Introduction

Microsoft Flight Simulator (MSFS) is an inexpensive flight simulation program designed for the entertainment software market. You don't need to be an experienced pilot to get into the cockpit and fly planes that range in size from the two-seat Piper Cub all the way up to the Boeing 747 jumbo jet.

MSFS provides a comprehensive virtual world that is truly global in scope. You can try flying different aircraft to new places anywhere in the world with total control of the flight problems you experience. You can change the seasons and fly any time of day or night, in good weather or bad.

MSFS is also is flexible and expandable. There are virtually hundreds of aircraft types available that can be added to the aircraft provided by Microsoft. Additional aircraft can be purchased from a number of third party software publishers and many can also be downloaded for free from enthusiast web sites.

Each aircraft in MSFS is represented by a set of files that define the flight dynamics, sounds, panel layout, 3D geometry and paint design for the aircraft. The flight dynamics for each aircraft are defined in two separate files: a binary AIR file and a text based aircraft configuration file. AIR files are machine-readable files that specify the aerodynamic coefficients MSFS uses.

Microsoft documented the MSFS AIR file development process and defined the required and optional flight dynamics coefficients in the on-line FSX/ESP Software Development Kit (SDK).

The AIR files shipped with MSFS originated as assembly language text files that were subsequently compiled with the assembler in MS Visual Studio. These files, referred to as ASM files in this document, contain the same data as an AIR file, but in a structured text format. ASM files are divided into token blocks, where each token block corresponds to a section in the AIR file.

Most third-party MSFS developers have out of necessity, used alternate methods to develop the flight dynamics for their add-on aircraft. These methods generally require editing an existing AIR file at the binary level using a flight dynamics editor. There are several freeware flight dynamics editors available that provide the required AIR file editing capabilities, but all of them require extensive knowledge of aerodynamics and flight mechanics to make an airplane fly realistically in MSFS. None of them provide any assistance to the flight dynamics developer in computing appropriate values for aerodynamic coefficients.

AirWizEd is a flight dynamics development system for MSFS that allows developers to edit MSFS flight dynamics files in detail, while simultaneously analyzing the flight dynamics in terms of real-world aircraft performance. When requested, it can also compute the flight dynamics coefficients required to solve aircraft performance problems including aircraft speed, climb rate, turn rate, and roll rate specifications.

AirWizEd performs the following functions:

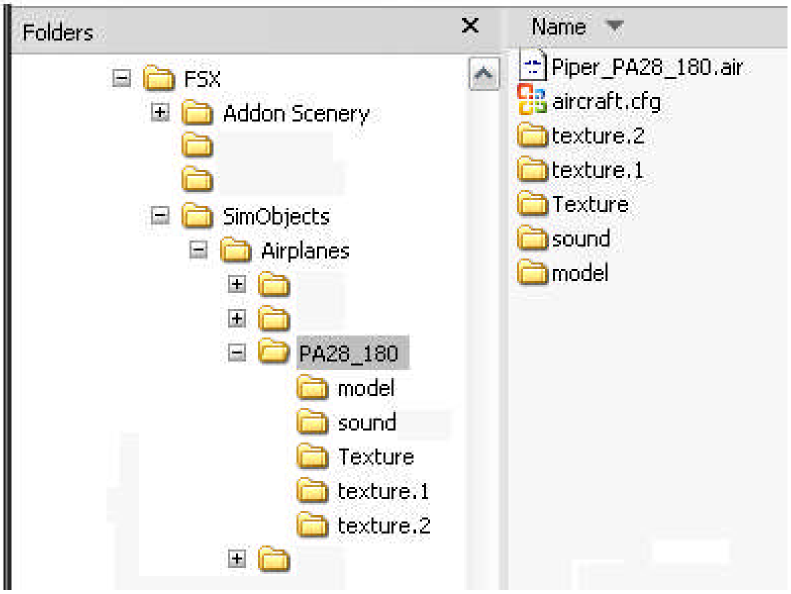
Read flight dynamics files (AIR, ASM and AIRCRAFT.CFG files),
Analyze aircraft simulation performance,
Calculate AIR file coefficients,
Edit AIR file coefficients,
Write flight dynamics files (AIR, ASM and AIRCRAFT.CFG files).

The AIR file editing features of AirWizEd were designed specifically for the parameters and coefficients documented in the FSX SDK.

