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Improving the Capability of Preliminary Aircraft Design Methodology by Incorporating Numerical Methods into Segments of a Proven Statistical Method

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IMPROVING THE CAPABILITY OF PRELIMINARY AIRCRAFT DESIGN METHODOLOGY BY INCORPORATING NUMERICAL METHODS INTO SECTIONS OF A PROVEN STATISTICAL METHOD

by

Igor Lebovic

A Thesis Submitted to the Graduate Studies Office
in Partial Fulfillment of the Requirements for the Degree of
Master of Science in Aerospace Engineering

Embry-Riddle Aeronautical University
Daytona Beach, Florida
Spring 2004
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IMPROVING THE CAPABILITY OF PRELIMINARY AIRCRAFT DESIGN

METHODOLOGY BY INCORPORATING NUMERICAL METHODS INTO

SEGMENTS OF A PROVEN STATISTICAL METHOD

by

Igor Lebovic

This thesis was prepared under the direction of the candidate's thesis committee chairman, Prof. Charles Eastlake, Department of Aerospace Engineering, and has been approved by the members of his thesis committee. It was submitted to the Aerospace Engineering Department and was accepted in partial fulfillment of the requirements for the degree of Master of Science in Aerospace Engineering.

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4/28/04
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The author wishes to express thanks to the entire Thesis Committee, whose members’ time and efforts resulted in successful completion of this thesis. Professor Eastlake’s experience in experimental and statistical performance estimation methods proved just as invaluable as Dr. Anderson’s expertise in paneling and numerical calculations. Last but not least, many of my long days in the CFD Lab were spent in company of Dr. Rohde, whose know-how and wit greatly shortened the duration of this study. A special thanks is also due to Mr. Peter Garrison from Aerologic, Inc., who readily answered all of my questions without regards to the time of the day, or day of the week.
ABSTRACT

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The purpose of this study was to identify any potential limitations of Roskam’s statistical aircraft flight performance estimation method, and to provide processes capable of improving those limitations. This project was conducted in collaboration with Diamond Aircraft Industries, and as any other general aviation manufacturer with limited time, manpower, and financial resources, Diamond wants the new process to be time and cost-effective. Presented in this study is a computational alternative that combines the speed and accuracy of low-order panel methods with the fully-coupled viscous/inviscid interaction method from the ISES code that was developed by Drela and Giles. Its benefit is the ability to optimize aerodynamic parameters that are ignored by statistical methods, such as multiple taper ratios, aerodynamic and geometric twist. Most notably, cost of this method is dramatically reduced by separating the computational domain into a separate one for lifting surfaces and one for fuselages.
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1. INTRODUCTION

1.1 Statement of the Problem

Statistical aircraft flight performance estimation methods have found widespread use in the general aviation community and in other fields of the aerospace industry. There are many sources of statistical aircraft flight performance data, and the methods known as Raymer’s method, Roskam’s method, and Datcom are three best-known ones. Their success is certainly due to their flight performance estimation accuracy, but it can also be traced back to the unsurpassed time and cost-effectiveness of these methods. However, all of these three methods also have the same natural shortcomings, which are typical of all statistically derived methods. Namely, not all aircraft design parameters can be analyzed and optimized. Nevertheless, any new preliminary aircraft design methodology aiming to replace or even just to improve statistical methods will not only have to be very accurate, but also time and cost-effective. Possible numerical alternatives are presented below.

Aerodynamic codes generally try to arrive at simplified solutions of Navier-Stokes equations. Navier-Stokes equations are based upon the existence of flow continuity, the conservation of momentum, and the conservation of energy. Unfortunately, they cannot be solved easily due to the microscopic scale of turbulence. Instead, turbulence is handled with separate empirically-derived models apart from the Navier-Stokes solution. The complexity and expense of those solutions dictates further simplification of the codes to be useful for iterative design applications.
The parabolized Navier-Stokes codes drop the viscous terms in the streamwise direction, ignoring the streamwise separation effects. This is the most commonly used method in modern commercial CFD packages, but aircraft analyses are still primarily computed on large computer clusters or supercomputers, since the computational requirements of full-size airplanes exceed the capacities of most desktops.

If all viscosity effects are ignored and a steady flow is assumed, the Euler equations are derived. The Euler codes can handle vortex formation, and with the addition of a separate boundary-layer code, they can also estimate viscous and separation effects. The potential flow equations are further simplified from the Euler equations by assuming irrotational flow. An important characteristic of an inviscid analysis is that in the absence of boundary layer separation, pressure drag cannot be computed. In contrast, friction drag can be predicted with good accuracy through boundary layer analysis, and the induced drag of lifting surfaces is closely approximated once the wake has stabilized. Incapable of computing pressure drag, this method is naturally best suited for analyzing well-streamlined bodies with little or no flow separation, such as lifting surfaces at low angles of attack (AOAs). The potential flow codes are not considered to belong to the true CFD methods, but they are probably the most widely used aerodynamics codes that treat the entire flowfield rather than just the surface conditions. This is in part due to their speed of execution, which depending on the number of panels and speed of the processor will take anywhere from one to ten minutes.

In addition to their speed, another advantage of panel programs is that many of them are released under the General Public License. In fact, PMARC-12 (Panel Method Ames Research Center), one of the best-known panel programs, was developed under a
NASA contract and is available at no charge. Clearly, if a method could be found that can be coupled with a panel program and is capable of predicting aerodynamics of fuselages with similar accuracy and at reasonable cost, an inexpensive and powerful alternative to statistical methods would become available.

In addition to this group of numerical methods, wind tunnel testing is a well-proven method of estimating aircraft flight performance. Unfortunately, its cost has prevented a widespread use of wind tunnel testing among the general aviation manufacturers. While the cost of running wind tunnel models is well below the one of running flight tests, it can still reach and exceed $500,000, a figure much higher than the cost of running commercial CFD codes. However, not all wind tunnels are that expensive. There is an abundance of smaller wind tunnels that do not quite match the high Reynolds numbers produced by full-size aircraft at cruise conditions, but that can still deliver accurate results as long as the boundary layer transition point on the model is at a location typical of higher Reynolds numbers. In order to ensure this situation, Reynolds numbers above 2 million should be used, which is about one order of magnitude larger than the critical Reynolds number of turbulence-free airflow.

If a model of Diamond Aircraft’s D-Jet, a single-engine business jet, was to be run in the wind tunnel at Embry-Riddle Aeronautical University with a 30 x 40 inch test section and maximum wind velocity of 200 ft/s, the largest Reynolds number than could be produced on the model’s smallest component in the streamwise direction, the wing, would be 250,000. Even with artificial tripping of boundary layers and use of empirical Reynolds number correction functions, it would be difficult to predict drag accurately. However, if only the fuselage was tested in ERAU’s wind tunnel, the largest Reynolds
number would climb to 4.4 million. This is not so much due to a slightly increased scale of the wind tunnel model, as it is due to a much larger length of the model’s smallest component in the streamwise direction. As a result, great cost savings can be achieved by coupling fuselage testing at small wind tunnels and lifting surfaces analysis with panel codes.

In order to evaluate the need for this novel concept, a Mathcad routine was created utilizing Roskam’s statistical method for flight performance analysis of D-Jet from Diamond Aircraft. Next, another Mathcad routine was created for the same analysis, this time using the 3D panel code Personal Simulation Works (PSW) and ERAU’s wind tunnel. Speed of execution of both methods was observed, their costs compared, and any potential limitations of the two methods identified. Finally, a conclusion was made regarding whether Roskam’s statistical method can be expanded or even replaced utilizing time and cost-effective processes.
1.2 Nomenclature

AOA Angle of attack

\( \text{AOA}_{\text{stall}} \) Angle of attack at which the maximum coefficient of lift is reached

AR Aspect ratio

BJK Velocity potential influence coefficient at control point of panel J due to a uniform distribution of unit source on panel K

\( C_d \) 2D coefficient of drag

\( C_D \) 3D coefficient of drag

\( C_{Di} \) Induced coefficient of drag

\( C_{JK} \) Velocity potential influence coefficient at control point of panel J due to a uniform distribution of unit doublet on panel K

\( C_f \) Local skin friction coefficient, \( \frac{2 \tau_w}{\rho U^2} \)

\( C_l \) 2D coefficient of lift

\( C_L \) 3D coefficient of lift

\( C_{l,h} \) 3D coefficient of lift of horizontal tail

\( C_{L,max} \) Maximum coefficient of lift

\( C_M \) 3D coefficient of moment

\( C_T \) Local shear stress integral coefficient, \( \frac{2}{\rho U^2 \delta} \int_0^\delta \tau \, d\xi \)

\( C_P \) Pressure coefficient

dS Differential surface element on configuration

e Span efficiency

H Boundary layer shape factor

MCP Maximum continuous power
\( \vec{n} \)  Unit normal vector to surface  
\( N_S \)  Total number of surface panels  
\( N_W \)  Total number of wake panels  
\( P \)  An arbitrary point in space  
\( \vec{r} \)  Vector between an arbitrary point \( P \) and a surface element \( dS \)  
\( S \)  Surface of the configuration  
\( S_\infty \)  Imaginary surface at infinity  
\( t \)  Time  
\( U \)  Velocity at the outer edge of the boundary layer  
\( u \)  Velocity in the boundary layer  
\( u_\tau \)  Friction velocity, \( \sqrt{\frac{f}{\rho}} \)  
\( \vec{V} \)  Velocity vector  
\( \vec{V}_{\mu PK} \)  Velocity influence coefficient at point \( P \) due to a uniform distribution of unit doublet on panel \( K \).  
\( \vec{V}_{\sigma PK} \)  Velocity influence coefficient at point \( P \) due to a uniform distribution of unit source on panel \( K \).  
\( W \)  Wake surface  
\( \Phi \)  Total velocity potential  
\( \phi \)  Perturbation velocity potential  
\( \phi_\infty \)  Free-stream velocity potential  
\( \mu \)  Doublet singularity strength per unit area  
\( \sigma \)  Source singularity strength per unit area  
\( \nu \)  Kinematic viscosity
<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>( \theta )</td>
<td>Momentum thickness</td>
</tr>
<tr>
<td>( \delta )</td>
<td>Boundary layer thickness</td>
</tr>
<tr>
<td>( \delta^* )</td>
<td>Displacement thickness</td>
</tr>
<tr>
<td>( \tau )</td>
<td>Shear stress</td>
</tr>
<tr>
<td>( \eta )</td>
<td>Generalized coordinate along streamline</td>
</tr>
<tr>
<td>( \zeta )</td>
<td>Generalized coordinate normal to surface along streamline</td>
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1.3 Review of the Literature

Raymer [1] covers many fields of aircraft design in a very descriptive manner and offers a statistical flight performance estimation method, which, however, in contrast to his narrations is applicable only to very common-type designs. Roskam [2, 3], on the other hand, is very limited in explanations, but offers a more complete statistical estimation method and a cookbook approach that is much like (in fact, partially derived from) the AFFDL Datcom. Lan and Roskam [4] are very similar in explanations to Raymer [1] and are a good addition to the manual-style instructions of Roskam [2, 3]. Many insightful explanations and empirical aerodynamic data can be found in Hoerner [5, 6], but what is missing is a common thread that leads from conceptual layout to final design. Eastlake [7] and Rae [8] are good sources for experimental work and were used for collection and evaluation of wind tunnel data. Schlichting and Truckenbrodt [9, 10] are very theory-oriented and were useful in creating the numerical flight performance estimation routine. Finally, Anderson [11], Katz [12], and McCormick [13] offer detailed insight into the techniques of potential flow solvers and were used for derivation of formulas shown in Section 3.2.
2. CURRENT PRELIMINARY AIRCRAFT DESIGN METHODOLOGY IN GENERAL AVIATION

2.1 Choice of Statistical Method

As mentioned previously, general aviation industry has adopted Raymer’s, Roskam’s, and Datcom statistical methods as their preferred preliminary aircraft design tools. Since all three of them have the same strengths and weaknesses, it is not of great importance which one of those methods is chosen for demonstration of the statistical approach. Since Diamond Aircraft, the project’s collaborator, has adopted Roskam’s method, it was decided to use it for this study as well.

2.2 Description of the Method

A Mathcad file was created to allow parameterization of the aircraft’s performance as a function of flight altitude, aircraft mass, flight speed, and temperature deviation from International Standard Atmosphere (ISA). Hence, iterative calculations can be performed with a click of a button, and any one of the flight performance parameters can be analyzed and plotted as a function of one of the above variables.

The object of study is D-Jet from Diamond Aircraft. D-Jet is an aircraft of 4,700 pounds Maximum Take-Off Weight (MTOW), able to carry five people up to 25,000 feet, with a cabin altitude of 8,000 feet, and a speed of 315 kts. The power is provided by a single FJ33-4A fanjet engine from Williams International. This aircraft is predicted to set new standards in fuel consumption and noise level, and its orthogonal and isometric views are shown in Figure 1.
Figure 1. Orthogonal and isometric views of D-Jet.
An integral part of every flight performance calculation are the engine performance data, which in this case are available from a Fortran program supplied by Williams International, the engine supplier. This engine deck was originally written to function as a stand-alone platform, with a text input file requiring new input for every single flight condition. Overview of the program’s structure and some of the input and output parameters is given in Figure 2.

![Figure 2. Original FJ33-4 engine deck.](image)

In order to integrate the engine deck into Mathcad, it had to be converted to a subroutine mode. First, the engine deck was modified to perform eleven sets of calculations starting the first set with a Mach number input of zero and finishing the last one with a Mach number of one. Changes made to the program are shown in Appendix A. Next, communication between the engine deck and Mathcad was established with the help of Excel macros written in Visual Basic for Applications (VBA). Excel spreadsheets embedded inside the Mathcad files are capable of recognizing a change in input variables that they are linked to and automatically execute new calculations based on the new input
data from Mathcad. This capability was used to activate a macro whenever Excel recognizes a change in input parameters. The VBA macro reads in the new command line arguments and launches a batch file that, in turn, executes the engine deck according to the new input from Mathcad. Since the macro has to wait for the engine deck to finish writing to the output file, it goes into sleep mode for two seconds and then retrieves the results from the output file and imports them into Excel. The VBA code is included in Appendix B and the structure of the modified sub-routine engine deck is shown below. The only parts of the original engine deck that remained unchanged are displayed in yellow.

Figure 3. Modified FJ33-4 engine deck.

As a result of its integration into Mathcad, the engine deck is capable of evaluating any of the input parameters that affect flight performance, which include power lever angle, flight altitude, program-mode, temperature deviation from international standard atmosphere (ISA), and Mach number. Engine performance is
evaluated at Sea Level, Flight Level (FL) 100 (10,000 ft), FL 200, FL 250, and FL 300. In addition, at each one of the altitudes engine performance is evaluated at 60%, 80%, and 100% of maximum continuous power. This results in a total of 15 different flight cases, and each one of them is evaluated by a different Excel spreadsheet. The input variables are entered in the top row, and the first one of them is the power lever angle (PLA). PLA settings are defined as follows:

- 90 degrees for take-off (Mach number of 0.3 must not be exceeded),
- 72 degrees for maximum continuous power,
- 62.4 degrees for 80% of maximum continuous power,
- 52.8 degrees for 60% of maximum continuous power, and
- 19 degrees for idle setting.

Power mode is the input variable which determines the format of input variables, and for the format presented in this paper power mode 17 is used. One of the embedded Excel spreadsheets is shown in Figure 4.
Figure 4. Embedded Excel spreadsheet with Visual Basic for Applications output.

In addition to an engine deck, airfoil’s polars are needed as well. The design of an airfoil usually starts with definition of desired or required characteristics. These can be a certain range of lift coefficients, Reynolds or Mach numbers, where the airfoil should perform best, stall characteristics, moment coefficient, thickness, low drag, high lift, or any combination of such requirements. Starting from this point, each designer has his own way and his preferred tools to proceed. Some like to use an inverse design code to prescribe flow parameters and get the resulting geometry (airfoil) from the code. Others like to use a starting airfoil and use analysis codes to continue in a trial and error style to
find a better airfoil shape. X-Foil is a second order panel method code, whose modules include airfoil design as well as airfoil analysis tools, so that both of the approaches described above can be followed using it. In this case, only airfoil analysis had to be performed since airfoil design was carried out in a separate process by Diamond Aircraft engineers. The resultant geometry was supplied by Diamond and evaluated in X-Foil. Unlike the engine deck, X-Foil is kept in main routine mode since its operation requires careful manipulation of geometry coordinates and automation of operator input is likely to result in output of inferior accuracy.

Let’s pause for a moment and remember a few statements made earlier. It was mentioned that panel codes use potential flow theory, which assumes irrotational and inviscid flow. How can then X-Foil be used to predict profile drag of an airfoil? X-Foil uses potential flow theory adjusted with Karman-Tsien correction to calculate the total velocity at each point on the airfoil surface and wake, with contributions from the freestream, the airfoil surface vorticity, and the equivalent viscous source distribution. This is incorporated into the viscous equations, yielding a nonlinear elliptic system which is solved by a full-Newton method. The viscous equations use empirical information to determine the onset of separation, and therefore careful attention must be paid to the limitations of such an approach. The empirical information supplied in X-Foil is valid only for well streamlined bodies such as lifting surfaces, and only in cases of negligible spanwise flow. In other words, only two-dimensional wing sections can be analyzed, and only on those wings that have little or no sweep. Figure 5 shows an overview of the branches of aerodynamic codes and illustrates the separate category that X-Foil occupies.
What Figure 5 tells us is that both categories of potential flow solvers, the pure and the coupled ones, have their share of strengths and limitations. The pure ones, on the one hand, do not rely on information that is only accurate for two-dimensional flow, and can therefore accurately represent the complex flows over entire wings. However, they do not have the capacity to model separation, and hence their outputs are not reliable for bodies that are not as well streamlined as lifting surfaces. Coupled panel codes, on the other hand, can only analyze two-dimensional airfoils, but they are capable of providing
accurate friction and pressure drag results. Fortunately, these two panel code types supplement each other, and together they are capable of predicting lift and drag of entire wings, as outlined in this paper’s section titled Program Mechanics. Figure 6 shows a sample X-Foil graphics output window.

Figure 6. Sample X-Foil graphics output.

Having discussed the origins of propulsion and airfoil data, let’s turn our attention to the overall structure of the statistical simulation program. Figure 7 provides the flowchart of Mathcad’s script.
As shown in Figure 7, submodules named Geometry, Lift Curve, and Polars require user input, whereas the rest of the program consists of autonomously operating calculation blocks that lead to estimation of the total drag. Finally, total drag combined with thrust data results in estimation of flight performance as a function of mass, altitude, thrust, velocity, and temperature.

All calculation blocks follow the instructions from Roskam [2, 3], and Appendix C includes a printout of the entire Mathcad script with detailed source references. Therefore, the technique of calculation appears to be documented enough and will not be described in any more detail in this section. It is important, however, to emphasize the nature of this estimation method and to understand its advantages and shortcomings. This is best done by looking at some typical calculations involved in this method. For
example, Figure 8 shows how the induced drag coefficient is calculated. The dotted curve on the left side of the graph results from the equation:

\[ C_{D_i} = \frac{C_L^2}{\pi e AR} \]

and is valid only for the incompressible flow speed regime, whereas the dotted curve on the far right side of the graph is a statistical approximation for the compressible flow regime. The inherent inaccuracy of this approach is highlighted by the fact that D-Jet’s induced drag coefficient at cruise is calculated by a linear interpolation of those two methods, shown with the solid curve that is placed between the dotted ones.

![Figure 8](image.png)

**Figure 8.** Statistical estimation of the induced drag coefficient.

Another source of inaccuracy is the method’s overall simplification of all possible aircraft geometries into a few commonly used ones. In fact, sometimes it is not possible
to specify geometry at all, but all aircraft use the same values for parameters which, as in the case of interference factors, are very geometry-dependent. Figure 9 illustrates that the wing-fuselage interference factor is only a function of the Mach and Reynolds numbers, but not of the radius of the intersection fillet. Unfortunately, there are large variations in the interference drag for each one of the aircraft configurations, and this method is obviously not well-suited for evaluating the best layout.

Figure 9. Wing-fuselage interference factor estimation.

Additional shortcomings include the following:

- Wing layout – Roskam assumes a single-tapered wing, and more complex layouts must be simplified in geometry to be analyzed.
- Span efficiency versus AOA – an approximated span efficiency must be used, and it is held constant for all flight conditions (in contrast to PSW, which is capable of calculating a span efficiency as a function of AOA and atmospheric conditions)
- Winglets – statistical methods cannot be used as a design tool for winglets, and even their generic performance estimation capabilities are very limited, since there is relatively little statistical data available on their performance.

- Fuselage moment contribution – Roskam does not provide means for calculating the moment produced by the fuselage as a function of AOA, and if those data are not available from experimental or numerical methods, the calculated trim drag will yield under-predicted results.

- Poor inlet interference approximation – inlet drag is computed in the same way as the fuselage drag, and the interference of the two bodies is not taken into account (which might be a good approximation for externally mounted engines, but it does not work very well for layouts with internal engines).

On the other hand, clear advantage of Roskam’s statistical method is the time of its computation. Changes in performance due to variation of parameters that can be modeled in Roskam’s method (such as wing area, span, aspect ratio) can be analyzed within seconds, making this method an efficient tool for preliminary design. In addition, Roskam’s method has proven accurate for large variety of aircraft design layouts. Its limited number of input flight performance parameters, however, prevents it from expanding from an evaluation method to an universal flight performance optimization tool.
3. NUMERICAL AND EXPERIMENTAL PROCESSES DESIGNED TO SUPPLEMENT STATISTICAL METHODS

3.1 Purpose of Supplemental Processes

Since Roskam’s method is conveniently structured as a drag build-up calculation, it is possible to substitute another method for parts of the calculation. For example, it was identified that Roskam’s fuselage drag estimation method lacks the ability to predict the fuselage moment as a function of AOA. Fortunately, this set of data can be supplied from, among other methods, wind tunnel testing, and can be seamlessly integrated into the statistical drag estimation. In the same way, entire components of aircraft can be evaluated with different methods.

In order to demonstrate the modularity of Roskam’s technique, a completely new Mathcad routine was created with the same parameterization as the statistical version, but consisting of modules that use different techniques of drag estimation. Despite its layout as a stand-alone platform, the new Mathcad routine is just as modular as the old one and they both can be used to supplement each other in parts of their calculation.

The new method was designed with a goal of eliminating many of the limitations that are associated with Roskam’s method while keeping the level of complexity as low as possible. Its feasibility, therefore, will be judged based not only on its accuracy, but on its computational and monetary costs as well. As discussed earlier, cost will be minimized by using ERAU’s wind tunnel for fuselage testing and the 3D panel code Personal Simulation Works for lifting surfaces drag evaluation.
3.2 Panel Method

Panel Method assumes a surface subdivided into a large number of generally rectangular panels and separates the field into inner and outer regions. Depending on the formulation, either one of them may be analyzed, the other remaining a fictitious flow. Most aerodynamic problems target the outer region. Flow is assumed to be incompressible, irrotational, and inviscid. Velocity potentials in both regions are assumed to satisfy Laplace's equation:

\[ \nabla^2 \Phi = 0 \quad \text{Ref. [13]} \]

Using Green's Theorem applied to the total velocity potential, the first integral represents the disturbance potential from a surface distribution of doublets whose strength is \((\Phi - \Phi_i)\) per unit area, and the second integral represents the contribution from a surface distribution of sources whose strength is \(-n \cdot (\nabla \Phi - \nabla \Phi_i)\) per unit area. This produces the following equation:

\[
\Phi_p = \frac{1}{4 \pi} \iint_{S+w+S_o} (\Phi - \Phi_i) \cdot \nabla \left( \frac{1}{r} \right) dS - \frac{1}{4 \pi} \iint_{S+w+S_o} \left( \frac{1}{r} \right) \cdot (\nabla \Phi - \nabla \Phi_i) dS \quad \text{Ref. [12]}
\]

Due to the fact that the perturbation potential at infinity is zero, the following simplification can be made:

\[
\Phi_p = \frac{1}{4 \pi} \iint_S (\Phi - \Phi_i) \cdot \nabla \left( \frac{1}{r} \right) dS - \frac{1}{4 \pi} \iint_S \left( \frac{1}{r} \right) \cdot (\nabla \Phi - \nabla \Phi_i) dS + \frac{1}{4 \pi} \iint_w (\Phi_U - \Phi_L) \cdot \nabla \left( \frac{1}{r} \right) dS + \phi_{sp} \quad \text{Ref. [12]}
\]
Integrals become singular at point P if it lies on the surface. The point is excluded from the integration by assuming a hemispherical deformation of the surface with P as its center. Evaluating the integral by assuming a hemispherical deformation of the surface with a point P as its center and allowing its radius to shrink to zero, the contribution at P becomes $1/2(\Phi - \Phi_i)_P$ if P is an exterior point, and if not, the negative of that value is assigned. Thus for interior surface points we get:

$$
\Phi_p = \frac{1}{4\pi} \iint_{S-P} (\Phi - \Phi_i) \vec{n} \cdot \nabla \left( \frac{1}{r} \right) \, dS - \frac{1}{4\pi} \iint_{S} \left( \frac{1}{r} \right) \vec{n} \cdot (\nabla \Phi - \nabla \Phi_i) \, dS \\
+ \frac{1}{4\pi} \iint_{W} (\Phi_U - \Phi_L) \vec{n} \cdot \nabla \left( \frac{1}{r} \right) \, dS + \phi_{\sigma p} - \frac{1}{2} (\Phi - \Phi_i)_P \quad \text{Ref. [12]}
$$

For points P inside the surface, the equation becomes:

$$
0 = \frac{1}{4\pi} \iint_{S-P} \phi \vec{n} \cdot \nabla \left( \frac{1}{r} \right) \, dS - \frac{1}{4\pi} \iint_{S} \left( \frac{1}{r} \right) \vec{n} \cdot (\nabla \Phi - \nabla \phi_{\sigma}) \, dS \\
+ \frac{1}{4\pi} \iint_{W} (\Phi_U - \Phi_L) \vec{n} \cdot \nabla \left( \frac{1}{r} \right) \, dS - \frac{1}{2} \phi_p \quad \text{Ref. [12]}
$$

We can also write for doublet and source strengths:

$$
4 \pi \mu = \phi = (\Phi - \phi_{\sigma}) \\
4 \pi \sigma = -\vec{n} \cdot (\nabla \Phi - \nabla \phi_{\sigma}) \quad \text{Ref. [12]}
$$
If the normal velocity at the surface is zero or has some known value we can write for surface source strengths:

\[ \sigma = \frac{1}{4\pi} \left( V_{\text{norm}} - \bar{n} \cdot \bar{V}_o \right) \]

Ref. [12]

The surface normal velocity (as often used for engine inlets and outlets) can be defined by the user and the onset velocity vector is known. This yields the following integral equation in which the doublet strength over the surface is unknown:

\[ 0 = -i\intju u' - v' f dS - 2i\pi ju ' + \intju u' j j dS + \intju u' j j dS \]

Ref. [12]

The potential at any point P can be expressed as:

\[ \Phi_p = \left[ \int_{S-P} \mu \bar{n} \cdot \nabla \left( \frac{1}{r^2} \right) dS - 2\pi \mu_p \right] + \int_S \frac{\sigma}{r} dS + \int_{w} \mu_w \bar{n} \cdot \nabla \left( \frac{1}{r} \right) dS + \phi_{in} \]

Ref. [12]

K may have one of the following three values:

1. if P is not on the surface, K is zero,

2. if P lies on a smooth part of the outer or inner surface, K becomes \(2\pi\) or \(-2\pi\), respectively, and

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3. If $P$ lies on a crease in the surface forming a solid angle, $K$ is equal to the angle.

When the surface is broken up into panels, a discretized form can be used, creating surface integrals over each panel. Because Cmarc is based on the low order panel method, it assumes that the strengths of sources and doublets are constant over a panel and, therefore, doublet and source strengths can be factored out of the discretized integrals.

Surface integrals are summed for all panels, which produces a set of simultaneous linear equations to be solved for the unknown doublet strength on each panel. The surface integrals represent the velocity potential influence coefficients $C_{JK}$ and $B_{JK}$ for each panel $K$ acting on the control point of a given panel $J$. The resultant equation becomes:

$$
\sum_{K=1}^{N_a} \left( \mu_K C_{JK} \right) + \sum_{K=1}^{N_a} \left( \sigma_K B_{JK} \right) + \sum_{L=1}^{N_b} \left( \mu_W C_{JL} \right) = 0 \quad \text{Ref. [12]}
$$

where

$$B_{JK} = \iint_{K} \frac{1}{r} \, dS \quad C_{JK} = \iint_{K} \vec{n} \cdot \nabla \left( \frac{1}{r} \right) \, dS \quad C_{JJK} = -2\pi$$

The equations above can be solved for all panels to form the coefficient matrix, since they are only functions of model geometry. Source values, which are known, can be transferred to the right side of the matrix equation. Wake doublet values can be found as.
functions of surface doublet values, leaving the surface doublet strengths the only unknowns.

Having obtained the influence coefficients, Cmarc solves iteratively for the unknown doublet strengths. Convergence is directed by applying to the current vector a correction vector derived from the history of previous solutions. Termination of the convergence is controlled by an iteration limit and a tolerance, both of which are set by the user in the input file. The tolerance is the percentage difference between successive values of the element in the solution vector that shows the largest change between successive iterations. Values between 0.01 and 0.0005 have proven satisfactory; 0.0005 is the default. Convergence usually occurs within 50 and 150 iterations on the first time step, and in fewer iterations thereafter.

Cmarc computes induced drag by evaluating the following integral along a line of intersection between the wake and a plane (also called Trefftz plane) normal to the velocity vector and located far downstream of the lifting surface:

\[ D_i = \frac{\rho}{2} \int_{\text{wake}} \Gamma V_n dl \]

Ref. [11]

where \( V_n \) is the normal component of the induced velocity on the wake at the Trefftz plane, and \( \Gamma \) is the circulation on the lifting surface at the corresponding spanwise location.
3.3 Personal Simulation Works

Personal Simulation Works is a streamline-body design and analysis package, comprising programs for surface definition, flow analysis, and data visualization. Its three principal elements are Loftsman/P, Cmarc, and Postmarc. Loftsman/P is a lofting program for wings, fuselages, and hulls. It provides complex wing and body shapes, full and partial fuel capacities in various flight attitudes, and facilities for designing flap and control surface sections and flap kinematics.

Cmarc is a inviscid fluid flow analysis code of the type known as a low order panel method. Low order panel methods, in which the calculated coefficient of pressure for each panel is applied uniformly over the entire panel, have been shown to provide virtually the same level of accuracy as higher-order methods, in which pressure gradients are calculated within panels, as long as the meshing of the model is sufficiently dense, particularly in areas of rapidly changing pressure coefficient. With desktop computers currently available in the Propulsion and Aerodynamics Computational Lab at ERAU, dense meshes of 5000 or more panels for a half-model can be analyzed in less than five minutes.

Postmarc is a graphic postprocessor for Cmarc and PMARC-12 output files. Postmarc provides rotatable and zoomable views of the body and wake, with color mappings of pressure, velocity, and Mach number; vector arrows representing local velocities, and on and off-body streamlines and wakes. On-body streamline display includes boundary layer analysis. Data may be displayed for a single output file or for the difference between two output files for the same body (for example with different AOAs or geometry dimensions).
Streamlines can be analyzed individually, for example to determine the location of laminar transition, or the entire surface of the model can be covered with streamlines and the boundary layer conditions calculated for each one. The complete boundary layer of the model can then be modeled, and such parameters as boundary-layer thickness and friction coefficient can be spectrum-plotted. The friction coefficient can be integrated over the surface to obtain the friction drag.

Knowing pressures over the complete airplane means knowing flight loads, and knowing how pressures vary with AOA means knowing stability derivatives. Digital Wind Tunnel, an optional component of PSW, calculates static and dynamic stability, elevator setting for trim, neutral point, and roll rate by repeatedly analyzing the model at various angles of attack and yaw and over a range of control-surface deflections.

3.4 Analysis Procedure

Detailed dimensions were obtained from Diamond, and solid modeling and meshing were done in Loftsman/P. The aircraft’s symmetric proportions made it possible that only the starboard side of the aircraft had to be created, meshed, and solved, whereas the port side was mirrored only for visualization purposes. The size of the grid was chosen based on the author’s previous experience with parabolized Navier-Stokes solvers, which require dense meshes. Unfortunately, the size of the final mesh by far exceeded 5,000 panels, which according to PSW’s co-developer Peter Garrison is the upper limit of a symmetric full-aircraft analysis. As a result, Cmarc analyses kept crashing and no solution could be obtained. Hence, meshing work had to be repeated and this time the final mesh size measured just under 4,000 panels. It should be noted that
even though the PSW package is far more developed than its predecessor PMARC-12, the meshing process is still partially manual and very time-intensive. Blending just two 3D surfaces can take a few hours.

Cmarc calculated the second mesh analyses on a 2GHz desktop within four minutes. A total of 9 runs were conducted for each one of the wing designs (which are described in Section 4.3), adding up to a total of 36 runs. In addition, numerous runs were conducted during the testing phase to ensure validity of the solution. Nonetheless, all of the PSW work was completed during one academic semester and utilizing relatively simple hardware, which is a testament to the software’s feasibility as an effective low-cost aircraft design tool.

Figure 10 shows a spectrum plot of Mach numbers at cruise speed and altitude. Red color displays regions of low and blue color regions of high Mach numbers. As could have been predicted, the nose of the aircraft and the base of the windshield are portrayed in red colors. The same is true for the inside region of the engine inlet, where the inlet geometry is designed to maximize static pressure. On the contrary, the top surface of the wing is all in blue, with the color intensity reaching a peak at the maximum thickness of the chord length and close to the root of the wing, since the root airfoil has a higher thickness-to-chord ratio than the airfoils used closer to the wing tip.
Figure 10. Mach number distribution.
Figure 11 shows the distribution of local static pressure coefficient. Red stands for low pressure, and blue for high pressure. The same reasoning as for the Mach number can be used, and accordingly, the top of the cabin shows a region of very low pressure. Figure 11 also clearly shows how the wing influences the pressure distribution on the fuselage, creating a region of low pressure on the fuselage section close to the wing.

Figure 12 is obtained by subtracting the incompressible coefficient of pressure values from the compressible values. Karman-Tsien correction was used in the compressible solution. According to Figure 12, coefficient of pressure drops in value up to 0.164 in cruise due to local compressibility effects. This result prompted the author not to neglect compressibility effects in numerical and statistical analyses.
Figure 11. Distribution of local static pressure coefficients.

*Coefficient of Pressure, Time state = 10

* c:\adjet14.bin
Figure 12. Difference between compressible and incompressible local static pressure coefficients.
On-body streamlines are calculated using a subsequent boundary layer analysis. Interestingly, Figure 13 shows that the streamlines that are sucked in by the engine are not at the lateral free-stream location of the air inlets. Instead, they flow along the lower surface of the fuselage and then curl sideways and upwards induced by the upwash from the wing. This leads to a more turbulent engine airflow than if the engines were positioned aft of the wings, as is usually seen on conventional business jet layouts (which cannot be used in this case, since this aircraft is powered by only one engine). The suction effect of the operating engine was produced by specifying a velocity 10% higher than the free-stream velocity at a boundary located five inches inside of the engine inlet and positioned normal to the free-stream flow direction. It is also worth noting that PSW predicts partial separation from the engine cowling just past the trailing edge of the wing, which is shown with a single streamline leaving the contour of the aircraft.

Figure 14 demonstrates PSW’s capability to plot off-body streamlines in any plane inside of the computational domain.
Figure 13. On-body streamlines plotted as a distribution of Mach number.
Figure 14. Off-body streamlines plotted as a distribution of Mach number.
3.5 Wind Tunnel Testing

The wind tunnel that was used is located at Embry-Riddle Aeronautical University, Daytona Beach, and was built primarily for instructional purposes. It is an open-circuit tunnel with a rectangular test section of 30 x 40 inches in cross-sectional area and 60 inches in length. The tunnel is powered by an electric 50 horsepower DC motor that drives a 66 inch diameter fan with eight blades, providing a maximum speed in the test section of 200 ft/s. Figure 15 shows the layout and dimensions of the wind tunnel.

Figure 15. ERAU 30 x 40 inch wind tunnel.
The force balance installed in the wind tunnel is a pyramidal strain gage balance system from Aerolab, remotely adjustable in angle of attack and yaw over a ±25 degrees range. Force balance data were collected with WINDT2002V2.vi LabView data acquisition and reduction program, which uses a PCI-6071E Data Acquisition Card. Base drag data were obtained from a conventional manometer.

As explained previously, only the fuselage was produced and tested. Diamond supplied the author with all the necessary dimensions of the fuselage and its solid model is shown in Figure 16.

Figure 16. Solid model of the fuselage.
CATIA V5 was used to create a tool path from the solid model, which then was fed into the Komo VR408P 3-Axis CNC milling machine. The material selected was high density blue styrofoam, which allowed easy sanding of the test model and installation of internal gear. The model has an internal 1.5 x 3.5 inch block of wood, which increased the structural stability and provided an adequate mount for the test balance strut. Figure 17 shows the wind tunnel model inside the test section.
Several tests were run with models of varying surface roughness to find the test model’s surface properties that produced the least amount of drag. Further, a base drag correction needed to be made due to the lack of the engine’s exhaust plume and the consequent wake formation at the wind tunnel model engine outlet. This was accomplished by measuring the surface pressure at the engine outlet, subtracting it from the static pressure in the engine’s outlet cross-sectional plane, and multiplying the result by the engine’s outlet area. The obtained value corresponds to the excess base drag, and it had to be measured separately for each test condition and subtracted from each drag result obtained from the force balance. This gives, in effect, the fuselage drag without any engine influence. The presence of the exhaust plume would have to be added back into the fuselage drag, but no attempt to quantify this effect was made in this study.

In addition, Reynolds number corrections were performed to balance the lower lift and higher drag produced due to the difference in Reynolds number between the wind tunnel experiment and the full-size aircraft at cruise. These corrections are empirically derived relations between the lift and drag results of the same model at different Reynolds numbers. ERAU has done its own comparisons and uses the following correction equations:

\[
(C_{L_{\text{MAX}}})_{\text{CORRECTED}} = (C_{L_{\text{MAX}}})_{\text{MEASURED}} \left( \frac{Re_{\text{FULLSIZE}}}{Re_{\text{MODEL}}} \right)^{0.13}
\]

\[
(C_{D_{\text{MAX}}})_{\text{CORRECTED}} = (C_{D_{\text{MAX}}})_{\text{MEASURED}} \left( \frac{Re_{\text{MODEL}}}{Re_{\text{FULLSIZE}}} \right)^{0.20}
\]
3.6 Program Mechanics

The numerical simulation program largely differs from the statistical one, as can be seen from its script’s flowchart shown below.

In addition to the geometry and airfoil data that also had to be supplied to the statistical simulation program, the numerical version requires additional results from the panel code and wind tunnel testing. The flowchart indicates that there are two separate domains in which user input is required. In reality, all data are entered at the same time and at the same location in the script; some of them are just looked up sooner than others, and the division of domains was used to illustrate the sequence of operations.

The following are the computational steps of the Mathcad routine, which is included in Appendix D:
1. Units, constants, and atmospheric conditions are created.

2. Engine performance data are calculated from the engine deck sub-routine.

3. Dimensions and geometry of the aircraft are defined.

4. Wing partitioning data, such as areas of partitions, spanwise location of partitions, and chord lengths along those spanwise locations are imported from PSW. Spanwise location and chord length of partitions are defined as shown below.

![Definition of wing partitions' geometry.](image)

5. $C_L$ and $C_M$ data are imported from PSW for each of the wing partitions for a range of AOAs from zero to 16 degrees with increments of 2 degrees.

6. Area-weighted $C_L$ average values are calculated for all AOAs. Symmetric lift distribution is assumed, as shown below.

$$C_L = \frac{\int_0^{\frac{S}{2}} C_{L_i} \cdot dS}{\frac{S}{2}} = \frac{\int_0^b C_{L_i} \cdot c_i \cdot dy}{\frac{S}{2}}$$
where: \( b = \) wing span

\[
C_i = \text{coefficient of lift of the } i\text{-th partition}
\]

\[
S = \text{wing area}
\]

\[
c_i = \text{chord length of the } i\text{-th partition}
\]

The \( C_L \) values calculated above stem from an inviscid solution and, hence, their \( C_L \) versus AOA curve is a linear function. In order to simulate separation effects, a function is built in which allows the \( C_L \) values of each one of the partitions to get only as high as the specified 3D \( C_{L\text{max}} \) value for that airfoil. In other words, the non-linear \( C_L \) versus alpha curve is approximated with a linear function which is limited to \( C_{L\text{max}} \). It is anticipated that this approximation will deliver slightly over-predicted average \( C_L \) values at high AOAs, but it should be accurate at cruise condition.

A graph is created for validation purposes. Plotted are the modified and unmodified \( C_L \) versus AOA curves so that they can be compared against each other. In addition, 2D lift curve data points were available for the same airfoil from a wind tunnel test conducted at German Aerospace Center. Those were converted to the 3D flow regime and displayed with other lift curves in Figure 20. It can be seen that the modified and unmodified lift curves, both displayed in red, only differ at high AOA. Interestingly, the modified lift curve for the entire wing does not exhibit a sharp \( C_{L\text{max}} \) transition behavior as do the partitions’ lift curves of which it is comprised. This is due to the fact that each one of the partitions experiences a slightly different AOA, and therefore, \( C_{L\text{max}} \) is not reached by all partitions at the same time. Comparing the modified approximation with
experimental data, the anticipated over-prediction of $C_l$ values at high AOAs can be observed. It happens primarily in three regions: at very low AOAs, at the transition from the linear range, and at AOAs beyond the $AOA_{stall}$. It should be noted, however, that the inaccuracies at very low AOAs and those beyond the $AOA_{stall}$ will never be felt, since Mathcad will only accept AOA values that correspond to positive $C_l$ values up to the $C_{l_{max}}$. Hence, the only region of inaccuracy that matters is the transition from linear to non-linear lift curve, and the deviation is judged to be tolerable.

![Figure 20. Modified, unmodified, and experimental $C_l$ versus AOA curves.](image)

9. Horizontal tail $C_l$ values are found for trimmed steady-level flight. The balance equation used for calculation is shown below.
\[ C_{M_w} + C_{M_f} - \left( \frac{W}{2 \rho v^2 S_w} + C_{L_H} \frac{S_H}{S_w} \right) \frac{x_{AC_w} - x_{CG}}{MAC_w} = C_{L_H} \frac{x_{AC_H} - x_{CG}}{MAC_H} \frac{S_H}{S_w} + C_{M_H} \frac{MAC_H}{MAC_w} \frac{S_H}{S_w} = 0 \]

where: 
- \( C_{M_w} \) = wing moment coefficient
- \( C_{M_f} \) = fuselage moment coefficient
- \( W \) = maximum take-off weight
- \( C_{L_H} \) = horizontal tail lift coefficient
- \( S_w \) = wing area
- \( S_H \) = horizontal tail area
- \( x_{AC_w} \) = wing aerodynamic center
- \( x_{CG} \) = center of gravity
- \( x_{AC_H} \) = horizontal tail aerodynamic center

10. Wing AOAs are found for horizontal cruise flight. This is accomplished by using Mathcad’s “Find” function, which in this case finds the common solution to the following two functions:

   function which relates the wing lift coefficient and AOA

   function which computes the required wing lift coefficient due to the aircraft weight, speed, and horizontal tail lift coefficient.

