Drag Calculator Project

Fall 2024

1 Introduction

One of the most important goals in aerodynamics is to calculate the drag over an airplane. Interestingly you will find (in future design courses) that designing an airplane starts with quantifying the drag over it against the lift. Moreover, drag is not important only for design, it is important for finding the optimum operating condition given an airplane configuration. In this project a unique airplane configuration will be assigned to each student to calculate the total at different speeds, the different components of drag, and the optimum operating condition. In this project, optimum operating condition is selected to be the point where Lift to Drag ratio is maximum.

We will use the procedure adopted from Shevell [1] and discussed in the lectures along with the discussion sessions. There are charts in appendix A that will be used throughout this project. As an example a problem similar to Shevell's problem 11.1 will be solved in section 2 and plots will be provided; you will be asked to submit results similar to what is shown in section 2.

Finally, to be able to reach the final goal you will have to rely on a programming tool and computer aided design tool. You are required to use MATLAB and Solidworks for this project.

2 A version of Problem 11.1 as an example

As mentioned before, a problem similar to Shevell's 11.1 will be worked through as an example. Moreover, most of the givens that we will rely on here will be the same for the project unless mentioned otherwise.

Consider an airplane cruising at an altitude with conditions of density, temperature and dynamic viscosity given as follows $\rho = 0.0008754 slugs/ft^3$, $T = 400°R$, $\mu = 3.025x10^7 lb * s/ft^2$. The airplane weighs 98,000 lb with true air speed of $v = 765 ft/s$ and has a geometry configuration given in Table 1. Notice that some variables, such as the wing sweep back angle, are given as symbols and a value at the same time. This is because these are the parameters that will be assigned uniquely to each student. However, for the demonstration purposes here, we will use the values given which are the same ones in problem 11.1. Notice that we did not consider the flap hinge fairings as well.

First we will start by solving this specific flight condition at $v = 765 ft/s$. Following the lecture, discussion notes and the charts in appendix A, the final results for this specific condition can be found in Table 2. This table adds up to define the $C_{D_p} = 0.0163$ (parasitic drag) of the airplane. A couple of key points: first, the skin friction coefficient in our calculations was done based on the typical transport aircraft roughness log-log curve (see Figure 2 (a) in Appendix A). This is very important to match your results with the given example and is required when you calculate the skin friction drag for your project. Second, the total parasitic drag along with aspect ratio will define the airplane induced drag using Figure 2 (d) provided in Appendix A. It is important to mention that in this chart, there is correction for the Oswald efficiency e_Λ based on the zero sweep angle Oswald efficiency $e_{\Lambda=0}$ and the aspect ratio. Please neglect this for the project and it is not considered here in this example. Hence, the induced drag coefficient at this operating condition will be $C_{D_i} = 0.00645$.

Table 1: Airplane Geometry

Wing		Fuselage	
Span	$= b_{wing} = 93.2\ ft$	Length	$= L_f = 107\ ft$
Planform area	$= 1000\ ft^2$	Diameter	$= D_f = 11.5\ ft$
Average t/c	$= 0.106$	Wetted area	$= S_{wet_f} = 3280\ ft^2$
Sweepback angle	$= \Lambda_{c/4,wing} = 24.5°$		(use 0.8 x $\pi D_f L_f$ to get the fuselage wetted area for your airplane)
Taper ratio	$= \sigma_{wing} = 0.2$		
Centerline Root chord	$= c_{r_{o,wing}} = 17.8\ ft$		
Wing area covered by fueslage	= 17 %		

Vertical Tail		Horizontal Tail	
Exposed planform area	$= 161\ ft^2$	Exposed planform area	$= 261\ ft^2$
t/c	$= 0.09\ ft$	t/c	$= 0.09\ ft$
Sweepback	= 43.5 °	Sweepback	= 31.6 °
Exposed Taper Ratio	= 0.8	Exposed Taper Ratio	= 0.35
Exposed Root Chord	$= 15.5\ ft$	Exposed Root Chord	$= 11.1\ ft$

Pylons		Nacelles	
Total wetted area	$= 117\ ft^2$	Total wetted area	$= 455\ ft^2$
t/c	$= 0.06\ ft$	Effective fineness rato	= 5.0
Sweepback	= 0 °	Length	$= 16.8\ ft$
Taper Ratio	= 1		
Chord	$= 16.2\ ft$		

Table 2: Results for the example similar to problem 11.1 at the operating condition $v = 765ft/s$