AirWizEd can also assist in creating flight dynamics 'from scratch' using the physical specifications and performance characteristics of the actual aircraft with its analysis and optional auto-calculation features.

Aircraft Definition Files

Each aircraft in MSFS is represented by a set of files that define the flight dynamics, sounds, panel layout, 3D geometry and paint design for the aircraft. The following diagram shows the FSX folder hierarchy and some of the files you might find for a PA28 Piper Cherokee:

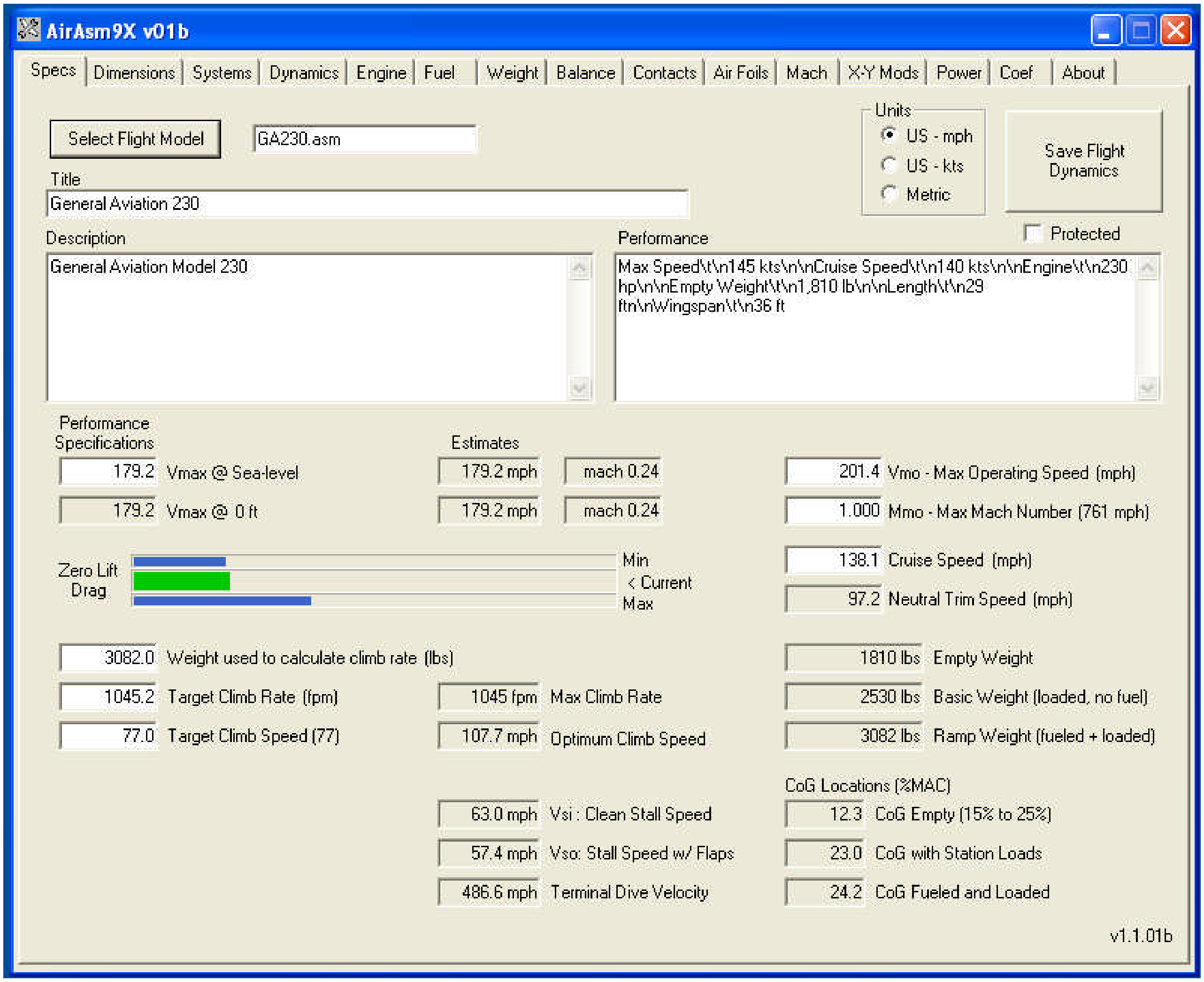


The simulator loads two data files at the start of each flight that define the characteristics of the aircraft selected by the user. These two data files are the text-based aircraft configuration file containing parameters like the dimensions and weight, and the binary AIR file that contains aerodynamic coefficients. Together, these files define the MSFS flight model. It is important to remember that these two files are a set and that changes in either can affect the flight characteristics and performance of the simulated aircraft.