11. Once the relationship between the AOA and aircraft weight and speed was known, a function was created which relates the \( C_L \) values calculated by PSW and aircraft weight and speed.
12. Prandtl-Glauert compressibility correction, which is shown below, is applied to the wing lift distribution.

\[
(C_{L_{\alpha}})_{\text{compressible}} = \frac{(C_{L_{\alpha}})_{\text{incompressible}}}{\sqrt{1 - M^2}}
\]

13. Figure 21 shows a plot of lift distributions for various AOAs, as well as the comparison of compressible and incompressible distributions, both marked with crosses. The graph shows that the compressibility effects can be noticed, and their result is a slight increase in local $C_L$ values. The previously mentioned $C_{L_{\text{max}}}$ condition is also displayed with a flat top of the lift distributions at high AOAs. As can be seen, there is a dip in the curves near the wingtip. That is the result of the unusually high break in the D-Jet wing’s leading edge sweep.
14. Airfoil polars are imported from X-Foil. Each airfoil was evaluated for three different Reynolds numbers and for an AOA range of negative five to twenty degrees with increments of half a degree. Tabulated results are shown in Figure 22, whereas the plots of $C_l$ versus AOA, $C_d$ versus AOA, and $C_l$ versus $C_d$ are shown in Figures 23, 24, and 25 respectively.
Figure 22. X-Foil C\textsubscript{1} and C\textsubscript{4} results for three different Reynolds numbers.
Figure 23. $C_l$ versus AOA.

Figure 24. $C_d$ versus AOA.
15. The next step involves assignment of X-Foil-derived $C_d$ values to PSW-derived $C_l$ values. As explained previously, the wing was split up into 23 spanwise segments, and PSW was used to find $C_l$ values for each one of these strips. Since the polars provide the relation between coefficients of lift and drag, $C_d$ values are now known for each one of the wing strips. In other words, the lift distribution is translated into a drag distribution, and both are computed in variation with Reynolds number. Reynolds number is programmed as a function of flight speed, altitude, temperature, and reference length. Since each one of the wing partitions has a different chord length, different Reynolds numbers are calculated for each one of the partitions. Since different polars are used for different Reynolds numbers, each one of the wing strips is assigned to a different polar curve.
16. Span efficiencies are calculated in PSW using the perturbation velocities induced by the wing and its wake (also known as the Trefftz Plane analysis). Finally, the total wing drag is computed by adding the zero-lift drag coefficient and the lift coefficient due to lift, and multiplying them both by the reference area and dynamic pressure.

17. Once the drag of the wing was known, the horizontal and vertical tail were analyzed. For the sake of simplicity, the strip method and PSW were not used for calculation of the lift and drag distribution of the tail. Instead, the balance equation from step 9 was used to find the $C_{Lh}$ value, which was then used for calculation of the profile and induced drag. Profile drag was determined using the same coefficient of lift to coefficient of drag transformation as for the wing, except that a different drag polar was employed. The induced drag was found using the formula from Prandtl’s classical lifting line theory (shown below) and a span efficiency value of 0.75 (taken from Roskam [3], section 4.4.1.2).

$$C_{D_i} = \frac{C_{L}^2}{\pi e AR}$$

18. Similarly as in the case of the wing, the horizontal tail zero-lift drag coefficient and drag coefficient due to lift were added, and then multiplied by the horizontal tail area and dynamic pressure. Vertical tail drag was calculated in the same way, except that the vertical tail drag coefficient was multiplied by the vertical tail area. Also, a zero side slip flight condition was assumed and therefore no induced drag calculated for the vertical tail.

19. The next step involved calculation of fuselage drag. As explained previously, the fuselage drag coefficient was obtained from wind tunnel testing. Following the
same programming steps as for the wing, the drag coefficient was calculated as a function of the aircraft AOA. The difference between the wing AOA and the fuselage AOA was found by setting the fuselage zero-lift AOA equal to the wing AOA at cruise condition. The purpose of this technique to minimize the aircraft drag at cruise condition. Results are shown in Figure 26.

![Figure 26. Fuselage C_d versus calibrated speed.](image)

20. The final step was to sum the drag results of all individual aircraft components and multiply them by a factor of 1.1, which is Diamond’s method (also used by many other general aviation manufacturers) of taking into account the interference drag and miscellaneous drag (caused by antennas, imperfections, etc.).
4. ASSESSMENT AND APPLICATION

4.1 Engine Performance

Since the engine performance data are an important factor in flight performance estimation, they will be presented and analyzed before the flight performance results of the statistical and numerical estimation methods are compared to each other. As mentioned before, identical engine decks and analysis procedures were used in both Mathcad routines. Figures 27-31 show plots of thrust versus true airspeed at various altitudes and power settings. Solid lines represent 100%, dash lines 80%, and dash-dot (dadot) lines 60% of maximum continuous power (MCP). Each one of the thrust curves decreases with airspeed, which is in accordance with theory. It can also be observed that the performance increase does not vary linearly with power settings. Figure 32 shows fuel consumption at sea level, FL 100, FL 200, FL 250, and FL 300, whereas Figures 33-37 display fuel consumption at various power settings.
Figure 27. Thrust versus true airspeed at sea level.
Figure 28. Thrust versus true airspeed at FL 100.
Figure 29. Thrust versus true airspeed at FL 200.
Figure 30. Thrust versus true airspeed at FL 250.
Figure 31. Thrust versus true airspeed at FL 300.
Figure 32. Fuel consumption at 100% MCP versus true airspeed at various altitudes.
Figure 33. Fuel consumption versus true airspeed at sea level.
Figure 34. Fuel consumption versus true airspeed at FL 100.
Figure 35. Fuel consumption versus true airspeed at FL 200.
Figure 36. Fuel consumption versus true airspeed at FL 250.
Figure 37. Fuel consumption versus true airspeed at FL 300.
4.2 Flight Performance Results

Recalling previous sections, two Mathcad files were created to evaluate D-Jet’s flight performance. Both files use the same engine performance analysis, and they both rely on the same method for creating airfoil polars. However, the rest of their code is very different: the first program uses Roskam’s statistical data to estimate drag of the aircraft, whereas the second program uses a combination of a panel method code and experimental wind tunnel testing to accomplish the same task. How did the results compare? What are their differences? Do they have similarities? Analysis of results and answers to these questions are presented below.

Figure 38 presents rates of climb at sea level and at various power settings produced with both methods; solid lines show statistical results, whereas dotted lines show results obtained with the method that incorporates wind tunnel testing and numerical predictions. Red, blue, and magenta colors are used for power settings of 100%, 80%, and 60% of maximum continuous power, respectively. Two features can be instantly observed: numerical results predict lower maximum rates of climb, but both analyses calculate similar level flight top speeds (that is, speeds at which the maximum rate of climb is zero).
Figure 38. Numerical and statistical rate of climb in ft/min versus true airspeed in knots at sea level.
Since both estimation methods predict similar top speeds, it can be concluded that they both estimated similar zero-lift drag results. On the contrary, based on the difference in rates of climb at lower velocities, different values of drag due to lift seem to have been calculated.

It is nearly impossible to determine which one of the methods delivered more accurate drag due to lift results, since no flight test data are available. What can be done, however, is to uncover the source of deviating results. Drag due to lift results of the two methods were compared against each other for each one of the aircraft components, and it was found out that the fuselage results differed significantly more than the drag values of the other components. The dotted line in Figure 39 shows the wind tunnel test model $C_D$ values, whereas the solid line shows the summation of statistically calculated $C_D$ values of fuselage, inlets, and windshield.

Figure 39. Fuselage $C_D$ values versus airspeed at sea level.

Which method predicted more accurate results? The disadvantage of the statistical approach is that it is not well-suited for innovative and rare designs, whereas the
experimental method might have been affected by the relatively low Reynolds number produced in ERAU’s wind tunnel. However, since no flight test data are available at this moment, it is not possible to conclude which method was more accurate.

4.3 Wing Layout Comparisons

D-Jet’s wing layout had not been finalized at the time of writing of this document. Two different wing areas and airfoils were in discussion, and Diamond was trying to find out which combination provided the best compromise between the rate of climb and cruise speed. All previous calculations were made using a wing area of 15.8 square meters, span of 11.8 meters, and an airfoil which was custom-designed for Diamond by the German Aerospace Center (DLR) and was called DLRBS. In addition, Diamond was also interested in the DOA5 airfoil, which was designed by Dornier and used on Do-228 aircraft. Finally, Diamond was also looking at the possibility of employing larger flaps and reducing the wing area to 12.8 square meters and span to 9.6 meters. For simplicity, each one of the design cases was given a name, as shown in Table 1.

<table>
<thead>
<tr>
<th>Design case name</th>
<th>Airfoil</th>
<th>Wing Area [m²]</th>
<th>Span [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>DLRBS/Large</td>
<td>DLRBS</td>
<td>15.8</td>
<td>11.8</td>
</tr>
<tr>
<td>DLRBS/Small</td>
<td>DLRBS</td>
<td>12.8</td>
<td>9.6</td>
</tr>
<tr>
<td>DOA5/Large</td>
<td>DOA5</td>
<td>15.8</td>
<td>11.8</td>
</tr>
<tr>
<td>DOA5/Small</td>
<td>DOA5</td>
<td>12.8</td>
<td>9.6</td>
</tr>
</tbody>
</table>
4.4 Analysis of Results

Upon request, Diamond provided the author with polars for both airfoils, but coordinates were available only for the DLRBS airfoil. This eliminated the possibility of using the numerical method, since its PSW panel code requires the airfoil coordinates in the definition of wing surface. Hence, the statistical method was used. Figures 40-63 show the calculated rates of climb of various wing layouts at various altitudes and power settings. Solid lines represent 100%, dash lines 80%, and dadot lines 60% of maximum continuous power. In addition, Figures 40, 46, 52, and 58 portray the aircraft’s flight performance at sea level as a function of various aircraft gross weights as well; curves with circles show aircraft weights of 1800 kg and those with crosses show weights of 2200 kg; curves with neither circles nor crosses represent the baseline weight of 2000 kg. As it can be seen, adding weight results in a higher drag due to lift and lower maximum rate of climb. On the contrary, cruise speeds are not significantly dependent on aircraft weight.

Cruise speeds, however, do vary significantly with altitude. As it can be seen from Figures 64-67, highest cruise speeds of each one of the wing designs are reached at different altitudes. Maximum rate of climb, in contrast, is always reached at sea level.
Figure 40. DLRBS/Large rate of climb versus true airspeed at various weights at sea level.
Figure 41. DLRBS/Large rate of climb versus true airspeed at sea level.
Figure 42. DLRBS/Large rate of versus true airspeed at FL 100.
Figure 43. DLRBS/Large rate of climb versus true airspeed at FL 200.
Figure 44. DLRBS/Large rate of climb versus true airspeed at FL 250.
Figure 45. DLRBS/Large rate of climb in versus true airspeed at FL 300.
Figure 46. DLRBS/Small rate of climb versus true airspeed at various weights at sea level.
Figure 47. DLRBS/Small rate of climb versus true airspeed at sea level.
Figure 48. DLRBS/Small rate of climb versus true airspeed at FL 100.
Figure 49. DLRBS/Small rate of climb versus true airspeed at FL 200.
Figure 50. DLRBS/Small rate of climb versus true airspeed at FL 250.
Figure 51. DLRBS/Small rate of climb versus true airspeed at FL 300.
Figure 52. DOA5/Large rate of climb versus true airspeed at various weights at sea level.
Figure 53. DOA5/Large rate of climb versus true airspeed at sea level.
Figure 54. DOA5/Large rate of climb versus true airspeed at FL 100.
Figure 55. DOA5/Large rate of climb versus true airspeed at FL 200.
Figure 56. DOAS/Large rate of climb in ft/min versus true airspeed in knots at FL 250.
Figure 57. DOA5/Large rate of climb versus true airspeed at FL 300.
Figure 58. DOA5/Small rate of climb versus true airspeed at various weights at sea level.
Figure 59. DOA5/Small rate of climb versus true airspeed at sea level.
Figure 60. DOA5/Small rate of climb versus true airspeed at FL 100.
Figure 61. DOA5/Small rate of climb versus true airspeed at FL 200.
Figure 62. DOA5/Small rate of climb versus true airspeed at FL 250.
Figure 63. DOA5/Small rate of climb versus true airspeed at FL 300.
Figure 64. DLRBS/Large rate of climb versus true airspeed.
Figure 65. DLRBS/Small rate of climb versus true airspeed.
Figure 66. DOA5/Large rate of climb versus true airspeed.
Figure 67. DOAS/Small rate of climb versus true airspeed.
In order to ease the analysis of trends regarding the maximum rates of climb and cruise speeds of various wing layouts, all results were summarized in Table 2.

Table 2. Performance results from various wing layouts.

<table>
<thead>
<tr>
<th>Airfoil</th>
<th>Altitude</th>
<th>Large Wing</th>
<th></th>
<th>Small Wing</th>
</tr>
</thead>
<tbody>
<tr>
<td>DOA5</td>
<td>SL</td>
<td>2900</td>
<td>277</td>
<td>2880</td>
</tr>
<tr>
<td></td>
<td>FL100</td>
<td>2580</td>
<td>296</td>
<td>2500</td>
</tr>
<tr>
<td></td>
<td>FL200</td>
<td>1980</td>
<td>310</td>
<td>1820</td>
</tr>
<tr>
<td></td>
<td>FL250</td>
<td>1500</td>
<td>310</td>
<td>1340</td>
</tr>
<tr>
<td></td>
<td>FL300</td>
<td>1080</td>
<td>309</td>
<td>870</td>
</tr>
<tr>
<td>DLRBS</td>
<td>SL</td>
<td>2910</td>
<td>284</td>
<td>2880</td>
</tr>
<tr>
<td></td>
<td>FL100</td>
<td>2590</td>
<td>308</td>
<td>2500</td>
</tr>
<tr>
<td></td>
<td>FL200</td>
<td>2000</td>
<td>328</td>
<td>1800</td>
</tr>
<tr>
<td></td>
<td>FL250</td>
<td>1540</td>
<td>333</td>
<td>1330</td>
</tr>
<tr>
<td></td>
<td>FL300</td>
<td>1100</td>
<td>326</td>
<td>840</td>
</tr>
</tbody>
</table>

In addition, Figures 68-72 show a graphical comparison of those results.
Figure 68. Rate of climb versus true airspeed at sea level.
Figure 69. Rate of climb versus true airspeed at FL 100.
Figure 70. Rate of climb versus true airspeed at FL 200.
Figure 71. Rate of climb versus true airspeed at FL 250.
Figure 72. Rate of climb versus true airspeed at FL 300.
It can be seen that there is not a single flight condition in which the DLRBS airfoil does not match or outperform the DOA5 airfoil. However, the question of wing span and area needs to be looked at more closely.

Wing area has, among others, the following two major effects on flight performance: its increase lowers the AOA and increases the form drag of the wing. However, the arrival of laminar airfoils has made it possible that an increase in wing area sometimes results in higher cruise speeds. This is because laminar buckets are limited to relatively low AOAs, and a wing with small area might fly at cruise conditions at AOAs that are outside the range of its airfoil’s laminar bucket. Increasing the wing area will result in higher overall drag assuming constant $C_D$ values. However, if the AOA of the wing consequently drops into the laminar bucket region, $C_D$ values do not stay constant but can be significantly reduced. For example, DLRBS airfoil’s $C_d$ values drop from 0.0078 to 0.0060 if $C_L$ is decreased from 0.25 to 0.1 at a Reynolds number of 2 million.

Table 2 shows that the cruise speed of the DLRBS airfoil-equipped wings is higher at low altitudes with the small wing area. Here, the effect of the lower form drag due to the small wing area can be felt. However, as the altitude and AOAs increase, the speed cruise shifts in favor of the wing with large area. This is due to the fact that the small wing needs 23% higher $C_L$ values in order to support the aircraft’s weight and it consequently falls out of the range of the laminar bucket at altitudes above 20,000 ft. This results in higher $C_D$ values, which in this case cannot be balanced by the smaller reference area. It should be noted that this effect cannot be achieved with the DOA5 airfoil; its laminar bucket’s range is too low for cruise $C_L$ values of both wings.
In the case of maximum rates of climb, the picture is much simpler. Here, the airspeeds are too low and $C_L$ values too large for laminar buckets. Instead, the driving parameter is drag due to lift, which increases with AOA of the wing. Large wings produce lower AOAs, and, consequently, higher rates of climb than small wings.

In conclusion, a wing equipped with the DLRBS airfoil and designed for a 25000 ft cruise altitude (as in the case of D-Jet) climbs and cruises faster with a 15.8 square meter wing area than with a wing area of 12.8 square meters. In addition, the larger wing also offers more space for fuel.
5. CONCLUSION

5.1 Numerical Versus Statistical Method

Roskam’s statistical approach has been in a wide-spread use for many years, and this paper has only confirmed its justification among the flight performance estimation methods. It is very time-efficient and only requires acquisition of literature which describes it. Accuracy of the statistical approach could only be checked with cruise speeds obtained by the modified method presented in this thesis, and Roskam’s predictions matched those results very closely. Overall, this more elaborate method seems to be required only for very unusual layouts that are outside the range of “normal” configurations used to generate Roskam’s equations. For all other, it is hard to imagine a flight performance estimation method that offers reliable results at such a low cost.

However, drawbacks of this method need to be mentioned as well. By default, it is not possible to arrive at innovative design solutions using the statistical method, since it is based on a collection of existing designs’ physical configuration data. Therefore, several geometric parameters (such as the number and location of wing sweep changes, aerodynamic and geometric twist) cannot be optimized using this method.

This is where the numerical method comes into play. Its panel code’s ability to analyze any arbitrary shape gives it a status one level above the statistical method in the hierarchy of aircraft analysis techniques.
5.2 Recommendation

Due to the lack of flight test data, it is hard to evaluate if the herein presented numerical method is capable of providing more accurate results than the statistical method. Certain is, however, that the new method provides more detailed information about the distribution of lift, and hence of drag as well. This information can be used to perform detailed optimization studies, clearly underlining the attraction of the panel code methods.

Since there was deviation of flight performance results originating in fuselage induced drag contributions, it can be argued that for future studies a better fuselage drag estimation technique should be coupled with the panel codes. Fortunately, there is an alternative available. With the current arrival of open source Navier-Stokes solvers and powerful desktops capable of running large analyses, it might be worthwhile to couple X-Foil and PSW for analysis of lifting surfaces and a Navier-Stokes code for analysis of the fuselage. The removal of the lifting surfaces would greatly reduce the size of computational domain that needs to be analyzed, and could hence allow time-effective and inexpensive calculation of the fuselage drag using Navier-Stokes codes.
REFERENCES


APPENDIX A

CHANGES MADE TO THE ENGINE DECK FORTRAN PROGRAM
USE F2KCLI

*Invokes the command line library*

CHARACTER(LEN=40) :: CMD
REAL(KIND=4) :: LINEIN
INTEGER :: NARG,IARG,ENVSWITCH

*Defines the format of the introduced variables*

NARG = COMMAND_ARGUMENT_COUNT()
if(NARG < 4) then
  PRINT*, 'Usage: CD1400NC.exe <XMN Mach> <ALT ft> <PA psia> <TA R>':
  & '[opt switch to loop]'
  PRINT*, ''
  PRINT*, 'Other values are defined in main.f'
  stop
end if

*Reads in and checks the number of arguments, produces an error message if less than four arguments*

ENVSWITCH = 0

*This variable is used to enable multiple iterations*

DO IARG = 1,NARG
  CALL GET_COMMAND_ARGUMENT(IARG,CMD)
  READ (CMD, *) LINEIN
  if(IARG.eq.1) ENGIN(01) = LINEIN
  if(IARG.eq.2) ENGIN(02) = LINEIN
  if(IARG.eq.3) ENGIN(03) = LINEIN
  if(IARG.eq.4) ENGIN(04) = LINEIN
  if(IARG.eq.5) ENVSWITCH = LINEIN
END DO

*Iterates as many times as the number of arguments and converts each time the string into a real number, which is then assigned to one of the program variables*

if(ENVSWITCH > 0) then
  do 999 j=1,ENVSWITCH
    call engsub
    engin(01)=engin(01)+0.1
  999 continue
else
  call engsub
end if

*Checks for number of iterations and increments the Mach number by 0.1. In case of ENVSWITCH being equal to 0 or 1, it does just one iteration for the elsewhere specified Mach number*
APPENDIX B

VISUAL BASIC FOR APPLICATIONS CODE
Private Declare Sub Sleep Lib "kernel32" (ByVal dwMilliseconds As Long)
Private Sub Workbook_SheetChange(ByVal Sh As Object, ByVal Target As Range)
Dim IR As Double
Dim IFreeFile As Long
Dim RunDirectory As String
Dim sFileText As String
Dim aFileLines() As String
Dim aFieldsInLine() As String
Dim curRow As Long
Dim curCol As Long
Dim strRunLine As String

Defines the Sleep function to wait for writing to the outtab txt file and defines the format of variables

Application EnableEvents = False

Since the Sheetchange event is used, Applications events needs to be turned off to prevent from getting stuck in a loop while sheet changes are written

RunDirectory = "C:\CD1400NC_MOD"
If Len(Dir(RunDirectory & "\outtab txt")) > 0 Then
    Kill RunDirectory & "\outtab txt"
End If
ChDir RunDirectory
strRunLine = "CD1400NC exe " & Worksheets(1) Cells(2, "B") & " " &Worksheets(1) Cells(3, "B")
strRunLine = strRunLine & " " & Worksheets(1) Cells(4, "B") & " " &Worksheets(1) Cells(5, "B")
strRunLine = strRunLine & " " & Worksheets(1) Cells(6, "B")
taskID = Shell(strRunLine, vbHide)

Defines the working directory, checks if the outtab txt file exists, then deletes it, strRunLine builds the command and arguments and Shell() runs it

CHECK_OUTPUT
Sleep 1000
If Len(Dir(RunDirectory & "\outtab txt")) > 0 Then
    IFreeFile = FreeFile
    Open RunDirectory & "\outtab txt" For Input As IFreeFile
    sFileText = Input$(LOF(IFreeFile), IFreeFile)
    Close IFreeFile

Waits for the program to run, checks if the file outtab txt has been written, opens the file and reads in the variables into sFileText

aFileLines = Split(sFileText, vbCrLf)

Used if more than one iteration

curRow = 2
curCol = 4
For ILineLoop = LBound(aFileLines) To UBound(aFileLines)
aFieldsOnLine = Split(aFileLines(ILineLoop), ",")
For IFieldLoop = LBound(aFieldsOnLine) To UBound(aFieldsOnLine)
sFieldValue = aFieldsOnLine(IFieldLoop)
End If
Worksheets(1).Cells(curRow, curCol).Value = sFieldValue
curRow = curRow + 1
Next
curRow = 2
curCol = curCol + 1
Next

Keeps track of the current location on the spreadsheet and reads in the sFileText values

Application.EnableEvents = True
Application events is turned on again

Else
' MsgBox ("Error reading output file." & vbCrLf & vbCrLf & "Click OK to retry. Use CNTL Break to stop.")
GoTo CHECK_OUTPUT
End If

Loops if the outtab.txt has not been written; error message is currently commented out and not being used

End Sub
APPENDIX C

STATISTICAL AIRCRAFT FLIGHT PERFORMANCE ESTIMATION

METHOD
D-JET FLIGHT PERFORMANCE ESTIMATION

1. Part of Graduate Thesis by Igor Lebovic, Embry-Riddle Aeronautical University
"Roskam's Empirical Flight Performance Estimation Methods"

Input:

AIRFOIL DATA

Airfoil: DLRBS

<table>
<thead>
<tr>
<th>CLEAN_Re75mio</th>
<th>0</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.0065</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>0.0058</td>
<td>0.09</td>
</tr>
<tr>
<td>2</td>
<td>0.004</td>
<td>0.16</td>
</tr>
<tr>
<td>3</td>
<td>0.0042</td>
<td>0.3</td>
</tr>
<tr>
<td>4</td>
<td>0.0048</td>
<td>0.5</td>
</tr>
<tr>
<td>5</td>
<td>0.0056</td>
<td>0.7</td>
</tr>
<tr>
<td>6</td>
<td>0.0075</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>0.012</td>
<td>1.4</td>
</tr>
</tbody>
</table>
### PITCHING MOMENT COEFFICIENTS AND CURVES

\[ C_{m0\_clean} = -0.025 \]

\[ C_{m\alpha\_clean} = -0.001844 \, \text{deg}^{-1} \]

#### AIRFOIL DATA

<table>
<thead>
<tr>
<th>CLEAN_Re83 mio</th>
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<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.0065</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>0.0058</td>
<td>0.09</td>
</tr>
<tr>
<td>2</td>
<td>0.004</td>
<td>0.16</td>
</tr>
<tr>
<td>3</td>
<td>0.0042</td>
<td>0.3</td>
</tr>
<tr>
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<td>0.5</td>
</tr>
<tr>
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<td>0.0055</td>
<td>0.7</td>
</tr>
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<td>6</td>
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<td>1</td>
</tr>
<tr>
<td>7</td>
<td>0.0109</td>
<td>1.35</td>
</tr>
</tbody>
</table>

<table>
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<th>CLEAN_Re120 mio</th>
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</thead>
<tbody>
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<td>0.0049</td>
<td>0.6</td>
</tr>
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<tr>
<td>6</td>
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<td>1</td>
</tr>
<tr>
<td>7</td>
<td>0.0095</td>
<td>1.3</td>
</tr>
</tbody>
</table>
WING DATA

$\Delta_{0.5c_w} = 0\text{ deg}\quad$ semi-chord sweep angle

$\iota_{w} = 0\text{ deg}\quad$ wing incidence angle / negative for up

$l_{m_w} = 1.4\text{ m}\quad$ mean aerodynamic chord

$S_{w} = 15.8\text{ m}^2\quad$ wing reference area

$b_{w} = 11.8\text{ m}\quad$ wing span

$S_{wfl} = 10\text{ m}^2\quad$ flapped wing area
FUSELAGE DATA

$l_{\text{fus}} = 11 \text{ m}$

$S_{\text{wet}_{\text{fus}}} = 29.376 \text{ m}^2$  
wetted area of the fuselage

$S_{\text{pit}_{\text{fus}}} = 9.35 \text{ m}^2$  
fuselage planform area - guestimation

$S_{\text{fus}} = 1.9295 \text{ m}^2$  
projected frontal area of the fuselage

$S_{b} = 0.2 \text{ m}^2$  
base area, flat base at the end of the fuselage
## EMPENNAGE DATA

### HORIZONTAL TAIL

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\varepsilon_h$</td>
<td>0.75</td>
<td>for T-Tails (Roskam 4 4 1 2, P 69)</td>
</tr>
<tr>
<td>$S_h$</td>
<td>$3.3 \ m^2$</td>
<td>horizontal tailplane surface (reference) Area</td>
</tr>
<tr>
<td>$b_h$</td>
<td>4 m</td>
<td>span of horizontal tail</td>
</tr>
<tr>
<td>$l_{ch,h}$</td>
<td>825 mm</td>
<td>mean aerodynamic chord of horizontal tail</td>
</tr>
<tr>
<td>$x_{NPh}$</td>
<td>11 m</td>
<td>guestimation</td>
</tr>
<tr>
<td>$t_h$</td>
<td>115 mm</td>
<td>thickness</td>
</tr>
<tr>
<td>$tipchord_h$</td>
<td>0.2 m</td>
<td></td>
</tr>
<tr>
<td>$\tau_h$</td>
<td>1</td>
<td>thickness ratio / ratio from root to tip (1= constant ratio over span)</td>
</tr>
<tr>
<td>$l_h$</td>
<td>1.2</td>
<td>rough guestimation</td>
</tr>
</tbody>
</table>
VERTICAL TAIL

\( s_v = 2.8 \ m^2 \)  \hspace{1cm} \text{vertical tailplane surface (reference) Area}

\( b_v = 1.7 \ m \)  \hspace{1cm} \text{span of vertical tail}

\( l_{u,v} = 1.855m \)  \hspace{1cm} \text{mean aerodynamic chord of vertical tail}

\( x_{vNP} = 9.8 \ m \)  \hspace{1cm} \text{position of ac pf vertical tail}

\( t_v = 238 \ mm \)  \hspace{1cm} \text{thickness}

\( \text{tipchord}_v = 945 \ mm \)

\( \text{rootchord}_v = 1.8 \ m \)

\( \tau_v = 1 \)  \hspace{1cm} \text{thickness ratio / ratio from root to tip (1 = constant ratio over span)}

\( L_v = 1.2 \)

EMPENNAGE DATA
TRIM DATA

\[ x_{NPwf} = 5080\text{mm} \quad \text{guessimation (equal to } x_{NPFR}) \]
\[ x_{CG} = 4730\text{mm} \quad \text{guessimation} \]
\[ C_{M0h} = 0 \quad \text{guess} \]
\[ x_{NPh} = 11\text{m} \]
\[ l_{\mu-h} = 0.825\text{m} \]
\[ l_{\mu-w} = 1.4\text{m} \]
\[ x_{ACw} = 5.08\text{m} \]
\[ x_{ACH} = 11\text{m} \]
\[ C_{M0w\_clean} = C_{m0\_clean} \]
\[ C_{M0f\_clean} = -0.055 \]
INLET DATA

$\text{Inlet length}$

$\text{Inlet length} = 2673 \text{ mm}$

$S_{\text{wet,n}} = 5 \text{ m}^2$  rough guessimation

$\frac{\text{Inlet planform area}}{\text{planform area}} = 1666079 \text{ mm}^2$  rough guesstimation
4.5.2. Installed Inlet Drag Coefficient Increment

c_n = 1398 mm  geometric parameters, defined in figure 4.40

b_n = d_n

\Delta c_{p1} = 0.2  0.2 for nacelle on top of the wing
                 -0.3 for nacelle below the wing

\theta_n = 0  nacelle incidence angle defined in figure 4.35

\Delta c_{p2} = -0.056  (\theta_n)

4.5.2.3. Cooling drag coefficient increment

S_{cooling} = 0.04 m^2

INLET DATA
CONSTANTS, UNITS & STANDARD ATMOSPHERE

US unit system active

\[ J = \text{joule} \quad W = \text{watt} \quad \text{kts} = 1.852 \, \text{kph} \quad \text{RPM} = \text{min}^{-1} \]

\[ H = 0 \, \text{ft}, \, 500 \, \text{ft} \, 35000 \, \text{ft} \quad v_{\text{CAS}} = 5 \, \text{kts}, 10 \, \text{kts} \, 360 \, \text{kts} \]

mass = 1800 kg, 1850 kg, 2200 kg
mass = 2000 kg

INTERNATIONAL STANDARD ATMOSPHERE (ISA)
DIN ISO 2533

\[ p_0 = 1.225 \, \frac{\text{kg}}{\text{m}^3} \quad p_0 = 101325 \, \text{Pa} \quad T_0 = 288.15 \, \text{K} \quad \gamma_H = -0.0065 \, \frac{\text{K}}{\text{m}} \]

\[ R = 287.05287 \, \frac{\text{J}}{\text{kg} \cdot \text{K}} \]

\[ p(H) = p_0 \left( 1 + \gamma_H \frac{H}{T_0} \right)^{-g \gamma_H R} \]
\[\text{dISA} = -30 \text{ K}, 0 \text{ K}, 30 \text{ K}\]

\[\text{dISA} = 0 \text{ K}\]

\[T_{\text{ISA}}(H, \text{dISA}) := T_0 + \text{dISA} + \gamma_T \cdot H\]

\[\rho(H, \text{dISA}) = \frac{\rho(H)}{R \cdot T_{\text{ISA}}(H, \text{dISA})}\]

\begin{align*}
&\text{Graph of } T_{\text{ISA}}(H, 0 \text{ K}) \text{ vs. } H \text{ (ft)} \\
&\text{Graph of } \rho(H, 0 \text{ K}) \text{ vs. } H \text{ (ft)}
\end{align*}
TRUE AIRSPEED

\[ \text{VTAS}(H, v_{\text{CAS}}, dISA) = v_{\text{CAS}} \sqrt{\frac{\rho_0}{\rho(H, dISA)}} \]

Graph showing \( \text{VTAS}(H, 150 \text{kts}, 0\text{k}) \) in kts versus \( H \) in ft.
VELOCITY OF SOUND / MACH NUMBER

\[ \kappa := 1.4 \]

\[ a(H, dISA) := \sqrt{\kappa \cdot R \cdot TISA(H, dISA)} \]

\[ M(H, vCAS, dISA) := \frac{VTAS(H, vCAS, dISA)}{a(H, dISA)} \]

![Graph showing the relationship between altitude (H) and velocity (\(a(H, 0K)\) in m/sec\(^{-1}\))](image1)

![Graph showing the relationship between altitude (H) and Mach number (\(M(H, 100kts, 0K)\))](image2)
\[ \frac{h_c}{\bar{v}_{CAS}} \]

DYNAMIC PRESSURE

\[ e_d = \frac{r}{v_{CAS}^2} \]
REYNOLDS FACTOR

For calculation of local Re-Numbers multiply the factor with the specific length

Interpolation of absolute viscosity (taken from Schlichting/Truckenbrot)

\[ i = 0 \text{ to } 6 \]

\[ T_1 = \mu_1 = \]

\begin{tabular}{|c|c|}
\hline
-20 & 15.6 \\
-10 & 16.2 \\
0 & 16.8 \\
10 & 17.4 \\
20 & 17.9 \\
40 & 19.1 \\
60 & 20.3 \\
\hline
\end{tabular}

\[ T_2 = \left( T_1 + 273.15 \right) \text{ K} \]

\[ \mu_2 = \mu_1 \times 10^{-6} \frac{\text{kg}}{\text{m sec}} \]

\[ T_2_i = \]

\begin{tabular}{|c|c|}
\hline
253.15 & K \\
263.15 & 0 \\
273.15 & 0 \\
283.15 & 0 \\
293.15 & 0 \\
313.15 & 0 \\
333.15 & 0 \\
\hline
\end{tabular}

\[ \text{Absolute viscosity} \]

\[ \text{splinevec}_\mu = \text{pspline}(T_2, \mu_2) \]

\[ \mu(H, \text{dISA}) = \text{interp}(\text{splinevec}_\mu, T_2, \mu_2, T_{\text{ISA}}(H, \text{dISA})) \]
\( \mu(0 \cdot \pi, 0 \cdot \kappa) = 0 \text{ lbf} \cdot \text{ft}^{-1} \text{sec}^{-1} \)

Reynolds factor

\[
f_{Re}(H, v_{CAS}, dISA) = \frac{\rho(H, dISA) \cdot v_{TAS}(H, v_{CAS}, dISA)}{\mu(H, dISA)}
\]
Prandtl-Glauert Trafo

\[ \beta(H, v_{\text{CAS}}, d\text{ISA}) := \left(1 - M(H, v_{\text{CAS}}, d\text{ISA})^2\right)^{0.5} \]
ENGINE PERFORMANCE

FJ33-4A

Power lever angle settings: 90 degrees for take off up to speeds of M=0.38, 72 degrees for maximum continuous power, and 19 degrees for idle setting.

SEA LEVEL // 100 % MAX CONTINUOUS / PLA 72°

| Power_Lever_Angle = 72 | Altitude_Feet = 0 ft | Power_Mode = 17 | Temperature_Deviation = 0 |

(Thrust_row)
(Speed_row)
(Fuel_row) =

## INPUTS

| XMN | 72 |
| ALT | 0  |
| PA  | 17 |
| TA  | 0  |

| Iterations | 15 |

## OUTPUTS

<table>
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<tr>
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<th>4</th>
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<td>903.6</td>
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(Power_Lever_Angle Altitude_Feet Power_Mode Temperature_Deviation)
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<td>1265.5</td>
<td>1161</td>
<td>1062.1</td>
<td>977.4</td>
<td>903.6</td>
<td>878.9</td>
<td>878.9</td>
<td>878.9</td>
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\[ \text{Thrust}_{SL} := \text{Thrust}_row^T \cdot \text{lbf} \]

<table>
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<td>0</td>
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<td>330.7</td>
<td>355.4</td>
<td>355.4</td>
<td>355.4</td>
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</table>

\[ \text{Speed}_{SL} := \text{Speed}_row^T \cdot \text{kts} \]

<table>
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</table>

\[ \text{Fuel}_{SL} := \text{Fuel}_row^T \cdot \text{lb/hr} \]

![Graph showing relationship between Thrust and Speed]
\( i := 0.9 \)

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<tr>
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<th>Speed _ SL _ i</th>
</tr>
</thead>
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<td>0 kts</td>
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</tr>
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<td>878.9</td>
<td>355.4</td>
</tr>
<tr>
<td>878.9</td>
<td>355.4</td>
</tr>
</tbody>
</table>

\[
\text{Power}_\_ \_ i = \text{Thrust}_\_ \_ i \cdot \text{VTAS} (0 \cdot \text{ft}, \text{Speed}_\_ \_ i, \text{dISA})
\]

\[
\text{Power}_\_ \_ i = \begin{array}{c}
0 \\
191418.147 \\
351488.859 \\
482199.301 \\
591809.148 \\
683801.292 \\
714786.576 \\
714786.576 \\
714786.576 \\
714786.576 \\
\end{array}
\]

\[
\text{Power}_\_ \_ i \cdot 10^7
\]

\[
\begin{array}{c}
0 \\
0 \\
2 \cdot 10^7 \\
0 \\
0 \\
0 \\
0 \\
0 \\
0 \\
0 \\
0 \\
\end{array}
\]

\[
\begin{array}{c}
0 \\
200 \\
400 \\
0 \\
0 \\
0 \\
0 \\
0 \\
0 \\
0 \\
0 \\
\end{array}
\]

\[
\text{Speed}_\_ \_ i \text{ kts}
\]

136
SEa Level // 80 % Max Continuous / PLA 62.4°

Power_Lever_Angle = 62.4
Altitude_Feet = 0 ft
Power_Mode = 17
Temperature_Deviation = 0

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<th>OUTPUTS</th>
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<tr>
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<tr>
<td>Pa 14.696</td>
<td>std day</td>
</tr>
<tr>
<td>Ta 518.69</td>
<td>std day</td>
</tr>
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<td>MN 0</td>
<td>std day</td>
</tr>
<tr>
<td>CAS 0</td>
<td>std day</td>
</tr>
<tr>
<td>Eram 0.998</td>
<td>std day</td>
</tr>
<tr>
<td>3x 18400</td>
<td>std day</td>
</tr>
<tr>
<td>LHV 109.02</td>
<td>std day</td>
</tr>
<tr>
<td>Aj 0</td>
<td>std day</td>
</tr>
<tr>
<td>DAY 0</td>
<td>std day</td>
</tr>
<tr>
<td>IENV 17</td>
<td>std day</td>
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*Power_Lever_Angle Altitude_Feet Power_Mode Temperature_Deviation*
Thrust_row =

<table>
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<tr>
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<th>4</th>
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</thead>
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Speed_row =

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<tbody>
<tr>
<td>0</td>
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<td>0</td>
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Fuel_row =

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<td>662.88</td>
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</tbody>
</table>

Thrust_SL_80MCP := Thrust_row^T \cdot \text{Ibf}

Speed_SL_80MCP := Speed_row^T \cdot \text{kts}

Fuel_SL_80MCP := Fuel_row^T \cdot \frac{\text{lb}}{\text{hr}}
\[ i = 0.9 \]

<table>
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<tr>
<th>Thrust_SL_80MCP _lbf</th>
<th>Speed_SL_80MCP _kts</th>
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<td>355.4</td>
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<td>760.5</td>
<td>355.4</td>
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</tbody>
</table>

\[ \text{Power}_{\text{SL 80MCP}} = \text{Thrust}_{\text{SL 80MCP}} \cdot \text{VTAS}(0 \cdot \text{ft, Speed}_{\text{SL 80MCP}}, \text{d} \text{ISA}) \]

\[ \text{Power}_{\text{SL 80MCP}} = \]

\[ \begin{array}{c}
\text{Power}_{\text{SL 80MCP}} = 170483.915 \\
311284.104 \\
424268.192 \\
516667.43 \\
592839.677 \\
618494.927 \\
618494.927 \\
618494.927
\end{array} \]

\[ \begin{array}{c}
\text{Speed}_{\text{SL 80MCP}} = 0 \\
66.1 \\
132.3 \\
198.4 \\
264.6 \\
330.7 \\
355.4 \\
355.4 \\
355.4
\end{array} \]
### SEA LEVEL // 60 % MAX CONTINOUS / PLA 52.8°

- **Power_Lever_Angle** = 52.8
- **Altitude_Feet** = 0 ft
- **Power_Mode** = 17
- **Temperature_Deviation** = 0

#### INPUTS

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#### OUTPUTS

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*(Power_Lever_Angle  Altitude_Feet  Power_Mode  Temperature_Deviation)*
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Thrust\_SL\_60MCP \(\hat{\text{M}}\text{C}P\) := Thrust\_row \(\hat{T}\) \cdot \text{lbf}

Speed\_SL\_60MCP := Speed\_row \(\hat{T}\) \cdot \text{kts}

Fuel\_SL\_60MCP := Fuel\_row \(\hat{T}\) \cdot \text{lb} \cdot \text{hr}^{-1}
\[ i := 0..9 \]

\[
\begin{array}{|c|c|c|}
\hline
\text{Thrust}_{SL\_60MCP_i} & \text{Speed}_{SL\_60MCP_i} & \text{Power}_{SL\_60MCP_i} \\
1002.4 & 66.1 & 0 \\
903.5 & 132.3 & 136662.423 \\
814.5 & 198.4 & 246587.145 \\
731 & 264.6 & 331878.061 \\
658.9 & 330.7 & 398959.533 \\
594.3 & 355.4 & 449737.835 \\
571.2 & 355.4 & 464542.146 \\
571.2 & 355.4 & 464542.146 \\
571.2 & 355.4 & 464542.146 \\
571.2 & 355.4 & 464542.146 \\
\hline
\end{array}
\]

\[ \text{Power}_{SL\_60MCP_i} = \text{Thrust}_{SL\_60MCP_i} \cdot \text{TAS}(0 \cdot \text{ft}, \text{Speed}_{SL\_60MCP_i}, \text{dISA}) \]

\[ \text{Power}_{SL\_60MCP_i} = \]

\[ \text{watt} \]

\[ \text{Speed}_{SL\_60MCP} \text{ kts} \]

\[ \text{Power}_{SL\_60MCP} \text{ watt} \]

\[ 6 \cdot 10^5 \]

\[ 2 \cdot 10^5 \]

\[ 0 \]

\[ 100 \]

\[ 200 \]

\[ 300 \]

\[ 4 \cdot 10^5 \]

\[ 6 \cdot 10^5 \]

\[ \text{Speed}_{SL\_60MCP} \text{ kts} \]
### Inputs

- **Power Lever Angle**: 72°
- **Altitude Feet**: 10000 ft
- **Power Mode**: 17
- **Temperature Deviation**: 0

