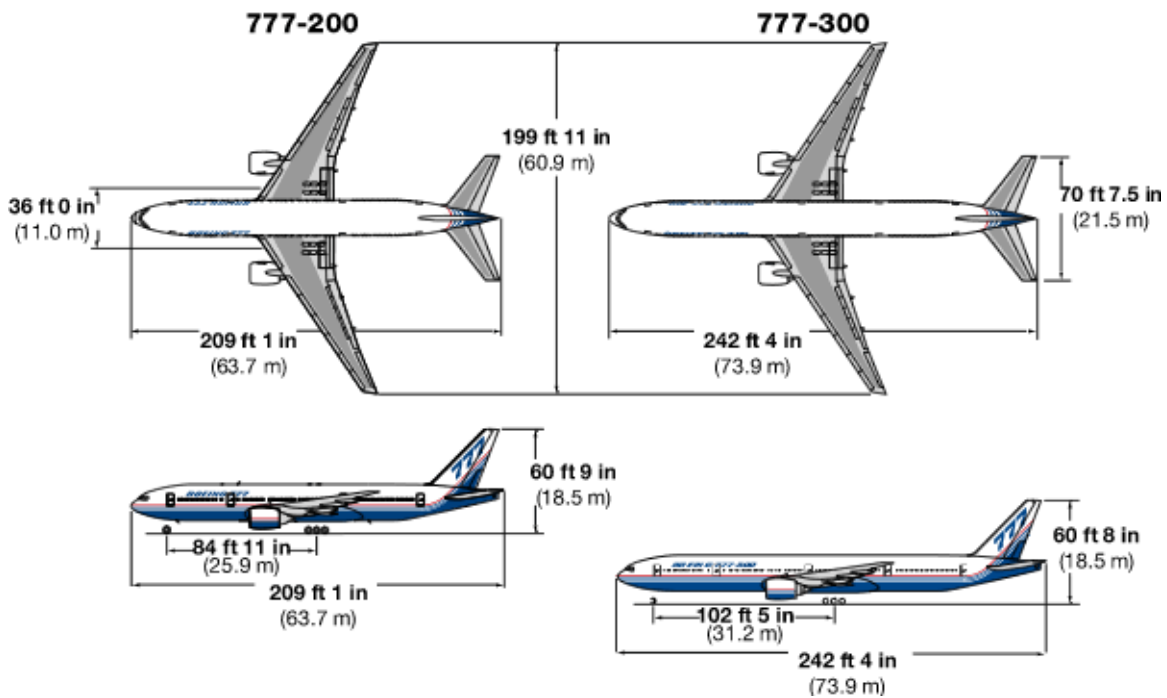


Figure 1 (Schematic of the Boeing 777-300)

The Reynolds number is used in order to determine the skin friction coefficient C_f from the graph (Pg. 179, Shevell, Fig. 11.2). The formula for Reynolds number based on length R_N is $\rho V L / \mu$, where,

$$\text{Density } \rho = 0.0023769 \text{ slugs/ft}^3$$

$$\text{Cruise Velocity } V = 0.83 \text{ mach} = 803.9 \text{ ft/s}$$

$$\text{Viscosity Coefficient } \mu = 2.87 \times 10^{-7} \text{ slugs / (ft)(s)}$$

I) Primary Dimensions of the various parts of the airplane:-

(note that dimensions not shown of the drawing are obtained by suitable scaling)

WING

Root Chord C_R : 36.63 ft

Tip Chord C_T : 9.9 ft

Mean aerodynamic Chord C_{mac} : $2/3 (C_R + C_T - C_R C_T / (C_R + C_T))$: 25.9 ft

Wing planform area S_{REF} : 4617.2 ft²

Wing exposed(wetted) area: 7747.2 ft² x 2% (7742.2 ft²) = 7902.1 ft²

Wing Thickness ratio (t/c) : 0.12 Sweep at quarter chord : 35°

FUSELAGE

Fuselage length: 242.3 ft
 Fuselage Diameter: 20.3 ft
 Fuselage Wetted Area: 13907 ft²

ENGINE NACELLES

Nacelle length: 16.7 ft
 Nacelle diameter: 9.9 ft
 Nacelle wetted area: 519.3 ft²

HORIZONTAL STABILIZER

Root Chord: 16.7 ft
 Tip Chord: 6.7 ft
 Mean Geometric Chord: 12.4 ft
 Wetted Area: 1280 ft²

VERTICAL STABILIZER

Root Chord: 26.64 ft
 Tip Chord: 9.9 ft
 Mean Geometric Chord: 19.5 ft
 Wetted Area: 1241 ft²

II) Sample calculation for fuselage parasite drag coefficient ($C_{D_{fuse}}$) :

Reynolds Number $R_{N, fuse} = (803.9)(242.3) / .0004379 = 4.448 \times 10^8$

Skin friction coefficient, $C_f = 0.0015$

Body Length/Diameter $L/D = 10.1$

Form Factor $K_{Fuse} = 1.07$

Fuselage parasitic drag contribution from equation (2) is,

$\Delta C_{Dp, fuse} = (.0015)(1.07)(13907) / (4617.2) = .00483$

III) TABULAR SUMMARY OF DRAG CONTRIBUTION

Component	Wetted Area (S wet) ft ²	Effective Length (ft)	Reference Area(S ref) ft ²	Reynolds Number (Re)
Fuselage	13907	242.3	4617.2	444816099.6
Wing	7902.1	25.9	4617.2	47547408.08
Nacelle	519.3	9.9	4617.2	18174491.89
Hor. Stab.	1280	12.4	4617.2	22764010.05
Ver. Stab.	1241	19.5	4617.2	35798241.61