For computational efficiency, MSFS 'compresses' all the physical bits and pieces of a real-world aircraft into a very simple virtual aircraft that consists of a mass, a wing and an engine. All of the aerodynamic forces produced by the wings, body, stabilizers, ailerons, elevator and rudder of a real aircraft are calculated at run-time from the dimensions of the virtual wing and the aerodynamic coefficients in the AIR file.

AirWizEd Specs Tab

AirWizEd has tabs for aircraft Specifications, Dimensions, Systems, Dynamics, Engine, Fuel, Weight, Balance, Contact points, Air Foils, Mach tables, X-Y Modifier tables, Power system coefficients, and Stability coefficients. The Specifications tab is used to browse, select and save flight model files.



Select Flight Model: GA230.asm

Units: ● US - mph ○ US - kts ○ Metric

☐ Protected

Title: General Aviation 230

Description: General Aviation Model 230

Performance: Max Speed\t\n145 kts\n\nCruise Speed\t\n140 kts\n\nEngine\t\n230 hp\n\nEmpty Weight\t\n1,810 lb\n\nLength\t\n29 ftn\nWingspan\t\n36 ft

Performance Specifications		Estimates			
179.2	Vmax @ Sea-level	179.2 mph	mach 0.24	201.4	Vmo - Max Operating Speed (mph)
179.2	Vmax @ 0 ft	179.2 mph	mach 0.24	1.000	Mmo - Max Mach Number (761 mph)
				138.1	Cruise Speed (mph)
				97.2	Neutral Trim Speed (mph)

3082.0	Weight used to calculate climb rate (lbs)			1810 lbs	Empty Weight
1045.2	Target Climb Rate (fpm)	1045 fpm	Max Climb Rate	2530 lbs	Basic Weight (loaded, no fuel)
77.0	Target Climb Speed (77)	107.7 mph	Optimum Climb Speed	3082 lbs	Ramp Weight (fueled + loaded)

		CoG Locations (%MAC)	
63.0 mph	Vsi : Clean Stall Speed	12.3	CoG Empty (15% to 25%)
57.4 mph	Vso: Stall Speed w/ Flaps	23.0	CoG with Station Loads
486.6 mph	Terminal Dive Velocity	24.2	CoG Fueled and Loaded

v1.1.01b

The AIR file and AIRCRAFT.CFG file formats have evolved over several generations of MSFS, and as a result, sections in the AIR file that were required by older versions are no longer used by the latest versions. In addition, some parameters that were stored in the AIR file for the older versions are now stored in the AIRCRAFT.CFG file. To ensure that flight models edited with AirWizEd can be used with any of the supported versions of MSFS, parameters from AIR files, ASM files, and AIRCRAFT.CFG files are merged into a consistent set of values and displayed on the AirWizEd data entry tabs. When AirWizEd saves the flight dynamics, equivalent values are written to AIR, ASM, and AIRCRAFT.CFG files, ensuring that all duplicated parameters are consistent across all of the output files.

To establish and maintain a consistent set of parameters, the flight dynamics files are always processed in the same order. When an AIR file is selected, AirWizEd resets its internal AIR file buffers to a set of built-in default values and then overwrites the defaults with the values read from the AIR file. If a corresponding ASM file is present, the ASM file values overwrite the AIR file values. The AIRCRAFT.CFG file is read last and its parameter values are also used to overwrite the corresponding AIR file parameter values.

An ASM file can also be opened directly. In this case, the parameters from the ASM file will overwrite the default AIR file values. The AIRCRAFT.CFG file is read last and its parameter values are used to overwrite the corresponding default AIR file parameter values.

It should be noted that there is no overlap between the AIR file and the AIRCRAFT.CFG file for the later versions of MSFS, For the older MSFS versions, the AIR file contained a number of parameters that are now stored in the AIRCRAFT.CFG file. It is very important to check and verify that all aircraft dimensions are accurate when starting work on any flight model.