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### Outputs

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**Note:** (Power_Lever_Angle Altitude_Feet Power_Mode Temperature_Deviation)
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Thrust_100 := \( \text{Thrust_row}^T \cdot \text{lb} \)

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Speed_100 := \( \text{Speed_row}^T \cdot \text{kts} \)

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Fuel_100 := \( \text{Fuel_row}^T \cdot \text{lb/\text{hr}} \)

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Thrust_100 = 0

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Speed_100 = 0

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Fuel_100 = 0
\( i = 0 \ldots 9 \)

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\( \text{Power}_{100_i} = \text{Thrust}_{100_i} \cdot \text{VTAS}(10000 \cdot \text{ft}, \text{Speed}_{100_i}, \text{dISA}) \)

\[
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411765.282 & 516053.597 \\
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605216.329 & 685557.509 \\
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715427.3 & 715427.3 \\
715427.3 & 715427.3 \\
\end{array}
\]
10,000 ft // 80 % MAX CONTINOUS / PLA 62.4°

Power Lever Angle = 62.4°
Altitude Feet = 10000 ft
Power Mode = 17
Temperature Deviation = 0

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* NOTICE: Temperature Deviation = 0
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</table>

**Speed row:**

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<th>8</th>
<th>9</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>54.9</td>
<td>109.9</td>
<td>165.1</td>
<td>220.7</td>
<td>276.8</td>
<td>333.4</td>
<td>355.1</td>
<td>355.1</td>
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</table>

**Fuel row:**

<table>
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<tbody>
<tr>
<td>0</td>
<td>528.12</td>
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<td>555.17</td>
<td>557.93</td>
<td>557.93</td>
<td>557.93</td>
</tr>
</tbody>
</table>

**Thrust 100 80MCP:**

\[
\text{Thrust}_{100\,80\text{MCP}} := \text{Thrust row}^T \cdot \text{Ibf}
\]

**Speed 100 80MCP:**

\[
\text{Speed}_{100\,80\text{MCP}} := \text{Speed row}^T \cdot \text{kts}
\]

**Fuel 100 80MCP:**

\[
\text{Fuel}_{100\,80\text{MCP}} := \text{Fuel row}^T \cdot \frac{\text{lb}}{\text{hr}}
\]
\[
i := 0.9
\]

\[
\text{Thrust}_{100\_80MCP_i} = \text{Speed}_{100\_80MCP_i} = \\
\begin{array}{lll}
1035.6 & \text{Ibf} & 0 \\
956.2 & & 54.9 \\
884.3 & & 109.9 \\
817.1 & & 165.1 \\
761.4 & & 220.7 \\
710.8 & & 276.8 \\
666.8 & & 333.4 \\
652.5 & & 355.1 \\
652.5 & & 355.1 \\
652.5 & & 355.1 \\
\end{array}
\]

\[
\text{Power}_{100\_80MCP_i} = \text{Thrust}_{100\_80MCP_i} \cdot \sqrt{\text{VTAS}(10000 \text{ ft}, \text{Speed}_{100\_80MCP_i}, \text{dL})} \\
\text{Power}_{100\_80MCP_i} = \\
\begin{array}{lll}
1397.87901 & & 0 \\
2587.89003 & & 2587.89003 \\
3592.28498 & & 3592.28498 \\
4474.69774 & & 4474.69774 \\
5239.16413 & & 5239.16413 \\
5919.83614 & & 5919.83614 \\
6169.92222 & & 6169.92222 \\
6169.92222 & & 6169.92222 \\
\end{array}
\]

![Graph showing the relationship between Power and Speed](image-url)
### Inputs

<table>
<thead>
<tr>
<th>XMN</th>
<th>52.8</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALT</td>
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<tr>
<td>PA</td>
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</tr>
<tr>
<td>TA</td>
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### Outputs

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(Power_Lever_Angle  Altitude_Feet  Power_Mode  Temperature_Deviation)
<table>
<thead>
<tr>
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<td>759.4</td>
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<tr>
<td></td>
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<td>0</td>
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<td>109.9</td>
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<td>220.7</td>
<td>276.8</td>
<td>333.4</td>
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<table>
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<th>9</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>423.69</td>
<td>424.25</td>
<td>425.99</td>
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<td>434.84</td>
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</table>

**Thrust 100 60MCP** := Thrust_row$^T$ - lbf

**Speed 100 60MCP** := Speed_row$^T$ - kts

**Fuel 100 60MCP** := Fuel_row$^T$ - lb/hr

**Thrust 100 60MCP** = 832.1

**Speed 100 60MCP** = 0

**Fuel 100 60MCP** = 0
\[
i := 0.9
\]

<table>
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<tr>
<th>Thrust_100_60MCP(_i)</th>
<th>Speed_100_60MCP(_i)</th>
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<td>832.1 lbf</td>
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<tr>
<td>693.3</td>
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<td>631.6</td>
<td>165.1</td>
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<td>493.5</td>
<td>333.4</td>
</tr>
<tr>
<td>481</td>
<td>355.1</td>
</tr>
<tr>
<td>481</td>
<td>355.1</td>
</tr>
<tr>
<td>481</td>
<td>355.1</td>
</tr>
</tbody>
</table>

\[
\text{Power}\_100\_60MCP\(_i\) := \text{Thrust}\_100\_60MCP\(_i\) \cdot \text{TAS}(10000 \text{ ft}, \text{Speed}\_100\_60MCP\(_i\), \text{dISA})
\]

\[
\text{Power}\_100\_60MCP\(_i\) = \begin{cases} 
0 \text{ watt} \\
111017.498 \\
202893.153 \\
277675.584 \\
340509.571 \\
391757.982 \\
438128.245 \\
454824.916 \\
454824.916 \\
454824.916 \\
\end{cases}
\]

![Graph showing relationship between Power\_100\_60MCP\(_i\) and Speed\_100\_60MCP\(_i\) in kts]
20,000 ft // 100 % MAX CONTINOUS / PLA 72°

Power_Lever_Angle = 72  \quad \quad Altitude_Feet = 20,000 ft  \quad \quad Power_Mode = 17  \quad \quad Temperature_Deviation = 0

\[
\begin{align*}
\text{Thrust_row} & = \quad \text{Speed_row} \\
\text{Fuel_row} & = \quad \text{INPUTS} \\
\text{XMN} & = 72 \\
\text{ALT} & = 20,000 \\
\text{PA} & = 17 \\
\text{TA} & = 0 \\
\text{Iterations} & = 15 \\
\end{align*}
\]

\[
\begin{array}{cccccccc}
\text{OUTPUTS} & \text{Case} & 1 & 2 & 3 & 4 & 5 & 6 & 7 \\
\text{ALT} & 20,000 & 20,000 & 20,000 & 20,000 & 20,000 & 20,000 & 20,000 \\
\text{Ta} & 447.36 & 447.36 & 447.36 & 447.36 & 447.36 & 447.36 & 447.36 \\
\text{MN} & 0.067 & 0.1 & 0.2 & 0.3 & 0.4 & 0.5 & 0.6 \\
\text{CAS} & 29.9 & 44.9 & 89.9 & 135.3 & 181.3 & 227.9 & 275.3 \\
\text{Eram} & 0.998 & 0.998 & 0.998 & 0.998 & 0.998 & 0.998 & 0.998 \\
\text{3x} & 18,400 & 18,400 & 18,400 & 18,400 & 18,400 & 18,400 & 18,400 \\
\text{LHV} & 109.02 & 109.02 & 109.02 & 109.02 & 109.02 & 109.02 & 109.02 \\
\text{A_j} & \text{std day} & \text{std day} & \text{std day} & \text{std day} & \text{std day} & \text{std day} & \text{std day} \\
\text{DAY} & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
\text{IENV} & 17 & 17 & 17 & 17 & 17 & 17 & 17 \\
\text{MODE} & 72 & 72 & 72 & 72 & 72 & 72 & 72 \\
\text{PCNWARE} & \text{NOTICE} & \text{NORMA} & \text{NORMA} & \text{NORMA} & \text{NORMA} & \text{NORMA} & \text{NORMA} & \text{NC} \\
\text{Fn} & 862.6 & 846.3 & 801.3 & 763.9 & 734 & 704.2 & 678.4 \\
\text{TSFC} & 0.536 & 0.548 & 0.587 & 0.63 & 0.673 & 0.715 & 0.757 \\
\text{HPrpm} & 48,041 & 48,052 & 48,109 & 48,212 & 48,327 & 48,385 & 48,442 \\
\text{LPrpm} & 22,424 & 22,424 & 22,424 & 22,424 & 22,383 & 22,383 & 22,060 \\
\text{Wf} & 462.64 & 463.8 & 470.19 & 481.18 & 493.68 & 503.24 & 513.81 \\
\end{array}
\]

(Power_Lever_Angle, Altitude_Feet, Power_Mode, Temperature_Deviation)
Thrust row:

<table>
<thead>
<tr>
<th></th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
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<th>8</th>
<th>9</th>
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</thead>
<tbody>
<tr>
<td>0</td>
<td>862.6</td>
<td>846.3</td>
<td>801.3</td>
<td>763.9</td>
<td>734</td>
<td>704.2</td>
<td>678.4</td>
<td>655.2</td>
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Speed row:

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<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
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</thead>
<tbody>
<tr>
<td>0</td>
<td>29.9</td>
<td>44.9</td>
<td>89.9</td>
<td>135.3</td>
<td>181.3</td>
<td>227.9</td>
<td>275.3</td>
<td>323.7</td>
<td>355.2</td>
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Fuel row:

<table>
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<th>3</th>
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<td>0</td>
<td>462.64</td>
<td>463.8</td>
<td>470.19</td>
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<td>513.81</td>
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<td>532.42</td>
<td>532.42</td>
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</tbody>
</table>

Thrust 200 := Thrust_row^T \cdot \text{lbf}

Speed 200 := Speed_row^T \cdot \text{kts}

Fuel 200 := Fuel_row^T \cdot \frac{\text{lb}}{\text{hr}}
\[ i = 0.9 \]

\[
\begin{array}{|l|l|l|}
\hline
\text{Thrust}_{200} & \text{Speed}_{200} & \text{Power}_{200} \\
\hline
862.6 \text{ lbf} & 29.9 \text{ kts} & 80855.491 \text{ watt} \\
846.3 & 44.9 & 119124.08 \\
801.3 & 89.9 & 225831.08 \\
763.9 & 135.3 & 324013.558 \\
734 & 181.3 & 417179.29 \\
704.2 & 227.9 & 503117.267 \\
678.4 & 275.3 & 585491.949 \\
655.2 & 323.7 & 664883.361 \\
642.3 & 355.2 & 715220.174 \\
642.3 & 355.2 & 715220.174 \\
\hline
\end{array}
\]

\[ \text{Power}_{200} = \text{Thrust}_{200} \cdot v_{TAS}(20000 \text{ ft}, \text{Speed}_{200}, \text{dISA}) \]

\[ \text{Power}_{200} \]
20,000 ft // 80% MAX CONTINOUS / PLA 62.4°

\[
\text{Power Lever Angle} = 62.4 \quad \text{Altitude Feet} = 20000 \quad \text{Power Mode} = 17 \quad \text{Temperature Deviation} = 0
\]

\[
\begin{array}{l}
\text{Thrust_row} = \text{Speed_row} = \text{Fuel_row} \\
\end{array}
\]

**INPUTS**

<table>
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**OUTPUTS**

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\[(\text{Power Lever Angle} \quad \text{Altitude Feet} \quad \text{Power Mode} \quad \text{Temperature Deviation})\]
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Thrust_{200\_80MCP} := \text{Thrust_row}^T \cdot \text{lbf}

Speed_{200\_80MCP} := \text{Speed_row}^T \cdot \text{kts}

Fuel_{200\_80MCP} := \text{Fuel_row}^T \cdot \frac{\text{lb}}{\text{hr}}

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Fuel_{200\_80MCP} =
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\[ i = 0.9 \]

\[
\text{Thrust}_{200\text{-80MCP}} = \text{Speed}_{200\text{-80MCP}} =
\begin{array}{ccc}
778.8 & 29.9 & \text{Ibf} \\
762.7 & 44.9 & \\
718.8 & 89.9 & \\
679.7 & 135.3 & \\
648.1 & 181.3 & \\
616.3 & 227.9 & \\
589.6 & 275.3 & \\
568.4 & 323.7 & \\
557.2 & 355.2 & \\
557.2 & 355.2 & \\
\end{array}
\]

\[
\text{Power}_{200\text{-80MCP}} = \text{Thrust}_{200\text{-80MCP}} \cdot \text{VTAS}(20000 \text{ ft}, \text{Speed}_{200\text{-80MCP}}, \text{dISA})
\]

\[
\begin{array}{ccc}
73000.529 & \\
107356.653 & \\
202580.033 & \\
288299.536 & \\
368356.809 & \\
440316.915 & \\
508853.262 & \\
576800.523 & \\
620458.79 & \\
620458.79 & \\
\end{array}
\]

\[
\frac{\text{Power}_{200\text{-80MCP}}}{\text{watt}}
\]

\[
\frac{\text{Speed}_{200\text{-80MCP}}}{\text{kts}}
\]

157
20,000ft // 60 % MAX CONTINOUS / PLA 52.8°

<table>
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<th>𝜏 MN 52.8</th>
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(Power_Lever_Angle Altitude_Feet Power_Mode Temperature_Deviation)
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Thrust_{200\_60MCP} := \text{Thrust\_row}^T \cdot \text{Ibf}

Speed_{200\_60MCP} := \text{Speed\_row}^T \cdot \text{kts}

Fuel_{200\_60MCP} := \text{Fuel\_row}^T \cdot \frac{\text{lb}}{\text{hr}}
\[ \begin{align*}
\text{Power}_{200\_60MCP_i} &= \text{Thrust}_{200\_60MCP_i} \cdot \sqrt{\text{TAS}(200\_000 \cdot \text{ft}, \text{Speed}_{200\_60MCP_i}, \text{dISA})} \\
\text{Thrust}_{200\_60MCP_i} &= \text{Speed}_{200\_60MCP_i} \\
\text{Speed}_{200\_60MCP_i} &= \begin{array}{|c|c|}
\hline
i & \text{lb} & \text{kts} \\
\hline
0 & 617.8 & 29.9 \\
1 & 602.6 & 44.9 \\
2 & 559.4 & 89.9 \\
3 & 521.9 & 135.3 \\
4 & 491.9 & 181.3 \\
5 & 464.4 & 227.9 \\
6 & 442.8 & 275.3 \\
7 & 426.9 & 323.7 \\
8 & 418.3 & 355.2 \\
9 & 418.3 & 355.2 \\
\hline
\end{array} \\
\text{Thrust}_{200\_60MCP_i} &= \begin{array}{|c|c|}
\hline
i & \text{lb} & \text{kts} \\
\hline
0 & 57909.254 & \text{watt} \\
1 & 84821.187 & \text{watt} \\
2 & 157656.191 & \text{watt} \\
3 & 221367.556 & \text{watt} \\
4 & 279578.328 & \text{watt} \\
5 & 331791.62 & \text{watt} \\
6 & 382157.775 & \text{watt} \\
7 & 433209.26 & \text{watt} \\
8 & 465789.504 & \text{watt} \\
9 & 465789.504 & \text{watt} \\
\hline
\end{array} \\
\text{Speed}_{200\_60MCP_i} &= \begin{array}{|c|c|}
\hline
i & \text{lb} & \text{kts} \\
\hline
0 & 617.8 & 29.9 \\
1 & 602.6 & 44.9 \\
2 & 559.4 & 89.9 \\
3 & 521.9 & 135.3 \\
4 & 491.9 & 181.3 \\
5 & 464.4 & 227.9 \\
6 & 442.8 & 275.3 \\
7 & 426.9 & 323.7 \\
8 & 418.3 & 355.2 \\
9 & 418.3 & 355.2 \\
\hline
\end{array} \\
\end{align*} \]
25.000 ft // 100 % MAX CONTINOUS / PLA 72°

Power_Lever_Angle = 72          Altitude_Feet = 25000 ft          Power_Mode = 17          Temperature_Deviation = 0

(**Inputs**)

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(**Outputs**)

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(Power_Lever_Angle Altitude_Feet Power_Mode Temperature_Deviation)
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Speed_row =
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Thrust_250 := Thrust_row^T \cdot \text{lbf}

Speed_250 := Speed_row^T \cdot \text{kts}

Fuel_250 := Fuel_row^T \cdot \text{lb/hr}

![Graph showing thrust, speed, and fuel consumption against speed]
\[ i = 0.9 \]

Thrust \(250_i\) = Speed \(250_i\) =

\[
\begin{array}{ccc}
704.2 & 53.8 & \text{lbf} \\
704.2 & 53.8 & \text{kts} \\
679.5 & 80.8 & \\
650.1 & 121.7 & \\
632.3 & 163.2 & \\
622.8 & 205.3 & \\
612.5 & 248.4 & \\
602.2 & 292.5 & \\
586.1 & 337.6 & \\
581 & 355.1 & \\
\end{array}
\]

\[ \text{Power}_{250_i} = \text{Thrust}_{250_i} \cdot \text{V}_{TAS}(25000 \text{ ft, Speed}_{250_i}, \text{dISA}) \]

\[ \text{Power}_{250_i} = \text{watt} \]

\[ \frac{\text{Power}_{250_i}}{\text{watt}} = 10^6 \]

\[ \frac{\text{Speed}_{250_i}}{\text{kts}} \]

\[ 0 \quad 100 \quad 200 \quad 300 \quad 400 \]

163
Power_Lever_Angle = 62.4°  Altitude_Feet = 25000 ft  Power_Mode = 17  Temperature_Deviation = 0

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(Power_Lever_Angle  Altitude_Feet  Power_Mode  Temperature_Deviation)
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**Thrust**

\[
\text{Thrust}_{250\_80MCP} := \text{Thrust}\_\text{row}^T \cdot \text{Ibf}
\]

**Speed**

\[
\text{Speed}_{250\_80MCP} := \text{Speed}\_\text{row}^T \cdot \text{kts}
\]

**Fuel**

\[
\text{Fuel}_{250\_80MCP} := \text{Fuel}\_\text{row}^T \cdot \frac{\text{lb}}{\text{hr}}
\]
\[ i := 0, 9 \]

\[
\begin{align*}
\text{Thrust}_{\text{250}_80\text{MCP}} & = \text{Speed}_{\text{250}_80\text{MCP}} = \\
647.3 & \quad \text{tbf} \quad 53.8 \quad \text{kts} \\
647.3 & \quad 53.8 \\
622.2 & \quad 80.8 \\
590.8 & \quad 121.7 \\
569.9 & \quad 163.2 \\
558.8 & \quad 205.3 \\
545.4 & \quad 248.4 \\
529.8 & \quad 292.5 \\
514.4 & \quad 337.6 \\
510.4 & \quad 355.1 \\
\end{align*}
\]

\[
\begin{align*}
\text{Power}_{\text{250}_80\text{MCP}_i} & := \text{Thrust}_{\text{250}_80\text{MCP}_i} \cdot \text{VTAS} \left( \text{25000 ft, Speed}_{\text{250}_80\text{MCP}_i}, \text{dISA} \right) \\
\text{Power}_{\text{250}_80\text{MCP}_i} & = \\
119043.506 & \\
119043.506 & \\
171853.822 & \\
245781.331 & \\
317933.755 & \\
392159.892 & \\
463110.42 & \\
529731.321 & \\
593637.36 & \\
619554 & \\
\end{align*}
\]

![Graph showing the relationship between Speed and Power for thrust values.](image)
Power_Lever_Angle = 52.8°  
Attitude_Feet = 25000 ft  
Power_Mode = 17  
Temperature_Deviation = 0

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(Power_Lever_Angle  Attitude_Feet  Power_Mode  Temperature_Deviation)
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Thrust_{250\_60MCP} = \text{T}_{\text{lb}}

Speed_{250\_60MCP} = \text{T}_{\text{kts}}

Fuel_{250\_60MCP} = \text{T}_{\text{lb/\text{hr}}}

Thrust_{250\_60MCP} = \text{T}_{\text{lb}}

Speed_{250\_60MCP} = \text{T}_{\text{kts}}

Fuel_{250\_60MCP} = \text{T}_{\text{lb/\text{hr}}}

Thrust_{250\_60MCP} = \text{T}_{\text{lb}}

Speed_{250\_60MCP} = \text{T}_{\text{kts}}

Fuel_{250\_60MCP} = \text{T}_{\text{lb/\text{hr}}}

168
\( i = 0.9 \)

\[
\text{Thrust}_{250\_60\text{MCP}} = \text{Speed}_{250\_60\text{MCP}} =
\begin{array}{c|c|c}
\text{526.8} & \text{53.8} & \text{526.8} \\
\text{526.8} & \text{53.8} & \text{501.6} \\
\text{501.6} & \text{80.8} & \\
\text{469.4} & \text{121.7} & \\
\text{445.8} & \text{163.2} & \\
\text{431} & \text{205.3} & \\
\text{418.3} & \text{248.4} & \\
\text{406.6} & \text{292.5} & \\
\text{395.6} & \text{337.6} & \\
\text{392.5} & \text{355.1} & \\
\end{array}
\]

\( \text{Power}_{250\_60\text{MCP}} = \text{Thrust}_{250\_60\text{MCP}} \cdot \text{VTAS}(25000\ \text{ft}, \text{Speed}_{250\_60\text{MCP}},\text{dISA}) \)

\[
\begin{array}{c|c|c|c|c|c|c|c|c|c|c}
\text{Power}_{250\_60\text{MCP}} & \text{96882.619} & \\
\text{96882.619} & \\
\text{138543.679} & \\
\text{195277.178} & \\
\text{248701.295} & \\
\text{302471.212} & \\
\text{355187.181} & \\
\text{406547.292} & \\
\text{456537.597} & \\
\text{476439.94} & \\
\end{array}
\]

\[
\begin{array}{c|c|c|c|c|c|c|c|c|c}
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\text{watt} & \\
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\text{watt} & \\
\text{watt} & \\
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\text{watt} & \\
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\text{watt} & \\
\end{array}
\]

\[
\begin{array}{c|c|c|c|c|c|c|c|c|c}
\text{Speed}_{250\_60\text{MCP}} & \text{0} & \text{100} & \text{200} & \text{300} & \\
\text{0} & \text{2} \cdot 10^5 & \text{4} \cdot 10^5 & \text{6} \cdot 10^5 & \\
\text{kts} & \\
\end{array}
\]
### INPUTS

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### OUTPUTS

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(Power_Lever_Angle Altitude_Feet Power_Mode Temperature_Deviation)

170
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Fuel row:

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```
Thrust_300 := Thrust_row^T \cdot \text{lf}
```