Table 1 (Component Data)

Component	Skin Friction Coeff (C_f)	Form Factor (k)	Drag contribution (C_{Dp})
Fuselage	0.0015	1.07	0.004834258
Wing	0.0014	1.22	0.002923154
Nacelle	0.0018	1	0.000202447
Hor. Stab.	0.0016	1.24	0.000550013
Ver. Stab.	0.0015	1.24	0.000499926

Table 2 (component parasitic drag)

IV) Calculation of total parasitic drag coefficient

The parasitic drag contributions for various components of the Boeing 777-300 are given below. Now we combine these in order to obtain the net parasitic drag coefficient.

Wing contribution $\Delta C_{Dp, wing} : 0.002923154$

Fuselage contribution $\Delta C_{Dp, fuse} : 0.004834258$

Vert. Stab. contribution $\Delta C_{Dp, vs} : 0.000499926$

Hor. Stab. $\Delta C_{Dp, hs} : 0.000550013$

Nacelle contribution x 2 $\Delta C_{Dp, wing} : 0.000202447 \times 2 = 0.00040489$

Engine Pylon contribution x 2 $\Delta C_{Dp, pylon} : 0.000020244 \times 2 = 0.00004048$

The total parasitic drag of the airplane is the summation of all the drag contributions reflected above and is equal to, $C_{Dp} = 0.00925$

In order to consider the effects of other factors that we cannot satisfactorily measure such as pitot tubes, lights, drains, radio antennae, surface gaps or base drag due to blunt rims, we consider a factor of 4% increase for drag contribution so our C_{Dp} becomes,

$$C_{Dp} = 0.00925 \times 1.04 = 0.009435$$

Additionally in order to account for control surface effects, gaps, vortex generators on wings, interference at interfaces etc we increase the drag factor by a further 6% (*Shevell page 184*) in order to obtain a net parasitic drag coefficient of **0.0106 for the Boeing 777-300**.

V) Assumptions Made

- 1) The fuselage wetted area is decreased by 10% from the corresponding cylinder area to account for nose and tail tapering.
- 2) The wetted area of the wing is increased by a factor of 2% in order to take into account the leading edge curvature.
- 3) Nacelles for the engines are approximated as cylindrical bodies and their form factor is taken to be 1 because of their considerably smaller size relative to the fuselage.
- 4) The wing pylons were difficult to measure because of their small size, hence their drag contribution was assumed to be 10% of the nacelle contribution.
- 5) The horizontal stabilizer drag was reduced by a factor of 50% in order to take into account the effects of it being in the high velocity wake area of the wing.

VI) Results

The parasitic drag for the long range high capacity passenger transport Boeing 777-300 was found to be **0.0106**. The airplane wing has an aspect ratio of 8.66 and an airplane efficiency factor of 0.88. The complete drag polar for the airplane is,

$$C_D = 0.0106 + (1/\pi e AR) C_L^2 \text{ or,}$$
$$C_D = \mathbf{0.0106 + 0.0417 C_L^2}$$

VII) References

1. Fundamental of flight, Second Edition, Richard S. Shevell 1989
2. Introduction to flight, Fifth Edition, John D. Anderson 2005
3. <http://www.boeing.com/commercial/777family/777technical.html>
4. <http://www.airliners.net/info/stats.main?id=107>
5. Jane's all the world aircraft

VIII) Computer Program

The C++ code for a simple program that can used to calculate the drag for an airplane follow,

```
#include<fstream>
int main()
{
    printf("Simple Program for parasitic drag calculation for an
    Airplane\n") ;
    printf("-----\n") ;
    printf("Input aircraft wing planform area (Reference area) :") ;
    double sref ;
    scanf("%f",&sref) ;
    int no ;
    printf("\nEnter number of components for drag calculation (For
    example, " ) ;
    printf("for 1 wing, 1 fuselage and 2 nacelles, enter 4) :") ;
    scanf("%d",&no) ;
    printf("\n") ;
    double drag[20] ;
    double tdrag=0 ;
    for(int j=1 ; j<=no ; j++)
    {
        double k, swet, cf ;
        printf("\n") ;
        printf("%s%d", "Component number ", j) ;
        printf("\n") ;
        printf("Enter form factor:") ;
        scanf("%f",&k) ;
        printf("Enter wetted area:") ;
        scanf("%f",&swet) ;
        printf("Enter skin friction coefficient:") ;
        scanf("%f",&cf) ;
        drag[j]=k*swet*cf ;
        printf("%f",drag[j]) ;
        tdrag+=drag[j] ;
    }
    printf("%s%f", "Total parasitic drag is :",tdrag) ;
    printf("\n\n Thank you for using the program ! \n\n" ) ;
    system("pause") ;
    return 0 ;
}
```