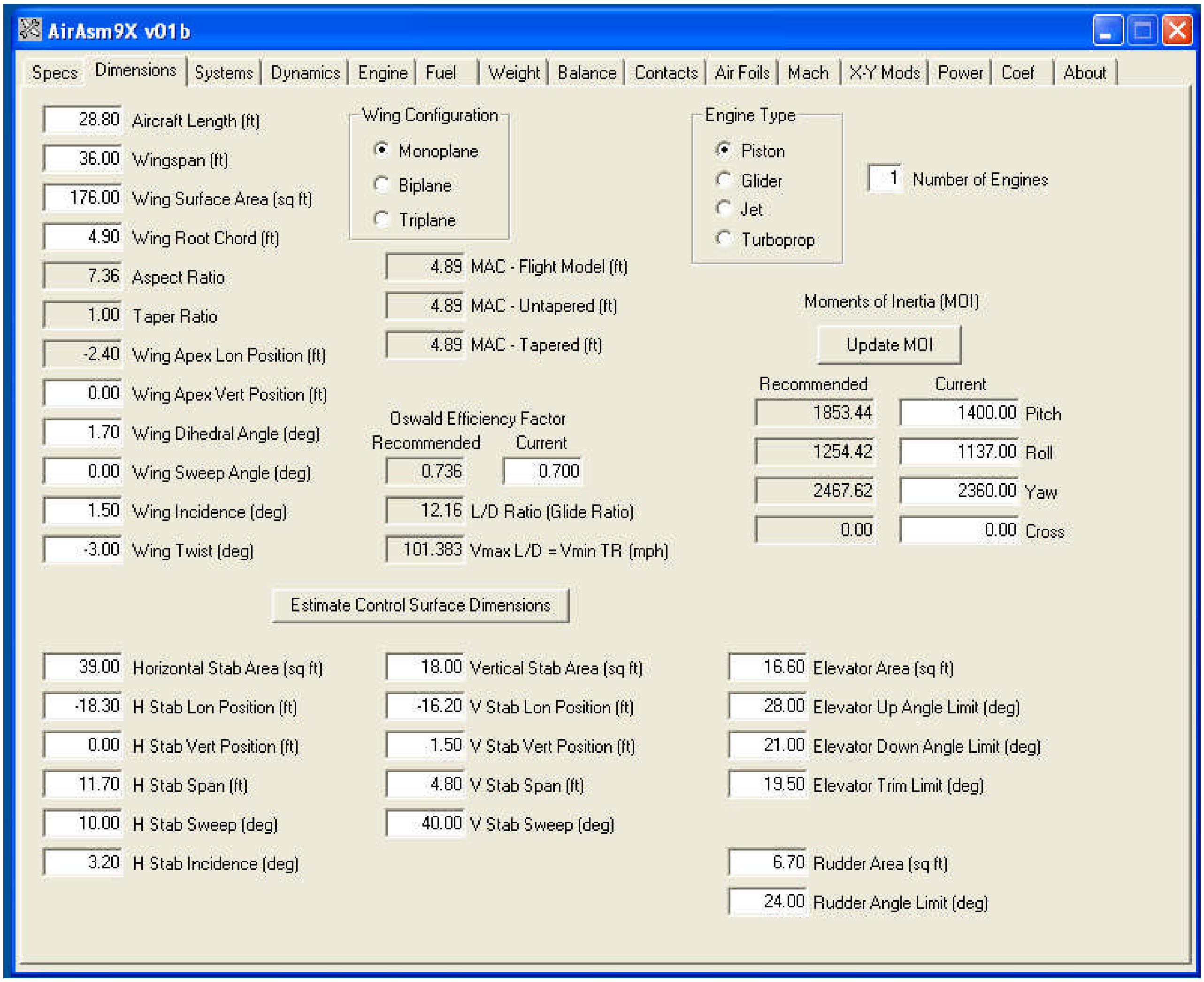
After all of the input files have been read, the dimensions, weights, power ratings, and aerodynamic coefficients are analyzed, and the estimated performance characteristics - maximum speeds, climb rates, roll rates, etc. - are displayed on the Specs tab. AirWizEd also saves its settings in a private section of the AIRCRAFT.CFG file for use in later editing sessions.