```
Speed_300 := Speed_row^T \cdot \text{kts}
```

```
Fuel_300 := Fuel_row^T \cdot \frac{\text{lb}}{\text{hr}}
```

```
\text{kg/hr}
```

---

```
Thrust_300 := \frac{\text{kg}}{\text{hr}}
```

```
\text{ft/s}
```

```
\text{kts}
```

---

171
\( i := 0 \ldots 9 \)

\[
\begin{array}{|c|c|}
\hline
\text{Thrust}_{300_i} & \text{Speed}_{300_i} \\
\hline
575.7 & 72.4 \\
575.7 & 72.4 \\
575.7 & 72.4 \\
553.6 & 109 \\
537 & 146.2 \\
527.2 & 184.1 \\
528.4 & 223 \\
533.3 & 262.8 \\
531.1 & 303.9 \\
530.2 & 324.9 \\
\hline
\end{array}
\]

\[
\text{Power}_{300_i} = \text{Thrust}_{300_i} \cdot \text{VTAS}(30000 \cdot \text{ft}, \text{Speed}_{300_i}, \text{dISA})
\]

\[
\text{Power}_{300_i} = \begin{cases} 
155932.117 \\
155932.117 \\
155932.117 \\
225747.713 \\
293712.505 \\
363103.111 \\
440827.269 \\
524321.569 \\
603820.399 \\
644451.463 \\
\end{cases}
\]

\[
\begin{array}{|c|c|}
\hline
\text{Speed}_{300_i} & \text{Power}_{300_i} \\
\hline
10 & 1 \times 10^5 \\
20 & 5 \times 10^5 \\
30 & \text{graph} \\
40 & \text{graph} \\
\hline
\end{array}
\]
30,000 ft // 80 % MAX CONTINOUS / PLA 62,4°

| Power_Lever_Angle = 62.4 | Altitude_Feet = 30000 ft | Power_Mode = 17 | Temperature_Deviation = 0 |

### INPUTS

- XMN: 62.4
- ALT: 30000
- PA: 17
- TA: 0
- Iterations: 15

### OUTPUTS

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((Power_Lever_Angle Altitude_Feet Power_Mode Temperature_Deviation))
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**Thrust**

$\text{Thrust}_{300 \text{ MCP}} := \text{Thrust}_\text{row}^\top \cdot \text{lbf}$

**Speed**

$\text{Speed}_{300 \text{ MCP}} := \text{Speed}_\text{row}^\top \cdot \text{kts}$

**Fuel**

$\text{Fuel}_{300 \text{ MCP}} := \text{Fuel}_\text{row}^\top \cdot \frac{\text{lb}}{\text{hr}}$
\[ i := 0 \ldots 9 \]

\[ \text{Thrust}_{300\,\text{80MCP}} = \text{Speed}_{300\,\text{80MCP}} = \]

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\[ \text{Power}_{300\,\text{80MCP}} = \text{Thrust}_{300\,\text{80MCP}} \cdot v_{\text{TAS}}(30000 \text{ ft}, \text{Speed}_{300\,\text{80MCP}}, \text{dISA}) \]

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![Graph showing Power vs Speed](image-url)
35000ft // 60 % MAX CONTINOUS / PLA 52,8°

Power_Lever_Angle = 52.8
Thrust_row

Altitude_Feet = 30000 ft
Speed_row

Power_Mode = 17
Fuel_row

Temperature_Deviation = 0

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(Power_Lever_Angle Altitude_Feet Power_Mode Temperature_Deviation)
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<tr>
<th>Thrust row</th>
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<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
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<th>9</th>
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<tbody>
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<td>437.3</td>
<td>437.3</td>
<td>437.3</td>
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<td>390.2</td>
<td>375.8</td>
<td>367.2</td>
<td>361.4</td>
<td>355.2</td>
<td>352.6</td>
</tr>
</tbody>
</table>

$\text{Thrust}_{300\_60\text{MCP}} = \text{Thrust}_{\text{row}}^T \cdot \text{Ibf}$

<table>
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<tr>
<th>Speed row</th>
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<th>2</th>
<th>3</th>
<th>4</th>
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<tbody>
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<td>72.4</td>
<td>72.4</td>
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<td>146.2</td>
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<td>223</td>
<td>262.8</td>
<td>303.9</td>
<td>324.9</td>
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$\text{Speed}_{300\_60\text{MCP}} = \text{Speed}_{\text{row}}^T \cdot \text{kts}$

<table>
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<tr>
<th>Fuel row</th>
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<th>2</th>
<th>3</th>
<th>4</th>
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<td>277.11</td>
<td>288.62</td>
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<td>303.95</td>
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</table>

$\text{Fuel}_{300\_60\text{MCP}} = \text{Fuel}_{\text{row}}^T \cdot \text{lb} / \text{hr}$

<table>
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<th>Thrust $300_60\text{MCP}$ (newton)</th>
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<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
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<td>352.6</td>
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<th>2</th>
<th>3</th>
<th>4</th>
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<td>184.1</td>
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</tbody>
</table>
\[ i = 0.9 \]

\[
\text{Thrust}_{300\_60MCP_i} = \text{Speed}_{300\_60MCP_i} = \]

<table>
<thead>
<tr>
<th>Thrust_300_60MCP_i</th>
<th>Speed_300_60MCP_i</th>
<th>Power_300_60MCP_i</th>
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<tbody>
<tr>
<td>437.3 lbf</td>
<td>72.4 kts</td>
<td>118445.57 watt</td>
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<tr>
<td>437.3 lbf</td>
<td>72.4 kts</td>
<td>118445.57 watt</td>
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<td>109 kts</td>
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<td>184.1 kts</td>
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<td>375.8 lbf</td>
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<td>306343.25 watt</td>
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<td>303.9 kts</td>
<td>355315.611 watt</td>
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<td>324.9 kts</td>
<td>403835.447 watt</td>
</tr>
<tr>
<td>352.6 lbf</td>
<td></td>
<td>428580.886 watt</td>
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</tbody>
</table>

\[ \text{Power}_{300\_60MCP_i} = \text{Thrust}_{300\_60MCP_i} \cdot \text{VTAS}(30000 \text{ ft}, \text{Speed}_{300\_60MCP_i}, \text{dISA}) \]
Thrust_SL
newton
Thrust_SL_80MCP
newton
Thrust_SL_60MCP
newton

Speed_SL
kts

0  50  100  150  200  250  300  350  400

0  2000  4000  6000  8000

180
Thrust_300
newton
4-4-
Thrust_300_80MCP
newton
4-4-
Thrust_300_60MCP
newton
184
Curve Regression

It is often necessary to store the thrust data in the form of a function instead of an array, as is the case above. Since the spline function requires strict monotonic behavior of the driving variable (which is not always the case in the thrust arrays), a regression is used to generate the function. The same reasoning and process are used below for the power data as well.

THRUST CURVES

SEA LEVEL 100% MCP

\[
\text{vCAS}_\text{SL} = \min(\text{Speed}_\text{SL}), (\min(\text{Speed}_\text{SL}) + 5\text{kts}) \max(\text{Speed}_\text{SL})
\]

\[
\text{Thrust}_\text{SL}_\text{reg\_vector} = \text{regress}\left(\frac{\text{Speed}_\text{SL}}{\text{kts}}, \frac{\text{Thrust}_\text{SL}}{\text{newton}}, 3\right)
\]

\[
\text{Thrust}_\text{SL}_\text{func}(\text{vCAS}_\text{SL}) = \text{interp}\left(\text{Thrust}_\text{SL}_\text{reg\_vector}, \frac{\text{Speed}_\text{SL}}{\text{kts}}, \frac{\text{Thrust}_\text{SL}}{\text{newton}}, \frac{\text{vCAS}_\text{SL}}{\text{kts}}\right)
\]

\[
\text{Thrust}_\text{SL}_\text{func}(\text{vCAS}_\text{SL}) = \text{Thrust}_\text{SL}_\text{func}(\text{vCAS}_\text{SL}) \text{ newton}
\]
SEA LEVEL 80% MCP

\[ \text{VCAS}_{\text{SL}_{80}} = \min(\text{Speed}_{\text{SL}_{80}}, \{\min(\text{Speed}_{\text{SL}_{80}}) + 5\text{kts}\}) \max(\text{Speed}_{\text{SL}_{80}}) \]

\[ \text{Thrust}_{\text{SL}_{80}}_{\text{reg\_vector}} = \text{regress}\left(\frac{\text{Speed}_{\text{SL}_{80}}}{\text{kts}}, \frac{\text{Thrust}_{\text{SL}_{80}}}{\text{newton}}\right) \]

\[ \text{Thrust}_{\text{SL}_{80}}_{\text{func}}(\text{VCAS}_{\text{SL}_{80}}) = \text{interp}\left(\text{Thrust}_{\text{SL}_{80}}_{\text{reg\_vector}}, \frac{\text{Speed}_{\text{SL}_{80}}}{\text{kts}}, \frac{\text{Thrust}_{\text{SL}_{80}}}{\text{newton}}\right) \]

\[ \text{Thrust}_{\text{SL}_{80}}_{\text{func}}(\text{VCAS}_{\text{SL}_{80}}) = \text{Thrust}_{\text{SL}_{80}}_{\text{func}}(\text{VCAS}_{\text{SL}_{80}}) \text{ newton} \]

SEA LEVEL 60% MCP

\[ \text{VCAS}_{\text{SL}_{60}} = \min(\text{Speed}_{\text{SL}_{60}}, \{\min(\text{Speed}_{\text{SL}_{60}}) + 5\text{kts}\}) \max(\text{Speed}_{\text{SL}_{60}}) \]

\[ \text{Thrust}_{\text{SL}_{60}}_{\text{reg\_vector}} = \text{regress}\left(\frac{\text{Speed}_{\text{SL}_{60}}}{\text{kts}}, \frac{\text{Thrust}_{\text{SL}_{60}}}{\text{newton}}\right) \]

\[ \text{Thrust}_{\text{SL}_{60}}_{\text{func}}(\text{VCAS}_{\text{SL}_{60}}) = \text{interp}\left(\text{Thrust}_{\text{SL}_{60}}_{\text{reg\_vector}}, \frac{\text{Speed}_{\text{SL}_{60}}}{\text{kts}}, \frac{\text{Thrust}_{\text{SL}_{60}}}{\text{newton}}\right) \]

\[ \text{Thrust}_{\text{SL}_{60}}_{\text{func}}(\text{VCAS}_{\text{SL}_{60}}) = \text{Thrust}_{\text{SL}_{60}}_{\text{func}}(\text{VCAS}_{\text{SL}_{60}}) \text{ newton} \]
**FL 100 100% MCP**

\[ v_{CAS_{100}} = \min(Speed_{100}), (\min(Speed_{100}) + 5\text{kts}) \max(Speed_{100}) \]

\[
\text{Thrust}_{100}\_\text{reg}\_\text{vector} = \text{regress}
\left( \frac{\text{Speed}_{100}}{\text{kts}}, \frac{\text{Thrust}_{100}}{\text{newton}}, 3 \right)
\]

\[
\text{Thrust}_{100}\_\text{func}(v_{CAS_{100}}) = \text{interp}
\left( \text{Thrust}_{100}\_\text{reg}\_\text{vector}, \frac{\text{Speed}_{100}}{\text{kts}}, \frac{\text{Thrust}_{100}}{\text{newton}}, \frac{v_{CAS_{100}}}{\text{kts}} \right)
\]

\[
\text{Thrust}_{100}\_\text{func}(v_{CAS_{100}}) = \text{Thrust}_{100}\_\text{func}(v_{CAS_{100}}) \text{ newton}
\]

**FL 100 80% MCP**

\[ v_{CAS_{100\_80MCP}} = \min(Speed_{100\_80MCP}), (\min(Speed_{100\_80MCP}) + 5\text{kts}) \max(Speed_{100\_80MCP}) \]

\[
\text{Thrust}_{100\_80MCP}\_\text{reg}\_\text{vector} = \text{regress}
\left( \frac{\text{Speed}_{100\_80MCP}}{\text{kts}}, \frac{\text{Thrust}_{100\_80MCP}}{\text{newton}}, 3 \right)
\]

\[
\text{Thrust}_{100\_80MCP}\_\text{func}(v_{CAS_{100\_80MCP}}) = \text{interp}
\left( \text{Thrust}_{100\_80MCP}\_\text{reg}\_\text{vector}, \frac{\text{Speed}_{100\_80MCP}}{\text{kts}}, \frac{\text{Thrust}_{100\_80MCP}}{\text{newton}}, \frac{v_{CAS_{100\_80MCP}}}{\text{kts}} \right)
\]

\[
\text{Thrust}_{100\_80MCP}\_\text{func}(v_{CAS_{100\_80MCP}}) = \text{Thrust}_{100\_80MCP}\_\text{func}(v_{CAS_{100\_80MCP}}) \text{ newton}
\]
FL 100 60% MCP

\[ \text{CAS}_{100\_60\text{MCP}} = \min(\text{Speed}_{100\_60\text{MCP}}), (\min(\text{Speed}_{100\_60\text{MCP}}) + 5\text{kts}) \max(\text{Speed}_{100\_60\text{MCP}}) \]

\[ \text{Thrust}_{100\_60\text{MCP\_reg\_vector}} = \text{regress}\left(\frac{\text{Speed}_{100\_60\text{MCP}}}{\text{kts}}, \frac{\text{Thrust}_{100\_60\text{MCP}}}{\text{newton}}, 3\right) \]

\[ \text{Thrust}_{100\_60\text{MCP\_func}(\text{CAS}_{100\_60\text{MCP}})} = \text{interp}\left(\frac{\text{Thrust}_{100\_60\text{MCP\_reg\_vector}}}{\text{kts}} \frac{\text{Speed}_{100\_60\text{MCP}}}{\text{kts}}, \frac{\text{Thrust}_{100\_60\text{MCP}}}{\text{newton}} \frac{\text{CAS}_{100\_60\text{MCP}}}{\text{kts}}\right) \]

\[ \text{Thrust}_{100\_60\text{MCP\_func}(\text{CAS}_{100\_60\text{MCP}})} = \text{Thrust}_{100\_60\text{MCP\_func}(\text{CAS}_{100\_60\text{MCP}})} \text{newton} \]

FL 200 100% MCP

\[ \text{CAS}_{200} = \min(\text{Speed}_{200}), (\min(\text{Speed}_{200}) + 5\text{kts}) \max(\text{Speed}_{200}) \]

\[ \text{Thrust}_{200\_\text{reg\_vector}} = \text{regress}\left(\frac{\text{Speed}_{200}}{\text{kts}}, \frac{\text{Thrust}_{200}}{\text{newton}}, 3\right) \]

\[ \text{Thrust}_{200\_\text{func}(\text{CAS}_{200})} = \text{interp}\left(\frac{\text{Thrust}_{200\_\text{reg\_vector}}}{\text{kts}} \frac{\text{Speed}_{200}}{\text{kts}}, \frac{\text{Thrust}_{200}}{\text{newton}} \frac{\text{CAS}_{200}}{\text{kts}}\right) \]

\[ \text{Thrust}_{200\_\text{func}(\text{CAS}_{200})} = \text{Thrust}_{200\_\text{func}(\text{CAS}_{200})} \text{newton} \]
FL 200 80% MCP

\[ \text{VCAS}_{200\_80MCP} = \min(\text{Speed}_{200\_80MCP}),\left(\min(\text{Speed}_{200\_80MCP}) + 5\text{kts}\right) \max(\text{Speed}_{200\_80MCP}) \]

\[ \text{Thrust}_{200\_80MCP\_reg\_vector} = \text{regress}\left(\frac{\text{Speed}_{200\_80MCP}}{\text{kts}}, \frac{\text{Thrust}_{200\_80MCP}}{\text{newton}}, 3\right) \]

\[ \text{Thrust}_{200\_80MCP\_func}(\text{VCAS}_{200\_80MCP}) = \text{interp}\left(\text{Thrust}_{200\_80MCP\_reg\_vector}, \frac{\text{Speed}_{200\_80MCP}}{\text{kts}}, \frac{\text{Thrust}_{200\_80MCP}}{\text{newton}}, \frac{\text{VCAS}_{200\_80MCP}}{\text{kts}}\right) \]

\[ \text{Thrust}_{200\_80MCP\_func}(\text{VCAS}_{200\_80MCP}) = \text{Thrust}_{200\_80MCP\_func}(\text{VCAS}_{200\_80MCP}) \text{ newton} \]

FL 200 60% MCP

\[ \text{VCAS}_{200\_60MCP} = \min(\text{Speed}_{200\_60MCP}),\left(\min(\text{Speed}_{200\_60MCP}) + 5\text{kts}\right) \max(\text{Speed}_{200\_60MCP}) \]

\[ \text{Thrust}_{200\_60MCP\_reg\_vector} = \text{regress}\left(\frac{\text{Speed}_{200\_60MCP}}{\text{kts}}, \frac{\text{Thrust}_{200\_60MCP}}{\text{newton}}, 3\right) \]

\[ \text{Thrust}_{200\_60MCP\_func}(\text{VCAS}_{200\_60MCP}) = \text{interp}\left(\text{Thrust}_{200\_60MCP\_reg\_vector}, \frac{\text{Speed}_{200\_60MCP}}{\text{kts}}, \frac{\text{Thrust}_{200\_60MCP}}{\text{newton}}, \frac{\text{VCAS}_{200\_60MCP}}{\text{kts}}\right) \]

\[ \text{Thrust}_{200\_60MCP\_func}(\text{VCAS}_{200\_60MCP}) = \text{Thrust}_{200\_60MCP\_func}(\text{VCAS}_{200\_60MCP}) \text{ newton} \]
**FL 250 100% MCP**

\[ v_{CAS_{250}} = \min(Speed_{250}), (\min(Speed_{250}) + 5\text{kts}) \max(Speed_{250}) \]

\[ \text{Thrust}_{250\_reg\_vector} = \text{regress}\left(\frac{\text{Speed}_{250}}{\text{kts}}, \frac{\text{Thrust}_{250}}{\text{newton}}\right), 3 \]

\[ \text{Thrust}_{250\_func}(v_{CAS_{250}}) = \text{interp}\left(\frac{\text{Thrust}_{250\_reg\_vector}}{\text{kts}}, \frac{\text{Speed}_{250}}{\text{kts}}, \frac{\text{Thrust}_{250}}{\text{newton}}, \frac{v_{CAS_{250}}}{\text{kts}}\right) \]

\[ \text{Thrust}_{250\_func}(v_{CAS_{250}}) = \text{Thrust}_{250\_func}(v_{CAS_{250}}) \text{ newton} \]

**FL 250 80% MCP**

\[ v_{CAS_{250\_80\text{MCP}}} = \min(Speed_{250\_80\text{MCP}}), (\min(Speed_{250\_80\text{MCP}}) + 5\text{kts}) \max(Speed_{250\_80\text{MCP}}) \]

\[ \text{Thrust}_{250\_80\text{MCP}\_reg\_vector} = \text{regress}\left(\frac{\text{Speed}_{250\_80\text{MCP}}}{\text{kts}}, \frac{\text{Thrust}_{250\_80\text{MCP}}}{\text{newton}}\right), 3 \]

\[ \text{Thrust}_{250\_80\text{MCP}\_func}(v_{CAS_{250\_80\text{MCP}}}) = \text{interp}\left(\frac{\text{Thrust}_{250\_80\text{MCP}\_reg\_vector}}{\text{kts}}, \frac{\text{Speed}_{250\_80\text{MCP}}}{\text{kts}}, \frac{\text{Thrust}_{250\_80\text{MCP}}}{\text{newton}}, \frac{v_{CAS_{250\_80\text{MCP}}}}{\text{kts}}\right) \]

\[ \text{Thrust}_{250\_80\text{MCP}\_func}(v_{CAS_{250\_80\text{MCP}}}) = \text{Thrust}_{250\_80\text{MCP}\_func}(v_{CAS_{250\_80\text{MCP}}}) \text{ newton} \]
FL 250 60% MCP

\[ VCAS_{250\,60MCP} = \min(Speed_{250\,60MCP}), (\min(Speed_{250\,60MCP}) + 5\text{kts}) \max(Speed_{250\,60MCP}) \]

\[ \text{Thrust}_{250\,60MCP\_reg\_vector} = \text{regress}\left(\frac{\text{Speed}_{250\,60MCP}}{\text{kts}}, \frac{\text{Thrust}_{250\,60MCP}}{\text{newton}}, 3\right) \]

\[ \text{Thrust}_{250\,60MCP\_func}(VCAS_{250\,60MCP}) = \text{interp}\left(\frac{\text{Thrust}_{250\,60MCP\_reg\_vector}}{\text{kts}}, \frac{\text{Speed}_{250\,60MCP}}{\text{kts}}, \frac{\text{Thrust}_{250\,60MCP}}{\text{newton}}, \frac{\text{VCAS}_{250\,60MCP}}{\text{kts}}\right) \]

\[ \text{Thrust}_{250\,60MCP\_func}(VCAS_{250\,60MCP}) = \text{Thrust}_{250\,60MCP\_func}(VCAS_{250\,60MCP})\text{ newton} \]

FL 300 100% MCP

\[ VCAS_{300} = \min(Speed_{300}), (\min(Speed_{300}) + 5\text{kts}) \max(Speed_{300}) \]

\[ \text{Thrust}_{300\_reg\_vector} = \text{regress}\left(\frac{\text{Speed}_{300}}{\text{kts}}, \frac{\text{Thrust}_{300}}{\text{newton}}, 3\right) \]

\[ \text{Thrust}_{300\_func}(VCAS_{300}) = \text{interp}\left(\frac{\text{Thrust}_{300\_reg\_vector}}{\text{kts}}, \frac{\text{Speed}_{300}}{\text{kts}}, \frac{\text{Thrust}_{300}}{\text{newton}}, \frac{\text{VCAS}_{300}}{\text{kts}}\right) \]

\[ \text{Thrust}_{300\_func}(VCAS_{300}) = \text{Thrust}_{300\_func}(VCAS_{300})\text{ newton} \]
FL 300 80% MCP

\[ v_{CAS\_300\_80MCP} = \min(Speed\_300\_80MCP), \left(\min(Speed\_300\_80MCP) + 5\text{kts}\right), \max(Speed\_300\_80MCP) \]

\[ \text{Thrust}\_300\_80MCP\_\text{reg\_vector} = \text{regress}\left(\frac{\text{Speed\_300\_80MCP}}{\text{kts}}, \frac{\text{Thrust\_300\_80MCP}}{\text{newton}}, 3\right) \]

\[ \text{Thrust}\_300\_80MCP\_\text{func}\left(v_{CAS\_300\_80MCP}\right) = \text{interp}\left(\frac{\text{Thrust}\_300\_80MCP\_\text{reg\_vector}}{\text{kts}}, \frac{\text{Speed\_300\_80MCP}}{\text{kts}}, \frac{\text{Thrust\_300\_80MCP}}{\text{newton}}, \frac{v_{CAS\_300\_80MCP}}{\text{kts}}\right) \]

\[ \text{Thrust}\_300\_80MCP\_\text{func}\left(v_{CAS\_300\_80MCP}\right) = \text{Thrust}\_300\_80MCP\_\text{func}\left(v_{CAS\_300\_80MCP}\right) \text{ newton} \]

FL 300 60% MCP

\[ v_{CAS\_300\_60MCP} = \min(Speed\_300\_60MCP), \left(\min(Speed\_300\_60MCP) + 5\text{kts}\right), \max(Speed\_300\_60MCP) \]

\[ \text{Thrust}\_300\_60MCP\_\text{reg\_vector} = \text{regress}\left(\frac{\text{Speed\_300\_60MCP}}{\text{kts}}, \frac{\text{Thrust\_300\_60MCP}}{\text{newton}}, 3\right) \]

\[ \text{Thrust}\_300\_60MCP\_\text{func}\left(v_{CAS\_300\_60MCP}\right) = \text{interp}\left(\frac{\text{Thrust}\_300\_60MCP\_\text{reg\_vector}}{\text{kts}}, \frac{\text{Speed\_300\_60MCP}}{\text{kts}}, \frac{\text{Thrust\_300\_60MCP}}{\text{newton}}, \frac{v_{CAS\_300\_60MCP}}{\text{kts}}\right) \]

\[ \text{Thrust}\_300\_60MCP\_\text{func}\left(v_{CAS\_300\_60MCP}\right) = \text{Thrust}\_300\_60MCP\_\text{func}\left(v_{CAS\_300\_60MCP}\right) \text{ newton} \]
FUEL CURVES

SEA LEVEL 100% MCP

\[ v_{CAS}_{SL} = \min(Speed\_SL), \left(\min(Speed\_SL) + 5\text{kts}\right) \max(Speed\_SL) \]

\[ Fuel\_SL\_reg\_vector = \text{regress}\left(\frac{\text{Speed\_SL}}{\text{kts}}, \frac{\text{Fuel\_SL}}{\text{kg/hr}}, 3\right) \]

\[ Fuel\_SL\_func(v_{CAS\_SL}) = \text{interp}\left(Fuel\_SL\_reg\_vector, \frac{\text{Speed\_SL}}{\text{kts}}, \frac{\text{Fuel\_SL}}{\text{kg/hr}}, v_{CAS\_SL}\right) \]

\[ Fuel\_SL\_func(v_{CAS\_SL}) = Fuel\_SL\_func(v_{CAS\_SL}) \frac{\text{kg}}{\text{hr}} \]

SEA LEVEL 80% MCP

\[ v_{CAS\_SL\_80MCP} = \min(Speed\_SL\_80MCP), \left(\min(Speed\_SL\_80MCP) + 5\text{kts}\right) \max(Speed\_SL\_80MCP) \]

\[ Fuel\_SL\_80MCP\_reg\_vector = \text{regress}\left(\frac{\text{Speed\_SL\_80MCP}}{\text{kts}}, \frac{\text{Fuel\_SL\_80MCP}}{\text{kg/hr}}, 3\right) \]

\[ Fuel\_SL\_80MCP\_func(v_{CAS\_SL\_80MCP}) = \text{interp}\left(Fuel\_SL\_80MCP\_reg\_vector, \frac{\text{Speed\_SL\_80MCP}}{\text{kts}}, \frac{\text{Fuel\_SL\_80MCP}}{\text{kg/hr}}, v_{CAS\_SL\_80MCP}\right) \]

\[ Fuel\_SL\_80MCP\_func(v_{CAS\_SL\_80MCP}) = Fuel\_SL\_80MCP\_func(v_{CAS\_SL\_80MCP}) \frac{\text{kg}}{\text{hr}} \]
SEA LEVEL 60% MCP

\[ v_{CAS_{SL\_60MCP}} = \min(Speed_{SL\_60MCP}), (\min(Speed_{SL\_60MCP}) + 5\text{kts}) \max(Speed_{SL\_60MCP}) \]

\[ \text{Fuel}_{SL\_60MCP\_reg\_vector} = \text{regress} \left\{ \frac{\text{Speed}_{SL\_60MCP}}{\text{kts}}, \frac{\text{Fuel}_{SL\_60MCP}}{\text{kg/hr}}, 3 \right\} \]

\[ \text{Fuel}_{SL\_60MCP\_func}(v_{CAS_{SL\_60MCP}}) = \text{interp} \left\{ \text{Fuel}_{SL\_60MCP\_reg\_vector}, \frac{\text{Speed}_{SL\_60MCP}}{\text{kts}}, \frac{\text{Fuel}_{SL\_60MCP}}{\text{kg/hr}}, \frac{v_{CAS_{SL\_60MCP}}}{\text{kts}} \right\} \]

\[ \text{Fuel}_{SL\_60MCP\_func}(v_{CAS_{SL\_60MCP}}) = \text{Fuel}_{SL\_60MCP\_func}(v_{CAS_{SL\_60MCP}}) \text{ kg/hr} \]

FL 100 100% MCP

\[ v_{CAS_{100}} = \min(Speed_{100}), (\min(Speed_{100}) + 5\text{kts}) \max(Speed_{100}) \]

\[ \text{Fuel}_{100\_reg\_vector} = \text{regress} \left\{ \frac{\text{Speed}_{100}}{\text{kts}}, \frac{\text{Fuel}_{100}}{\text{kg/hr}}, 3 \right\} \]

\[ \text{Fuel}_{100\_func}(v_{CAS_{100}}) = \text{interp} \left\{ \text{Fuel}_{100\_reg\_vector}, \frac{\text{Speed}_{100}}{\text{kts}}, \frac{\text{Fuel}_{100}}{\text{kg/hr}}, \frac{v_{CAS_{100}}}{\text{kts}} \right\} \]

\[ \text{Fuel}_{100\_func}(v_{CAS_{100}}) = \text{Fuel}_{100\_func}(v_{CAS_{100}}) \text{ kg/hr} \]
FL 100 80% MCP

\[
\begin{align*}
V_{CAS\_100\_80MCP} &= \min(\text{Speed\_100\_80MCP}), \left(\min(\text{Speed\_100\_80MCP}) + 5\text{kts}\right) \max(\text{Speed\_100\_80MCP})
\end{align*}
\]

\[
\begin{align*}
\text{Fuel\_100\_80MCP\_reg\_vector} &= \text{regress} \left( \frac{\text{Speed\_100\_80MCP}}{\text{kts}}, \frac{\text{Fuel\_100\_80MCP}}{\text{kg/hr}}, 3 \right)
\end{align*}
\]

\[
\begin{align*}
\text{Fuel\_100\_80MCP\_func}(V_{CAS\_100\_80MCP}) &= \text{interp} \left( \text{Fuel\_100\_80MCP\_reg\_vector}, \frac{\text{Speed\_100\_80MCP}}{\text{kts}}, \frac{\text{Fuel\_100\_80MCP}}{\text{kg/hr}}, \frac{V_{CAS\_100\_80MCP}}{\text{kts}} \right)
\end{align*}
\]

\[
\begin{align*}
\text{Fuel\_100\_80MCP\_func}(V_{CAS\_100\_80MCP}) &= \frac{\text{Fuel\_100\_80MCP\_func}(V_{CAS\_100\_80MCP})}{\text{kg/hr}}
\end{align*}
\]

FL 100 60% MCP

\[
\begin{align*}
V_{CAS\_100\_60MCP} &= \min(\text{Speed\_100\_60MCP}), \left(\min(\text{Speed\_100\_60MCP}) + 5\text{kts}\right) \max(\text{Speed\_100\_60MCP})
\end{align*}
\]

\[
\begin{align*}
\text{Fuel\_100\_60MCP\_reg\_vector} &= \text{regress} \left( \frac{\text{Speed\_100\_60MCP}}{\text{kts}}, \frac{\text{Fuel\_100\_60MCP}}{\text{kg/hr}}, 3 \right)
\end{align*}
\]

\[
\begin{align*}
\text{Fuel\_100\_60MCP\_func}(V_{CAS\_100\_60MCP}) &= \text{interp} \left( \text{Fuel\_100\_60MCP\_reg\_vector}, \frac{\text{Speed\_100\_60MCP}}{\text{kts}}, \frac{\text{Fuel\_100\_60MCP}}{\text{kg/hr}}, \frac{V_{CAS\_100\_60MCP}}{\text{kts}} \right)
\end{align*}
\]

\[
\begin{align*}
\text{Fuel\_100\_60MCP\_func}(V_{CAS\_100\_60MCP}) &= \frac{\text{Fuel\_100\_60MCP\_func}(V_{CAS\_100\_60MCP})}{\text{kg/hr}}
\end{align*}
\]

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**FL 200 100% MCP**

\[
v_{\text{CAS}_{200}} = \min(\text{Speed}_{200}), (\min(\text{Speed}_{200}) + 5\text{kts}) \quad \max(\text{Speed}_{200})
\]

\[
\text{Fuel}_{200}\_\text{reg\_vector} = \text{regress}\left(\frac{\text{Speed}_{200}}{\text{kts}}, \frac{\text{Fuel}_{200}}{\text{kg}}\right)
\]

\[
\text{Fuel}_{200}\_\text{func}(v_{\text{CAS}_{200}}) = \text{interp}\left(\text{Fuel}_{200}\_\text{reg\_vector}, \frac{\text{Speed}_{200}}{\text{kts}}, \frac{\text{Fuel}_{200}}{\text{kg}}, \frac{v_{\text{CAS}_{200}}}{\text{kts}}\right)
\]

\[
\text{Fuel}_{200}\_\text{func}(v_{\text{CAS}_{200}}) = \text{Fuel}_{200}\_\text{func}(v_{\text{CAS}_{200}}) \quad \text{kg}\frac{\text{hr}}{}\]

**FL 200 80% MCP**

\[
v_{\text{CAS}_{200}\_80\text{MCP}} = \min(\text{Speed}_{200\_80\text{MCP}}), (\min(\text{Speed}_{200\_80\text{MCP}}) + 5\text{kts}) \quad \max(\text{Speed}_{200\_80\text{MCP}})
\]

\[
\text{Fuel}_{200\_80\text{MCP}\_\text{reg\_vector}} = \text{regress}\left(\frac{\text{Speed}_{200\_80\text{MCP}}}{\text{kts}}, \frac{\text{Fuel}_{200\_80\text{MCP}}}{\text{kg}}\right)
\]

\[
\text{Fuel}_{200\_80\text{MCP}\_\text{func}}(v_{\text{CAS}_{200}\_80\text{MCP}}) = \text{interp}\left(\text{Fuel}_{200\_80\text{MCP}\_\text{reg\_vector}}, \frac{\text{Speed}_{200\_80\text{MCP}}}{\text{kts}}, \frac{\text{Fuel}_{200\_80\text{MCP}}}{\text{kg}}, \frac{v_{\text{CAS}_{200\_80\text{MCP}}}}{\text{kts}}\right)
\]

\[
\text{Fuel}_{200\_80\text{MCP}\_\text{func}}(v_{\text{CAS}_{200\_80\text{MCP}}}) = \text{Fuel}_{200\_80\text{MCP}\_\text{func}}(v_{\text{CAS}_{200\_80\text{MCP}}}) \quad \text{kg}\frac{\text{hr}}{}\]
FL 200 60% MCP

\[ \nu_{CAS, 200, 60MCP} = \min(Speed_{200, 60MCP}), \left(\min(Speed_{200, 60MCP}) + 5\text{kts}\right) \max(Speed_{200, 60MCP}) \]

\[ \text{Fuel}_{200, 60MCP} = \text{regress}\left(\begin{array}{c}
\text{Speed}_{200, 60MCP} \\
\text{Fuel}_{200, 60MCP}
\end{array}\right), 3 \]

\[ \text{Fuel}_{200, 60MCP} = \text{interp}\left(\begin{array}{c}
\text{Fuel}_{200, 60MCP} \\
\text{Speed}_{200, 60MCP} \\
\nu_{CAS, 200, 60MCP}
\end{array}\right) \]

FL 250 100% MCP

\[ \nu_{CAS, 250} = \min(Speed_{250}), \left(\min(Speed_{250}) + 5\text{kts}\right) \max(Speed_{250}) \]

\[ \text{Fuel}_{250} = \text{regress}\left(\begin{array}{c}
\text{Speed}_{250} \\
\text{Fuel}_{250}
\end{array}\right), 3 \]

\[ \text{Fuel}_{250} = \text{interp}\left(\begin{array}{c}
\text{Fuel}_{250} \\
\text{Speed}_{250} \\

\nu_{CAS, 250}
\end{array}\right) \]

\[ \text{Fuel}_{250} = \text{Fuel}_{250} \]

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FL 250 80% MCP

\[ v_{CAS_{250\_80MCP}} = \min(Speed_{250\_80MCP}), \left(\min(Speed_{250\_80MCP}) + 5\text{kts}\right) \max(Speed_{250\_80MCP}) \]

\[ \text{Fuel}_{250\_80MCP\_reg\_vector} = \text{regress} \left( \frac{\text{Speed}_{250\_80MCP}}{\text{kts}}, \frac{\text{Fuel}_{250\_80MCP}}{\text{kg/hr}} \right)^3 \]

\[ \text{Fuel}_{250\_80MCP\_func}(v_{CAS_{250\_80MCP}}) = \text{interp} \left( \frac{\text{Speed}_{250\_80MCP}}{\text{kts}}, \frac{\text{Fuel}_{250\_80MCP}}{\text{kg/hr}}, \frac{v_{CAS_{250\_80MCP}}}{\text{kts}} \right) \]

\[ \text{Fuel}_{250\_80MCP\_func}(v_{CAS_{250\_80MCP}}) = \text{Fuel}_{250\_80MCP\_func}(v_{CAS_{250\_80MCP}}) \text{ kg/hr} \]

FL 250 60% MCP

\[ v_{CAS_{250\_60MCP}} = \min(Speed_{250\_60MCP}), \left(\min(Speed_{250\_60MCP}) + 5\text{kts}\right) \max(Speed_{250\_60MCP}) \]

\[ \text{Fuel}_{250\_60MCP\_reg\_vector} = \text{regress} \left( \frac{\text{Speed}_{250\_60MCP}}{\text{kts}}, \frac{\text{Fuel}_{250\_60MCP}}{\text{kg/hr}} \right)^3 \]

\[ \text{Fuel}_{250\_60MCP\_func}(v_{CAS_{250\_60MCP}}) = \text{interp} \left( \frac{\text{Speed}_{250\_60MCP}}{\text{kts}}, \frac{\text{Fuel}_{250\_60MCP}}{\text{kg/hr}}, \frac{v_{CAS_{250\_60MCP}}}{\text{kts}} \right) \]

\[ \text{Fuel}_{250\_60MCP\_func}(v_{CAS_{250\_60MCP}}) = \text{Fuel}_{250\_60MCP\_func}(v_{CAS_{250\_60MCP}}) \text{ kg/hr} \]
FL 300 100% MCP

\[ v_{CAS\_300} = \min(\text{Speed}_300), (\min(\text{Speed}_300) + 5\text{kts}) \max(\text{Speed}_300) \]

\[
\text{Fuel}_300\_\text{reg\_vector} = \text{regress}\left(\frac{\text{Speed}_300}{\text{kts}}, \frac{\text{Fuel}_300}{\text{kg/hr}}, 3\right)
\]

\[
\text{Fuel}_300\_\text{func}(v_{CAS\_300}) = \text{interp}\left(\text{Fuel}_300\_\text{reg\_vector}, \frac{\text{Speed}_300}{\text{kts}}, \frac{\text{Fuel}_300}{\text{kg/hr}}, \frac{v_{CAS\_300}}{\text{kts}}\right)
\]

\[
\text{Fuel}_300\_\text{func}(v_{CAS\_300}) = \text{Fuel}_300\_\text{func}(v_{CAS\_300}) \frac{\text{kg}}{\text{hr}}
\]

FL 300 80% MCP

\[ v_{CAS\_300\_80MCP} = \min(\text{Speed}_300\_80MCP), (\min(\text{Speed}_300\_80MCP) + 5\text{kts}) \max(\text{Speed}_300\_80MCP) \]

\[
\text{Fuel}_300\_80MCP\_\text{reg\_vector} = \text{regress}\left(\frac{\text{Speed}_300\_80MCP}{\text{kts}}, \frac{\text{Fuel}_300\_80MCP}{\text{kg/hr}}, 3\right)
\]

\[
\text{Fuel}_300\_80MCP\_\text{func}(v_{CAS\_300\_80MCP}) = \text{interp}\left(\text{Fuel}_300\_80MCP\_\text{reg\_vector}, \frac{\text{Speed}_300\_80MCP}{\text{kts}}, \frac{\text{Fuel}_300\_80MCP}{\text{kg/hr}}, \frac{v_{CAS\_300\_80MCP}}{\text{kts}}\right)
\]

\[
\text{Fuel}_300\_80MCP\_\text{func}(v_{CAS\_300\_80MCP}) = \text{Fuel}_300\_80MCP\_\text{func}(v_{CAS\_300\_80MCP}) \frac{\text{kg}}{\text{hr}}
\]
**FL 300 60% MCP**

\[ v_{\text{CAS\_300\_60MCP}} = \min(\text{Speed\_300\_60MCP}), \left(\min(\text{Speed\_300\_60MCP}) + 5\text{kts}\right) \max(\text{Speed\_300\_60MCP}) \]

\[ \text{Fuel\_300\_60MCP\_reg\_vector} = \text{regress}\left(\frac{\text{Speed\_300\_60MCP}}{\text{kts}}, \frac{\text{Fuel\_300\_60MCP}}{\text{kg/hr}}, 3\right) \]

\[ \text{Fuel\_300\_60MCP\_func}\left(v_{\text{CAS\_300\_60MCP}}\right) = \text{interp}\left(\frac{\text{Fuel\_300\_60MCP\_reg\_vector}}{\text{kts}}, \frac{\text{Speed\_300\_60MCP}}{\text{kg/hr}}, \frac{\text{Fuel\_300\_60MCP}}{\text{kts}}, \frac{v_{\text{CAS\_300\_60MCP}}}{\text{kts}}\right) \]

\[ \text{Fuel\_300\_60MCP\_func}\left(v_{\text{CAS\_300\_60MCP}}\right) = \text{Fuel\_300\_60MCP\_func}\left(v_{\text{CAS\_300\_60MCP}}\right) \frac{\text{kg}}{\text{hr}} \]
POWER CURVES

SEA LEVEL 100% MCP

\[
\text{Power}_{\text{SL}}\_\text{reg}_\text{vector} = \text{regress}\left(\frac{\text{Speed}_{\text{SL}}}{\text{kts}}, \frac{\text{Power}_{\text{SL}}}{\text{watt}}\right)
\]

\[
\text{Power}_{\text{SL}}\_\text{func}(\text{VCAS}_{\text{SL}}) = \text{interp}\left(\text{Power}_{\text{SL}}\_\text{reg}_\text{vector}, \frac{\text{Speed}_{\text{SL}}}{\text{kts}}, \frac{\text{Power}_{\text{SL}}}{\text{watt}}\right)
\]

\[
\text{Power}_{\text{SL}}\_\text{func}(\text{VCAS}_{\text{SL}}) = \text{Power}_{\text{SL}}\_\text{func}(\text{VCAS}_{\text{SL}}) \text{ watt}
\]

SEA LEVEL 80% MCP

\[
\text{Power}_{\text{SL}}\_80\text{MCP}\_\text{reg}_\text{vector} = \text{regress}\left(\frac{\text{Speed}_{\text{SL}}\_80\text{MCP}}{\text{kts}}, \frac{\text{Power}_{\text{SL}}\_80\text{MCP}}{\text{watt}}\right)
\]

\[
\text{Power}_{\text{SL}}\_80\text{MCP}\_\text{func}(\text{VCAS}_{\text{SL}}\_80\text{MCP}) = \text{interp}\left(\text{Power}_{\text{SL}}\_80\text{MCP}\_\text{reg}_\text{vector}, \frac{\text{Speed}_{\text{SL}}\_80\text{MCP}}{\text{kts}}, \frac{\text{Power}_{\text{SL}}\_80\text{MCP}}{\text{watt}}\right)
\]

\[
\text{Power}_{\text{SL}}\_80\text{MCP}\_\text{func}(\text{VCAS}_{\text{SL}}\_80\text{MCP}) = \text{Power}_{\text{SL}}\_80\text{MCP}\_\text{func}(\text{VCAS}_{\text{SL}}\_80\text{MCP}) \text{ watt}
\]

SEA LEVEL 60% MCP

\[
\text{Power}_{\text{SL}}\_60\text{MCP}\_\text{reg}_\text{vector} = \text{regress}\left(\frac{\text{Speed}_{\text{SL}}\_60\text{MCP}}{\text{kts}}, \frac{\text{Power}_{\text{SL}}\_60\text{MCP}}{\text{watt}}\right)
\]

\[
\text{Power}_{\text{SL}}\_60\text{MCP}\_\text{func}(\text{VCAS}_{\text{SL}}\_60\text{MCP}) = \text{interp}\left(\text{Power}_{\text{SL}}\_60\text{MCP}\_\text{reg}_\text{vector}, \frac{\text{Speed}_{\text{SL}}\_60\text{MCP}}{\text{kts}}, \frac{\text{Power}_{\text{SL}}\_60\text{MCP}}{\text{watt}}\right)
\]

\[
\text{Power}_{\text{SL}}\_60\text{MCP}\_\text{func}(\text{VCAS}_{\text{SL}}\_60\text{MCP}) = \text{Power}_{\text{SL}}\_60\text{MCP}\_\text{func}(\text{VCAS}_{\text{SL}}\_60\text{MCP}) \text{ watt}
\]
FL 100 100% MCP

\[
\text{Power}_{100\_\text{reg\_vector}} = \text{regress}\left(\frac{\text{Speed}_{100}}{\text{kts}}, \frac{\text{Power}_{100}}{\text{watt}}, 3\right)
\]

\[
\text{Power}_{100\_\text{func}}(\text{VCAS}_{100}) = \text{interp}\left(\frac{\text{Speed}_{100}}{\text{kts}}, \frac{\text{Power}_{100}}{\text{watt}}, \frac{\text{VCAS}_{100}}{\text{kts}}\right)
\]

\[
\text{Power}_{100\_\text{func}}(\text{VCAS}_{100}) = \text{Power}_{100\_\text{func}}(\text{VCAS}_{100}) \text{ watt}
\]

FL 100 80% MCP

\[
\text{Power}_{100\_80\text{MCP\_reg\_vector}} = \text{regress}\left(\frac{\text{Speed}_{100\_80\text{MCP}}}{\text{kts}}, \frac{\text{Power}_{100\_80\text{MCP}}}{\text{watt}}, 3\right)
\]

\[
\text{Power}_{100\_80\text{MCP\_func}}(\text{VCAS}_{100\_80\text{MCP}}) = \text{interp}\left(\frac{\text{Speed}_{100\_80\text{MCP\_reg\_vector}}}{\text{kts}}, \frac{\text{Power}_{100\_80\text{MCP}}}{\text{watt}}, \frac{\text{VCAS}_{100\_80\text{MCP}}}{\text{kts}}\right)
\]

\[
\text{Power}_{100\_80\text{MCP\_func}}(\text{VCAS}_{100\_80\text{MCP}}) = \text{Power}_{100\_80\text{MCP\_func}}(\text{VCAS}_{100\_80\text{MCP}}) \text{ watt}
\]

FL 100 60% MCP

\[
\text{Power}_{100\_60\text{MCP\_reg\_vector}} = \text{regress}\left(\frac{\text{Speed}_{100\_60\text{MCP}}}{\text{kts}}, \frac{\text{Power}_{100\_60\text{MCP}}}{\text{watt}}, 3\right)
\]

\[
\text{Power}_{100\_60\text{MCP\_func}}(\text{VCAS}_{100\_60\text{MCP}}) = \text{interp}\left(\frac{\text{Speed}_{100\_60\text{MCP\_reg\_vector}}}{\text{kts}}, \frac{\text{Power}_{100\_60\text{MCP}}}{\text{watt}}, \frac{\text{VCAS}_{100\_60\text{MCP}}}{\text{kts}}\right)
\]

\[
\text{Power}_{100\_60\text{MCP\_func}}(\text{VCAS}_{100\_60\text{MCP}}) = \text{Power}_{100\_60\text{MCP\_func}}(\text{VCAS}_{100\_60\text{MCP}}) \text{ watt}
\]
FL 200 100% MCP

\[ \text{Power}_{200\_\text{reg\_vector}} = \text{regress}\left( \frac{\text{Speed}_{200}}{\text{watt}}, \frac{\text{Power}_{200}}{\text{kts}} \right) \]