#	Component	L_{eff}	Re	C_f	K	S_{wet}	C_{D_P}
1	Wing	11.1263	2.4631E+07	0.002843	1.2135	1693.2	5.8419/1000
2	Fuselage	107	2.3687E+08	0.001997	1.1055	3280	7.243/1000
3	H. Tail	8.0715	1.7868E+07	0.003013	1.1602	532.44	1.861/1000
4	V. Tail	14.0074	3.1009E+07	0.002731	1.1281	328.44	1.0117/1000
5	Pylons	16.2	3.5863E+07	0.002663	1.1347	117	0.3536/1000
6	Nacelles	16.8	3.7192E+07	0.002647	1.2885	455	1.5517/1000

With this, we only know the total drag at one operating condition and we do not know if this is the optimum or not. So, to answer this question, we have to compute the aircraft drag at a range of different operating speeds. Then we will be able to plot the parasitic drag, induced drag and the total drag versus the velocity (this will require that you digitize the plots being used in this calculation). This range will be $v_{range} = 230 - 880ft/s$ for this problem and for the problem you will be assigned. The result of this calculation is shown in Figure 1 (a). Notice the behavior of the different drag components with respect to increasing velocity. The parasitic drag keeps increasing with velocity, however the induced drag decreases tremendously with velocity. The point where they both are equal defines the minimum drag point as shown for the the total drag curve. Finally, the lift (which is constant and is equal to the weight) will be used to determine the lift to drag ratio plot in Figure 1 (b). Then the maximum of this ratio is the most efficient point and the optimum L/D_{max} with $v_{optimum} = 617ft/s$.

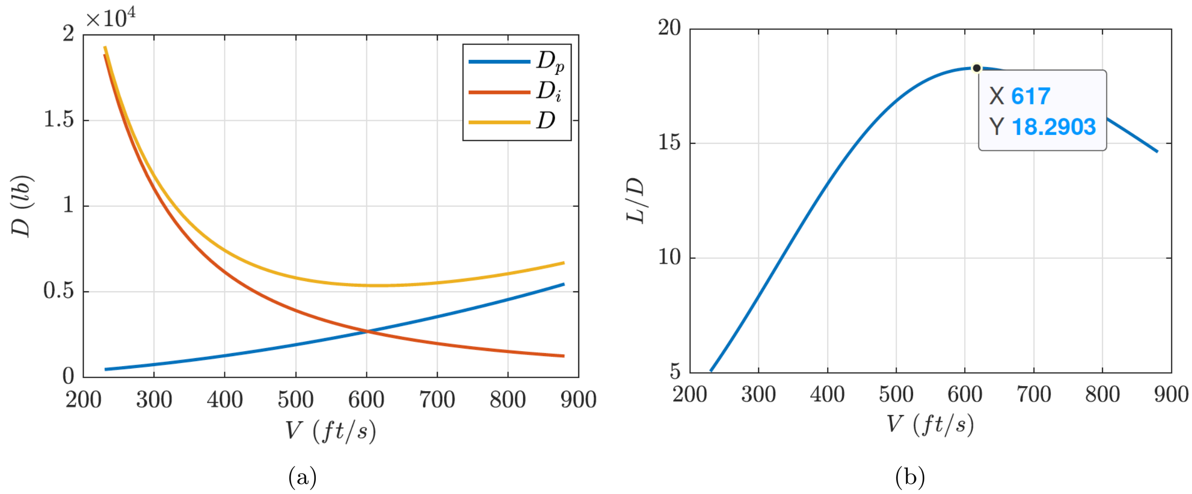


Figure 1: (a) Parasitic, induced and total drag trend versus velocity; (b) Lift to drag ratio behavior defining the operating condition at L/D_{max}.

3 Assignment

You will be assigned a unique airplane configuration, in other words, b_{wing}, $c_{r_{o,wing}}$, σ_{wing}, $\Lambda_{c/4,wing}$, L_f, D_f. For this problem, you will use the BOEING 737 ROOT AIRFOIL at the root and the BOEING 737 OUTBOARD AIRFOIL at the tip, both of which can be found on http://airfoiltools.com/. In addition, rather than using the estimation relationship in class to determine the exposed wetted area of the wing ($S_{wet,wing} = 2 * 1.02 * S_{REF}$), you will instead determine $S_{wet,wing}$ by creating a Solidworks part of your wing from your unique dimensions and using a measure tool to measure the surface area. Note that the wing area covered by the fuselage, the wing planform area, and the average t/c of the wing in Table 1 will also have to be recalculated by you for your unique configuration. You will compute the wetted area of the fuselage based on the given relation in Table 1. Based on these numbers along with the rest of givens in Table 1, you can find the optimum operating condition of your airplane.