AirWizEd has two aircraft Performance Specifications: Vmax @ sea-level (enabled for all aircraft types) and Vmax at altitude (only enabled for turbocharged piston engines). To automatically recalculate the appropriate aerodynamic coefficients for matching these aircraft Performance Specifications, use the ‘Recalculate…’ button on the Engine tab. The performance estimates displayed are calculated from the current set of aircraft parameters and flight dynamics coefficients

When the flight dynamics are saved, an AIR file, a corresponding ASM file and an AIRCRAFT.CFG file are written. The AIR file and AIRCRAFT.CFG file are compatible with all versions of MSFS from FS2000 to FSX. The ASM file contains only FSX parameters.

Dimensions

The physical characteristics on the Dimensions tab are critical to getting an accurate virtual representation of the aircraft being modeled. All linear measurements and surface area inputs on the Dimensions tab are critical. If the values are wrong, the flight dynamics will not represent the aircraft you're attempting to model, and may not perform as expected in the simulator.



28.80 Aircraft Length (ft)
36.00 Wingspan (ft)
176.00 Wing Surface Area (sq ft)
4.90 Wing Root Chord (ft)
7.36 Aspect Ratio
1.00 Taper Ratio
-2.40 Wing Apex Lon Position (ft)
0.00 Wing Apex Vert Position (ft)
1.70 Wing Dihedral Angle (deg)
0.00 Wing Sweep Angle (deg)
1.50 Wing Incidence (deg)
-3.00 Wing Twist (deg)

Wing Configuration
● Monoplane
○ Biplane
○ Triplane

4.89 MAC - Flight Model (ft)
4.89 MAC - Untapered (ft)
4.89 MAC - Tapered (ft)

Oswald Efficiency Factor

Recommended	Current
0.736	0.700

12.16 L/D Ratio (Glide Ratio)
101.383 Vmax L/D = Vmin TR (mph)

Engine Type
● Piston
○ Glider
○ Jet
○ Turboprop

1 Number of Engines

Moments of Inertia (MOI)

Recommended	Current	
1853.44	1400.00	Pitch
1254.42	1137.00	Roll
2467.62	2360.00	Yaw
0.00	0.00	Cross

39.00 Horizontal Stab Area (sq ft)
-18.30 H Stab Lon Position (ft)
0.00 H Stab Vert Position (ft)
11.70 H Stab Span (ft)
10.00 H Stab Sweep (deg)
3.20 H Stab Incidence (deg)

18.00 Vertical Stab Area (sq ft)
-16.20 V Stab Lon Position (ft)
1.50 V Stab Vert Position (ft)
4.80 V Stab Span (ft)
40.00 V Stab Sweep (deg)

16.60 Elevator Area (sq ft)
28.00 Elevator Up Angle Limit (deg)
21.00 Elevator Down Angle Limit (deg)
19.50 Elevator Trim Limit (deg)
6.70 Rudder Area (sq ft)
24.00 Rudder Angle Limit (deg)

Scale drawings are probably the best source of the necessary dimensions, but some of the required data can also be found in aircraft manuals and reference books.

The following measurements are critical for AirWizEd to generate accurate flight dynamics:

Wingspan - The distance from wing tip to wing tip.

Length - The distance from the tip of the nose to the tip of the tail.

Wing Surface Area - Includes the area 'shadowed' by the fuselage.

Wing Root Chord - The distance from the wing's leading edge to trailing edge where the wing meets the fuselage.

Vertical Wing Position - The distance from the vertical center line to the center of the wing.

Wing Dihedral - The angle formed by the left and right wings.

Horizontal Stabilizer Area - The surface area of the horizontal stabilizer, including the area 'shadowed' by the fuselage. Does not include the elevator area. Be careful here, some books include the elevator area.

Elevator Area - The surface area of the elevator.

Horizontal Stabilizer Longitudinal Position - The distance from the leading edge of the wing to the leading edge of the horizontal stabilizer.

Vertical Stabilizer Area - The surface area of the vertical stabilizer. Does not include the rudder area. Be careful here, some books include the rudder area.

Rudder Area - The surface area of the rudder .

Vertical Stabilizer Longitudinal Position - The distance from the leading edge of the wing to the leading edge of the vertical stabilizer.

Wing Configuration

The number of wings in FS is actually always one, but AirWizEd determines a 'virtual' number of wings by dividing the wing area by the product of the wing span and the root chord. If the result is less than one, it's a 'monoplane'. Between 1 and 2 is a biplane, and larger than two is a triplane.