\[ \text{Power}_{200\_\text{func}(\text{VCAS}_{200})} = \text{interp}\left( \text{Power}_{200\_\text{reg\_vector}}, \frac{\text{Speed}_{200}}{\text{kts}}, \frac{\text{Power}_{200}}{\text{watt}}, \frac{\text{VCAS}_{200}}{\text{kts}} \right) \]

\[ \text{Power}_{200\_\text{func}(\text{VCAS}_{200})} = \text{Power}_{200\_\text{func}(\text{VCAS}_{200})} \text{ watt} \]

FL 200 80% MCP

\[ \text{Power}_{200\_80\text{MCP}\_\text{reg\_vector}} = \text{regress}\left( \frac{\text{Speed}_{200\_80\text{MCP}}}{\text{watt}}, \frac{\text{Power}_{200\_80\text{MCP}}}{\text{kts}} \right) \]

\[ \text{Power}_{200\_80\text{MCP}\_\text{func}(\text{VCAS}_{200\_80\text{MCP}})} = \text{interp}\left( \text{Power}_{200\_80\text{MCP}\_\text{reg\_vector}}, \frac{\text{Speed}_{200\_80\text{MCP}}}{\text{kts}}, \frac{\text{Power}_{200\_80\text{MCP}}}{\text{watt}}, \frac{\text{VCAS}_{200\_80\text{MCP}}}{\text{kts}} \right) \]

\[ \text{Power}_{200\_80\text{MCP}\_\text{func}(\text{VCAS}_{200\_80\text{MCP}})} = \text{Power}_{200\_80\text{MCP}\_\text{func}(\text{VCAS}_{200\_80\text{MCP}})} \text{ watt} \]

FL 200 60% MCP

\[ \text{Power}_{200\_60\text{MCP}\_\text{reg\_vector}} = \text{regress}\left( \frac{\text{Speed}_{200\_60\text{MCP}}}{\text{watt}}, \frac{\text{Power}_{200\_60\text{MCP}}}{\text{kts}} \right) \]

\[ \text{Power}_{200\_60\text{MCP}\_\text{func}(\text{VCAS}_{200\_60\text{MCP}})} = \text{interp}\left( \text{Power}_{200\_60\text{MCP}\_\text{reg\_vector}}, \frac{\text{Speed}_{200\_60\text{MCP}}}{\text{kts}}, \frac{\text{Power}_{200\_60\text{MCP}}}{\text{watt}}, \frac{\text{VCAS}_{200\_60\text{MCP}}}{\text{kts}} \right) \]

\[ \text{Power}_{200\_60\text{MCP}\_\text{func}(\text{VCAS}_{200\_60\text{MCP}})} = \text{Power}_{200\_60\text{MCP}\_\text{func}(\text{VCAS}_{200\_60\text{MCP}})} \text{ watt} \]
FL 250 100% MCP

\[
\text{Power}_\text{250\_reg\_vector} = \text{regress} \left( \frac{\text{Speed}_{250}}{\text{kts}}, \frac{\text{Power}_\text{250}}{\text{watt}}, 3 \right)
\]

\[
\text{Power}_\text{250\_func}(\text{vCAS}_{250}) = \text{interp} \left( \text{Power}_\text{250\_reg\_vector}, \frac{\text{Speed}_{250}}{\text{kts}}, \frac{\text{Power}_\text{250}}{\text{watt}}, \frac{\text{vCAS}_{250}}{\text{kts}} \right)
\]

\[
\text{Power}_\text{250\_func}(\text{vCAS}_{250}) = \text{Power}_\text{250\_func}(\text{vCAS}_{250}) \text{ watt}
\]

FL 250 80% MCP

\[
\text{Power}_\text{250\_80MCP\_reg\_vector} = \text{regress} \left( \frac{\text{Speed}_{250\_80MCP}}{\text{kts}}, \frac{\text{Power}_\text{250\_80MCP}}{\text{watt}}, 3 \right)
\]

\[
\text{Power}_\text{250\_80MCP\_func}(\text{vCAS}_{250\_80MCP}) = \text{interp} \left( \text{Power}_\text{250\_80MCP\_reg\_vector}, \frac{\text{Speed}_{250\_80MCP}}{\text{kts}}, \frac{\text{Power}_\text{250\_80MCP}}{\text{watt}}, \frac{\text{vCAS}_{250\_80MCP}}{\text{kts}} \right)
\]

\[
\text{Power}_\text{250\_80MCP\_func}(\text{vCAS}_{250\_80MCP}) = \text{Power}_\text{250\_80MCP\_func}(\text{vCAS}_{250\_80MCP}) \text{ watt}
\]

FL 250 60% MCP

\[
\text{Power}_\text{250\_60MCP\_reg\_vector} = \text{regress} \left( \frac{\text{Speed}_{250\_60MCP}}{\text{kts}}, \frac{\text{Power}_\text{250\_60MCP}}{\text{watt}}, 3 \right)
\]

\[
\text{Power}_\text{250\_60MCP\_func}(\text{vCAS}_{250\_60MCP}) = \text{interp} \left( \text{Power}_\text{250\_60MCP\_reg\_vector}, \frac{\text{Speed}_{250\_60MCP}}{\text{kts}}, \frac{\text{Power}_\text{250\_60MCP}}{\text{watt}}, \frac{\text{vCAS}_{250\_60MCP}}{\text{kts}} \right)
\]

\[
\text{Power}_\text{250\_60MCP\_func}(\text{vCAS}_{250\_60MCP}) = \text{Power}_\text{250\_60MCP\_func}(\text{vCAS}_{250\_60MCP}) \text{ watt}
\]
FL 300 100% MCP

\[
\text{Power}_{300\_\text{reg\_vector}} = \text{regress} \left( \frac{\text{Speed}_{300}}{\text{kts}}, \frac{\text{Power}_{300}}{\text{watt}}, 3 \right)
\]

\[
\text{Power}_{300\_\text{func}(\text{vCAS}_{300})} = \text{interp} \left( \text{Power}_{300\_\text{reg\_vector}}, \frac{\text{Speed}_{300}}{\text{kts}}, \frac{\text{Power}_{300}}{\text{watt}}, \frac{\text{vCAS}_{300}}{\text{kts}} \right)
\]

\[
\text{Power}_{300\_\text{func}(\text{vCAS}_{300})} = \text{Power}_{300\_\text{func}(\text{vCAS}_{300})} \text{ watt}
\]

FL 300 80% MCP

\[
\text{Power}_{300\_80\text{MCP\_reg\_vector}} = \text{regress} \left( \frac{\text{Speed}_{300\_80\text{MCP}}}{\text{kts}}, \frac{\text{Power}_{300\_80\text{MCP}}}{\text{watt}}, 3 \right)
\]

\[
\text{Power}_{300\_80\text{MCP\_func}(\text{vCAS}_{300\_80\text{MCP}})} = \text{interp} \left( \text{Power}_{300\_80\text{MCP\_reg\_vector}}, \frac{\text{Speed}_{300\_80\text{MCP}}}{\text{kts}}, \frac{\text{Power}_{300\_80\text{MCP}}}{\text{watt}}, \frac{\text{vCAS}_{300\_80\text{MCP}}}{\text{kts}} \right)
\]

\[
\text{Power}_{300\_80\text{MCP\_func}(\text{vCAS}_{300\_80\text{MCP}})} = \text{Power}_{300\_80\text{MCP\_func}(\text{vCAS}_{300\_80\text{MCP}})} \text{ watt}
\]

FL 300 60% MCP

\[
\text{Power}_{300\_60\text{MCP\_reg\_vector}} = \text{regress} \left( \frac{\text{Speed}_{300\_60\text{MCP}}}{\text{kts}}, \frac{\text{Power}_{300\_60\text{MCP}}}{\text{watt}}, 3 \right)
\]

\[
\text{Power}_{300\_60\text{MCP\_func}(\text{vCAS}_{300\_60\text{MCP}})} = \text{interp} \left( \text{Power}_{300\_60\text{MCP\_reg\_vector}}, \frac{\text{Speed}_{300\_60\text{MCP}}}{\text{kts}}, \frac{\text{Power}_{300\_60\text{MCP}}}{\text{watt}}, \frac{\text{vCAS}_{300\_60\text{MCP}}}{\text{kts}} \right)
\]

\[
\text{Power}_{300\_60\text{MCP\_func}(\text{vCAS}_{300\_60\text{MCP}})} = \text{Power}_{300\_60\text{MCP\_func}(\text{vCAS}_{300\_60\text{MCP}})} \text{ watt}
\]
AIRFOIL DATA [CLEAN]

AIRFOIL DATA / CLEAN PROFILE  \( \alpha = 0.05 \), 1.8

AIRFOIL DATA IMPORT

\[ cd\_clean\_Re75mio = CLEAN\_Re75mio \]
\[ cl\_clean\_Re75mio = CLEAN\_Re75mio \]
\[ c75_d(\alpha) = \text{Interp}(cl\_clean\_Re75mio, cd\_clean\_Re75mio, \alpha) \]

\[ cd\_clean\_Re83mio = CLEAN\_Re83mio \]
\[ cl\_clean\_Re83mio = CLEAN\_Re83mio \]
\[ c83_d(\alpha) = \text{Interp}(cl\_clean\_Re83mio, cd\_clean\_Re83mio, \alpha) \]

\[ cd\_clean\_Re120mio = CLEAN\_Re120mio \]
\[ cl\_clean\_Re120mio = CLEAN\_Re120mio \]
\[ c120_d(\alpha) = \text{Interp}(cl\_clean\_Re120mio, cd\_clean\_Re120mio, \alpha) \]
INTERPOLATION FOR Re NUMBER

\[ Re_{75} = 7.5 \times 10^6 \quad Re_{83} = 8.3 \times 10^6 \quad Re_{120} = 12 \times 10^6 \]

\[ Re_w(H,v,\text{CAS,diSA}) = 1.4 \times f_{Re}(H,v,\text{CAS,diSA}) \]

\[ c_{d_clean}(\varphi, H, v, \text{CAS,diSA}) = \begin{cases} 
  c_{75d}(\varphi) & \text{if } 0 \leq Re_w(H,v,\text{CAS,diSA}) \leq Re_{75} \\
  c_{75d}(\varphi) + \frac{Re_w(H,v,\text{CAS,diSA}) - Re_{75}}{Re_{83} - Re_{75}} (c_{83d}(\varphi) - c_{75d}(\varphi)) & \text{if } Re_{75} \leq Re_w(H,v,\text{CAS,diSA}) \leq Re_{83} \\
  c_{83d}(\varphi) + \frac{Re_w(H,v,\text{CAS,diSA}) - Re_{83}}{Re_{120} - Re_{83}} (c_{120d}(\varphi) - c_{83d}(\varphi)) & \text{if } Re_{83} \leq Re_w(H,v,\text{CAS,diSA}) \leq Re_{120} \\
  c_{120d}(\varphi) & \text{if } Re_{120} \leq Re_w(H,v,\text{CAS,diSA})
\end{cases} \]
AIRFOIL LIFT CURVE

\[ i = 0.6 \]

\[ c_{l,\text{clean}} \]

\[ \alpha_{\text{clean}} \]

\[
\begin{array}{c|c|c}
\alpha & c_{l,\text{clean}} & \alpha_{\text{clean}} \\
\hline
0.225 & 0 \text{ deg} & \\
1.2 & 7.5 \text{ deg} & \\
1.44 & 11.3 \text{ deg} & \\
1.56 & 13.7 \text{ deg} & \\
1.61 & 17.0 \text{ deg} & \\
1.64 & 20.3 \text{ deg} & \\
1.56 & 23.0 \text{ deg} & \\
\end{array}
\]

\[ \alpha = -10 \text{ deg}, -9.9 \text{ deg}, 25 \text{ deg} \]

\[ c_{l,\text{clean}}(\alpha) = \text{interp}(\alpha_{\text{clean}}, c_{l,\text{clean}}, \alpha) \]

\[ \frac{c_{l,\text{clean}}(\alpha)}{\alpha_{\text{clean}}} \]

\[ \frac{\alpha}{\text{deg}} \]

\[ \frac{\alpha_{\text{clean}}}{\text{deg}} \]

\[ \text{Fig. 12.13a} \]

\[ \text{Fig. 12.13b} \]

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AIRFOIL DATA [CLEAN]
WING DATA

\[ \text{Re}_\text{w}(H, \text{v}_\text{CAS}, \text{dISA}) = \frac{1}{\mu_{\text{w}}} \text{f}_\text{Re}(H, \text{v}_\text{CAS}, \text{dISA}) \]

\[ \lambda_w = \frac{b_w^2}{S_w} \quad \text{wing aspect ratio (geometric)} \]

\[ \lambda_w = 8.813 \]

\[ c_{\text{mean}_w} = \frac{S_w}{b_w} \quad \text{mean geometric chord} \]

\[ c_{\text{mean}_w} = 1.339 \text{m} \]

\[ S_{\text{WC}} = S_w - S_{\text{WFL}} \]

\[ S_{\text{WC}} = 5.8 \text{m}^2 \quad \text{non-flapped / clean wing area} \]

\[ \frac{b_{\text{WFL}}}{c_{\text{mean}_w}} \quad \text{flapped wing span} \]

\[ b_{\text{WFL}} = 7.468 \text{m} \]

\[ \lambda_{\text{WFL}} = \frac{b_{\text{WFL}}^2}{S_{\text{WFL}}} \]

\[ \lambda_{\text{WFL}} = 5.578 \]
FUSELAGE DATA

This section generates the basic aerodynamic and geometric variables from the input that was supplied above.

\[ R_{N_{fus}}(H, v_{CAS}, d_{SI}) = f_{Re}(H, v_{CAS}, d_{SI}) \]

Reynolds Number of the fuselage

\[ d_{fus} = \sqrt{\frac{4}{\pi}} S_{fus} \]

equivalent \( d_f \) for non-circular cross-section of fuselage

\[ d_{fus} = 1.5674 \text{ m} \]

\[ d_b = \sqrt{\frac{4}{\pi}} S_b \]

base diameter of the aft base area

\[ d_b = 0.505 \text{ m} \]

\[ f_{fus} = \frac{l_{fus}}{d_{fus}} \]

finess ratio of the fuselage

\[ f_{fus} = 7.018 \]
EMPENNAGE DATA

HORIZONTAL TAILPLANE

\[ \Lambda_h = \frac{b_h^2}{S_h} \]

Horizontal tail geometric aspect ratio / see figures 2.5 - 2.7

\[ \Lambda_h = 4.8485 \]

\[ c_{\text{mean}_h} = \frac{S_h}{b_h} \]

Mean geometric chord of the horizontal tail

\[ c_{\text{mean}_h} = 0.825 \text{ m} \]

\[ c_{\text{emp}_e_h} = c_{\text{mean}_h} \]

Exposed empennage surface / exposed mean geometric chord

\[ \lambda_h = \frac{t_{\text{chord}_h}}{c_{\text{emp}_e_h}} \]

Horizontal tailplane taper ratio

\[ \lambda_h = 0.2424 \]

\[ S_{\text{wet}_\text{emp}_h} = 2 \ S_h \left( 1 + 0.25 \ \frac{t_h}{c_{\text{emp}_e_h}} \ \frac{1 + \tau_h \ \lambda_h}{1 + \lambda_h} \right) \]

\[ S_{\text{wet}_\text{emp}_h} = 6.83 \text{ m}^2 \]
VERTICAL TAILPLANE

\[ \Lambda_v = \frac{b_v^2}{S_v} \]

\[ \Lambda_v = 1.0321 \]

mean geometric chord of the vertical tail

\[ c_{\text{mean}_v} = \frac{S_v}{b_v} \]

\[ c_{\text{mean}_v} = 1.647 \text{m} \]

Vertical tailplane surface wetted area (Figure 4.6 / Appendix B)

\[ c_{\text{emp}_e_v} = c_{\text{mean}_v} \]

exposed empennage surface / exposed mean geometric chord

\[ \lambda_v = \frac{t_{\text{chord}_v}}{r_{\text{ootchord}_v}} \]

horizontal tailplane taper ratio

\[ \lambda_v = 0.525 \]

\[ S_{\text{wet}_\text{emp}_v} = 2 \ S_v \left( 1 + 0.25 \ \frac{l_v}{c_{\text{emp}_e_v}} \ \frac{1 + \tau_v \ \lambda_v}{1 + \lambda_v} \right) \]

\[ S_{\text{wet}_\text{emp}_v} = 5.802 \text{m}^2 \]

EMPENNAGE GEOMETRY
TRIM AERODYNAMICS [CLEAN]

TRIM DATA

\[ C_{M0w,clean} = C_{m0,clean} \]

TRIM REQUIREMENT / CLEAN
Evaluates the required lift coefficient of the horizontal tail, needed for trimmed balance condition.

TRIM REQUIREMENT / BALANCE CONDITION

\[
\begin{align*}
&x_{NPwf} = 5.08 \text{ m} \\
&x_{CG} = 4.73 \text{ m} \\
&x_{NPh} = 11 \text{ m} \\
&l_{\mu_h} = 0.825 \text{ m} \\
&l_{\mu_w} = 1.4 \text{ m} \\
&CM_{0wf,clean} = -0.025
\end{align*}
\]

\[
\begin{align*}
&x_{ACw} = 5.08 \text{ m} \\
&x_{ACH} = 11 \text{ m} \\
&CM_{0w,clean} = C_{m0,clean} \\
&CM_{0f,clean} = -0.055
\end{align*}
\]

for 15% SM
same as old
from 0 deg mean PSW
CM min from WT
\[ Clh\_clean(v_{CAS}, mass) := \left( C_{M0w\_clean} + C_{M0f\_clean} - \frac{mass \cdot g}{qS(v_{CAS}) \cdot S_W} \right) \frac{x_{ACW} - x_{CG}}{l_{\mu\_w}} \]

\[ \frac{S_h}{S_W} \left( \frac{x_{ACW} - x_{CG}}{l_{\mu\_w}} + \frac{x_{ACH} - x_{CG}}{l_{\mu\_w}} \right) \]

TRIM AERODYNAMICS [CLEAN]
WING AERODYNAMICS [CLEAN]

WING AERODYNAMICS / CLEAN

WING LIFT

\[ C_{L\text{w, clean}}(\text{mass, } V_{\text{CAS}}) := \frac{\text{mass} \cdot g}{q_s(V_{\text{CAS}}) \cdot S_w} + C_{Lh, \text{ clean}}(V_{\text{CAS}}, \text{mass}) \cdot \frac{S_h}{S_w} \]

horizontal cruise flight

WING LIFT CURVE

\[ c_{L_w, \text{ clean}}(\alpha) = c_{L_{\text{clean}}1}(\alpha) \]

\[ C_{L_w, \text{ clean}}(\alpha) := \frac{c_{L_w, \text{ clean}}(\alpha) \cdot \Lambda_{W}}{\Lambda_{W} + 2} \]
WING ANGLE OF ATTACK

$\alpha := 5 \cdot \text{deg}$  

expected value for $\alpha$ must be defined for the numerical method

Given

$C_{L_w\text{clean}}(\alpha) = C_{L_w\text{clean}}(\text{mass,VCAS})$

$\alpha_{w\text{clean}}(\text{mass,VCAS}) := \text{Find}(\alpha)$

$\alpha_{w\text{clean}}(2000\text{kg,215kts}) = -0.41 \text{deg}$
WING DRAG

WING ZERO LIFT DRAG

DRAG COEFFICIENT DUE TO FRICTION

\[ C_{D_{0w\_clean}}(H, \text{mass}, v_{CAS}, dISA) = C_{d\_clean}\left(C_{l\_clean\_1}(\alpha_{w\_clean}(\text{mass}, v_{CAS})), H, v_{CAS}, dISA\right) \]

\[ C_{D_{0w\_clean}}(25000 \text{ ft}, 2000 \text{ kg}, 350 \text{ kts}, 0\text{k}) = 0.006 \]

WAVE DRAG COEFFICIENT

Page 34, Chapter 4: Figure 4.11 is reproduced with running variables x and y and interpolated with Mach number

\[ t_c\text{\_ratio} = 0.13 \]

\[ \Lambda_w t_c\text{\_ratio}^3 = 4.464 \]

\[ \text{figure411}(H, v_{CAS}, dISA) = \sqrt{\frac{M (H, v_{CAS}, dISA)^2 - 1}{1 - \frac{1}{t_c\text{\_ratio}^3}}} \]
\begin{align*}
\begin{array}{c|c}
0  & 3.7 \\
0.2 & 3.65 \\
0.4 & 3.6  \\
0.6 & 3.55 \\
0.8 & 3.2  \\
1   & 1.85  \\
1.2 & 0.6  \\
1.4 & 0.1  \\
1.6 & 0    \\
1.8 & 0    \\
2.0 & 0    \\
\end{array}
\end{align*}

Note these are the coordinates of the curve for (Aspect Ratio * t/c) values of 4.0. For results of 3.5 and below, different curves from Figure 4.11, page 35, should be used.

\begin{align*}
\text{wave1} &= \text{p spline}(x, y) \\
\text{wave2}(H, v_{\text{CAS}}, d_{\text{ISA}}) &= \text{interp}(\text{wave1}, x, y, \text{figure411}(H, v_{\text{CAS}}, d_{\text{ISA}})) \\
\text{wave3}(H, v_{\text{CAS}}, d_{\text{ISA}}) &= \text{wave2}(H, v_{\text{CAS}}, d_{\text{ISA}})^{3} \\
\text{wave3}(25000 \text{ ft, 350 kts, 0K}) &= 0.067
\end{align*}
Total Zero Lift Drag Coefficient

\[ C_{D_{0w,v\_clean}}(H, \text{mass}, v_{\text{CAS}}, dISA) := C_{D_{0w\_clean}}(H, \text{mass}, v_{\text{CAS}}, dISA) + \text{wave3}(H, v_{\text{CAS}}, dISA) \]

Note: it is strange that the zero lift drag coefficient decreases with altitude. This is due to the Roskam's wave drag dependency on the Mach Number, which rises with altitude. The results will be kept as they are, since high speed flight at low altitude is not one of the important and useful performance parameters. That scenario's results, however, will be overpredicted and this should be kept in mind.
WING DRAG DUE TO LIFT

Page 37, Chapter 4: Figure 4.13a, graph 3 is reproduced with running variables xy and z and interpolated with Mach number.

\[ \text{figure413}(H, \text{vcAS}, \text{dIL}) = \frac{M(H, \text{vcAS}, \text{dIL})^2 - 1}{2 \text{tc_ratio}^3} \]

\[ i = 0 \text{ to } 12 \]

\[ x_i, y_i, z_i = \]

<table>
<thead>
<tr>
<th>z_i</th>
<th>xy_i</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.225</td>
<td>-4</td>
</tr>
<tr>
<td>0.23</td>
<td>-3.5</td>
</tr>
<tr>
<td>0.24</td>
<td>-3</td>
</tr>
<tr>
<td>0.26</td>
<td>-2.5</td>
</tr>
<tr>
<td>0.28</td>
<td>-2</td>
</tr>
<tr>
<td>0.3</td>
<td>-1.5</td>
</tr>
<tr>
<td>0.325</td>
<td>-1</td>
</tr>
<tr>
<td>0.355</td>
<td>-0.5</td>
</tr>
<tr>
<td>0.38</td>
<td>0</td>
</tr>
<tr>
<td>0.395</td>
<td>0.5</td>
</tr>
<tr>
<td>0.405</td>
<td>1</td>
</tr>
<tr>
<td>0.415</td>
<td>1.5</td>
</tr>
<tr>
<td>0.42</td>
<td>2</td>
</tr>
</tbody>
</table>
\text{lift1} = \text{pspline}(xy, z)\\
\text{lift2}(H, v_{CAS}, dISL) := \text{interp(lift1, xy, z, figure413(H, v_{CAS}, dISL))}\\
\text{lift3}(H, v_{CAS}, dISL) = \frac{\text{lift2}(H, v_{CAS}, dISL)}{1 - \frac{1}{3} \text{tc\_ratio}}\\
\text{lift3}(25000 \text{ ft}, 350 \text{ kts}, 0K) = 0.166
Two different calculation methods are necessary, one for the subsonic and one for transonic speed range.

Subsonic speed range:

\[ C_{DLw, \text{clean}}(\text{mass}, \text{VCAS}) = \frac{C_{L, \text{w, clean}}(\alpha_{w, \text{clean}}(\text{mass}, \text{VCAS}))^2}{\pi \Lambda_w} \]

Transonic speed range:

\[ C_{DLw, \text{clean}}(H, \text{mass}, \text{VCAS}, \text{dISA}) = C_{L, \text{clean}}(\alpha_{w, \text{clean}}(\text{mass}, \text{VCAS}))^2 \text{ lift}(H, \text{VCAS}, \text{dISA}) \]

Interpolation of calculation methods:

\[
C_{DLw, \text{clean}}(H, \text{mass}, \text{VCAS}, \text{dISA}) = \begin{cases} 
C_{DLw, \text{clean}}(\text{mass}, \text{VCAS}) & \text{if } 0 \leq M(H, \text{VCAS}, \text{dISA}) \leq 0.25 \\
C_{DLw, \text{clean}}(\text{mass}, \text{VCAS}) + \frac{M(H, \text{VCAS}, \text{dISA}) - 0.25}{0.8 - 0.25} \left( C_{DLw, \text{clean}}(H, \text{mass}, \text{VCAS}, \text{dISA}) - C_{DLw, \text{clean}}(\text{mass}, \text{VCAS}) \right) & \text{if } 0.25 < M(H, \text{VCAS}, \text{dISA}) \leq 1.0 
\end{cases}
\]
TOTAL WING DRAG

\[ C_{D_{\text{w, clean}}} (H, \text{mass, } v_{\text{CAS, dISA}}) = C_{D_{0w, v, clean}} (H, \text{mass, } v_{\text{CAS, dISA}}) + C_{D_{Lw, clean3}} (H, \text{mass, } v_{\text{CAS, dISA}}) \]

WING AERODYNAMICS [CLEAN]
FUSELAGE DRAG COEFFICIENT

4.3 FUSELAGE DRAG COEFFICIENT PREDICTION

4.3.1 Transonic Fuselage Drag Coefficient

\[ C_{D0_{fus}} \text{ fuselage zero-lift coefficient / see 4.3.2.1} \]
\[ C_{DL_{fus}} \text{ fuselage drag coefficient due to lift / see 4.3.2.2} \]

4.3.1.1. Fuselage zero-lift drag coefficient

Wing fuselage interference factor (figure 4.1)

Interpolation (bi-linear) of the wing/fuselage interference factor from values for \( M = 0.25 - M = 0.9 \)

\( j = 0, 18 \)

\[ Re = 1 \times 10^5, 1 \times 10^6, 1 \times 10^7, 1 \times 10^8, 1 \times 10^9 \]
<table>
<thead>
<tr>
<th>$\text{RwM03}_j$</th>
<th>0.868</th>
<th>0.877</th>
<th>0.875</th>
<th>0.878</th>
<th>0.877</th>
<th>0.888</th>
<th>0.882</th>
<th>0.884</th>
<th>0.890</th>
<th>0.909</th>
<th>0.904</th>
<th>0.909</th>
<th>0.913</th>
<th>0.915</th>
<th>0.915</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{RwM04}_j$</td>
<td>0.925</td>
<td>0.921</td>
<td>0.929</td>
<td>0.931</td>
<td>0.932</td>
<td>0.935</td>
<td>0.939</td>
<td>0.941</td>
<td>0.942</td>
<td>0.949</td>
<td>0.958</td>
<td>0.961</td>
<td>0.966</td>
<td>0.968</td>
<td>0.971</td>
</tr>
<tr>
<td>$\text{RwM05}_j$</td>
<td>0.955</td>
<td>0.958</td>
<td>0.963</td>
<td>0.966</td>
<td>0.968</td>
<td>0.971</td>
<td>0.972</td>
<td>0.989</td>
<td>0.992</td>
<td>0.994</td>
<td>0.996</td>
<td>0.994</td>
<td>1.009</td>
<td>1.013</td>
<td>1.015</td>
</tr>
<tr>
<td>$\text{RwM06}_j$</td>
<td>0.985</td>
<td>0.969</td>
<td>0.973</td>
<td>0.976</td>
<td>0.978</td>
<td>0.979</td>
<td>0.982</td>
<td>0.984</td>
<td>0.989</td>
<td>0.991</td>
<td>1.015</td>
<td>1.015</td>
<td>1.015</td>
<td>1.015</td>
<td>1.015</td>
</tr>
<tr>
<td>$\text{RwM07}_j$</td>
<td>1.025</td>
<td>1.023</td>
<td>1.025</td>
<td>1.028</td>
<td>1.030</td>
<td>1.032</td>
<td>1.035</td>
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<td>1.012</td>
<td>1.015</td>
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<td>1.095</td>
<td>1.095</td>
<td>1.095</td>
</tr>
</tbody>
</table>
splinevec09 := pspline(Refus, RwfM09)
RwfM09_i(Re) := interp(splinevec09, Refus, RwfM09, Re)

splinevec08 := pspline(Refus, RwfM08)
RwfM08_i(Re) := interp(splinevec08, Refus, RwfM08, Re)

splinevec06 := pspline(Refus, RwfM06)
RwfM06_i(Re) := interp(splinevec06, Refus, RwfM06, Re)

splinevec025 := pspline(Refus, RwfM025)
RwfM025_i(Re) := interp(splinevec025, Refus, RwfM025, Re)

splinevec085 := pspline(Refus, RwfM085)
RwfM085_i(Re) := interp(splinevec085, Refus, RwfM085, Re)

splinevec07 := pspline(Refus, RwfM07)
RwfM07_i(Re) := interp(splinevec07, Refus, RwfM07, Re)

splinevec04 := pspline(Refus, RwfM04)
RwfM04_i(Re) := interp(splinevec04, Refus, RwfM04, Re)
\[
R_{\text{M025}} \leftarrow \text{interp}(\text{splinevec025, Refus, } R_{\text{M025}} \text{, RN fused}(H, \text{VCAS, dISA}))
\]
\[
R_{\text{M04}} \leftarrow \text{interp}(\text{splinevec04, Refus, } R_{\text{M04}} \text{, RN fused}(H, \text{VCAS, dISA}))
\]
\[
R_{\text{M06}} \leftarrow \text{interp}(\text{splinevec06, Refus, } R_{\text{M06}} \text{, RN fused}(H, \text{VCAS, dISA}))
\]
\[
R_{\text{M07}} \leftarrow \text{interp}(\text{splinevec07, Refus, } R_{\text{M07}} \text{, RN fused}(H, \text{VCAS, dISA}))
\]
\[
R_{\text{M08}} \leftarrow \text{interp}(\text{splinevec08, Refus, } R_{\text{M08}} \text{, RN fused}(H, \text{VCAS, dISA}))
\]
\[
R_{\text{M085}} \leftarrow \text{interp}(\text{splinevec085, Refus, } R_{\text{M085}} \text{, RN fused}(H, \text{VCAS, dISA}))
\]
\[
R_{\text{M09}} \leftarrow \text{interp}(\text{splinevec09, Refus, } R_{\text{M09}} \text{, RN fused}(H, \text{VCAS, dISA}))
\]
\[
\text{interp}(\text{splinevec025, Refus, } R_{\text{M025}} \text{, RN fused}(H, \text{VCAS, dISA})) \text{ if } (0 \leq M(H, \text{VCAS, dISA}) < 0.25)
\]
\[
\left[ \frac{(R_{\text{M025}} - R_{\text{M04}}) - 0.4}{0.25 - 0.4} + R_{\text{M04}} \right] \text{ if } (0.25 \leq M(H, \text{VCAS, dISA}) < 0.4)
\]
\[
\left[ \frac{(R_{\text{M04}} - R_{\text{M06}}) - 0.6}{0.4 - 0.6} + R_{\text{M06}} \right] \text{ if } (0.4 \leq M(H, \text{VCAS, dISA}) < 0.6)
\]
\[
\left[ \frac{(R_{\text{M06}} - R_{\text{M07}}) - 0.7}{0.6 - 0.7} + R_{\text{M07}} \right] \text{ if } (0.6 \leq M(H, \text{VCAS, dISA}) < 0.7)
\]
\[
\left[ \frac{(R_{\text{M07}} - R_{\text{M08}}) - 0.8}{0.7 - 0.8} + R_{\text{M08}} \right] \text{ if } (0.7 \leq M(H, \text{VCAS, dISA}) < 0.8)
\]
\[
\left[ \frac{(R_{\text{M08}} - R_{\text{M085}}) - 0.85}{0.8 - 0.85} + R_{\text{M085}} \right] \text{ if } (0.8 \leq M(H, \text{VCAS, dISA}) < 0.85)
\]
\[
\left[ \frac{(R_{\text{M085}} - R_{\text{M09}}) - 0.9}{0.85 - 0.9} + R_{\text{M09}} \right] \text{ if } (0.85 \leq M(H, \text{VCAS, dISA}) < 0.9)
\]
Roskam says that the interference factor approaches 1 at speeds in excess of M=0.9. This can be observed in the graph below, and therefore the graph is potentially correct. However, the graph indicates that the skin friction drag and pressure drag positively influence each other at sea level and speeds between 160-340 Ckts, which is questionable. However, this procedure will be used until proven wrong. Below is shown the option of setting all values lower than 1 equal to 1.

\[
R_{\text{wr}2}(H, v_{\text{CAS}}, d\text{ISA}) = \begin{cases} 
R_{\text{wr}}(H, v_{\text{CAS}}, d\text{ISA}) & \text{if } 1 \leq R_{\text{wr}}(H, v_{\text{CAS}}, d\text{ISA}) \\
1 & \text{if } R_{\text{wr}}(H, v_{\text{CAS}}, d\text{ISA}) < 1
\end{cases}
\]
Turbulent flat plate friction coefficient

\[ C_{f, fus}(H, v_{CAS}, dISA) := C_{f, fus}(H, v_{CAS}, dISA) + \frac{M(H, v_{CAS}, dISA)}{0.9} \times (C_{f, fus2}(H, v_{CAS}, dISA) - C_{f, fus}(H, v_{CAS}, dISA)) \]
Roskam dictates the use of the $M=0.6$ curve for the entire transonic speed range, therefore an if statement is needed.

$$C_{f_{fus}}(H, V_{CAS}, dISA) = \begin{cases} C_{f_{fus}}(H, V_{CAS}, dISA) & \text{if } M(H, V_{CAS}, dISA) \leq 0.6 \\ C_{f_{fus}}(H, V_{CAS}, dISA) + \frac{0.6}{0.9} (C_{f_{fus2}}(H, V_{CAS}, dISA) - C_{f_{fus}}(H, V_{CAS}, dISA)) & \text{if } 0.6 \leq M(H, V_{CAS}, dISA) \end{cases}$$

$$C_{df\text{-}fus}(H, V_{CAS}, dISA) = C_{f_{fus4}}(H, V_{CAS}, dISA) \frac{S_{\text{wet\text{-}fus}}}{S_{W}}$$
**Fuselage pressure drag coefficient**

Note that similarly to the previous section, the curve $M=0.6$ is used for the transonic speed range.

\[
C_{dp_{fus}}(H,v_{CAS},dISA) = C_{f_{fus}4}(H,v_{CAS},dISA) \left[ \frac{60}{(\frac{H_{fus}}{\delta_{fus}})^3} + 0.0025 \left( \frac{H_{fus}}{\delta_{fus}} \right) \right] \frac{S_{wet_{fus}}}{S_w}
\]

**Fuselage base drag coefficient**

Base area was guestimated and should be updated once more data become available.

\[
C_{D0_{fus_{base}}}(H,v_{CAS},dISA) = R_{wf}(H,v_{CAS},dISA) \ C_{f_{fus}4}(H,v_{CAS},dISA) \ \left[ 1 + \frac{60}{(\frac{H_{fus}}{\delta_{fus}})^3} + 0.0025 \left( \frac{H_{fus}}{\delta_{fus}} \right) \right] \frac{S_{wet_{fus}}}{S_w}
\]

\[
C_{Db_{fus}}(H,v_{CAS},dISA) = \sqrt{\frac{0.029 \ (\frac{d_b}{\delta_{fus}})^3 \ (\frac{S_{fus}}{S_{w}})}{C_{D0_{fus_{base}}}(H,v_{CAS},dISA) \ (\frac{S_{w}}{S_{fus}})}}
\]

$C_{Db_{fus}}(30000 \ ft, 350 \ kts, 0\kappa) = 0.001$
Fuselage wave drag coefficient

Note: Figure 4.22 shows that the wave drag in this case becomes significant only after M=0.99 and will therefore be neglected.

Total fuselage zero lift coefficient (4.30)

\[ C_{D0_{fus}}(H,v_{CAS},d{ISA}) = R_w(H,v_{CAS},d{ISA}) \cdot (C_{df_{fus}}(H,v_{CAS},d{ISA}) + C_{dp_{fus}}(H,v_{CAS},d{ISA})) + C_{Db_{fus}}(H,v_{CAS},d{ISA}) \]
4.3.1.2. Fuselage drag coefficient due to lift

\[ \alpha = \text{Fuselage angle of attack in radians, which is the same as the airplane angle of attack (Figure 4.18)} \]

\[ \alpha_{\text{fus clean}}(\text{mass}, \text{v}_{\text{CAS}}) = \alpha_{\text{W clean}}(\text{mass}, \text{v}_{\text{CAS}}) + \text{w} \]

**Ratio of the drag of the finite cylinder to the drag of an infinite cylinder (Figure 4.19)**

This calculation takes indirectly the length of the fuselage into account.

\[ \kappa = 0 \text{ 7} \]

\[
\begin{array}{c|c}
\kappa & \eta_{k} \\
\hline
0 & 0.5 \\
2 & 0.56 \\
4 & 0.6 \\
6 & 0.64 \\
8 & 0.67 \\
10 & 0.69 \\
12 & 0.71 \\
14 & 0.725 \\
\end{array}
\]

\[ \text{splinevec}_{\eta} = \text{pspline}(\text{fr}, \eta_{\eta}) \]

\[ \eta_{\text{fus}}(\text{fr}) = \text{interp}(\text{splinevec}_{\eta}, \text{fr}, \eta_{\eta}, \text{fr}) \]

\[ \eta_{\text{fus}} = \text{interp}(\text{splinevec}_{\eta}, \text{fr}, \eta_{\eta}, \text{fr}_{\text{us}}) \]
Experimental steady state cross-flow drag coefficient of a circular cylinder (Figure 4.20)

\[ 1 = 0.9 \]

\[ M_{c,\text{clean}}(\text{mass}, H, v_{\text{CAS}}, d_{\text{ISA}}) = M(H, v_{\text{CAS}}, d_{\text{ISA}}) \cdot \sin(\alpha_{fus,\text{clean}}(\text{mass}, v_{\text{CAS}})) \]

\[ c_{d_{c,\text{clean}}} = \frac{MM_{c}}{\text{MMc}} \]

\[ \text{MM} = 0.01, 0.02, 1 \]

\[ \text{splineveccd} = \text{pspline(MM_{c}, ccd)} \]

\[ c_{d_{c,\text{clean}}}(\text{mass}, H, v_{\text{CAS}}, d_{\text{ISA}}) = \text{interp}(\text{splineveccd}, \text{MM_{c}}, ccd, M_{c,\text{clean}}(\text{mass}, H, v_{\text{CAS}}, d_{\text{ISA}})) \]

Subsonic fuselage drag coefficient due to lift (4.33)

\[ C_{D_{L,\text{fus,\text{clean}}}}(\text{mass}, H, v_{\text{CAS}}, d_{\text{ISA}}) = \frac{2}{\text{S}_{b}} \left( \alpha_{\text{fus,\text{clean}}}(\text{mass}, v_{\text{CAS}}) \right)^2 + \eta_{\text{fus}} \cdot c_{d_{c,\text{clean}}}(\text{mass}, H, v_{\text{CAS}}, d_{\text{ISA}}) \cdot \left( \alpha_{\text{fus,\text{clean}}}(\text{mass}, v_{\text{CAS}}) \right)^3 \cdot \text{S}_{\text{plf,\text{fus}}} \]

Transonic fuselage drag coefficient due to lift (4.39)

\[ C_{D_{L,\text{fus,\text{clean,\text{trans}}}}}(\text{mass}, v_{\text{CAS}}) = \left( \alpha_{\text{fus,\text{clean}}}(\text{mass}, v_{\text{CAS}}) \right)^2 \cdot \frac{S_{b}}{S_{w}} \]
Note: base area was guessed and therefore transonic drag results will not be used. Also, when in doubt, it is common engineering practice to take the more conservative results, which in this case come from the subsonic calculation method.

**Total fuselage drag coefficient (4.3.2)**

\[
C_{D_{fus\_clean}}(mass,H,\text{VCAS},dISA) = C_{D_{0\_fus}}(H,\text{VCAS},dISA) + C_{DL_{fus\_clean\_trans}}(mass,H,\text{VCAS},dISA)
\]
4.8 WINDSHIELD DRAG PREDICTION

4.8.2 Windshield drag prediction

\[ \Delta C_D_{WS} = 0.002 \]  incremental drag coefficient due to windshield / see figure 4.68

\[ C_D_{WS} = \Delta C_D_{WS} \frac{S_{fus}}{S_W} \quad (4.80) \]

Note: Roskam does not offer a method for calculating the transonic windshield drag, therefore the subsonic values will be used as an approximation.
EMPENNAGE AERODYNAMICS [CLEAN]

EMPENNAGE DRAG COEFFICIENT

divided in 2 parts: $c_{D0\_emp}$ empennage zero-lift drag coefficient
$c_{DL\_emp}$ empennage drag coefficient due to lift

$\Lambda_{tail} = 10 \ deg$

$\lambda = \cos(\Lambda_{tail})$

$\lambda = 0.985$

$k = 0.5$

$\cos(\lambda) \_ k = R_{LS0 \ 25} \_ k = R_{LS0 \ 6} \_ k = R_{LS0 \ 8} \_ k = R_{LS0 \ 9} \_ k =$

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<td>$1.34$</td>
</tr>
<tr>
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<td>$1.07$</td>
<td>$1.13$</td>
<td>$1.25$</td>
<td>$1.35$</td>
</tr>
</tbody>
</table>
\[ R_L S(H, v_{CAS}, d_{ISA}) = \begin{cases} 
\text{funRLSO} 25 & \text{if } 0 \leq M(H, v_{CAS}, d_{ISA}) \leq 0.25 \\
\left[ \text{funRLSO} 25 + \frac{M(H, v_{CAS}, d_{ISA}) - 0.25}{0.6 - 0.25} \right] \left[ \text{funRLSO} 6 - \text{funRLSO} 25 \right] & \text{if } 0.25 \leq M(H, v_{CAS}, d_{ISA}) \leq 0.6 \\
\left[ \text{funRLSO} 6 + \frac{M(H, v_{CAS}, d_{ISA}) - 0.6}{0.8 - 0.6} \right] \left[ \text{funRLSO} 8 - \text{funRLSO} 6 \right] & \text{if } 0.6 \leq M(H, v_{CAS}, d_{ISA}) \leq 0.8 \\
\left[ \text{funRLSO} 8 + \frac{M(H, v_{CAS}, d_{ISA}) - 0.8}{0.9 - 0.8} \right] \left[ \text{funRLSO} 9 - \text{funRLSO} 8 \right] & \text{if } 0.8 \leq M(H, v_{CAS}, d_{ISA}) \leq 0.9 
\end{cases} \]
Empennage zero-lift drag coefficient:

\[ R_{LS} \]

lifting surface correction factor (figure 4.2) with the individual empennage surface sweep angle taken from wing / neglecting empennage sweep angle

\[ R_{LS_h}(H, v_{CAS}, \alpha_{SA}) = R_{LS}(H, v_{CAS}, \alpha_{SA}) \]

horizontal tailplane / lifting surface correction factor

\[ R_{LS_v}(H, v_{CAS}, \alpha_{SA}) := R_{LS}(H, v_{CAS}, \alpha_{SA}) \]

vertical tailplane / lifting surface correction factor

Reynolds Number of the horizontal tailplane (4.7)

\[ R_{N_{emp\_h}}(H, v_{CAS}, \alpha_{SA}) := f_\text{Re}(H, v_{CAS}, \alpha_{SA}) \cdot c_{e\_emp\_h} \]

Reynolds Number of the vertical tailplane (4.7)

\[ R_{N_{emp\_v}}(H, v_{CAS}, \alpha_{SA}) := f_\text{Re}(H, v_{CAS}, \alpha_{SA}) \cdot c_{e\_emp\_v} \]
Turbulent flat plate friction coefficient of the empennage surface (figure 4.3) as function of Mach Number and Reynolds Number RN

Horizontal Tailplane:

\[
C_{f_{emp1\_h}}(H, V_{CAS}, dISA) = \frac{0.455}{(\log(R_{N_{emp\_h}}(H, V_{CAS}, dISA)))^{2.58}}
\]

\[
C_{f_{emp2\_h}}(H, V_{CAS}, dISA) = \frac{0.43}{(\log(R_{N_{emp\_h}}(H, V_{CAS}, dISA)))^{2.58}}
\]

\[
C_{f_{emp3\_h}}(H, V_{CAS}, dISA) = C_{f_{emp1\_h}}(H, V_{CAS}, dISA) + \frac{M(H, V_{CAS}, dISA)}{0.9} \left( C_{f_{emp2\_h}}(H, V_{CAS}, dISA) - C_{f_{emp1\_h}}(H, V_{CAS}, dISA) \right)
\]

Roskam dictates the use of the M=0.6 curve for the entire transonic speed range, therefore an if statement is needed.

\[
C_{f_{emp4\_h}}(H, V_{CAS}, dISA) = \begin{cases} 
C_{f_{emp3\_h}}(H, V_{CAS}, dISA) & \text{if } M(H, V_{CAS}, dISA) \leq 0.6 \\
C_{f_{emp1\_h}}(H, V_{CAS}, dISA) + \frac{0.6}{0.9} \left( C_{f_{emp2\_h}}(H, V_{CAS}, dISA) - C_{f_{emp1\_h}}(H, V_{CAS}, dISA) \right) & \text{if } 0.6 < M(H, V_{CAS}, dISA)
\end{cases}
\]

\[
C_{f_{emp\_h}}(H, V_{CAS}, dISA) = C_{f_{emp4\_h}}(H, V_{CAS}, dISA) \frac{S_{w_{emp\_h}}}{S_{w}}
\]
Vertical Tailplane:

\[
C_{f_{emp1,v}}(H, v_{CAS, dISA}) = \frac{0.455}{(\log(R_{N_{emp,v}}(H, v_{CAS, dISA})))^{2.58}}
\]

\[
C_{f_{emp2,v}}(H, v_{CAS, dISA}) = \frac{0.43}{(\log(R_{N_{emp,v}}(H, v_{CAS, dISA})))^{2.58}}
\]

\[
C_{f_{emp3,v}}(H, v_{CAS, dISA}) = C_{f_{emp1,v}}(H, v_{CAS, dISA}) + \frac{M(H, v_{CAS, dISA})}{0.9} \left( C_{f_{emp2,v}}(H, v_{CAS, dISA}) - C_{f_{emp1,v}}(H, v_{CAS, dISA}) \right)
\]

Roskam dictates the use of the \( M=0.6 \) curve for the entire transonic speed range, therefore an if statement is needed.

\[
C_{f_{emp4,v}}(H, v_{CAS, dISA}) = \begin{cases} 
C_{f_{emp3,v}}(H, v_{CAS, dISA}) & \text{if } M(H, v_{CAS, dISA}) \leq 0.6 \\
C_{f_{emp1,v}}(H, v_{CAS, dISA}) + \frac{0.6}{0.9} \left( C_{f_{emp2,v}}(H, v_{CAS, dISA}) - C_{f_{emp1,v}}(H, v_{CAS, dISA}) \right) & \text{if } 0.6 \leq M(H, v_{CAS, dISA})
\end{cases}
\]

\[
C_{f_{emp,v}}(H, v_{CAS, dISA}) = C_{f_{emp4,v}}(H, v_{CAS, dISA}) \frac{S_{wet_{emp,v}}}{S_w}
\]
EMPENNAGE ZERO LIFT DRAG without Wave Drag

\[
C_{D0\_emp\_h}(H, v_{CAS}, d_{lSA}) = R_{LS\_h}(H, v_{CAS}, d_{lSA}) C_{t\_emp\_h}(H, v_{CAS}, d_{lSA}) \left[ 1 + L_{h} \left( \frac{t_{h}}{c_{emp\_e\_h}} \right) + 100 \left( \frac{t_{h}}{c_{emp\_e\_h}} \right)^{4} \right] \frac{S_{wet\_emp\_h}}{S_{w}}
\]

\[
C_{D0\_emp\_v\_prelim}(H, v_{CAS}, d_{lSA}) = R_{LS\_v}(H, v_{CAS}, d_{lSA}) C_{t\_emp\_v}(H, v_{CAS}, d_{lSA}) \left[ 1 + L_{v} \left( \frac{t_{v}}{c_{emp\_e\_v}} \right) + 100 \left( \frac{t_{v}}{c_{emp\_e\_v}} \right)^{4} \right] \frac{S_{wet\_emp\_v}}{S_{w}}
\]