Doing the programming task in a single shot using MATLAB will be challenging and the sources of errors will be to many. Based on that you are encouraged to perform the programming task in this order:

1. Solve the given example for the single operating condition by hand relying on appendix A, and make sure you can generate the same value in Table 2. Assume that the wing has the skin friction coefficient of the standard transport aircraft given in Figure 2 (a). Use Figures 2 (b), (c), and (d) to obtain the form factors and Oswald efficiency.

2. Digitize the typical transport aircraft roughness, the form factor curve for fuselage-like bodies and the airplane efficiency factor e using a digitizing tool such as webplot digitizer and then curve fit them using MATLAB. There is a pre-recorded session going over this that is available on canvas under resources. Note: neglect the correction for e based on the aspect ratio and the sweep back angle in this project as indicated before.

3. Write a MATLAB code for the same problem and make sure that it results in the same values given in the table and the one you found by your hand calculation. This will help a lot in debugging your code.

4. Loop this code so that you are able to reconstruct the results in Figure 1.

5. Solve your given problem by hand at the same velocity in the example given $v = 765 ft/s$.

6. Solve the same point using your code.

7. Generate the graphs in Figure 1 that corresponds to your unique airplane and find the optimum operating condition.

Following this route will be a lot easier than jumping right into typing your code at the beginning. In addition, by following it, will allow you to score partial credit based on the deliverables in the *Deliverables* section.

For the Solidworks portion, it is recommended you follow the procedure given in the instructional video on the canvas webpage resources to model your unique wing and obtain $S_{wet,wing}$ and other wing dimensions. You can assume that the wing lies on the diameter of the fuselage.

4 Deliverables

The list of what must be submitted for full credit is below. The submission should include a single pdf file, a fully executable (.m) MATLAB file to be run, and a Solidworks part file (.sldprt) of your modeled wing.

1. Cover page with your name and your unique b_{wing}, $c_{r_{o,wing}}$, σ_{wing}, $\Lambda_{c/4,wing}$, L_f, D_f, S_{wet_f} values. Otherwise, we will not be able to grade your report.

2. Overview of the assignment and summary of the drag calculation process.

3. Results

   (a) Hand calculations of one single operating condition for your aircraft at $v = 765 ft/s$

   (b) Plots similar to Figure 1 for your unique aircraft.

   (c) The optimum operating condition for your airplane.

4. Conclusions

   (a) Why does the drag behave like this with increasing velocity? Answer in the context of your unique airplane.

   (b) Do we have to increase the parasitic drag or decrease it to maximize the flight speed? Answer in the context of your unique airplane.

5. Attach your code as an appendix in the pdf file.

6. Attach a top-down screenshot of your Solidworks wing showing its key dimensions and exposed surface area measured as an appendix in the pdf file.

7. Submit a fully executable MATLAB code on canvas. This code will be executed and its output will be checked against what is submitted in the report.

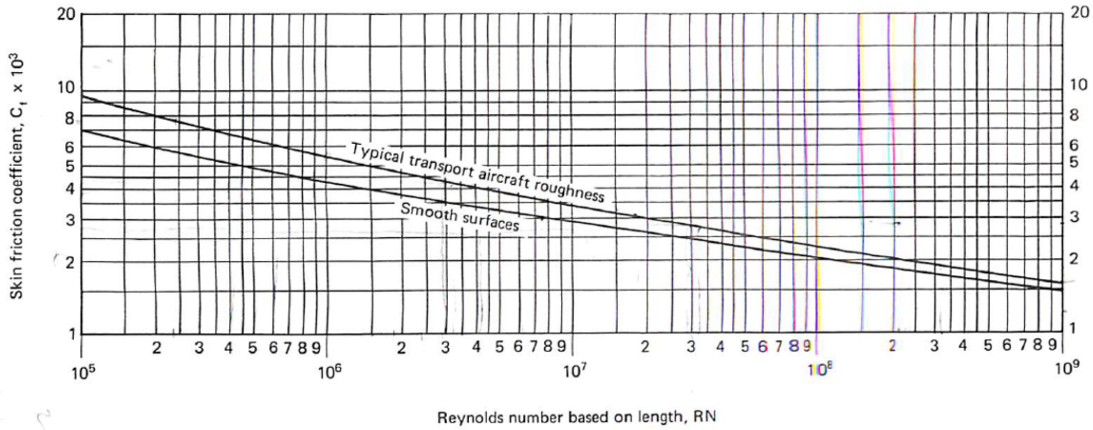
8. Submit a Solidworks part file (.sldprt) of your modeled wing. This will be opened and checked as a part of your final grade.