For a monoplane with a normal tapered wing, the wing area will always be less than the 'footprint' defined by the wing span multiplied by the root chord. If the wing area is larger than this footprint, then there must be more than one wing.

Many existing flight models use the mean chord as the root chord, and round-off errors can often cause the wing’s ‘footprint’ to be slightly less than the wing surface area. The solution is to use a larger (and more likely correct) value for the root chord.

AirWizEd was designed with the assumption that the aircraft's wing is tapered and that the root is wider than the tip. If this is not the case, then use the maximum chord width as the root chord.

Estimate Control Surface Dimensions

AirWizEd can use the stabilizer and control surface parameters to estimate the stability and control coefficients for the air file. The **Estimate Control Surface Dimensions** feature may be useful when the actual parameter values are unknown, or when the actual aircraft is tail-less.

The **Estimate Control Surface Dimensions** button, located on the Dimensions tab, may be used to estimate values for the stabilizer and control surface parameters. The current values of aircraft length, wingspan, and wing surface area are used to automatically update the following aircraft parameters:

Horizontal stabilizer area
Horizontal stabilizer span
Horizontal stabilizer longitudinal position
Horizontal stabilizer vertical position
Horizontal stabilizer incidence
Horizontal stabilizer sweep

Vertical stabilizer area
Vertical stabilizer span
Vertical stabilizer longitudinal position
Vertical stabilizer vertical position
Vertical stabilizer sweep