Empennage zero lift wave drag coefficient / Assumption: unswept wing

Horizontal Tailplane:

Page 34, Chapter 4: Figure 4.11 is reproduced with running variables x and y and interpolated with Mach number.

tc\_ratio = 0.13

\[
\text{tc\_ratio} = 0.13
\]

\[
\Lambda_{h} \text{ tc\_ratio}^{3} = 2.456
\]

\[
\text{figure411\_h}(H, v_{CAS}, d_{lSA}) = \frac{1}{\text{tc\_ratio}^{3}} \left[ M(H, v_{CAS}, d_{lSA})^{2} - 1 \right]
\]
\begin{align*}
i = 0 \quad & 10 \\
x_{i,h} &= \begin{array}{c|c|c|c|c|c|c|c|c|c|c}
0 & 3.3 \\
0.2 & 3.275 \\
0.4 & 3.25 \\
0.6 & 3.13 \\
0.8 & 2.5 \\
1 & 1.25 \\
1.2 & 0.45 \\
1.4 & 0.1 \\
1.6 & 0 \\
1.8 & 0 \\
2.0 & 0 \\
\end{array} \\
\text{Note: this are the coordinates of the curve for (Aspect Ratio \times t/c) values of 2.0. For result deviations of more than +/- 0.5, different curves from Figure 4.11, page 35, should be used.}
\end{align*}

\begin{align*}
\text{wave}1_{h} &= \text{pspline}(x_{h}, y_{h}) \\
\text{wave}2_{h}(H, v_{CAS}, dISA) &= \text{interp}(\text{wave}1_{h}, x_{h}, y_{h}, \text{figure}411_{h}(H, v_{CAS}, dISA)) \\
\text{wave}3_{h}(H, v_{CAS}, dISA) &= \frac{5}{3} \text{wave}2_{h}(H, v_{CAS}, dISA) \times \text{tc_ratio}^3 \\
\text{wave}3_{h}(25000 \text{ ft}, 350 \text{ kts}, 0\text{k}) &= 0.046
\end{align*}
\[ y_h \text{, wave}_2_h(25000\text{ft}, \text{VCAS, OK}) \]

\[ x_h, \text{figure}_411_h(25000\text{ft}, \text{VCAS, OK}) \]

\[ \text{CD}_0_{\text{emp}}_h(25000\text{ft}, \text{VCAS, OK}) \]

\[ \text{wave}_3_h(25000\text{ft}, \text{VCAS, OK}) \]

\[ \text{VCAS} \text{ kts} \]
Vertical Tailplane:

Page 34, Chapter 4: Figure 4.11 is reproduced with running variables x and y and interpolated with Mach number.

tc_ratio = 0.13

\[ \frac{1}{\Lambda_v \ tc_ratio^3} = 0.523 \]

\[ J_{M(H,VCAS,dlSA)} = \frac{\sqrt{\left[M(H,VCAS,dlSA)\right]^2 - 1}}{1 - \frac{1}{tc_ratio^3}} \]

\( i = 0 \ldots 10 \)

\[ (x_v)_i = y_v_i = \]

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<th>y_v</th>
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</thead>
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</tbody>
</table>

Note: this are the coordinates of the curve for (Aspect Ratio * t/c) values of 0.5. For result deviations of more than +/- 0.25, different curves from Figure 4.11, page 35, should be used.
wave1_v := pspline(x_v, y_v)

\[
\text{wave2}_v(H, v_{CAS}, dISA) := \text{interp}(\text{wave1}_v, x_v, y_v, \text{figure411}_v(H, v_{CAS}, dISA))
\]

\[
\text{wave3}_v(H, v_{CAS}, dISA) := \text{wave2}_v(H, v_{CAS}, dISA) \cdot \text{tc\_ratio}^\frac{5}{3}
\]

wave3_v(25000 ft, 350 kts, 0K) = 0.009

It is doubtful if the zero lift coefficient of the vertical tail should have higher values at low speeds than at higher ones. It appears as if this calculation method binds the angle of attack into the vertical tail calculation, which is incorrect. For that reason, an if statement is built in and its curve shown in the graph below.
\[ C_{D0\_emp\_v}(H,v_{CAS},dISA) = \begin{cases} C_{D0\_emp\_v\_prelim}(H,v_{CAS},dISA) & \text{if } 250 \text{ kts} \leq v_{CAS} \\ C_{D0\_emp\_v\_prelim}(H,250 \text{ kts},dISA) & \text{if } v_{CAS} \leq 250 \text{ kts} \end{cases} \]
Total Zero Lift Drag Coefficient

\[
C_{D0\_emp}(H, v_{CAS}, dISA) = C_{D0\_emp\_h}(H, v_{CAS}, dISA) + \text{wave}_3\_h(H, v_{CAS}, dISA) + C_{D0\_emp\_v}(H, v_{CAS}, dISA) + \text{wave}_3\_v(H, v_{CAS}, dISA)
\]

Note: it is strange that the zero lift drag coefficient decreases with altitude. This is due to the Roskam's wave drag dependency on the Mach Number, which rises with altitude. The results will be kept as they are, since high speed flight at low altitude is not one of the important and useful performance parameters. That scenario's results, however, will be overpredicted and this should be kept in mind.
EMPENNAGE DRAG DUE TO LIFT (INCLUDING REQUIRED TRIM LIFT)

Page 37, Chapter 4: Figure 4.13a, graph 3 is reproduced with running variables xy_h and z_h and interpolated with Mach number.

\[
\text{figure413}_h(H, v_{CAS}, d_{lSA}) = \frac{M(H, v_{CAS}, d_{lSA})^2 - 1}{2} \\
\frac{1}{tc\_ratio^3}
\]

\(i = 0\) \(12\)

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\[ \text{lift1}_h := \text{pspline}(xy_h, z_h) \]

\[ \text{lift2}_h(H, v_{CAS}, dISA) := \text{interp}(\text{lift1}_h, xy_h, z_h, \text{figure413}_h(H, v_{CAS}, dISA)) \]

\[ \text{lift3}_h(H, v_{CAS}, dISA) := \frac{\text{lift2}_h(H, v_{CAS}, dISA)}{\left(-\frac{1}{3}\right)^{\frac{1}{3} \cdot \text{tc\_ratio}}} \]

\[ \text{lift3}_h(25000 \cdot ft, 350 \cdot kts, 0K) = 0.166 \]
Two different calculation methods are necessary, one for the subsonic and one for transonic speed range.

Subsonic speed range:

\[ CDL_{\text{emp},\text{clean}}(\text{mass}, \text{VCAS}) = \frac{C_{\text{Lh, clean}}(\text{VCAS, mass})^2}{\pi \Lambda_h \epsilon_h} \frac{S_h}{S_w} \]

Transonic speed range:

\[ CDL_{\text{emp},\text{clean}2}(H, \text{mass}, \text{VCAS, dISA}) = C_{\text{Lh, clean}}(\text{VCAS, mass})^2 \text{ lift3}(H, \text{VCAS, dISA}) \]

Interpolation of calculation methods

\[ CDL_{\text{emp},\text{clean}3}(H, \text{mass}, \text{VCAS, dISA}) = \begin{cases} CDL_{\text{emp},\text{clean}}(\text{mass, VCAS}) & \text{if } 0 \leq M(H, \text{VCAS, dISA}) \leq 0.3 \\ CDL_{\text{emp},\text{clean}}(\text{mass, VCAS}) + \frac{M(H, \text{VCAS, dISA}) - 0.3}{0.8 - 0.3} (CDL_{\text{emp},\text{clean}2}(H, \text{mass, VCAS, dISA}) - CDL_{\text{emp},\text{clean}}(\text{mass, VCAS})) & \text{if } 0.3 < M(H, \text{VCAS, dISA}) \leq \text{cutoff} \end{cases} \]
TOTAL EMPENNAGE DRAG

\[ \text{CDL}_{\text{emp clean}}(2000\text{ kg}, \text{VCAS}) \]

\[ \text{CDL}_{\text{emp clean}}(25000\text{ ft}, 2000\text{ kg}, \text{VCAS}, 0\text{K}) \]

\[ \text{CDL}_{\text{emp clean}}(25000\text{ ft}, 2000\text{ kg}, \text{VCAS}, 0\text{K}) \]

\[ \text{TOTAL EMPENNAGE DRAG} \]

\[ \text{CD}_{\text{emp clean}}(H, \text{VCAS}, \text{mass}, \text{dISA}) = \text{CD}_0_{\text{emp}}(H, \text{VCAS}, \text{dISA}) + \text{CDL}_{\text{emp clean3}}(H, \text{mass}, \text{VCAS}, \text{dISA}) \]

\[ \text{EMPENNAGE AERODYNAMICS [CLEAN]} \]
4.5 INLET DRAG COEFFICIENT PREDICTION

4.5.1. Isolated Inlet Drag Coefficient Increment (Interference)

Note: Inlets are integrated in the fuselage and are positioned left and right just before the root of the wing. This makes it difficult to treat it as two isolated bodies, since only a part of their skin is exposed to the freestream. Hence, they will be treated as one body that is formed when the two inlets are connected to each other instead of to the fuselage.

Reynolds Number of the inlet (4.31)

\[ R_{n} (H, v_{CAS}, d_{ISA}) = f_{Re}(H, v_{CAS}, d_{ISA}) \ln \]

Turbulent flat plate skin friction coefficient of the inlet (figure 4.3) as a function of Reynolds Number

\[ C_{f,n}(H, v_{CAS}, d_{ISA}) = \frac{0.455}{(\log(R_{n}(H, v_{CAS}, d_{ISA})))^{2.58}} \]

\[ C_{f,n2}(H, v_{CAS}, d_{ISA}) = \frac{0.43}{(\log(R_{n}(H, v_{CAS}, d_{ISA})))^{2.58}} \]

\[ C_{f,n3}(H, v_{CAS}, d_{ISA}) = C_{f,n}(H, v_{CAS}, d_{ISA}) + \frac{M(H, v_{CAS}, d_{ISA})}{0.9} \left( C_{f,n2}(H, v_{CAS}, d_{ISA}) - C_{f,n}(H, v_{CAS}, d_{ISA}) \right) \]
Roskam dictates the use of the $M=0.6$ curve for the entire transonic speed range, therefore an if statement is needed:

$$C_{f_{n4}}(H, v_{CAS}, dISA) = \begin{cases} C_{f_{n3}}(H, v_{CAS}, dISA) & \text{if } M(H, v_{CAS}, dISA) \leq 0.6 \\ C_{f_{n4}}(H, v_{CAS}, dISA) + \frac{6}{0.9} \left( C_{f_{n2}}(H, v_{CAS}, dISA) - C_{f_{n4}}(H, v_{CAS}, dISA) \right) & \text{if } 0.6 < M(H, v_{CAS}, dISA) \end{cases}$$

$$C_{df_{n}}(H, v_{CAS}, dISA) = C_{f_{n4}}(H, v_{CAS}, dISA) \frac{S_{wet_{n}}}{S_{w}}$$

**Inlet pressure drag coefficient**

Note that similarly to the previous section, the curve $M=0.6$ is used for the transonic speed range:

$$C_{dp_{n}}(H, v_{CAS}, dISA) = C_{f_{n4}}(H, v_{CAS}, dISA) \left[ \frac{60}{(\frac{L_n}{d_n})^3} + 0.0025 \left( \frac{L_n}{d_n} \right) \right] \frac{S_{wet_{n}}}{S_{w}}$$

It is not clear if only a fraction of this drag should be used because of the airflow through the turbine.

**Inlet base drag coefficient**

Inlet base area was already included in the base area of the fuselage.

**Inlet wave drag coefficient**

Note Figure 4.22 shows that the wave drag in this case becomes significant only after $M=0.99$ and will therefore be neglected.
Total inlet zero lift coefficient (4.30)

\[ C_{D0,n}(H, v_{CAS}, dISA) = C_{df,n}(H, v_{CAS}, dISA) + C_{dp,n}(H, v_{CAS}, dISA) \]
EMPENNAGE DRAG DUE TO LIFT

**Inlet angle of attack in radians** (set equal to the wing angle of attack)

Inlet angle of attack can be estimated as follows

\[ \alpha_n = \alpha_w + i_n + \epsilon_n \]

- \( \alpha_w \) wing angle of attack
- \( i_n \) inlet incidence angle (see figure 4 35)
- \( \epsilon_n \) inlet upwash angle (depends on position / see figure 4 36)

\[ \alpha_n\_clean(\text{mass, } \nu\text{CAS}) = \alpha_w\_clean(\text{mass, } \nu\text{CAS}) \]
Ratio of the drag of the finite cylinder to the drag of an infinite cylinder (Figure 4.19)

\[ k = 0.7 \]

\[ f_{fr_k} := \eta \eta_k := \]

\begin{tabular}{|c|c|}
\hline
0 & 0.5 \\
2 & 0.56 \\
4 & 0.6 \\
6 & 0.64 \\
8 & 0.67 \\
10 & 0.69 \\
12 & 0.71 \\
14 & 0.725 \\
\hline
\end{tabular}

\[ f_r := 0..15 \]

\[ \text{splinevecn} := \text{pspline}(fr, \eta \eta) \]

\[ \eta n2(fr) := \text{interp}(\text{splinevecn}, fr, \eta \eta, fr) \]

\[ \eta n := \text{interp}(\text{splinevecn}, fr, \eta \eta, frn) \]
Experimental steady state cross-flow drag coefficient of a circular cylinder (Figure 4.20)

\[ \alpha_n \text{_clean}(\text{mass, VCAS}) \]

\[ \text{ccd, MMc} \]

\[ \cd_{\text{cn,clean}}(\text{mass, H, VCAS, dlSA}) := \text{splineveccd}(\text{MMc, ccd}) \]

\[ \cd_{\text{cn,clean}}(\text{mass, H, VCAS, dlSA}) := \text{interp}(\text{splineveccd, MMc, ccd, MCn_clean(mass, H, VCAS, dlSA)}) \]

Subsonic inlet drag coefficient due to lift (4.33)

\[ C_{DL \_n \_clean}(\text{mass, H, VCAS, dlSA}) := \eta_n \cdot \cd_{\text{cn,clean}}(\text{mass, H, VCAS, dlSA}) \cdot (\alpha_n \text{_clean}(\text{mass, VCAS}))^3 \cdot S_{Plf \_n} \]
Transonic fuselage drag coefficient due to lift (4.39)

\[ CD_{L\_n\_clean\_trans}(mass, v_{CAS}) = \left( \alpha_{n\_clean}(mass, v_{CAS}) \right)^2 \cdot \frac{S_b}{S_w} \]

Note: There is no inlet base area, and therefore Roskam's transonic drag coefficient due to lift cannot be used. Nevertheless, an experiment is shown above where the base area of the fuselage was taken and the transonic drag calculated. It is clearly evident that the deviations between the two curves are minimal, and therefore subsonic drag estimation will be used for all speed ranges.
4.5.2 Installed Nacelle Drag Coefficient Increment

NOTE:
This method provides the "interference" drag increment due to nacelle installations.

4.5.2.2 Fuselage/nacelle interference drag coefficient

Note: $C_{dn'}$ was found from Figure 4.42 for $C_l = 0$ and $F_a^2$ was selected for the case of no local area ruling.

$$C_{dn} = 0.075$$

$$F_a^2 = 1$$

$$C_{D_{n_{int}}} = F_a^2 \left( C_{dn} - 0.05 \right) \left( \frac{S_{plf_{n}}}{S_w} \right)$$

$$C_{D_{n_{int}}} = 0.003$$

4.5.2.3 Cooling drag coefficient increment

At this point, it is not clear by which means the engine is being cooled. In absence of better methods, Roskam's approach for propeller engines is used.

$$C_{D_{n_{cool}}} = 1 \left( \frac{S_{cooling}}{S_w} \right)$$

Total inlet drag coefficient (4.29)

$$C_{D_{n_{clean}}}(mass, H, v_{CAS}, dISA) = C_{D_{n_{int}}} + C_{D_{L_{n_{clean}}}}(mass, H, v_{CAS}, dISA) + C_{D_{0_{n}}}(H, v_{CAS}, dISA) + C_{D_{n_{cool}}}$$

INLET AERODYNAMICS [CLEAN]
APPENDIX D

NUMERICAL AIRCRAFT FLIGHT PERFORMANCE ESTIMATION METHOD
D-JET FLIGHT PERFORMANCE ESTIMATION

2. Part of Graduate Thesis by Igor Lebovic, Embry-Riddle Aeronautical University
"Numerical and Experimental Flight Performance Estimation Methods"

Input:

- **WING DATA**

  - \( \Delta_0 S_{c_w} = 0 \) deg : semi-chord sweep angle
  - \( i_w = -3 \) deg : wing incidence angle / negative for up
  - \( l_{\mu_w} = 1.35 \) m : mean aerodynamic chord
  - \( S_w = 15.8 \) \( m^2 \) : wing reference area
  - \( b_w = 11.8 \) m : wing span
  - \( S_{wfl} = 10 \) \( m^2 \) : flapped wing area

- **WING DATA**
FUSELAGE DATA

$l_{fus} = 8.510 \text{ m}$

$S_{wet\_fus} = 15 \text{ m}^2$  wetted area of the fuselage

$S_{plf\_fus} = 5 \text{ m}^2$  fuselage planform area - guestimation

$S_{fus} = 1378690.58 \text{ mm}^2$  projected frontal area of the fuselage / from CAD drawing

$S_b = 0.2 \text{ m}^2$  base area, flat base at the end of the fuselage
EMPENNAGE DATA

HORIZONTAL TAIL

ε₀ₙ = 0.75  

S₀ₙ = 3.8 m²  

b₀ₙ = 3.9 m  

l₀ₙ = 766.7 mm  

xₙ₀ₙ = 7.372 m  

th = 128 mm  

tipchordₙ = 0.4268 m  

τₙ = 1  

0.75 for T-Tails (Roskam 4.4.12, P 69)

horizontal tailplane surface (reference) Area

span of horizontal tail

mean aerodynamic chord of horizontal tail

guestimation

Airfoil thickness location parameter (figure 4.4) using the maximum thickness location associated with the horizontal / vertical tailplane airfoil

rough guestimation
VERTICAL TAIL

\[ S_v = 2.8 \text{ m}^2 \]

vertical tailplane surface (reference) Area

\[ b_v = 1.9 \text{ m} \]

span of vertical tail

\[ l_{\mu,v} = 1.855 \text{ m} \]

mean aerodynamic chord of vertical tail

\[ x_{vNP} = 6.721 \text{ m} \]

position of ac pf vertical tail

\[ t_v = 148 \text{ mm} \]

thickness

\[ \text{tipchord}_v = 945 \text{ mm} \]

\[ \text{rootchord}_v = 1.8 \text{ m} \]

\[ \tau_v = 1 \]

thickness ratio / ratio from root to tip (1 = constant ratio over span)

\[ L_v = 1.2 \]

EMPENNAGE DATA
TRIM DATA

\[ X_{NPF} = 2380 \text{mm} \] guestimation (equal to \( x_{NPF} \))

\[ X_{CG} = 2350 \text{mm} \] guestimation

\[ C_{MOh} = 0 \] guess

\[ 2194 + 156 = 2350 \] max FWD CG

\[ 2194 + 303 = 2497 \] max AFT CG

\[ c_{m0\_clean} = -0.0655 \]

\[ c_{m0\_clean} = \frac{-0.001844}{\text{deg}} \]
CONSTANTS, UNITS & STANDARD ATMOSPHERE

US unit system active

\[ J = \text{joule} \quad W = \text{watt} \quad \text{kts} = 1.852 \text{ kph} \quad \text{RPM} = \text{min}^{-1} \]

\[ H = 0 \text{ ft}, 500 \text{ ft}, 35000 \text{ ft} \quad V_{\text{CAS}} = 5 \text{ kts}, 10 \text{ kts}, 360 \text{ kts} \]

\[ \text{mass} = 1800 \text{ kg}, 1850 \text{ kg}, 2200 \text{ kg} \]

\[ \text{mass} = 2000 \text{ kg} \]

INTERNATIONAL STANDARD ATMOSPHERE (ISA)

DIN ISO 2533

\[ \rho_0 = 1.225 \frac{\text{kg}}{\text{m}^3} \quad p_0 = 101325 \text{ Pa} \quad T_0 = 288.15 \text{ K} \quad \gamma_H = -0.0065 \frac{\text{K}}{\text{m}} \]

\[ R = 287.05287 \frac{\text{J}}{\text{kg} \times \text{K}} \]

\[ \rho(H) = \rho_0 \left(1 + \gamma_H \frac{H}{T_0} \right)^{-rac{\gamma_H R}{g}} \]
\[ \text{dISA} = -30 \text{ K}, 0 \text{ K}, 30 \text{ K} \quad \text{ISA deviation} \]

\[ \text{dISA} = 0 \text{ K} \]

\[ T_{\text{ISA}}(H, \text{dISA}) = T_0 + \text{dISA} + \gamma H \cdot H \]

\[ \rho(H, \text{dISA}) = \frac{\rho(H)}{R \cdot T_{\text{ISA}}(H, \text{dISA})} \]

![Graph 1](image1.png)

![Graph 2](image2.png)
TRUE AIRSPEED

\[ v_{\text{TAS}}(H, v_{\text{CAS}}, d\text{ISA}) = v_{\text{CAS}} \sqrt{\frac{\rho_0}{\rho(H, d\text{ISA})}} \]

\[ v_{\text{TAS}}(H,150\text{ kts},0K) \]

\[ \text{kts} \]
VELOCITY OF SOUND / MACH NUMBER

\[ \kappa := 1.4 \]

\[ a(H, \text{dISA}) := \sqrt{\kappa \cdot R \cdot T_{\text{ISA}}(H, \text{dISA})} \]

\[ M(H, \text{V CAS}, \text{dISA}) := \frac{\text{V TAS}(H, \text{V CAS}, \text{dISA})}{a(H, \text{dISA})} \]
REYNOLDS FACTOR

For calculation of local Re-Numbers multiply the factor with the specific length

Interpolation of absolute viscosity (taken from Schlichting/Truckenbrot)

\[ i = 0.6 \]

\[ T_1 = \mu_1 = \]

\[
\begin{array}{|c|c|}
\hline
-20 & 15.6 \\
-10 & 16.2 \\
0 & 16.8 \\
10 & 17.4 \\
20 & 17.9 \\
40 & 19.1 \\
60 & 20.3 \\
\hline
\end{array}
\]

\[ T_2 = \left( T_1 + 273.15 \right) K \quad \mu_2 = \mu_1 \times 10^{-6} \frac{kg}{m \cdot sec} \]

\[
\begin{array}{|c|c|c|}
\hline
T_2 & \mu_2 & \frac{kg}{m^3} \\
253.15 & 0 & \frac{2}{ft \cdot sec^{-1}} \\
263.15 & 0 & \frac{1}{m^3} \\
273.15 & 0 & \frac{2}{ft \cdot sec^{-1}} \\
283.15 & 0 & \frac{1}{m^3} \\
293.15 & 0 & \frac{2}{ft \cdot sec^{-1}} \\
313.15 & 0 & \frac{1}{m^3} \\
333.15 & 0 & \frac{2}{ft \cdot sec^{-1}} \\
\hline
\end{array}
\]

Absolute viscosity

\[
splinevec{\mu} = \text{spline}(T_2, \mu_2)
\]

\[
\mu(H, d\text{ISA}) = \text{interp}(\text{splinevec}{\mu}, T_2, \mu_2, T_{\text{ISA}}(H, d\text{ISA}))
\]
\( \mu(0 \cdot \text{ft}, 0 \cdot \text{k}) = 0 \text{lbft}^{-1} \text{sec}^{-1} \)

**Reynolds factor**

\[
\text{Re}(H, v_{CAS}, dISA) = \frac{\rho(H, dISA) \cdot v_{TAS}(H, v_{CAS}, dISA)}{\mu(H, dISA)}
\]
Prandtl-Glauert Trafo

\[ \beta(H, v_{\text{CAS}}, d\text{ISA}) := \left(1 - M(H, v_{\text{CAS}}, d\text{ISA})^2\right)^{0.5} \]

\[ \beta(H, 100 \text{ kts}, 0 \text{K}) \]

\[ 0.94 \quad 0.96 \quad 0.98 \quad 1 \]

\[ 0 \quad 2 \cdot 10^4 \quad 4 \cdot 10^4 \]

\[ H \quad \text{ft} \]

[CONSTANTS, UNITS & ATMOSPHERE]
Power lever angle settings: 90 degrees for take off up to speeds of M=0.38, 72 degrees for maximum continuous power, and 19 degrees for idle setting.

### SEA LEVEL // 100 % MAX CONTINUOUS / PLA 72°

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<td>0.998</td>
<td>109.02</td>
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*(Power_Lever_Angle Altitude_Feet Power_Mode Temperature_Deviation)*
<table>
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<tr>
<th>Thrust_row</th>
<th>Speed_row</th>
<th>Fuel_row</th>
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<tr>
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</tr>
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</table>

Thrust<sub>SL</sub> := Thrust<sub>row</sub> • lbf

Speed<sub>SL</sub> := Speed<sub>row</sub> • kts

Fuel<sub>SL</sub> := Fuel<sub>row</sub> • hr

Thrust<sub>SL</sub> = 100 200

Speed<sub>SL</sub> = 300

Fuel<sub>SL</sub> = 282
\[
\begin{align*}
  i &= 0.9 \\
  \text{Thrust}_{SL} &= \begin{bmatrix} 1378.9 & 1265.5 & 1161 & 1062.1 & 977.4 & 903.6 & 878.9 & 878.9 & 878.9 \end{bmatrix} \text{ lbf} \\
  \text{Speed}_{SL} &= \begin{bmatrix} 0 & 66.1 & 132.3 & 198.4 & 264.6 & 330.7 & 355.4 & 355.4 & 355.4 \end{bmatrix} \text{ kts} \\
  \text{Power}_{SL} &= \text{Thrust}_{SL} \cdot \text{vtas}(0, \text{Speed}_{SL}, \text{dISA}) \\
  \text{Power}_{SL} &= \begin{bmatrix} 0 & 191418.147 & 351488.859 & 482199.301 & 591809.148 & 683801.292 & 714786.576 & 714786.576 & 714786.576 \end{bmatrix} \text{ watt} \
\end{align*}
\]
SEA LEVEL // 80 % MAX CONTINUOUS / PLA 62.4°

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<th>Outputs</th>
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<td>Power_Mode = 17</td>
<td>Temperature_Deviation = 0</td>
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<table>
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<td>TA</td>
<td>3</td>
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<tr>
<td>Iterations</td>
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</tr>
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<td>Thrust_row</td>
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<td>Speed_row</td>
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*(Power_Lever_Angle Altitude_Feet Power_Mode Temperature_Deviation)*
Thrust_row =

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<th>9</th>
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<tbody>
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<td>934.5</td>
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<td>783.4</td>
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Speed_row =

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<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>66.1</td>
<td>132.3</td>
<td>198.4</td>
<td>264.6</td>
<td>330.7</td>
<td>355.4</td>
<td>355.4</td>
<td>355.4</td>
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Fuel_row =

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<th>4</th>
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<tbody>
<tr>
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<td>661.04</td>
<td>662.88</td>
<td>662.88</td>
<td>662.88</td>
<td>662.88</td>
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</table>

Thrust_SL_80MCP := Thrust_row \cdot \text{lbf}

Speed_SL_80MCP := Speed_row \cdot \text{kts}

Fuel_SL_80MCP := Fuel_row \cdot \text{hr}
\[
\text{Power}_{\text{SL} \_80\text{MCP}} = \text{Power}_{\text{SL} \_80\text{MCP}} \cdot \text{VTAS}(0 \cdot \text{ft}, \text{Speed}_{\text{SL} \_80\text{MCP}}, \text{dISA})
\]

\[
\begin{array}{c|c|c}
\text{Thrust}_{\text{SL} \_80\text{MCP}} & \text{Speed}_{\text{SL} \_80\text{MCP}} & \text{Power}_{\text{SL} \_80\text{MCP}} \\
\hline
1235 & 0 & 0 \\
1127.1 & 66.1 & 170483.915 \\
1028.2 & 132.3 & 311284.104 \\
934.5 & 198.4 & 424268.192 \\
853.3 & 264.6 & 516667.43 \\
783.4 & 330.7 & 592839.677 \\
760.5 & 355.4 & 618494.927 \\
760.5 & 355.4 & 618494.927 \\
760.5 & 355.4 & 618494.927 \\
760.5 & 355.4 & 618494.927 \\
\end{array}
\]
SEA LEVEL // 60 % MAX CONTINUOUS / PLA 52.8°

Power_Lever_Angle = 52.8
Altitude_Feet = 0 ft
Power_Mode = 17
Temperature_Deviation = 0

<table>
<thead>
<tr>
<th>Case</th>
<th>XMN</th>
<th>ALT</th>
<th>PA</th>
<th>TA</th>
<th>Iterations</th>
<th>Power Mode</th>
<th>Temperature_Deviation</th>
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<td>0.2</td>
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<td>518.69</td>
<td>0.998</td>
<td>18400</td>
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<td>518.69</td>
<td>0.998</td>
<td>18400</td>
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<tr>
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<td>518.69</td>
<td>0.998</td>
<td>18400</td>
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<td>518.69</td>
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<td>18400</td>
<td>109.02</td>
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NOTICE

Valid for (Power_Lever_Angle Altitude_Feet Power_Mode Temperature_Deviation)
### Thrust and Speed Tables

<table>
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<th>Speed</th>
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<th>Fuel</th>
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<td>355.4</td>
</tr>
</tbody>
</table>

### Thrust SL 60MCP

\[ \text{Thrust SL 60MCP} = \text{Thrust row}^T \cdot \text{Ibf} \]

### Speed SL 60MCP

\[ \text{Speed SL 60MCP} = \text{Speed row}^T \cdot \text{kts} \]

### Fuel SL 60MCP

\[ \text{Fuel SL 60MCP} = \text{Fuel row} \cdot \text{T lb/hr} \]
\( i = 0.9 \)

\[
\text{Thrust}_{\text{SL\_60MCP}} = \text{Speed}_{\text{SL\_60MCP}} =
\begin{array}{c|c|c}
1002.4 & \text{lb} & 0 \\
903.5 & 66.1 & \\
814.5 & 132.3 & \\
731 & 198.4 & \\
658.9 & 264.6 & \\
594.3 & 330.7 & \\
571.2 & 355.4 & \\
571.2 & 355.4 & \\
571.2 & 355.4 & \\
571.2 & 355.4 & \\
\end{array}
\]

\[
\text{Power}_{\text{SL\_60MCP}} = \text{Thrust}_{\text{SL\_60MCP}} \cdot \text{V}_{\text{TAS}}(0\cdot \text{ft}, \text{Speed}_{\text{SL\_60MCP}}, \text{dISA})
\]

\[
\text{Power}_{\text{SL\_60MCP}} = \begin{cases} \text{watt} \\
136662.423 \\
246587.145 \\
331878.061 \\
398959.533 \\
449737.835 \\
464542.146 \\
464542.146 \\
464542.146 \\
\end{cases}
\]

\[
\text{Power}_{\text{SL\_60MCP}} \quad \text{watt}
\]

\[
\text{Speed}_{\text{SL\_60MCP}} \quad \text{kts}
\]

\[
\begin{array}{c}
0 \\
100 \\
200 \\
300 \\
\end{array}
\]

\[
\begin{array}{c}
2 \times 10^5 \\
4 \times 10^5 \\
6 \times 10^5 \\
\end{array}
\]

\[
\text{Speed}_{\text{SL\_60MCP}} \quad \text{kts}
\]

\[
\begin{array}{c}
0 \\
100 \\
200 \\
300 \\
\end{array}
\]

\[
\begin{array}{c}
0 \\
2 \times 10^5 \\
4 \times 10^5 \\
6 \times 10^5 \\
\end{array}
\]

289
10,000 ft // 100 % MAX CONTINOUS / PLA 72°

<table>
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(Power_Lever_Angle Altitude_Feet Power_Mode Temperature_Deviation)
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<td>626.99</td>
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<td>629.91</td>
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</table>

\[ \text{Thrust}_{100} = \text{Thrust}_{\text{row}} \cdot \text{Ibf} \]

\[ \text{Speed}_{100} = \text{Speed}_{\text{row}} \cdot \text{kts} \]

\[ \text{Fuel}_{100} = \text{Fuel}_{\text{row}} \cdot \text{lb/hr} \]
\( i = 0.9 \)

\[
\begin{array}{c|c|c}
\text{Thrust}_{100} & \text{Speed}_{100} & \text{Power}_{100} \\
\hline
1166.1 & 0 & 0 \\
1082.4 & 54.9 & 158237.214 \\
1006.6 & 109.9 & 294579.905 \\
936.6 & 165.1 & 411765.282 \\
878.1 & 220.7 & 516053.597 \\
821.1 & 276.8 & 605216.329 \\
772.2 & 333.4 & 685557.509 \\
756.6 & 355.1 & 715427.3 \\
756.6 & 355.1 & 715427.3 \\
756.6 & 355.1 & 715427.3 \\
\end{array}
\]

\( \text{Power}_{100} = \text{Thrust}_{100} \cdot \text{V TAS}(10000 \text{ ft}, \text{Speed}_{100}, \text{dISA}) \)
10.000 ft // 80 % MAX CONTINOUS / PLA 62,4°

### Power_LEver_Angle = 62.4  Altitude_Feet = 10000 ft  Power_Mode = 17  Temperature_Deviation = 0

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<th>Fuel_row</th>
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#### INPUTS

| XMN | 62.4 | ALT | 10000 | PA | 17 | TA | 0 | Iterations | 15 |

#### OUTPUTS

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(Power_LEver_Angle  Altitude_Feet  Power_Mode  Temperature_Deviation)

293
Thrust row =

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Fuel row =

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Thrust\_100\_80MCP := Thrust\_row^T \cdot \text{Ibf}

Speed\_100\_80MCP := Speed\_row^T \cdot \text{kts}

Fuel\_100\_80MCP := Fuel\_row^T \cdot \frac{\text{lb}}{\text{hr}}
\( i := 0.9 \)

\[
\begin{array}{|c|c|c|}
\hline
\text{Thrust}_{100\_80MCP_i} & \text{Speed}_{100\_80MCP_i} & \text{Power}_{100\_80MCP_i} \\
\hline
1035.6 & 0 & 0 \\
956.2 & 54.9 & 139787.901 \\
884.3 & 109.9 & 258789.003 \\
817.1 & 165.1 & 359228.498 \\
761.4 & 220.7 & 447469.774 \\
710.8 & 276.8 & 523916.413 \\
666.8 & 333.4 & 591983.614 \\
652.5 & 355.1 & 616992.22 \\
652.5 & 355.1 & 616992.22 \\
652.5 & 355.1 & 616992.22 \\
\hline
\end{array}
\]

\[ \text{Power}_{100\_80MCP_i} = \text{Thrust}_{100\_80MCP_i} \times \text{VTAS}(10000 \text{ ft}, \text{Speed}_{100\_80MCP_i}, \text{dISA}) \]
Power_Lever_Angle = 52.8

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**OUTPUTS**

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(Power_Lever_Angle Altitude_Feet Power_Mode Temperature_Deviation)
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**Thrust_row**

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**Thrust_100_60MCP := Thrust_row^T . lbf**

**Speed_100_60MCP := Speed_row^T . kts**

**Fuel_100_60MCP := Fuel_row^T . lb/hr**
\[
i = 0.9
\]

Thrust_{100\_60MCP_i} = Speed_{100\_60MCP_i} =

\begin{array}{c|c}
\text{lb} & \text{kts} \\
832.1 & 0 \\
759.4 & 54.9 \\
693.3 & 109.9 \\
631.6 & 165.1 \\
579.4 & 220.7 \\
531.5 & 276.8 \\
493.5 & 333.4 \\
481 & 355.1 \\
481 & 355.1 \\
481 & 355.1 \\
\end{array}

Power_{100\_60MCP_i} = \text{Thrust}_{100\_60MCP_i} \cdot \text{VTAS}(10000 \text{ ft, Speed}_{100\_60MCP_i}, \text{dISA})

Power_{100\_60MCP_i} =

\begin{array}{c}
0 \\
111017.498 \\
202893.153 \\
277675.584 \\
340509.571 \\
391757.982 \\
438128.245 \\
454824.916 \\
454824.916 \\
454824.916 \\
\end{array}

\[
\begin{array}{c}
\text{watt} \\
\text{watt} \\
\text{watt} \\
\text{watt} \\
\text{watt} \\
\text{watt} \\
\text{watt} \\
\text{watt} \\
\text{watt} \\
\text{watt} \\
\end{array}
\]

\[
\begin{array}{c}
2 \times 10^5 \\
3 \times 10^5 \\
4 \times 10^5 \\
5 \times 10^5 \\
6 \times 10^5 \\
\end{array}
\]

\[
\begin{array}{c}
0 \\
100 \\
200 \\
300 \\
\end{array}
\]

\[
\begin{array}{c}
\text{Speed}_{100\_60MCP_i} \text{ kts} \\
\text{watt} \\
\text{watt} \\
\text{watt} \\
\text{watt} \\
\end{array}
\]
20,000 ft // 100 % MAX CONTINOUS / PLA 72°

Power_Lever_Angle = 72  
Altitude_Feet = 20000 ft  
Power_Mode = 17  
Temperature_Deviation = 0

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Thrust_row
Speed_row
Fuel_row

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(Power_Lever_Angle Altitude_Feet Power_Mode Temperature_Deviation)
Thrust row =

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Fuel row =

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\[\text{Thrust}_{200} := \text{Thrust} \_\text{row} \cdot \text{Ibf}\]
\[\text{Speed}_{200} := \text{Speed} \_\text{row} \cdot \text{kts}\]
\[\text{Fuel}_{200} := \text{Fuel} \_\text{row} \cdot \text{lb/ hr}\]
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\[
i = 0.9
\]

\[
\text{Power}_{200} = \text{Thrust}_{200} \cdot \text{VTAS}(20000 \text{ ft}, \text{Speed}_{200}, \text{dISA})
\]
20,000 ft // 80 % MAX CONTINUOUS / PLA 62.4°

Power_Lever.Angle = 62.4  Altitude_Feet = 20000 ft  Power_Mode = 17  Temperature_Deviation = 0

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(Power_Lever.Angle  Altitude_Feet  Power_Mode  Temperature_Deviation)
Thrust row =

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Speed row =

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Fuel row =

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Thrust\_200\_80MCP := Thrust\_row^T \cdot \text{lbf}

Speed\_200\_80MCP := Speed\_row^T \cdot \text{kts}

Fuel\_200\_80MCP := Fuel\_row^T \cdot \text{lb/hr}

Thrust\_200\_80MCP =

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Fuel\_200\_80MCP =

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303
\[ i = 0.9 \]

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\[ \text{Power}_i = \text{Thrust}_i \cdot \text{V TAS}(20000 \cdot \text{ft}, \text{Speed}_i, \text{dISA}) \]
### Inputs

- **XMN**: 52.8
- **ALT**: 20000
- **PA**: 17
- **TA**: 0
- **Iterations**: 15

### Outputs

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(Power_Lever_Angle Altitude_Feet Power_Mode Temperature_Deviation)
### Thrust Row

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### Speed Row

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**Thrust_{200\_60MCP}** := Thrust_row^{T} \cdot \text{Ibf}

**Speed_{200\_60MCP}** := Speed_row^{T} \cdot \text{kts}

**Fuel_{200\_60MCP}** := Fuel_row^{T} \cdot \text{lb/hr}

**Thrust_{200\_60MCP} (newton)**

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<td>418.3</td>
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**Speed_{200\_60MCP (kts)}**

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<td>323.7</td>
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<td>355.2</td>
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\[ i := 0.9 \]

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<td>355.2</td>
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<td>418.3</td>
<td>355.2</td>
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\[ \text{Power}_200_60MCP_i := \text{Thrust}_200_60MCP_i \cdot \text{V TAS}(20000 \cdot \text{R}, \text{Speed}_200_60MCP_i, \text{dISA}) \]

\[ \text{Power}_200_60MCP_i = \]

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</thead>
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<td>84821.187</td>
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<td>157656.191</td>
</tr>
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<td>221367.556</td>
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<td>331791.62</td>
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<tr>
<td>382157.775</td>
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<tr>
<td>433209.26</td>
</tr>
<tr>
<td>465789.504</td>
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<td>465789.504</td>
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</table>
\begin{center}
\textbf{25.000 ft // 100 \% MAX CONTINOUS / PLA 72°}
\end{center}

\begin{itemize}
\item Power\_Lever\_Angle = 72
\item Altitude\_Feet = 25000 ft
\item Power\_Mode = 17
\item Temperature\_Deviation = 0
\end{itemize}

\begin{tabular}{|c|c|c|c|c|c|c|c|c|}
\hline
\textbf{INPUTS} & & & & & & & & \\
\hline
\textbf{XMN} & 72 & & & & & & & \\
\textbf{ALT} & 25000 & & & & & & & \\
\textbf{PA} & 17 & & & & & & & \\
\textbf{TA} & 0 & & & & & & & \\
\hline
\textbf{OUTPUTS} & & & & & & & & \\
\hline
\textbf{Case} & 1 & 2 & 3 & 4 & 5 & 6 & 7 & \\
\textbf{ALT} & 25000 & 25000 & 25000 & 25000 & 25000 & 25000 & 25000 & \\