Finally, any copying or severe reliance on other efforts in your report, code, or Solidworks part (including ChatGPT, it is not safe to fly in airplanes analyzed by this) will be considered as an academic integrity case and will be reported to the faculty.

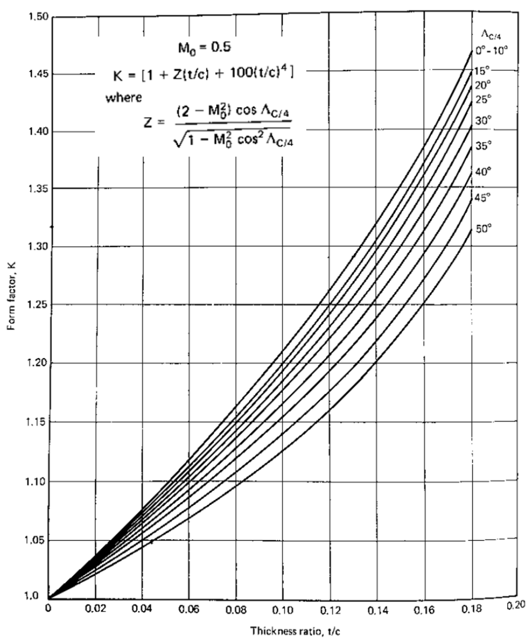
5 References

[1] R. S. Shevell, Fundamentals of flight, 2nd ed. Upper Saddle River, NJ: Prentice Hall, 1989.

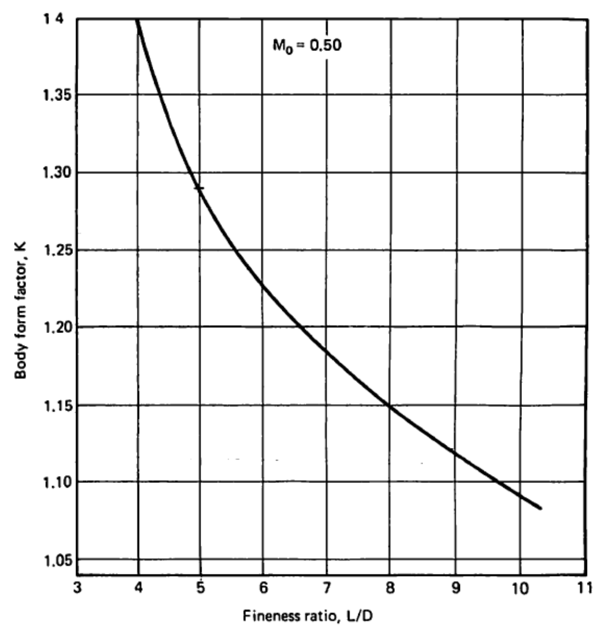
6 Appendix



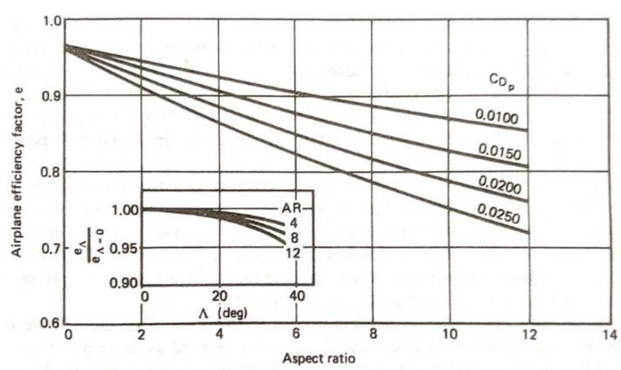
(a) Figure 11.2 [1], Flat plate skin friction coefficient



(b) Figure 11.3 [1], Aero surface form factor



(c) Figure 11.4 [1], Fineness ratio vs. form factor



(d) Figure 11.8 [1], Airplane efficiency factor, e

Figure 2: Reference graphs for drag project