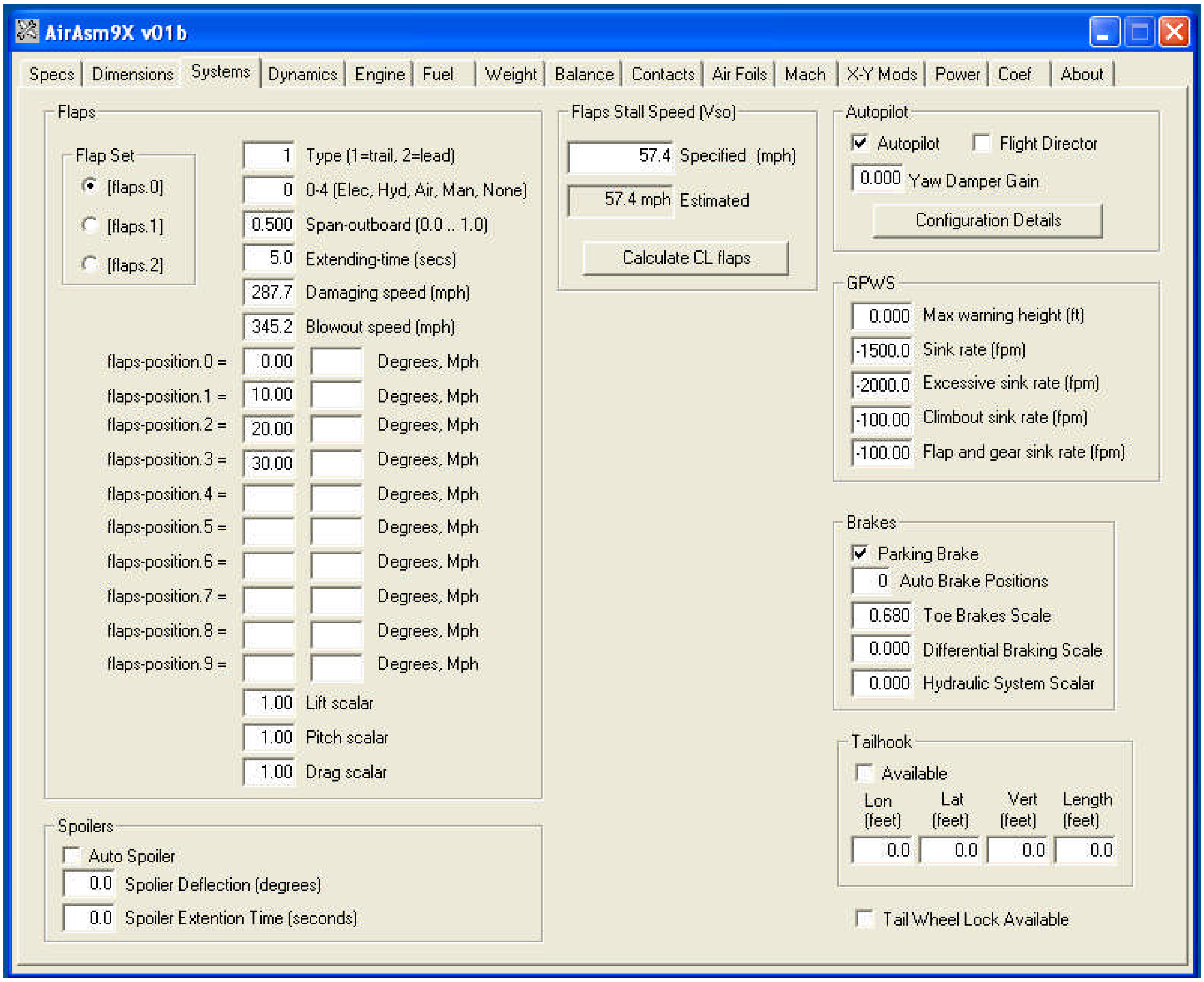
Elevator area
Rudder area
Aileron area

Using the **Estimate Control Surface Dimensions** button will automatically set the control surface deflection limits to the following values:

elevator_up_limit	25.0
elevator_down_limit	25.0
aileron_up_limit	20.0
aileron_down_limit	20.0
rudder_limit	30.0
elevator_trim_limit	20.0

Systems

The current flap, spoiler, and brake configurations are displayed and can be edited on this tab.



Flaps

Flap Set
● [flaps.0]
○ [flaps.1]
○ [flaps.2]

1 Type (1=trail, 2=lead)
0 0-4 (Elec, Hyd, Air, Man, None)
0.500 Span-outboard (0.0 .. 1.0)
5.0 Extending-time (secs)
287.7 Damaging speed (mph)
345.2 Blowout speed (mph)

flaps-position.0 = 0.00 Degrees, Mph
flaps-position.1 = 10.00 Degrees, Mph
flaps-position.2 = 20.00 Degrees, Mph
flaps-position.3 = 30.00 Degrees, Mph
flaps-position.4 = Degrees, Mph
flaps-position.5 = Degrees, Mph
flaps-position.6 = Degrees, Mph
flaps-position.7 = Degrees, Mph
flaps-position.8 = Degrees, Mph
flaps-position.9 = Degrees, Mph

1.00 Lift scalar
1.00 Pitch scalar
1.00 Drag scalar

Spoilers
☐ Auto Spoiler
0.0 Spolier Deflection (degrees)
0.0 Spoiler Extention Time (seconds)

Flaps Stall Speed (Vso)
57.4 Specified (mph)
57.4 mph Estimated

Autopilot
☑ Autopilot ☐ Flight Director
0.000 Yaw Damper Gain

GPWS
0.000 Max warning height (ft)
-1500.0 Sink rate (fpm)
-2000.0 Excessive sink rate (fpm)
-100.00 Climbout sink rate (fpm)
-100.00 Flap and gear sink rate (fpm)

Brakes
☑ Parking Brake
0 Auto Brake Positions
0.680 Toe Brakes Scale
0.000 Differential Braking Scale
0.000 Hydraulic System Scalar