\textbf{Pa} & 5.453 & 5.453 & 5.453 & 5.453 & 5.453 & 5.453 & 5.453 & \\
\textbf{Ta} & 429.53 & 429.53 & 429.53 & 429.53 & 429.53 & 429.53 & 429.53 & \\
\textbf{MN} & 0.133 & 0.133 & 0.2 & 0.3 & 0.4 & 0.5 & 0.6 & \\
\textbf{CAS} & 53.8 & 53.8 & 80.8 & 121.7 & 163.2 & 205.3 & 248.4 & \\
\textbf{Eram} & 0.998 & 0.998 & 0.998 & 0.998 & 0.998 & 0.998 & 0.998 & \\
\textbf{3x} & 18400 & 18400 & 18400 & 18400 & 18400 & 18400 & 18400 & \\
\textbf{LHV} & 109.02 & 109.02 & 109.02 & 109.02 & 109.02 & 109.02 & 109.02 & \\
\textbf{Aj} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \\
\textbf{DAY} & 17 & 17 & 17 & 17 & 17 & 17 & 17 & \\
\textbf{MODE} & 72 & 72 & 72 & 72 & 72 & 72 & 72 & \\
\textbf{Fn} & 704.2 & 704.2 & 679.5 & 650.1 & 632.3 & 622.8 & 612.5 & \\
\textbf{TSFC} & 0.558 & 0.558 & 0.584 & 0.626 & 0.666 & 0.705 & 0.742 & \\
\textbf{HPrpm} & 47633 & 47633 & 47673 & 47770 & 47916 & 48088 & 48224 & \\
\textbf{LPrpm} & 22424 & 22424 & 22424 & 22424 & 22424 & 22424 & 22339 & \\
\textbf{Wf} & 392.82 & 392.82 & 396.95 & 406.74 & 421.26 & 438.97 & 454.62 & \\
\hline
\end{tabular}

\begin{center}
\textbf{(Power\_Lever\_Angle Altitude\_Feet Power\_Mode Temperature\_Deviation)}
\end{center}
<table>
<thead>
<tr>
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<tr>
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<tr>
<td>0 53.8 53.8 80.8 121.7 163.2 205.3 248.4 292.5 337.6 355.1</td>
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<tr>
<td>Fuel_row</td>
</tr>
<tr>
<td>0 392.82 392.82 396.95 406.74 421.26 438.97 454.62 468.94 478.89 483.34</td>
</tr>
</tbody>
</table>

\[ \text{Thrust}_{250} := \text{Thrust\_row}^T \cdot \text{lb} \]

\[ \text{Speed}_{250} := \text{Speed\_row}^T \cdot \text{kts} \]

\[ \text{Fuel}_{250} := \text{Fuel\_row}^T \cdot \text{hr} \]

\[ \text{Thrust}_{250} = \begin{array}{ccc|ccc|ccc} 0 & 704.2 & 704.2 & 679.5 & 650.1 & 632.3 & 622.8 & 612.5 & 602.2 & 586.1 & 581 \\
1 & 704.2 & 679.5 & 650.1 & 632.3 & 622.8 & 612.5 & 602.2 & 586.1 & 581 & 53.8 \\
2 & 679.5 & 650.1 & 632.3 & 622.8 & 612.5 & 602.2 & 586.1 & 581 & 53.8 & 53.8 \\
3 & 650.1 & 632.3 & 622.8 & 612.5 & 602.2 & 586.1 & 581 & 53.8 & 53.8 & 80.8 \\
4 & 632.3 & 622.8 & 612.5 & 602.2 & 586.1 & 581 & 53.8 & 53.8 & 80.8 & 121.7 \\
5 & 622.8 & 612.5 & 602.2 & 586.1 & 581 & 53.8 & 53.8 & 80.8 & 121.7 & 163.2 \\
6 & 612.5 & 602.2 & 586.1 & 581 & 53.8 & 53.8 & 80.8 & 121.7 & 163.2 & 205.3 \\
7 & 602.2 & 586.1 & 581 & 53.8 & 53.8 & 80.8 & 121.7 & 163.2 & 205.3 & 248.4 \\
8 & 586.1 & 581 & 53.8 & 53.8 & 80.8 & 121.7 & 163.2 & 205.3 & 248.4 & 292.5 \\
9 & 581 & 53.8 & 53.8 & 80.8 & 121.7 & 163.2 & 205.3 & 248.4 & 292.5 & 337.6 \\
\end{array} \]

\[ \text{Fuel}_{250} = \begin{array}{ccc|ccc|ccc} 0 & 392.82 & 392.82 & 396.95 & 406.74 & 421.26 & 438.97 & 454.62 & 468.94 & 478.89 & 483.34 \\
1 & 392.82 & 396.95 & 406.74 & 421.26 & 438.97 & 454.62 & 468.94 & 478.89 & 483.34 & 178.18 \\
2 & 396.95 & 406.74 & 421.26 & 438.97 & 454.62 & 468.94 & 478.89 & 483.34 & 178.18 & 178.18 \\
3 & 406.74 & 421.26 & 438.97 & 454.62 & 468.94 & 478.89 & 483.34 & 178.18 & 178.18 & 180.053 \\
4 & 421.26 & 438.97 & 454.62 & 468.94 & 478.89 & 483.34 & 178.18 & 178.18 & 180.053 & 184.494 \\
5 & 438.97 & 454.62 & 468.94 & 478.89 & 483.34 & 178.18 & 178.18 & 180.053 & 184.494 & 191.08 \\
6 & 454.62 & 468.94 & 478.89 & 483.34 & 178.18 & 178.18 & 180.053 & 184.494 & 191.08 & 199.113 \\
7 & 468.94 & 478.89 & 483.34 & 178.18 & 178.18 & 180.053 & 184.494 & 191.08 & 199.113 & 206.212 \\
8 & 478.89 & 483.34 & 178.18 & 178.18 & 180.053 & 184.494 & 191.08 & 199.113 & 206.212 & 212.708 \\
9 & 483.34 & 178.18 & 178.18 & 180.053 & 184.494 & 191.08 & 199.113 & 206.212 & 212.708 & 217.221 \\
\end{array} \]
\[ i := 0.9 \]

\[ \text{Thrust}_{250_i} = \text{Speed}_{250_i} = \]

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<td>337.6</td>
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<tr>
<td>581</td>
<td>355.1</td>
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</table>

\[ \text{Power}_{250_i} = \text{Thrust}_{250_i} \cdot \sqrt{TAS \cdot 25000 \cdot \text{ft}\cdot\text{Speed}_{250_i}\cdot\text{dISA}} \]

\[ \text{Power}_{250_i} = \]

\[ \begin{align*}
129507.859 \\
129507.859 \\
187680.283 \\
270450.988 \\
352745.241 \\
437074.411 \\
520086.418 \\
602121.936 \\
676381.915 \\
705252.496
\end{align*}\]

![Graph showing relationship between Speed_{250_i} and Power_{250_i}](image)
### Power_Lever_Angle = 62.4°  Altitude_Feet = 25000 ft  Power_Mode = 17  Temperature_Deviation = 0

#### INPUTS

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<th>TA</th>
<th>Iterations</th>
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#### OUTPUTS

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*Notice: Temperature_Deviation = 0*

---

(Power_Lever_Angle  Altitude_Feet  Power_Mode  Temperature_Deviation)
Thrust row:

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Speed_row:

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Fuel_row:

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Thrust_{250\,80MCP} := \text{Thrust_row}^T \cdot \text{Ibf}

Speed_{250\,80MCP} := \text{Speed_row}^T \cdot \text{kts}

Fuel_{250\,80MCP} := \text{Fuel_row}^T \cdot \text{lb/\text{hr}}
\[ i := 0 .. 9 \]

\[
\begin{array}{c|c|c}
\text{Thrust}_{250\,80\text{MCP}}_i & \text{Speed}_{250\,80\text{MCP}}_i & \text{Power}_{250\,80\text{MCP}}_i = \text{Thrust}_{250\,80\text{MCP}}_i \cdot \text{VTAS}(25000\,\text{ft},\text{Speed}_{250\,80\text{MCP}}_i,\text{dISA}) \\
647.3 & 53.8 & 119043.506 \\
647.3 & 53.8 & 119043.506 \\
622.2 & 80.8 & 171853.822 \\
590.8 & 121.7 & 245781.331 \\
569.9 & 163.2 & 317933.755 \\
558.8 & 205.3 & 392159.892 \\
545.4 & 248.4 & 463110.42 \\
529.8 & 292.5 & 529731.321 \\
514.4 & 337.6 & 593637.36 \\
510.4 & 355.1 & 619554 \\
\end{array}
\]
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<td>Power_Mode = 17</td>
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</tr>
<tr>
<td>Temperature_Deviation = 0</td>
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<tr>
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Thrust\_250\_60MCP := Thrust\_row^T \cdot \text{ Ibf}

Speed\_250\_60MCP := Speed\_row^T \cdot \text{ kts}

Fuel\_250\_60MCP := Fuel\_row^T \cdot \frac{\text{lb}}{\text{hr}}

![Graph showing thrust as a function of speed]
\[ i := 0.9 \]

\[ \text{Thrust}_{250\_60\text{MCP}} = \text{Speed}_{250\_60\text{MCP}} = \]

\begin{array}{|c|c|c|}
\hline
\text{lbf} & \text{kts} & \text{watt} \\
526.8 & 53.8 & 96882.619 \\
526.8 & 53.8 & 96882.619 \\
501.6 & 80.8 & 138543.679 \\
469.4 & 121.7 & 195277.178 \\
445.8 & 163.2 & 248701.295 \\
431 & 205.3 & 302471.212 \\
418.3 & 248.4 & 355187.181 \\
406.6 & 292.5 & 406547.292 \\
395.6 & 337.6 & 456537.597 \\
392.5 & 355.1 & 476439.94 \\
\hline
\end{array}

\[ \text{Power}_{250\_60\text{MCP}} = \text{Thrust}_{250\_60\text{MCP}} \cdot \text{VTAS}(25000 \cdot \text{ft}, \text{Speed}_{250\_60\text{MCP}}, \text{dISA}) \]

\[ \text{Power}_{250\_60\text{MCP}} = \]

\[ \text{Graph:} \]

- Power \( \text{watt} \) vs. Speed \( \text{kts} \)
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Speed \_row =

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Thrust \_300 := \text{Thrust} \_row ^T \cdot \text{lbf}

Speed \_300 := \text{Speed} \_row ^T \cdot \text{kts}

Fuel \_300 := \text{Fuel} \_row ^T \cdot \frac{\text{lb}}{\text{hr}}
\[ i = 0.9 \]

\[
\text{Thrust}_{300} = \begin{array}{c|c}
575.7 & 72.4 \\
575.7 & 72.4 \\
575.7 & 109 \\
537 & 146.2 \\
527.2 & 184.1 \\
528.4 & 223 \\
533.3 & 262.8 \\
531.1 & 303.9 \\
530.2 & 324.9 \\
\end{array}
\]

\[
\text{Speed}_{300} = \begin{array}{c|c}
575.7 & 72.4 \\
575.7 & 72.4 \\
575.7 & 109 \\
537 & 146.2 \\
527.2 & 184.1 \\
528.4 & 223 \\
533.3 & 262.8 \\
531.1 & 303.9 \\
530.2 & 324.9 \\
\end{array}
\]

\[
\text{Power}_{300} = \text{Thrust}_{300} \cdot \text{VTAS}(30000 \cdot \text{ft}, \text{Speed}_{300}, \text{dISA})
\]

\[
\text{Power}_{300} = \begin{array}{c}
155932.117 \\
155932.117 \\
155932.117 \\
225747.713 \\
293712.505 \\
363103.111 \\
440827.269 \\
524321.569 \\
603820.399 \\
644451.463 \\
\end{array}
\]
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**INPUTS**

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**Power_Mode**

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**Temperature_Deviation**

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Thrust\_300\_80MCP := \text{Thrust\_row}^T \cdot \text{lbf}

Speed\_300\_80MCP := \text{Speed\_row}^T \cdot \text{kts}

Fuel\_300\_80MCP := \text{Fuel\_row}^T \cdot \frac{\text{lb}}{\text{hr}}

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\[ i = 0.9 \]

\[
\text{Thrust}_{300\text{,}80\text{MCP}} = \text{Speed}_{300\text{,}80\text{MCP}} = \text{Power}_{300\text{,}80\text{MCP}} = \text{VTAS}^{(30000 \text{ ft, Speed}_{300\text{,}80\text{MCP}}, \text{dISA})}
\]

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<th>Speed_{300\text{,}80\text{MCP}}</th>
<th>Power_{300\text{,}80\text{MCP}}</th>
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\[
\text{Power}_{300\text{,}80\text{MCP}} = \text{VTAS}^{(30000 \text{ ft, Speed}_{300\text{,}80\text{MCP}}, \text{dISA})}
\]

\[
\text{Power}_{300\text{,}80\text{MCP}} = \text{VTAS}^{(30000 \text{ ft, Speed}_{300\text{,}80\text{MCP}}, \text{dISA})}
\]

\[
\text{Power}_{300\text{,}80\text{MCP}} = \text{VTAS}^{(30000 \text{ ft, Speed}_{300\text{,}80\text{MCP}}, \text{dISA})}
\]
**35000ft // 60 % MAX CONTINUOUS / PLA 52.8°**

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(Power_Lever_Angle Altitude_Feet Power_Mode Temperature_Deviation)
Thrust_row =

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Speed_row =

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Fuel_row =

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</table>

Thrust_{300\_60MCP} := \text{Thrust_row}^T \cdot \text{lbf}

Speed_{300\_60MCP} := \text{Speed_row}^T \cdot \text{kts}

Fuel_{300\_60MCP} := \text{Fuel_row}^T \cdot \frac{\text{lb}}{\text{hr}}

Thrust_{300\_60MCP} = \begin{bmatrix} 0 \\
0 \\
1 \\
2 \\
3 \\
4 \\
5 \\
6 \\
7 \\
8 \\
9 \\
\end{bmatrix}

Speed_{300\_60MCP} = \begin{bmatrix} 0 \\
0 \\
1 \\
2 \\
3 \\
4 \\
5 \\
6 \\
7 \\
8 \\
9 \\
\end{bmatrix}

Fuel_{300\_60MCP} = \begin{bmatrix} 0 \\
0 \\
1 \\
2 \\
3 \\
4 \\
5 \\
6 \\
7 \\
8 \\
9 \\
\end{bmatrix}
$i = 0.9$

<table>
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<tr>
<th>Thrust$_{300_60MCP}$</th>
<th>Speed$_{300_60MCP}$</th>
</tr>
</thead>
<tbody>
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<tr>
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<tr>
<td>352.6</td>
<td>324.9</td>
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</table>

Power$_{300\_60MCP} :=$ Thrust$_{300\_60MCP} \cdot v_{\text{TAS}}(30000 \text{ ft}, \text{Speed}_{300\_60MCP}, \text{dISA})$

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![Graph](image-url)
6000

Thrust 100
newton

4000

Thrust_100_80MCP
newton

2000

Speed_100
kts

100

50

150

200

250

300

350

400

6000

4000

2000

0

0

0
Curve Regression

It is often necessary to store the thrust data in the form of a function instead of an array, as is the case above. Since the spline function requires strict monotonic behavior of the driving variable (which is not always the case in the thrust arrays), a regression is used to generate the function. The same reasoning and process are used below for the power data as well.

THRUSt CURVES

SEA LEVEL 100% MCP

\[ v_{CAS\_SL} = \min(Speed\_SL), (\min(Speed\_SL) + 5\text{kts}) \max(Speed\_SL) \]

\[ Thrust\_SL\_reg\_vector = \text{regress} \left( \frac{Speed\_SL}{\text{kts}}, \frac{Thrust\_SL}{\text{newton}}, 3 \right) \]

\[ Thrust\_SL\_func(\text{VCAS\_SL}) = \text{interp} \left( Thrust\_SL\_reg\_vector, \frac{Speed\_SL}{\text{kts}}, \frac{Thrust\_SL}{\text{newton}}, \frac{\text{VCAS\_SL}}{\text{kts}} \right) \]

\[ Thrust\_SL\_func(\text{VCAS\_SL}) = Thrust\_SL\_func(\text{VCAS\_SL}) \text{ newton} \]
SEA LEVEL 80% MCP

\[ v_{CAS, SL_{-}80MCP} = \min(Speed_{SL_{-}80MCP}), (\min(Speed_{SL_{-}80MCP}) + 5\text{kts}) \] \[ \max(Speed_{SL_{-}80MCP}) \]

Thrust\_SL\_80MCP\_reg\_vector = \text{regress}\left( \frac{\text{Speed\_SL\_80MCP}}{\text{kts}}, \frac{\text{Thrust\_SL\_80MCP}}{\text{newton}} \right) ^{3}

\[ \text{Thrust\_SL\_80MCP\_func}(v_{CAS, SL_{-}80MCP}) = \text{interp}\left( \frac{\text{Thrust\_SL\_80MCP\_reg\_vector}}{\text{kts}}, \frac{\text{Speed\_SL\_80MCP}}{\text{kts}}, \frac{\text{Thrust\_SL\_80MCP}}{\text{newton}}, \frac{v_{CAS, SL_{-}80MCP}}{\text{kts}} \right) \]

Thrust\_SL\_80MCP\_func(v_{CAS, SL_{-}80MCP}) = \text{Thrust\_SL\_80MCP\_func}(v_{CAS, SL_{-}80MCP}) \text{ newton}

SEA LEVEL 60% MCP

\[ v_{CAS, SL_{-}60MCP} = \min(Speed_{SL_{-}60MCP}), (\min(Speed_{SL_{-}60MCP}) + 5\text{kts}) \] \[ \max(Speed_{SL_{-}60MCP}) \]

Thrust\_SL\_60MCP\_reg\_vector = \text{regress}\left( \frac{\text{Speed\_SL\_60MCP}}{\text{kts}}, \frac{\text{Thrust\_SL\_60MCP}}{\text{newton}} \right) ^{3}

\[ \text{Thrust\_SL\_60MCP\_func}(v_{CAS, SL_{-}60MCP}) = \text{interp}\left( \frac{\text{Thrust\_SL\_60MCP\_reg\_vector}}{\text{kts}}, \frac{\text{Speed\_SL\_60MCP}}{\text{kts}}, \frac{\text{Thrust\_SL\_60MCP}}{\text{newton}}, \frac{v_{CAS, SL_{-}60MCP}}{\text{kts}} \right) \]

Thrust\_SL\_60MCP\_func(v_{CAS, SL_{-}60MCP}) = \text{Thrust\_SL\_60MCP\_func}(v_{CAS, SL_{-}60MCP}) \text{ newton}
FL 100 100% MCP

\[ v_{\text{CAS}_{100}} = \min(Speed_{100}), (\min(Speed_{100}) + 5\text{kts}) \max(Speed_{100}) \]

\[ \text{Thrust}_{100\_\text{reg\_vector}} = \text{regress}\left(\frac{\text{Speed}_{100}}{\text{kts}}, \frac{\text{Thrust}_{100}}{\text{newton}}, 3\right) \]

\[ \text{Thrust}_{100\_\text{func}((v_{\text{CAS}_{100}}))} = \text{interp}\left(\text{Thrust}_{100\_\text{reg\_vector}}, \frac{\text{Speed}_{100}}{\text{kts}}, \frac{\text{Thrust}_{100}}{\text{newton}}, \frac{v_{\text{CAS}_{100}}}{\text{kts}}\right) \]

\[ \text{Thrust}_{100\_\text{func}((v_{\text{CAS}_{100}}))} = \text{Thrust}_{100\_\text{func}((v_{\text{CAS}_{100}}))} \text{ newton} \]

FL 100 80% MCP

\[ v_{\text{CAS}_{100\_80MCP}} = \min(Speed_{100\_80MCP}), (\min(Speed_{100\_80MCP}) + 5\text{kts}) \max(Speed_{100\_80MCP}) \]

\[ \text{Thrust}_{100\_80MCP\_\text{reg\_vector}} = \text{regress}\left(\frac{\text{Speed}_{100\_80MCP}}{\text{kts}}, \frac{\text{Thrust}_{100\_80MCP}}{\text{newton}}, 3\right) \]

\[ \text{Thrust}_{100\_80MCP\_\text{func}((v_{\text{CAS}_{100\_80MCP}}))} = \text{interp}\left(\text{Thrust}_{100\_80MCP\_\text{reg\_vector}}, \frac{\text{Speed}_{100\_80MCP}}{\text{kts}}, \frac{\text{Thrust}_{100\_80MCP}}{\text{newton}}, \frac{v_{\text{CAS}_{100\_80MCP}}}{\text{kts}}\right) \]

\[ \text{Thrust}_{100\_80MCP\_\text{func}((v_{\text{CAS}_{100\_80MCP}}))} = \text{Thrust}_{100\_80MCP\_\text{func}((v_{\text{CAS}_{100\_80MCP}}))} \text{ newton} \]
FL 100 60% MCP

\[ v_{CAS\_100\_60MCP} = \min(Speed\_100\_60MCP), (\min(Speed\_100\_60MCP) + 5\text{kts}) \max(Speed\_100\_60MCP) \]

\[ \text{Thrust}\_100\_60MCP\_\text{reg\_vector} = \text{regress} \left( \frac{\text{Speed}\_100\_60MCP}{\text{kts}}, \frac{\text{Thrust}\_100\_60MCP}{\text{newton}}, 3 \right) \]

\[ \text{Thrust}\_100\_60MCP\_\text{func}(v_{CAS\_100\_60MCP}) = \text{interp} \left( \frac{\text{Thrust}\_100\_60MCP\_\text{reg\_vector}}{\text{kts}}, \frac{\text{Speed}\_100\_60MCP}{\text{newton}}, \frac{v_{CAS\_100\_60MCP}}{\text{kts}} \right) \]

\[ \text{Thrust}\_100\_60MCP\_\text{func}(v_{CAS\_100\_60MCP}) = \text{Thrust}\_100\_60MCP\_\text{func}(v_{CAS\_100\_60MCP}) \text{newton} \]

FL 200 100% MCP

\[ v_{CAS\_200} = \min(Speed\_200), (\min(Speed\_200) + 5\text{kts}) \max(Speed\_200) \]

\[ \text{Thrust}\_200\_\text{reg\_vector} = \text{regress} \left( \frac{\text{Speed}\_200}{\text{kts}}, \frac{\text{Thrust}\_200}{\text{newton}}, 3 \right) \]

\[ \text{Thrust}\_200\_\text{func}(v_{CAS\_200}) = \text{interp} \left( \frac{\text{Thrust}\_200\_\text{reg\_vector}}{\text{kts}}, \frac{\text{Speed}\_200}{\text{newton}}, \frac{v_{CAS\_200}}{\text{kts}} \right) \]

\[ \text{Thrust}\_200\_\text{func}(v_{CAS\_200}) = \text{Thrust}\_200\_\text{func}(v_{CAS\_200}) \text{newton} \]
**FL 200 80% MCP**

\[
\text{VCAS}_{200\_80MCP} = \min(\text{Speed}_{200\_80MCP}, (\min(\text{Speed}_{200\_80MCP}) + 5\text{kts}) \max(\text{Speed}_{200\_80MCP})
\]

\[
\text{Thrust}_{200\_80MCP\_reg\_vector} = \text{regress}\left(\frac{\text{Speed}_{200\_80MCP}}{\text{kts}}, \frac{\text{Thrust}_{200\_80MCP}}{\text{newton}}, 3\right)
\]

\[
\text{Thrust}_{200\_80MCP\_func(\text{VCAS}_{200\_80MCP})} = \text{interp}\left(\text{Thrust}_{200\_80MCP\_reg\_vector}, \frac{\text{Speed}_{200\_80MCP}}{\text{kts}}, \frac{\text{Thrust}_{200\_80MCP}}{\text{newton}}, \frac{\text{VCAS}_{200\_80MCP}}{\text{kts}}\right)
\]

\[
\text{Thrust}_{200\_80MCP\_func(\text{VCAS}_{200\_80MCP})} = \text{Thrust}_{200\_80MCP\_func(\text{VCAS}_{200\_80MCP})} \text{newton}
\]

**FL 200 60% MCP**

\[
\text{VCAS}_{200\_60MCP} = \min(\text{Speed}_{200\_60MCP}, (\min(\text{Speed}_{200\_60MCP}) + 5\text{kts}) \max(\text{Speed}_{200\_60MCP})
\]

\[
\text{Thrust}_{200\_60MCP\_reg\_vector} = \text{regress}\left(\frac{\text{Speed}_{200\_60MCP}}{\text{kts}}, \frac{\text{Thrust}_{200\_60MCP}}{\text{newton}}, 3\right)
\]

\[
\text{Thrust}_{200\_60MCP\_func(\text{VCAS}_{200\_60MCP})} = \text{interp}\left(\text{Thrust}_{200\_60MCP\_reg\_vector}, \frac{\text{Speed}_{200\_60MCP}}{\text{kts}}, \frac{\text{Thrust}_{200\_60MCP}}{\text{newton}}, \frac{\text{VCAS}_{200\_60MCP}}{\text{kts}}\right)
\]

\[
\text{Thrust}_{200\_60MCP\_func(\text{VCAS}_{200\_60MCP})} = \text{Thrust}_{200\_60MCP\_func(\text{VCAS}_{200\_60MCP})} \text{newton}
\]
**FL 250 100% MCP**

\[ v_{CAS_{250}} = \min(Speed_{250}), \left(\min(Speed_{250}) + 5\text{ kts}\right) \max(Speed_{250}) \]

\[ \text{Thrust}_{250\_\text{reg\_vector}} = \text{regress}\left(\frac{\text{Speed}_{250}}{\text{kts}}, \frac{\text{Thrust}_{250}}{\text{newton}}, 3\right) \]

\[ \text{Thrust}_{250\_func(v_{CAS_{250}})} = \text{interp}\left(\frac{\text{Thrust}_{250\_\text{reg\_vector}}}{\text{kts}}, \frac{\text{Speed}_{250}}{\text{newton}}, \frac{\text{v_{CAS_{250}}}}{\text{kts}}\right) \]

\[ \text{Thrust}_{250\_func(v_{CAS_{250}})} = \text{Thrust}_{250\_func(v_{CAS_{250}})} \text{ newton} \]

**FL 250 80% MCP**

\[ v_{CAS_{250\_80MCP}} = \min(Speed_{250\_80MCP}), \left(\min(Speed_{250\_80MCP}) + 5\text{ kts}\right) \max(Speed_{250\_80MCP}) \]

\[ \text{Thrust}_{250\_80MCP\_reg\_vector} = \text{regress}\left(\frac{\text{Speed}_{250\_80MCP}}{\text{kts}}, \frac{\text{Thrust}_{250\_80MCP}}{\text{newton}}, 3\right) \]

\[ \text{Thrust}_{250\_80MCP\_func(v_{CAS_{250\_80MCP}})} = \text{interp}\left(\frac{\text{Thrust}_{250\_80MCP\_reg\_vector}}{\text{kts}}, \frac{\text{Speed}_{250\_80MCP}}{\text{newton}}, \frac{\text{v_{CAS_{250\_80MCP}}}}{\text{kts}}\right) \]

\[ \text{Thrust}_{250\_80MCP\_func(v_{CAS_{250\_80MCP}})} = \text{Thrust}_{250\_80MCP\_func(v_{CAS_{250\_80MCP}})} \text{ newton} \]
**FL 250 60% MCP**

\[
\text{\( v_{CAS\_250\_60MCP} = \min(\text{Speed\_250\_60MCP}), (\min(\text{Speed\_250\_60MCP}) + 5\text{kts}) \max(\text{Speed\_250\_60MCP}) \)}
\]

\[
\text{\( \text{Thrust\_250\_60MCP\_reg\_vector} = \text{regress}\left(\frac{\text{Speed\_250\_60MCP}}{\text{kts}}, \frac{\text{Thrust\_250\_60MCP}}{\text{newton}}\right), 3 \)}
\]

\[
\text{\( \text{Thrust\_250\_60MCP\_func}(v_{CAS\_250\_60MCP}) = \text{interp}\left(\frac{\text{Thrust\_250\_60MCP\_reg\_vector}}, \frac{\text{Speed\_250\_60MCP}}{\text{kts}}, \frac{\text{Thrust\_250\_60MCP}}{\text{newton}}\right), \frac{v_{CAS\_250\_60MCP}}{\text{kts}}\)}
\]

\[
\text{\( \text{Thrust\_250\_60MCP\_func}(v_{CAS\_250\_60MCP}) = \text{Thrust\_250\_60MCP\_func}(v_{CAS\_250\_60MCP}) \text{ newton} \)}
\]

**FL 300 100% MCP**

\[
\text{\( v_{CAS\_300} = \min(\text{Speed\_300}), (\min(\text{Speed\_300}) + 5\text{kts}) \max(\text{Speed\_300}) \)}
\]

\[
\text{\( \text{Thrust\_300\_reg\_vector} = \text{regress}\left(\frac{\text{Speed\_300}}{\text{kts}}, \frac{\text{Thrust\_300}}{\text{newton}}\right), 3 \)}
\]

\[
\text{\( \text{Thrust\_300\_func}(v_{CAS\_300}) = \text{interp}\left(\frac{\text{Thrust\_300\_reg\_vector}}, \frac{\text{Speed\_300}}{\text{kts}}, \frac{\text{Thrust\_300}}{\text{newton}}\right), \frac{v_{CAS\_300}}{\text{kts}}\)}
\]

\[
\text{\( \text{Thrust\_300\_func}(v_{CAS\_300}) = \text{Thrust\_300\_func}(v_{CAS\_300}) \text{ newton} \)}
\]
FL 300 80% MCP

\[
\text{VCAS}_{300\_80\text{MCP}} = \min(\text{Speed}_{300\_80\text{MCP}}), (\min(\text{Speed}_{300\_80\text{MCP}}) + 5\text{kts}) \max(\text{Speed}_{300\_80\text{MCP}})
\]

\[
\text{Thrust}_{300\_80\text{MCP\_reg\_vector}} = \text{regress}\left(\frac{\text{Speed}_{300\_80\text{MCP}}}{\text{kts}}, \frac{\text{Thrust}_{300\_80\text{MCP}}}{\text{newton}}, 3\right)
\]

\[
\text{Thrust}_{300\_80\text{MCP\_func}}(\text{VCAS}_{300\_80\text{MCP}}) = \text{interp}\left(\text{Thrust}_{300\_80\text{MCP\_reg\_vector}}, \frac{\text{Speed}_{300\_80\text{MCP}}}{\text{kts}}, \frac{\text{Thrust}_{300\_80\text{MCP}}}{\text{newton}}, \frac{\text{VCAS}_{300\_80\text{MCP}}}{\text{kts}}\right)
\]

\[
\text{Thrust}_{300\_80\text{MCP\_func}}(\text{VCAS}_{300\_80\text{MCP}}) = \text{Thrust}_{300\_80\text{MCP\_func}}(\text{VCAS}_{300\_80\text{MCP}}) \text{ newton}
\]

FL 300 60% MCP

\[
\text{VCAS}_{300\_60\text{MCP}} = \min(\text{Speed}_{300\_60\text{MCP}}), (\min(\text{Speed}_{300\_60\text{MCP}}) + 5\text{kts}) \max(\text{Speed}_{300\_60\text{MCP}})
\]

\[
\text{Thrust}_{300\_60\text{MCP\_reg\_vector}} = \text{regress}\left(\frac{\text{Speed}_{300\_60\text{MCP}}}{\text{kts}}, \frac{\text{Thrust}_{300\_60\text{MCP}}}{\text{newton}}, 3\right)
\]

\[
\text{Thrust}_{300\_60\text{MCP\_func}}(\text{VCAS}_{300\_60\text{MCP}}) = \text{interp}\left(\text{Thrust}_{300\_60\text{MCP\_reg\_vector}}, \frac{\text{Speed}_{300\_60\text{MCP}}}{\text{kts}}, \frac{\text{Thrust}_{300\_60\text{MCP}}}{\text{newton}}, \frac{\text{VCAS}_{300\_60\text{MCP}}}{\text{kts}}\right)
\]

\[
\text{Thrust}_{300\_60\text{MCP\_func}}(\text{VCAS}_{300\_60\text{MCP}}) = \text{Thrust}_{300\_60\text{MCP\_func}}(\text{VCAS}_{300\_60\text{MCP}}) \text{ newton}
\]
FUEL CURVES

SEA LEVEL 100% MCP

\[ V_{CAS, SL} = \min(Speed_{SL}), (\min(Speed_{SL}) + \text{5kts}) \max(Speed_{SL}) \]

\[ \text{Fuel}_{SL, \text{reg vector}} = \text{regress} \left( \frac{\text{Speed}_{SL}}{\text{kts}}, \frac{\text{Fuel}_{SL}}{\text{kg/hr}} \right)^3 \]

\[ \text{Fuel}_{SL, \text{func}}(V_{CAS, SL}) = \text{interp} \left( \text{Fuel}_{SL, \text{reg vector}}, \frac{\text{Speed}_{SL}}{\text{kts}}, \frac{\text{Fuel}_{SL}}{\text{kg/hr}}, V_{CAS, SL} \frac{\text{v CAS}_{SL}}{\text{kts}} \right) \]

\[ \text{Fuel}_{SL, \text{func}}(V_{CAS, SL}) = \text{Fuel}_{SL, \text{func}}(V_{CAS, SL}) \]

SEA LEVEL 80% MCP

\[ V_{CAS, SL, 80MCP} = \min(Speed_{SL, 80MCP}), (\min(Speed_{SL, 80MCP}) + \text{5kts}) \max(Speed_{SL, 80MCP}) \]

\[ \text{Fuel}_{SL, 80MCP, \text{reg vector}} = \text{regress} \left( \frac{\text{Speed}_{SL, 80MCP}}{\text{kts}}, \frac{\text{Fuel}_{SL, 80MCP}}{\text{kg/hr}} \right)^3 \]

\[ \text{Fuel}_{SL, 80MCP, \text{func}}(V_{CAS, SL, 80MCP}) = \text{interp} \left( \text{Fuel}_{SL, 80MCP, \text{reg vector}}, \frac{\text{Speed}_{SL, 80MCP}}{\text{kts}}, \frac{\text{Fuel}_{SL, 80MCP}}{\text{kg/hr}}, V_{CAS, SL, 80MCP} \frac{\text{v CAS}_{SL, 80MCP}}{\text{kts}} \right) \]

\[ \text{Fuel}_{SL, 80MCP, \text{func}}(V_{CAS, SL, 80MCP}) = \text{Fuel}_{SL, 80MCP, \text{func}}(V_{CAS, SL, 80MCP}) \]
SEA LEVEL 60% MCP

\[ v_{CAS_{SL\_60MCP}} = \min(Speed_{SL\_60MCP}), (\min(Speed_{SL\_60MCP}) + 5 \text{kts}) \max(Speed_{SL\_60MCP}) \]

\[ Fuel_{SL\_60MCP\_reg\_vector} = \text{regress} \left( \frac{\text{Speed}_{SL\_60MCP}}{\text{kts}}, \frac{\text{Fuel}_{SL\_60MCP}}{\text{kg}} \right)^3 \]

\[ Fuel_{SL\_60MCP\_func(v_{CAS\_SL\_60MCP})} = \text{interp} \left( Fuel_{SL\_60MCP\_reg\_vector}, \frac{\text{Speed}_{SL\_60MCP}}{\text{kts}}, \frac{\text{Fuel}_{SL\_60MCP}}{\text{kg}} \right) \frac{\text{V}_{CAS\_SL\_60MCP}}{\text{kts}} \]

\[ Fuel_{SL\_60MCP\_func(v_{CAS\_SL\_60MCP})} = Fuel_{SL\_60MCP\_func(v_{CAS\_SL\_60MCP})} \frac{\text{kg}}{\text{hr}} \]

FL 100 100% MCP

\[ v_{CAS\_100} = \min(Speed_{100}), (\min(Speed_{100}) + 5 \text{kts}) \max(Speed_{100}) \]

\[ Fuel_{100\_reg\_vector} = \text{regress} \left( \frac{\text{Speed}_{100}}{\text{kts}}, \frac{\text{Fuel}_{100}}{\text{kg}} \right)^3 \]

\[ Fuel_{100\_func(v_{CAS\_100})} = \text{interp} \left( Fuel_{100\_reg\_vector}, \frac{\text{Speed}_{100}}{\text{kts}}, \frac{\text{Fuel}_{100}}{\text{kg}} \right) \frac{\text{V}_{CAS\_100}}{\text{kts}} \]

\[ Fuel_{100\_func(v_{CAS\_100})} = Fuel_{100\_func(v_{CAS\_100})} \frac{\text{kg}}{\text{hr}} \]
**FL 100 80% MCP**

\[
V_{CAS_{100\,80MCP}} = \min(\text{Speed}_{100\,80MCP}), (\min(\text{Speed}_{100\,80MCP}) + 5\text{kts}) \max(\text{Speed}_{100\,80MCP})
\]

\[
\text{Fuel}_{100\,80MCP}\_\text{reg\_vector} = \text{regress}\left(\frac{\text{Speed}_{100\,80MCP}}{\text{kts}}, \frac{\text{Fuel}_{100\,80MCP}}{\text{kg/ hr}}, 3\right)
\]

\[
\text{Fuel}_{100\,80MCP}\_\text{func}(V_{CAS_{100\,80MCP}}) = \text{interp}\left(\frac{\text{Fuel}_{100\,80MCP}\_\text{reg\_vector}}{\text{kts}}, \frac{\text{Speed}_{100\,80MCP}}{\text{kg/ hr}}, \frac{V_{CAS_{100\,80MCP}}}{\text{kts}}\right)
\]

\[
\text{Fuel}_{100\,80MCP}\_\text{func}(V_{CAS_{100\,80MCP}}) = \text{Fuel}_{100\,80MCP}\_\text{func}(V_{CAS_{100\,80MCP}}) \frac{\text{kg/ hr}}{}
\]

**FL 100 60% MCP**

\[
V_{CAS_{100\,60MCP}} = \min(\text{Speed}_{100\,60MCP}), (\min(\text{Speed}_{100\,60MCP}) + 5\text{kts}) \max(\text{Speed}_{100\,60MCP})
\]

\[
\text{Fuel}_{100\,60MCP}\_\text{reg\_vector} = \text{regress}\left(\frac{\text{Speed}_{100\,60MCP}}{\text{kts}}, \frac{\text{Fuel}_{100\,60MCP}}{\text{kg/ hr}}, 3\right)
\]

\[
\text{Fuel}_{100\,60MCP}\_\text{func}(V_{CAS_{100\,60MCP}}) = \text{interp}\left(\frac{\text{Fuel}_{100\,60MCP}\_\text{reg\_vector}}{\text{kts}}, \frac{\text{Speed}_{100\,60MCP}}{\text{kg/ hr}}, \frac{V_{CAS_{100\,60MCP}}}{\text{kts}}\right)
\]

\[
\text{Fuel}_{100\,60MCP}\_\text{func}(V_{CAS_{100\,60MCP}}) = \text{Fuel}_{100\,60MCP}\_\text{func}(V_{CAS_{100\,60MCP}}) \frac{\text{kg/ hr}}{}
\]
FL 200 100% MCP

\[ v_{\text{CAS}_200} = \min(\text{Speed}_{200}), (\min(\text{Speed}_{200}) + 5\text{kts}) \max(\text{Speed}_{200}) \]

\[ \text{Fuel}_{200\_\text{reg\_vector}} = \text{regress}\left(\frac{\text{Speed}_{200}}{\text{kts}}, \frac{\text{Fuel}_{200}}{\text{kg/hr}}\right), 3 \]

\[ \text{Fuel}_{200\_\text{func}}(v_{\text{CAS}_200}) = \text{interp}\left(\text{Fuel}_{200\_\text{reg\_vector}}\right), \frac{\text{Speed}_{200}}{\text{kts}}, \frac{\text{Fuel}_{200}}{\text{kg/hr}}, \frac{v_{\text{CAS}_200}}{\text{kts}} \]

\[ \text{Fuel}_{200\_\text{func}}(v_{\text{CAS}_200}) = \text{Fuel}_{200\_\text{func}}(v_{\text{CAS}_200}) \frac{\text{kg}}{\text{hr}} \]

FL 200 80% MCP

\[ v_{\text{CAS}_200\_80\text{MCP}} = \min(\text{Speed}_{200\_80\text{MCP}}), (\min(\text{Speed}_{200\_80\text{MCP}}) + 5\text{kts}) \max(\text{Speed}_{200\_80\text{MCP}}) \]

\[ \text{Fuel}_{200\_80\text{MCP\_reg\_vector}} = \text{regress}\left(\frac{\text{Speed}_{200\_80\text{MCP}}}{\text{kts}}, \frac{\text{Fuel}_{200\_80\text{MCP}}}{\text{kg/hr}}\right), 3 \]

\[ \text{Fuel}_{200\_80\text{MCP\_func}}(v_{\text{CAS}_200\_80\text{MCP}}) = \text{interp}\left(\text{Fuel}_{200\_80\text{MCP\_reg\_vector}}, \frac{\text{Speed}_{200\_80\text{MCP}}}{\text{kts}}, \frac{\text{Fuel}_{200\_80\text{MCP}}}{\text{kg/hr}}, \frac{v_{\text{CAS}_200\_80\text{MCP}}}{\text{kts}} \right) \]

\[ \text{Fuel}_{200\_80\text{MCP\_func}}(v_{\text{CAS}_200\_80\text{MCP}}) = \text{Fuel}_{200\_80\text{MCP\_func}}(v_{\text{CAS}_200\_80\text{MCP}}) \frac{\text{kg}}{\text{hr}} \]
**FL 200 60% MCP**

\[
v_{\text{CAS}_200\_60\text{MCP}} = \min(\text{Speed}_{200\_60\text{MCP}}), (\min(\text{Speed}_{200\_60\text{MCP}}) + 5\text{kts}) \max(\text{Speed}_{200\_60\text{MCP}})
\]

\[
\text{Fuel}_{200\_60\text{MCP\_reg\_vector}} = \text{regress}\left(\frac{\text{Speed}_{200\_60\text{MCP}}}{\text{kts}}, \frac{\text{Fuel}_{200\_60\text{MCP}}}{\text{kg/\text{hr}}}, 3\right)
\]

\[
\text{Fuel}_{200\_60\text{MCP\_func}(v_{\text{CAS}_{200\_60\text{MCP}}})} = \text{interp}\left(\text{Fuel}_{200\_60\text{MCP\_reg\_vector}}, \frac{\text{Speed}_{200\_60\text{MCP}}}{\text{kts}}, \frac{\text{Fuel}_{200\_60\text{MCP}}}{\text{kg/\text{hr}}}, \frac{v_{\text{CAS}_{200\_60\text{MCP}}}}{\text{kts}}\right)
\]

\[
\text{Fuel}_{200\_60\text{MCP\_func}(v_{\text{CAS}_{200\_60\text{MCP}}})} = \text{Fuel}_{200\_60\text{MCP\_func}(v_{\text{CAS}_{200\_60\text{MCP}}})} \frac{\text{kg/\text{hr}}}{\text{hr}}
\]

**FL 250 100% MCP**

\[
v_{\text{CAS}_{250}} = \min(\text{Speed}_{250}), (\min(\text{Speed}_{250}) + 5\text{kts}) \max(\text{Speed}_{250})
\]

\[
\text{Fuel}_{250\_reg\_vector} = \text{regress}\left(\frac{\text{Speed}_{250}}{\text{kts}}, \frac{\text{Fuel}_{250}}{\text{kg/\text{hr}}}, 3\right)
\]

\[
\text{Fuel}_{250\_func}(v_{\text{CAS}_{250}}) = \text{interp}\left(\text{Fuel}_{250\_reg\_vector}, \frac{\text{Speed}_{250}}{\text{kts}}, \frac{\text{Fuel}_{250}}{\text{kg/\text{hr}}}, \frac{v_{\text{CAS}_{250}}}{\text{kts}}\right)
\]

\[
\text{Fuel}_{250\_func}(v_{\text{CAS}_{250}}) = \text{Fuel}_{250\_func}(v_{\text{CAS}_{250}}) \frac{\text{kg/\text{hr}}}{\text{hr}}
\]
FL 250 80% MCP

\[ v_{CAS_{250\_80MCP}} = \min(Speed_{250\_80MCP}), (\min(Speed_{250\_80MCP}) + 5\text{kts}) \max(Speed_{250\_80MCP}) \]

\[ \text{Fuel}_{250\_80MCP\_reg\_vector} = \text{regress} \left( \frac{\text{Speed}_{250\_80MCP}}{\text{kts}}, \frac{\text{Fuel}_{250\_80MCP}}{\text{kg/hr}} \right)^3 \]

\[ \text{Fuel}_{250\_80MCP\_func}(v_{CAS_{250\_80MCP}}) = \text{interp} \left( \frac{\text{Fuel}_{250\_80MCP\_reg\_vector}}{\text{kts}}, \frac{\text{Speed}_{250\_80MCP}}{\text{kg/hr}}, \frac{\text{Fuel}_{250\_80MCP}}{\text{kts}}, \frac{v_{CAS_{250\_80MCP}}}{\text{kts}} \right) \]

\[ \text{Fuel}_{250\_80MCP\_func}(v_{CAS_{250\_80MCP}}) = \text{Fuel}_{250\_80MCP\_func}(v_{CAS_{250\_80MCP}}) \frac{\text{kg}}{\text{hr}} \]

FL 250 60% MCP

\[ v_{CAS_{250\_60MCP}} = \min(Speed_{250\_60MCP}), (\min(Speed_{250\_60MCP}) + 5\text{kts}) \max(Speed_{250\_60MCP}) \]

\[ \text{Fuel}_{250\_60MCP\_reg\_vector} = \text{regress} \left( \frac{\text{Speed}_{250\_60MCP}}{\text{kts}}, \frac{\text{Fuel}_{250\_60MCP}}{\text{kg/hr}} \right)^3 \]

\[ \text{Fuel}_{250\_60MCP\_func}(v_{CAS_{250\_60MCP}}) = \text{interp} \left( \frac{\text{Fuel}_{250\_60MCP\_reg\_vector}}{\text{kts}}, \frac{\text{Speed}_{250\_60MCP}}{\text{kg/hr}}, \frac{\text{Fuel}_{250\_60MCP}}{\text{kts}}, \frac{v_{CAS_{250\_60MCP}}}{\text{kts}} \right) \]

\[ \text{Fuel}_{250\_60MCP\_func}(v_{CAS_{250\_60MCP}}) = \text{Fuel}_{250\_60MCP\_func}(v_{CAS_{250\_60MCP}}) \frac{\text{kg}}{\text{hr}} \]
FL 300 100% MCP

\[ v_{CAS_{300}} = \min(\text{Speed}_{300}), (\min(\text{Speed}_{300}) + 5\text{kts}) \max(\text{Speed}_{300}) \]

\[
\text{Fuel}_{300\_\text{reg\_vector}} = \text{regress}\left(\frac{\text{Speed}_{300}}{\text{kts}}, \frac{\text{Fuel}_{300}}{\text{kg/hr}}, 3\right)
\]

\[
\text{Fuel}_{300\_\text{func}\left(v_{CAS_{300}}\right)} = \text{interp}\left(\text{Fuel}_{300\_\text{reg\_vector}}, \frac{\text{Speed}_{300}}{\text{kts}}, \frac{\text{Fuel}_{300}}{\text{kg/hr}}, v_{CAS_{300}} \text{kts}\right)
\]

\[
\text{Fuel}_{300\_\text{func}\left(v_{CAS_{300}}\right)} = \text{Fuel}_{300\_\text{func}\left(v_{CAS_{300}}\right)} \frac{\text{kg}}{\text{hr}}
\]

FL 300 80% MCP

\[ v_{CAS_{300\_80MCP}} = \min(\text{Speed}_{300\_80MCP}), (\min(\text{Speed}_{300\_80MCP}) + 5\text{kts}) \max(\text{Speed}_{300\_80MCP}) \]

\[
\text{Fuel}_{300\_80MCP\_\text{reg\_vector}} = \text{regress}\left(\frac{\text{Speed}_{300\_80MCP}}{\text{kts}}, \frac{\text{Fuel}_{300\_80MCP}}{\text{kg/hr}}, 3\right)
\]

\[
\text{Fuel}_{300\_80MCP\_\text{func}\left(v_{CAS_{300\_80MCP}}\right)} = \text{interp}\left(\text{Fuel}_{300\_80MCP\_\text{reg\_vector}}, \frac{\text{Speed}_{300\_80MCP}}{\text{kts}}, \frac{\text{Fuel}_{300\_80MCP}}{\text{kg/hr}}, v_{CAS_{300\_80MCP}} \text{kts}\right)
\]

\[
\text{Fuel}_{300\_80MCP\_\text{func}\left(v_{CAS_{300\_80MCP}}\right)} = \text{Fuel}_{300\_80MCP\_\text{func}\left(v_{CAS_{300\_80MCP}}\right)} \frac{\text{kg}}{\text{hr}}
\]
FL 300 60% MCP

\[ v_{\text{CAS}_{\text{300 60MCP}}} = \min(\text{Speed}_{\text{300 60MCP}}), (\min(\text{Speed}_{\text{300 60MCP}}) + 5 \text{kts}) \max(\text{Speed}_{\text{300 60MCP}}) \]

\[
\text{Fuel}_{\text{300 60MCP\_reg\_vector}} = \text{regress}\left( \frac{\text{Speed}_{\text{300 60MCP}}}{\text{kts}}, \frac{\text{Fuel}_{\text{300 60MCP}}}{\text{kg/hr}} \right),^3
\]

\[
\text{Fuel}_{\text{300 60MCP\_func}}(v_{\text{CAS}_{\text{300 60MCP}}}) = \text{interp}\left( \frac{\text{Speed}_{\text{300 60MCP}}}{\text{kts}}, \frac{\text{Fuel}_{\text{300 60MCP}}}{\text{kg/hr}}, \frac{v_{\text{CAS}_{\text{300 60MCP}}}}{\text{kts}} \right)
\]

\[
\text{Fuel}_{\text{300 60MCP\_func}}(v_{\text{CAS}_{\text{300 60MCP}}}) = \text{Fuel}_{\text{300 60MCP\_func}}(v_{\text{CAS}_{\text{300 60MCP}}}) \frac{\text{kg}}{\text{hr}}
\]
POWER CURVES

SEA LEVEL 100% MCP

\[
\text{Power}_{\text{SL}}_{\text{reg\_vector}} = \text{regress}\left(\frac{\text{Speed}_{\text{SL}}}{\text{kts}}, \frac{\text{Power}_{\text{SL}}}{\text{watt}}\right, 3 \right)
\]

\[
\text{Power}_{\text{SL}}_{\text{func}(\text{VCAS}_{\text{SL}})} = \text{interp}\left(\text{Power}_{\text{SL}}_{\text{reg\_vector}}, \frac{\text{Speed}_{\text{SL}}}{\text{kts}}, \frac{\text{Power}_{\text{SL}}}{\text{watt}}, \frac{\text{VCAS}_{\text{SL}}}{\text{kts}}\right)
\]

\[
\text{Power}_{\text{SL}}_{\text{func}(\text{VCAS}_{\text{SL}})} = \text{Power}_{\text{SL}}_{\text{func}(\text{VCAS}_{\text{SL}})} \text{ watt}
\]

SEA LEVEL 80% MCP

\[
\text{Power}_{\text{SL,80MCP}}_{\text{reg\_vector}} = \text{regress}\left(\frac{\text{Speed}_{\text{SL,80MCP}}}{\text{kts}}, \frac{\text{Power}_{\text{SL,80MCP}}}{\text{watt}}\right, 3 \right)
\]

\[
\text{Power}_{\text{SL,80MCP}}_{\text{func}(\text{VCAS}_{\text{SL,80MCP}})} = \text{interp}\left(\text{Power}_{\text{SL,80MCP}}_{\text{reg\_vector}}, \frac{\text{Speed}_{\text{SL,80MCP}}}{\text{kts}}, \frac{\text{Power}_{\text{SL,80MCP}}}{\text{watt}}, \frac{\text{VCAS}_{\text{SL,80MCP}}}{\text{kts}}\right)
\]

\[
\text{Power}_{\text{SL,80MCP}}_{\text{func}(\text{VCAS}_{\text{SL,80MCP}})} = \text{Power}_{\text{SL,80MCP}}_{\text{func}(\text{VCAS}_{\text{SL,80MCP}})} \text{ watt}
\]

SEA LEVEL 60% MCP

\[
\text{Power}_{\text{SL,60MCP}}_{\text{reg\_vector}} = \text{regress}\left(\frac{\text{Speed}_{\text{SL,60MCP}}}{\text{kts}}, \frac{\text{Power}_{\text{SL,60MCP}}}{\text{watt}}\right, 3 \right)
\]

\[
\text{Power}_{\text{SL,60MCP}}_{\text{func}(\text{VCAS}_{\text{SL,60MCP}})} = \text{interp}\left(\text{Power}_{\text{SL,60MCP}}_{\text{reg\_vector}}, \frac{\text{Speed}_{\text{SL,60MCP}}}{\text{kts}}, \frac{\text{Power}_{\text{SL,60MCP}}}{\text{watt}}, \frac{\text{VCAS}_{\text{SL,60MCP}}}{\text{kts}}\right)
\]

\[
\text{Power}_{\text{SL,60MCP}}_{\text{func}(\text{VCAS}_{\text{SL,60MCP}})} = \text{Power}_{\text{SL,60MCP}}_{\text{func}(\text{VCAS}_{\text{SL,60MCP}})} \text{ watt}
\]
FL 100 100% MCP

\[
\text{Power}_{100}\_\text{reg\_vector} = \text{regress}\left(\frac{\text{Speed}_{100}\_\text{kts}}{\text{Power}_{100}\_\text{watt}}, 3\right)
\]

\[
\text{Power}_{100}\_\text{func}(\text{VCAS}\_100) = \text{interp}\left(\text{Power}_{100}\_\text{reg\_vector}, \frac{\text{Speed}_{100}\_\text{kts}}{\text{watt}}, \frac{\text{Power}_{100}\_\text{watt}}{\text{kts}}, \frac{\text{VCAS}_{100}}{\text{kts}}\right)
\]

\[
\text{Power}_{100}\_\text{func}(\text{VCAS}\_100) = \text{Power}_{100}\_\text{func}(\text{VCAS}\_100) \text{\ watt}
\]

FL 100 80% MCP

\[
\text{Power}_{100\_80}\_\text{MCP\_reg\_vector} = \text{regress}\left(\frac{\text{Speed}_{100\_80}\_\text{MCP}\_\text{kts}}{\text{Power}_{100\_80}\_\text{MCP\_watt}}, 3\right)
\]

\[
\text{Power}_{100\_80}\_\text{MCP\_func}(\text{VCAS}_{100\_80}\_\text{MCP}) = \text{interp}\left(\text{Power}_{100\_80}\_\text{MCP\_reg\_vector}, \frac{\text{Speed}_{100\_80}\_\text{MCP}\_\text{kts}}{\text{watt}}, \frac{\text{Power}_{100\_80}\_\text{MCP\_watt}}{\text{kts}}, \frac{\text{VCAS}_{100\_80}\_\text{MCP}}{\text{kts}}\right)
\]

\[
\text{Power}_{100\_80}\_\text{MCP\_func}(\text{VCAS}_{100\_80}\_\text{MCP}) = \text{Power}_{100\_80}\_\text{MCP\_func}(\text{VCAS}_{100\_80}\_\text{MCP}) \text{\ watt}
\]

FL 100 60% MCP

\[
\text{Power}_{100\_60}\_\text{MCP\_reg\_vector} = \text{regress}\left(\frac{\text{Speed}_{100\_60}\_\text{MCP}\_\text{kts}}{\text{Power}_{100\_60}\_\text{MCP\_watt}}, 3\right)
\]

\[
\text{Power}_{100\_60}\_\text{MCP\_func}(\text{VCAS}_{100\_60}\_\text{MCP}) = \text{interp}\left(\text{Power}_{100\_60}\_\text{MCP\_reg\_vector}, \frac{\text{Speed}_{100\_60}\_\text{MCP}\_\text{kts}}{\text{watt}}, \frac{\text{Power}_{100\_60}\_\text{MCP\_watt}}{\text{kts}}, \frac{\text{VCAS}_{100\_60}\_\text{MCP}}{\text{kts}}\right)
\]

\[
\text{Power}_{100\_60}\_\text{MCP\_func}(\text{VCAS}_{100\_60}\_\text{MCP}) = \text{Power}_{100\_60}\_\text{MCP\_func}(\text{VCAS}_{100\_60}\_\text{MCP}) \text{\ watt}
\]
FL 200 100% MCP

\[
\text{Power}_{200\_\text{reg\_vector}} = \text{regress} \left( \frac{\text{Speed}_{200}}{\text{kts}}, \frac{\text{Power}_{200}}{\text{watt}} \right)^3
\]

\[
\text{Power}_{200\_\text{func}(\text{VCAS}_{200})} = \text{interp} \left( \text{Power}_{200\_\text{reg\_vector}}, \frac{\text{Speed}_{200}}{\text{kts}}, \frac{\text{Power}_{200}}{\text{watt}}, \frac{\text{VCAS}_{200}}{\text{kts}} \right)
\]

\[
\text{Power}_{200\_\text{func}(\text{VCAS}_{200})} = \text{Power}_{200\_\text{func}(\text{VCAS}_{200})} \text{ watt}
\]

FL 200 80% MCP

\[
\text{Power}_{200\_80\text{MCP\_reg\_vector}} = \text{regress} \left( \frac{\text{Speed}_{200\_80\text{MCP}}}{\text{kts}}, \frac{\text{Power}_{200\_80\text{MCP}}}{\text{watt}} \right)^3
\]

\[
\text{Power}_{200\_80\text{MCP\_func}(\text{VCAS}_{200\_80\text{MCP}})} = \text{interp} \left( \text{Power}_{200\_80\text{MCP\_reg\_vector}}, \frac{\text{Speed}_{200\_80\text{MCP}}}{\text{kts}}, \frac{\text{Power}_{200\_80\text{MCP}}}{\text{watt}}, \frac{\text{VCAS}_{200\_80\text{MCP}}}{\text{kts}} \right)
\]

\[
\text{Power}_{200\_80\text{MCP\_func}(\text{VCAS}_{200\_80\text{MCP}})} = \text{Power}_{200\_80\text{MCP\_func}(\text{VCAS}_{200\_80\text{MCP}})} \text{ watt}
\]

FL 200 60% MCP

\[
\text{Power}_{200\_60\text{MCP\_reg\_vector}} = \text{regress} \left( \frac{\text{Speed}_{200\_60\text{MCP}}}{\text{kts}}, \frac{\text{Power}_{200\_60\text{MCP}}}{\text{watt}} \right)^3
\]

\[
\text{Power}_{200\_60\text{MCP\_func}(\text{VCAS}_{200\_60\text{MCP}})} = \text{interp} \left( \text{Power}_{200\_60\text{MCP\_reg\_vector}}, \frac{\text{Speed}_{200\_60\text{MCP}}}{\text{kts}}, \frac{\text{Power}_{200\_60\text{MCP}}}{\text{watt}}, \frac{\text{VCAS}_{200\_60\text{MCP}}}{\text{kts}} \right)
\]

\[
\text{Power}_{200\_60\text{MCP\_func}(\text{VCAS}_{200\_60\text{MCP}})} = \text{Power}_{200\_60\text{MCP\_func}(\text{VCAS}_{200\_60\text{MCP}})} \text{ watt}
\]
FL 250 100% MCP

\[
\text{Power}_{250\_\text{reg\_vector}} = \text{regress}\left(\frac{\text{Speed}_{250}}{\text{kts}}, \frac{\text{Power}_{250}}{\text{watt}}, 3\right)
\]

\[
\text{Power}_{250\_\text{func}(\text{VCAS}_{250})} = \text{interp}\left(\text{Power}_{250\_\text{reg\_vector}}, \frac{\text{Speed}_{250}}{\text{kts}}, \frac{\text{Power}_{250}}{\text{watt}}, \frac{\text{VCAS}_{250}}{\text{kts}}\right)
\]

\[
\text{Power}_{250\_\text{func}(\text{VCAS}_{250})} = \text{Power}_{250\_\text{func}(\text{VCAS}_{250})} \text{ watt}
\]

FL 250 80% MCP

\[
\text{Power}_{250\_80\text{MCP\_reg\_vector}} = \text{regress}\left(\frac{\text{Speed}_{250\_80\text{MCP}}}{\text{kts}}, \frac{\text{Power}_{250\_80\text{MCP}}}{\text{watt}}, 3\right)
\]

\[
\text{Power}_{250\_80\text{MCP\_func}(\text{VCAS}_{250\_80\text{MCP}})} = \text{interp}\left(\text{Power}_{250\_80\text{MCP\_reg\_vector}}, \frac{\text{Speed}_{250\_80\text{MCP}}}{\text{kts}}, \frac{\text{Power}_{250\_80\text{MCP}}}{\text{watt}}, \frac{\text{VCAS}_{250\_80\text{MCP}}}{\text{kts}}\right)
\]

\[
\text{Power}_{250\_80\text{MCP\_func}(\text{VCAS}_{250\_80\text{MCP}})} = \text{Power}_{250\_80\text{MCP\_func}(\text{VCAS}_{250\_80\text{MCP}})} \text{ watt}
\]

FL 250 60% MCP

\[
\text{Power}_{250\_60\text{MCP\_reg\_vector}} = \text{regress}\left(\frac{\text{Speed}_{250\_60\text{MCP}}}{\text{kts}}, \frac{\text{Power}_{250\_60\text{MCP}}}{\text{watt}}, 3\right)
\]

\[
\text{Power}_{250\_60\text{MCP\_func}(\text{VCAS}_{250\_60\text{MCP}})} = \text{interp}\left(\text{Power}_{250\_60\text{MCP\_reg\_vector}}, \frac{\text{Speed}_{250\_60\text{MCP}}}{\text{kts}}, \frac{\text{Power}_{250\_60\text{MCP}}}{\text{watt}}, \frac{\text{VCAS}_{250\_60\text{MCP}}}{\text{kts}}\right)
\]

\[
\text{Power}_{250\_60\text{MCP\_func}(\text{VCAS}_{250\_60\text{MCP}})} = \text{Power}_{250\_60\text{MCP\_func}(\text{VCAS}_{250\_60\text{MCP}})} \text{ watt}
\]
FL 300 100% MCP

\[
\text{Power}_{300\_\text{reg\_vector}} = \text{regress}\left(\frac{\text{Speed}_{300}}{\text{kts}}, \frac{\text{Power}_{300}}{\text{watt}}, 3\right)
\]

\[
\text{Power}_{300\_\text{func}(\text{VCAS}_{300})} = \text{interp}\left(\text{Power}_{300\_\text{reg\_vector}}, \frac{\text{Speed}_{300}}{\text{kts}}, \frac{\text{Power}_{300}}{\text{watt}}, \frac{\text{VCAS}_{300}}{\text{kts}}\right)
\]

\[
\text{Power}_{300\_\text{func}(\text{VCAS}_{300})} = \text{Power}_{300\_\text{func}(\text{VCAS}_{300})} \text{ watt}
\]

FL 300 80% MCP

\[
\text{Power}_{300\_80MCP\_\text{reg\_vector}} = \text{regress}\left(\frac{\text{Speed}_{300\_80MCP}}{\text{kts}}, \frac{\text{Power}_{300\_80MCP}}{\text{watt}}, 3\right)
\]

\[
\text{Power}_{300\_80MCP\_\text{func}(\text{VCAS}_{300\_80MCP})} = \text{interp}\left(\text{Power}_{300\_80MCP\_\text{reg\_vector}}, \frac{\text{Speed}_{300\_80MCP}}{\text{kts}}, \frac{\text{Power}_{300\_80MCP}}{\text{watt}}, \frac{\text{VCAS}_{300\_80MCP}}{\text{kts}}\right)
\]

\[
\text{Power}_{300\_80MCP\_\text{func}(\text{VCAS}_{300\_80MCP})} = \text{Power}_{300\_80MCP\_\text{func}(\text{VCAS}_{300\_80MCP})} \text{ watt}
\]

FL 300 60% MCP

\[
\text{Power}_{300\_60MCP\_\text{reg\_vector}} = \text{regress}\left(\frac{\text{Speed}_{300\_60MCP}}{\text{kts}}, \frac{\text{Power}_{300\_60MCP}}{\text{watt}}, 3\right)
\]

\[
\text{Power}_{300\_60MCP\_\text{func}(\text{VCAS}_{300\_60MCP})} = \text{interp}\left(\text{Power}_{300\_60MCP\_\text{reg\_vector}}, \frac{\text{Speed}_{300\_60MCP}}{\text{kts}}, \frac{\text{Power}_{300\_60MCP}}{\text{watt}}, \frac{\text{VCAS}_{300\_60MCP}}{\text{kts}}\right)
\]

\[
\text{Power}_{300\_60MCP\_\text{func}(\text{VCAS}_{300\_60MCP})} = \text{Power}_{300\_60MCP\_\text{func}(\text{VCAS}_{300\_60MCP})} \text{ watt}
\]
ENGINE PERFORMANCE
WING DATA

\[ Re_w(H, V_{CAS}, dL/SA) = \frac{1}{\mu_w} f_{Re}(H, V_{CAS}, dL/SA) \]

\[ \frac{b_w^2}{S_w} \quad \text{wing aspect ratio (geometric)} \]

\[ \Lambda_w = 8.813 \]

\[ c_{\text{mean}_w} = \frac{S_w}{b_w} \quad \text{mean geometric chord} \]

\[ c_{\text{mean}_w} = 1.339 \text{m} \]

\[ S_{wc} = S_w - S_{wfl} \]

\[ S_{wc} = 5.8 \text{m}^2 \quad \text{non-flapped / clean wing area} \]

\[ b_{wfl} = \frac{S_{wfl}}{c_{\text{mean}_w}} \quad \text{flaped wing span} \]

\[ b_{wfl} = 7.468 \text{m} \]

\[ \frac{b_{wfl}^2}{S_{wfl}} \quad \Lambda_{wfl} = 5.578 \]

WING GEOMETRY
**FUSELAGE GEOMETRY**

**FUSELAGE DATA**

This section generates the basic aerodynamic and geometric variables from the input that was supplied above.

\[ R_{\text{fus}}(H, \text{VCAS}, \text{d}l\text{SA}) = f_{\text{Re}}(H, \text{VCAS}, \text{d}l\text{SA}) \cdot l_{\text{fus}} \]

- Reynolds Number of the fuselage

\[ df_{\text{fus}} = \sqrt{\frac{4}{\pi} S_{\text{fus}}} \]

- Equivalent \( df \) for non-circular cross-section of fuselage

\[ df_{\text{fus}} = 1.3249 \text{ m} \]

\[ d_{b} = \sqrt{\frac{4}{\pi} S_{b}} \]

- Base diameter of the aft base area

\[ d_{b} = 0.505 \text{ m} \]

\[ f_{\text{frus}} = \frac{l_{\text{fus}}}{d_{\text{fus}}} \]

- Finness ratio of the fuselage

\[ f_{\text{frus}} = 6.423 \]
EMPENNAGE GEOMETRY

EMPENNAGE DATA

HORIZONTAL TAILPLANE

\[ \lambda_h = \frac{b_h^2}{S_h} \]

horizontal tail geometric aspect ratio / see figures 2.5-2.7

\[ \lambda_h = 4.0026 \]

\[ c_{\text{mean}_h} = \frac{S_h}{b_h} \]

mean geometric chord of the horizontal tail

\[ c_{\text{mean}_h} = 0.974 \text{m} \]

\[ c_{\text{emp}_e_h} = c_{\text{mean}_h} \]

exposed empennage surface / exposed mean geometric chord

\[ \lambda_h = \frac{t \text{chord}_h}{c_{\text{emp}_e_h}} \]

horizontal tailplane taper ratio

\[ \lambda_h = 0.438 \]

\[ S_{\text{wet}_\text{emp}_h} = 2S_h \left( 1 + 0.25 \frac{t_h}{c_{\text{emp}_e_h}} \frac{1 + t_h \lambda_h}{1 + \lambda_h} \right) \]

\[ S_{\text{wet}_\text{emp}_h} = 7.85 \text{m}^2 \]
VERTICAL TAILPLANE

\[ \Lambda_v = \frac{b_v^2}{S_v} \]

vertical tail geometric aspect ratio / see figures 2 5 - 2 7

\[ \Lambda_v = 1.2893 \]

mean geometric chord of the vertical tail

\[ c_{\text{mean}_v} = \frac{S_v}{b_v} \]

\[ c_{\text{mean}_v} = 1.474 \text{ m} \]

Vertical tailplane surface wetted area (Figure 4 6 / Appendix B)

\[ c_{\text{emp}_v} = c_{\text{mean}_v} \]

exposed empennage surface / exposed mean geometric chord

\[ \lambda_v = \frac{\text{tipchord}_v}{\text{rootchord}_v} \]

horizontal tailplane taper ratio

\[ \lambda_v = 0.525 \]

\[ S_{\text{wet_emp}_v} = 2S_v \left( 1 + 0.25 \frac{t_v}{c_{\text{emp}_v}} \frac{1 + \tau_v \lambda_v}{1 + \lambda_v} \right) \]

\[ S_{\text{wet_emp}_v} = 5.741 \text{ m}^2 \]

F EMPENNAGE GEOMETRY
## WING LIFT (PSW)

### Area, Span, and Chord Data of Wing Segments Used in PSW

*a = 0 to 23*

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<th>span&lt;sub&gt;a&lt;/sub&gt;</th>
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### 3D CL AND CM DATA AT DIFFERENT AOAs

Values of alfa below refer to the coordinate system in the panel code, which is not necessarily the same as the one used here.

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Panel model used was testwing3
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\]

\[
\text{CL}_{\text{mean}0} = 0.301
\]

\[
\text{CL}_{\text{mean}4} = \frac{\text{area}_{\text{CL3d4}}}{\sum \text{area}}
\]

\[
\text{CL}_{\text{mean}4} = 0.659
\]

\[
\text{CL}_{\text{mean}8} = \frac{\text{area}_{\text{CL3d8}}}{\sum \text{area}}
\]

\[
\text{CL}_{\text{mean}8} = 1.013
\]

\[
\text{CL}_{\text{mean}12} = \frac{\text{area}_{\text{CL3d12}}}{\sum \text{area}}
\]

\[
\text{CL}_{\text{mean}12} = 1.362
\]

\[
\text{CL}_{\text{mean}16} = \frac{\text{area}_{\text{CL3d16}}}{\sum \text{area}}
\]

\[
\text{CL}_{\text{mean}16} = 1.7
\]

\[
\text{CL}_{\text{mean}2} = \frac{\text{area}_{\text{CL3d2}}}{\sum \text{area}}
\]

\[
\text{CL}_{\text{mean}2} = 0.481
\]

\[
\text{CL}_{\text{mean}6} = \frac{\text{area}_{\text{CL3d6}}}{\sum \text{area}}
\]

\[
\text{CL}_{\text{mean}6} = 0.836
\]

\[
\text{CL}_{\text{mean}10} = \frac{\text{area}_{\text{CL3d10}}}{\sum \text{area}}
\]

\[
\text{CL}_{\text{mean}10} = 1.188
\]

\[
\text{CL}_{\text{mean}14} = \frac{\text{area}_{\text{CL3d14}}}{\sum \text{area}}
\]

\[
\text{CL}_{\text{mean}14} = 1.534
\]
<p>| CLviscid(sp) = interp(span, CL3d0, sp) | CLfunct(sp) = |
| CLviscid2(sp) = interp(span, CL3d2, sp) | CLviscid2(sp) if CLviscid2(sp) ≤ CLmax |
| CLmax if CLviscid2(sp) &gt; CLmax |
| CLviscid4(sp) = interp(span, CL3d4, sp) | CLviscid4(sp) if CLviscid4(sp) ≤ CLmax |
| CLmax if CLviscid4(sp) &gt; CLmax |
| CLviscid6(sp) = interp(span, CL3d6, sp) | CLviscid6(sp) if CLviscid6(sp) ≤ CLmax |
| CLmax if CLviscid6(sp) &gt; CLmax |
| CLviscid8(sp) = interp(span, CL3d8, sp) | CLviscid8(sp) if CLviscid8(sp) ≤ CLmax |
| CLmax if CLviscid8(sp) &gt; CLmax |
| CLviscid10(sp) = interp(span, CL3d10, sp) | CLviscid10(sp) if CLviscid10(sp) ≤ CLmax |
| CLmax if CLviscid10(sp) &gt; CLmax |
| CLviscid12(sp) = interp(span, CL3d12, sp) | CLviscid12(sp) if CLviscid12(sp) ≤ CLmax |
| CLmax if CLviscid12(sp) &gt; CLmax |
| CLviscid14(sp) = interp(span, CL3d14, sp) | CLviscid14(sp) if CLviscid14(sp) ≤ CLmax |
| CLmax if CLviscid14(sp) &gt; CLmax |
| CLviscid16(sp) = interp(span, CL3d16, sp) | CLviscid16(sp) if CLviscid16(sp) ≤ CLmax |
| CLmax if CLviscid16(sp) &gt; CLmax |</p>
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<tr>
<th>$\text{Clave}_0$</th>
<th>$\frac{1}{\text{span}_{23} - \text{span}<em>0} \left( \int</em>{\text{span}<em>0}^{\text{span}</em>{23}} \text{CLftfunct}(sp) , dsp \right)$</th>
<th>$\text{Clave}_2$</th>
<th>$\frac{1}{\text{span}_{23} - \text{span}<em>0} \left( \int</em>{\text{span}<em>0}^{\text{span}</em>{23}} \text{CLftfunct}(sp) , dsp \right)$</th>
</tr>
</thead>
<tbody>
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<td>$\frac{1}{\text{span}_{23} - \text{span}<em>0} \left( \int</em>{\text{span}<em>0}^{\text{span}</em>{23}} \text{CLftfunct}(sp) , dsp \right)$</td>
<td>$\text{Clave}_2 = 0.479$</td>
<td>$\frac{1}{\text{span}_{23} - \text{span}<em>0} \left( \int</em>{\text{span}<em>0}^{\text{span}</em>{23}} \text{CLftfunct}(sp) , dsp \right)$</td>
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<tr>
<td>$\text{Clave}_4 = 0.657$</td>
<td>$\frac{1}{\text{span}_{23} - \text{span}<em>0} \left( \int</em>{\text{span}<em>0}^{\text{span}</em>{23}} \text{CLftfunct}(sp) , dsp \right)$</td>
<td>$\text{Clave}_6 = 0.834$</td>
<td>$\frac{1}{\text{span}_{23} - \text{span}<em>0} \left( \int</em>{\text{span}<em>0}^{\text{span}</em>{23}} \text{CLftfunct}(sp) , dsp \right)$</td>
</tr>
<tr>
<td>$\text{Clave}_8 = 1.01$</td>
<td>$\frac{1}{\text{span}_{23} - \text{span}<em>0} \left( \int</em>{\text{span}<em>0}^{\text{span}</em>{23}} \text{CLftfunct}(sp) , dsp \right)$</td>
<td>$\text{Clave}_10 = 1.185$</td>
<td>$\frac{1}{\text{span}_{23} - \text{span}<em>0} \left( \int</em>{\text{span}<em>0}^{\text{span}</em>{23}} \text{CLftfunct}(sp) , dsp \right)$</td>
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<tr>
<td>$\text{Clave}_{12} = 1.299$</td>
<td>$\frac{1}{\text{span}_{23} - \text{span}<em>0} \left( \int</em>{\text{span}<em>0}^{\text{span}</em>{23}} \text{CLftfunct}(sp) , dsp \right)$</td>
<td>$\text{Clave}_{14} = 1.324$</td>
<td>$\frac{1}{\text{span}_{23} - \text{span}<em>0} \left( \int</em>{\text{span}<em>0}^{\text{span}</em>{23}} \text{CLftfunct}(sp) , dsp \right)$</td>
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<tr>
<td>$\text{Clave}_{16} = 1.337$</td>
<td>$\frac{1}{\text{span}_{23} - \text{span}<em>0} \left( \int</em>{\text{span}<em>0}^{\text{span}</em>{23}} \text{CLftfunct}(sp) , dsp \right)$</td>
<td></td>
<td></td>
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</table>
AIRFOIL LIFT CURVE FROM DA-40/42 USED FOR CALIBRATION

\[ \begin{array}{cccc}
\text{angle}_b & \text{coeff}_b & \text{inviscid}_b & \text{\text{\text{c}}l_{\text{clean}}}_i \\
1.0\text{deg} & \text{CLave0} & \text{CLmean0} & -0.47 \\
3.0\text{deg} & \text{CLave2} & \text{CLmean2} & -0.09 \\
5.0\text{deg} & \text{CLave4} & \text{CLmean4} & 0.28 \\
7.0\text{deg} & \text{CLave6} & \text{CLmean6} & 0.97 \\
9.0\text{deg} & \text{CLave8} & \text{CLmean8} & 1.44 \\
11.0\text{deg} & \text{CLave10} & \text{CLmean10} & 1.56 \\
13.0\text{deg} & \text{CLave12} & \text{CLmean12} & 1.61 \\
15.0\text{deg} & \text{CLave14} & \text{CLmean14} & 1.64 \\
17.0\text{deg} & \text{CLave14} & \text{CLmean16} & 1.56 \\
\end{array} \]

\[ \alpha = -10 \text{deg}, -9.9 \text{deg}, 25 \text{deg} \]

\[ \text{splinevec}_{\text{clean}} = \text{pspline}(\alpha_{\text{clean}}, \text{c}_{l_{\text{clean}}}) \]

\[ \text{c}_{l_{\text{clean}}} = \text{interp(splinevec}_{\text{clean}}, \alpha_{\text{clean}}, \text{c}_{l_{\text{clean}}, \alpha}) \]

\[ \text{c}_{l_{\text{w_clean}}} = \text{c}_{l_{\text{clean}}} \]

\[ \text{c}_{l_{\text{w_clean}}} = \frac{\text{c}_{l_{\text{w_clean}}} \Lambda_w}{\Lambda_w + 2} \]
\[ \alpha := -10 \text{ deg}, -9.9 \text{ deg}, 25 \text{ deg} \]

\[ \text{lift\_curve} := \text{pspline}(\text{angle}, \text{coeff}) \]

\[ \text{lift\_curve}(\alpha) := \text{interp(lift\_curve, angle, coeff, \alpha)} \]
TRIM AERODYNAMICS [CLEAN]

TRIM REQUIREMENT / CLEAN
Evaluates the required lift coefficient of the horizontal tail, needed for trimmed balance condition.

\[ C_{M0wf\_clean} = C_{m0\_clean} \]

TRIM REQUIREMENT / BALANCE CONDITION

<table>
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<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
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<td>( x_{NPwf} )</td>
<td>2.38 m</td>
</tr>
<tr>
<td>( x_{CG} )</td>
<td>2.35 m</td>
</tr>
<tr>
<td>( l_{\mu_h} )</td>
<td>0.767 m</td>
</tr>
<tr>
<td>( l_{\mu_w} )</td>
<td>1.35 m</td>
</tr>
<tr>
<td>( x_{ACw} )</td>
<td>2.575 m</td>
</tr>
<tr>
<td>( x_{ACh} )</td>
<td>7.372 m</td>
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</table>

\[ CM_{\text{mean0}} = \frac{\text{area}}{CM_{3d0}} \sum \text{area} \]

\[ CM_{\text{mean0}} = -0.056 \]

for 15% SM

same as old

from 0 deg mean PSW

CM min from WT

\[ 0 = C_{M0w\_clean} + C_{M0f\_clean} = \left( \frac{\text{mass}}{q(s(V_{CAS})} + \frac{C_{Lh\_clean}}{S_h} \right) \frac{x_{ACw} - x_{CG}}{l_{\mu\_w}} \frac{x_{ACh} - x_{CG}}{l_{\mu\_w}} + \frac{C_{M0h}}{l_{\mu\_w}} \frac{Sh}{S_w} \]
CLh_clean(VCAS, mass) := 
\[
\frac{C_{Mw\_clean} + C_{Mf\_clean} - \left( \frac{mass \cdot g}{qs(VCAS) \cdot S_w} \cdot \frac{x_{ACw} - x_{CG}}{I_{\mu\_w}} \right)}{S_h \cdot \left( \frac{x_{ACw} - x_{CG}}{I_{\mu\_w}} + \frac{x_{ACCh} - x_{CG}}{I_{\mu\_w}} \right)}
\]
WING ANGLE OF ATTACK

\[ C_{\text{LW clean}}(\text{mass}, \text{v CAS}) = \frac{\text{mass} \cdot g}{q_{\infty}(\text{v CAS}) \cdot S_{\infty}} + C_{\text{Lh clean}}(\text{v CAS}, \text{mass}) \cdot \frac{S_{h}}{S_{\infty}} \]  

horizontal cruise flight

\[ \alpha := 0 \text{ deg} \quad \text{expected value for } \alpha \text{ must be defined for the numerical method} \]

Given

\[ \text{lift curve}(\alpha) = C_{\text{LW clean}}(\text{mass}, \text{v CAS}) \]

\[ \alpha_{\text{W clean}}(\text{mass}, \text{v CAS}) := \text{Find}(\alpha) \]

\[ \alpha_{\text{W clean}}(2000 \text{ kg}, 220 \text{ kts}) = -0.974 \text{ deg} \]
LIFT DISTRIBUTION

\[ \text{angle}_0 = 1 \text{ deg} \]
\[ \text{angle}_1 = 3 \text{ deg} \]
\[ \text{angle}_2 = 5 \text{ deg} \]
\[ \text{angle}_3 = 7 \text{ deg} \]
\[ \text{angle}_4 = 9 \text{ deg} \]
\[ \text{angle}_5 = 11 \text{ deg} \]
\[ \text{angle}_6 = 13 \text{ deg} \]
\[ \text{angle}_7 = 15 \text{ deg} \]
\[ \text{angle}_8 = 17 \text{ deg} \]

\[ \text{CL3Dincomp}(\text{mass}, \text{VCAS}, \text{span}) = \]
\[ \begin{align*}
\alpha_{w\_clean}(\text{mass}, \text{VCAS}) \quad & \quad \text{deg} \\
\angle_0 \quad & \quad \text{deg} \\
\angle_1 \quad & \quad \text{deg} \\
\angle_2 \quad & \quad \text{deg} \\
\angle_3 \quad & \quad \text{deg} \\
\angle_4 \quad & \quad \text{deg} \\
\angle_5 \quad & \quad \text{deg} \\
\angle_6 \quad & \quad \text{deg} \\
\angle_7 \quad & \quad \text{deg} \\
\angle_8 \quad & \quad \text{deg}
\end{align*} \]

\[ \text{CLfunct}(\text{span}) + \]
\[ \frac{\alpha_{w\_clean}(\text{mass}, \text{VCAS})}{\angle_0} - \frac{\angle_1}{\angle_0} \left( \text{CLfunct}_{2}(\text{span}) - \text{CLfunct}_{0}(\text{span}) \right) \]
\[ \text{CLfunct}_{2}(\text{span}) + \]
\[ \frac{\alpha_{w\_clean}(\text{mass}, \text{VCAS})}{\angle_1} - \frac{\angle_2}{\angle_1} \left( \text{CLfunct}_{4}(\text{span}) - \text{CLfunct}_{2}(\text{span}) \right) \]
\[ \text{CLfunct}_{4}(\text{span}) + \]
\[ \frac{\alpha_{w\_clean}(\text{mass}, \text{VCAS})}{\angle_2} - \frac{\angle_3}{\angle_2} \left( \text{CLfunct}_{6}(\text{span}) - \text{CLfunct}_{4}(\text{span}) \right) \]
\[ \text{CLfunct}_{6}(\text{span}) + \]
\[ \frac{\alpha_{w\_clean}(\text{mass}, \text{VCAS})}{\angle_3} - \frac{\angle_4}{\angle_3} \left( \text{CLfunct}_{8}(\text{span}) - \text{CLfunct}_{6}(\text{span}) \right) \]
\[ \text{CLfunct}_{8}(\text{span}) + \]
\[ \frac{\alpha_{w\_clean}(\text{mass}, \text{VCAS})}{\angle_4} - \frac{\angle_5}{\angle_4} \left( \text{CLfunct}_{10}(\text{span}) - \text{CLfunct}_{8}(\text{span}) \right) \]

\text{if } -10 \leq \frac{\alpha_{w\_clean}(\text{mass}, \text{VCAS})}{\text{deg}} < \frac{\text{angle}_1}{\text{deg}}

\text{if } \frac{\angle_1}{\text{deg}} \leq \frac{\alpha_{w\_clean}(\text{mass}, \text{VCAS})}{\text{deg}} < \frac{\angle_2}{\text{deg}}

\text{if } \frac{\angle_2}{\text{deg}} \leq \frac{\alpha_{w\_clean}(\text{mass}, \text{VCAS})}{\text{deg}} < \frac{\angle_3}{\text{deg}}

\text{if } \frac{\angle_3}{\text{deg}} \leq \frac{\alpha_{w\_clean}(\text{mass}, \text{VCAS})}{\text{deg}} < \frac{\angle_4}{\text{deg}}

\text{if } \frac{\angle_4}{\text{deg}} \leq \frac{\alpha_{w\_clean}(\text{mass}, \text{VCAS})}{\text{deg}} < \frac{\angle_5}{\text{deg}}
\[\frac{\alpha_w_{clean}(mass, V_{CAS})}{\text{deg}} - \frac{\angle_5}{\text{deg}} = \frac{CL_{func10}(span)}{\text{deg}} - \frac{CL_{func16}(span)}{\text{deg}}\]

\[\frac{\alpha_w_{clean}(mass, V_{CAS})}{\text{deg}} - \frac{\angle_6}{\text{deg}} = \frac{CL_{func12}(span)}{\text{deg}} - \frac{CL_{func16}(span)}{\text{deg}}\]

\[\frac{\alpha_w_{clean}(mass, V_{CAS})}{\text{deg}} - \frac{\angle_7}{\text{deg}} = \frac{CL_{func14}(span)}{\text{deg}} - \frac{CL_{func16}(span)}{\text{deg}}\]

\[CL_{3D}(mass, V_{CAS}, \text{span}, H, \text{dISA}) = \frac{CL_{3Dincomp}(mass, V_{CAS}, \text{span})}{\beta(H, V_{CAS}, \text{dISA})}\]

\[CL_{3D}(2000\text{kg}, 220\text{kts}, 9.826\text{m}, 25000\text{ft}, 0\text{K}) = 0.171\]
LIFT DISTRIBUTION

- CLfunct0(sp)
- CLfunct2(sp)
- CLfunct4(sp)
- CLfunct6(sp)
- CLfunct8(sp)
- CLfunct10(sp)
- CLfunct12(sp)
- CLfunct14(sp)
- CLfunct16(sp)
- CL3Dincomp(2000kg, 220kts, sp)
- CL3D(2000kg, 220kts, sp, 25000ft, 0K)
- CLave0
- CLave2
### WING DRAG (X-FOIL)

#### 2D Wing

Re = 8.3 million

\[ c_2 = 0 \quad 17 \]

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<th>( \text{CDte}_1c_2 )</th>
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</table>
\[ CD_w(mass, v_{CAS}, span, H, \text{di}SA) = \text{interp}(CLte1, CDte1, CL3D(mass, v_{CAS}, span, H, \text{di}SA)) \]

Note: areas of the wing segments used below for calculation of drag only correspond to the starboard wing, therefore they need to be multiplied by 2.

**DRAG COMPUTED USING VARYING RE**

\[ \text{Drag}_\text{form}(mass, v_{CAS}, H, \text{di}SA) = \sum_a CD_w(mass, v_{CAS}, span_a, H, \text{di}SA) \left(2 \text{ area}_a \right) q_s(v_{CAS}) \]

\[ \text{Drag}_\text{form}(2000\text{kg}, 220\text{kts}, 25000\text{ft}, 0\text{K}) = 452.83 \text{newton} \]
Drag due to lift

\[ \alpha_{\text{lift}} = 0 \text{ deg}, 0.1 \text{ deg}, 25 \text{ deg} \]

\[ \text{spaneff} = \text{interp}(\text{angle}, \text{speff}, \alpha) \]

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<th>\text{speff}_{\text{aa}}</th>
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</tbody>
</table>
\[ \text{CDL}(\text{mass}, \text{VCAS}) := \frac{\text{lift_curve}(\alpha_{\text{w clean}}(\text{mass, VCAS}))^2}{\pi \cdot \Lambda_W \cdot \text{spaneff_curve}(\alpha_{\text{w clean}}(2000\text{kg, VCAS}))} \]

\[ \text{CDL_{ellipt}}(\text{mass}, \text{VCAS}) := \frac{\text{lift_curve}(\alpha_{\text{w clean}}(\text{mass, VCAS}))^2}{\pi \cdot \Lambda_W} \]

\[ \text{Drag}_{\text{lift}}(\text{mass, VCAS}) := \text{CDL}(\text{mass, VCAS}) \left( 2 \cdot \sum \text{area} \right) \cdot q_s(\text{VCAS}) \]
Total wing drag

\[
\text{Drag}_{\text{wing}}(\text{mass}, \text{VCAS}, \text{H}, \text{dISA}) := \text{Drag}_{\text{form}}(\text{mass}, \text{VCAS}, \text{H}, \text{dISA}) + \text{Drag}_{\text{lift}}(\text{mass}, \text{VCAS})
\]

\[
\text{Drag}_{\text{wing}}(2000\, \text{kg}, 220\, \text{kts}, 25000\, \text{ft}, 0\, \text{K}) = 516.631\, \text{newton}
\]
## 2D Tail

Airfoil used: NACA 0014  
Re: 4mio

\[ \alpha_{\text{tail}} = \begin{array}{c|c|c}
\text{deg} & C_{\text{tail}} & C_{\text{Dtail}} \\
-4.5 & -0.5994 & 0.00730 \\
-4 & -0.5333 & 0.00698 \\
-3.5 & -0.4670 & 0.00670 \\
-3 & -0.4006 & 0.00645 \\
-2.5 & -0.3341 & 0.00625 \\
-2 & -0.2674 & 0.00609 \\
-1.5 & -0.2006 & 0.00596 \\
-1 & -0.1337 & 0.00587 \\
-0.5 & -0.0668 & 0.00581 \\
0 & 0.0000 & 0.00578 \\
0.5 & 0.0668 & 0.00581 \\
1 & 0.1336 & 0.00587 \\
1.5 & 0.2006 & 0.00596 \\
2 & 0.2674 & 0.00609 \\
2.5 & 0.3341 & 0.00625 \\
3 & 0.4006 & 0.00645 \\
3.5 & 0.4669 & 0.00670 \\
4 & 0.5333 & 0.00698 \\
4.5 & 0.5994 & 0.00730 \\
5 & 0.6659 & 0.00764 \\
\end{array} \]
\[ C_L_h(mass, v_CAS, H, dISA) := \frac{C_L_h\_clean(v_CAS, mass)}{\beta(H, v_CAS, dISA)} \]

\[ CD_{hor\_tail\_form}(mass, v_CAS, H, dISA) := \text{interp}(C_L_{tail}, C_D_{tail}, C_L_h(mass, v_CAS, H, dISA)) \cdot \frac{S_h}{S_w} \]

\[ CD_{ver\_tail} := CD_{tail} \cdot \frac{S_v}{S_w} \]
Drag due to lift

\[ C_{D_{\text{hor\_tail\_lift}}}(\text{mass}, \text{v}_{\text{CAS}}, H, \text{dISA}) = \frac{C_{L_h}(\text{mass}, \text{v}_{\text{CAS}}, H, \text{dISA})^2}{\pi \cdot h \cdot \phi_h} \cdot \frac{S_h}{S_W} \]

Total tail drag

\[ C_{D_{\text{tail}}}(\text{mass}, \text{v}_{\text{CAS}}, H, \text{dISA}) = C_{D_{\text{hor\_tail\_form}}}(\text{mass}, \text{v}_{\text{CAS}}, H, \text{dISA}) + C_{D_{\text{hor\_tail\_lift}}}(\text{mass}, \text{v}_{\text{CAS}}, H, \text{dISA}) + C_{D_{\text{ver\_tail}}} \]

\[ C_{D_{\text{tail\_drag}}}(\text{mass}, \text{v}_{\text{CAS}}, H, \text{dISA}) = C_{D_{\text{tail}}}(\text{mass}, \text{v}_{\text{CAS}}, H, \text{dISA}) \left(2 \cdot \sum \text{area} \right) q_{\text{s}}(\text{v}_{\text{CAS}}) \]
### Fuselage

\[ e = 0 \quad 25 \quad \text{CMfuse}_\text{min} = -0.055 \]

<table>
<thead>
<tr>
<th>fusealpha_e</th>
<th>CLfuse_e</th>
<th>CDfuse_e</th>
</tr>
</thead>
<tbody>
<tr>
<td>-5 deg</td>
<td>-0.0325</td>
<td>0.0249</td>
</tr>
<tr>
<td>-4 deg</td>
<td>-0.0252</td>
<td>0.0237</td>
</tr>
<tr>
<td>-3 deg</td>
<td>-0.0179</td>
<td>0.0224</td>
</tr>
<tr>
<td>-2 deg</td>
<td>-0.0115</td>
<td>0.0218</td>
</tr>
<tr>
<td>-1 deg</td>
<td>-0.0049</td>
<td>0.0213</td>
</tr>
<tr>
<td>0 deg</td>
<td>0.0016</td>
<td>0.0210</td>
</tr>
<tr>
<td>1 deg</td>
<td>0.0090</td>
<td>0.0212</td>
</tr>
<tr>
<td>2 deg</td>
<td>0.0152</td>
<td>0.0216</td>
</tr>
<tr>
<td>3 deg</td>
<td>0.0191</td>
<td>0.0219</td>
</tr>
<tr>
<td>4 deg</td>
<td>0.0218</td>
<td>0.0223</td>
</tr>
<tr>
<td>5 deg</td>
<td>0.0243</td>
<td>0.0226</td>
</tr>
<tr>
<td>6 deg</td>
<td>0.0256</td>
<td>0.0231</td>
</tr>
<tr>
<td>7 deg</td>
<td>0.0280</td>
<td>0.0237</td>
</tr>
<tr>
<td>8 deg</td>
<td>0.0304</td>
<td>0.0246</td>
</tr>
<tr>
<td>9 deg</td>
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<td>0.0254</td>
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<tr>
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<td>0.0269</td>
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<tr>
<td>11 deg</td>
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<tr>
<td>12 deg</td>
<td>0.0329</td>
<td>0.0291</td>
</tr>
<tr>
<td>13 deg</td>
<td>0.0334</td>
<td>0.0307</td>
</tr>
</tbody>
</table>
$\alpha = -5 \text{ deg.}, -4.9 \text{ deg.}, 20 \text{ deg}$

$CD\text{fuse}_\alpha(a) = \text{interp}(\text{fuse}\alpha, CD\text{fuse}, a)$

$CD\text{fuse}_w(\text{mass, }v_{\text{CAS}}) = CD\text{fuse}_\alpha(\alpha_{\text{w_clean}}(\text{mass, }v_{\text{CAS}}))$

$CD\text{fuse}(\text{mass, }v_{\text{CAS}}, H, \text{dISA}) = CD\text{fuse}_w(\text{mass, }v_{\text{CAS}}) \left( \frac{47 \text{ in } f_{\text{Re}}}{f_{\text{Re}}(H, v_{\text{CAS}}, \text{dISA})} \right)^{0.13}$

$\text{Drag}_\text{fuse}(\text{mass, }v_{\text{CAS}}, H, \text{dISA}) = CD\text{fuse}(\text{mass, }v_{\text{CAS}}, H, \text{dISA}) \left( 2 \sum \text{area} \right) \rho v_{\text{CAS}}$

<table>
<thead>
<tr>
<th>$\alpha$</th>
<th>CDfuse (0.0345)</th>
<th>CDfuse (0.0352)</th>
<th>CDfuse (0.0355)</th>
<th>CDfuse (0.0363)</th>
<th>CDfuse (0.0369)</th>
<th>CDfuse (0.0371)</th>
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<tbody>
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<tr>
<td>17deg</td>
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<tr>
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</tr>
<tr>
<td>19deg</td>
<td>0.0371</td>
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</tr>
<tr>
<td>20deg</td>
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<td>0.0372</td>
<td>0.0372</td>
<td>0.0372</td>
<td>0.0372</td>
<td>0.0372</td>
<td>0.0372</td>
</tr>
</tbody>
</table>
$C_{Dfus}(2000kg, v_{CAS}, 25000ft, 0k)$

FUSELAGE DRAG