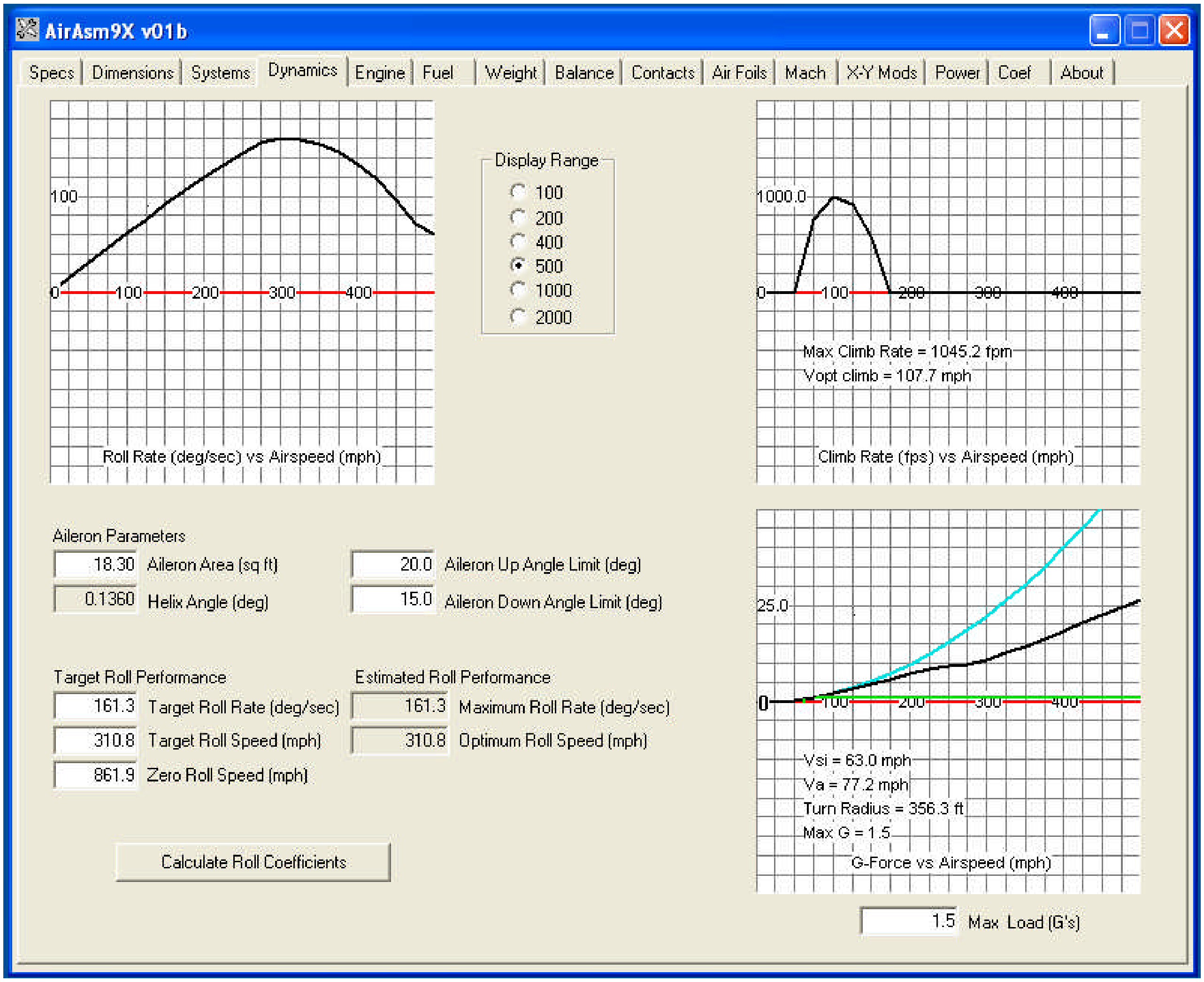
Tailhook
☐ Available

Lon (feet)	Lat (feet)	Vert (feet)	Length (feet)
0.0	0.0	0.0	0.0

☐ Tail Wheel Lock Available

Dynamics – Roll, Climb, and Turn Rates

AirWizEd estimates roll, climb and turn rates throughout the entire speed range and shows these estimates in graphical form on the Dynamics tab:



Display Range
○ 100
○ 200
○ 400
● 500
○ 1000
○ 2000

Max Climb Rate = 1045.2 fpm
Vopt climb = 107.7 mph

Aileron Parameters
18.30 Aileron Area (sq ft)
0.1360 Helix Angle (deg)
20.0 Aileron Up Angle Limit (deg)
15.0 Aileron Down Angle Limit (deg)

Target Roll Performance
161.3 Target Roll Rate (deg/sec)
310.8 Target Roll Speed (mph)
861.9 Zero Roll Speed (mph)

Estimated Roll Performance
161.3 Maximum Roll Rate (deg/sec)
310.8 Optimum Roll Speed (mph)

Vsi = 63.0 mph
Va = 77.2 mph
Turn Radius = 356.3 ft
Max G = 1.5

1.5 Max Load (G's)

Roll rates are a function of airspeed. At low speeds, roll rates are more or less linear and increase proportionally with airspeed. However, as the airspeed increases, ailerons become less effective due to many physical factors, and this causes the roll rate to flatten out and eventually decrease at very high speeds.

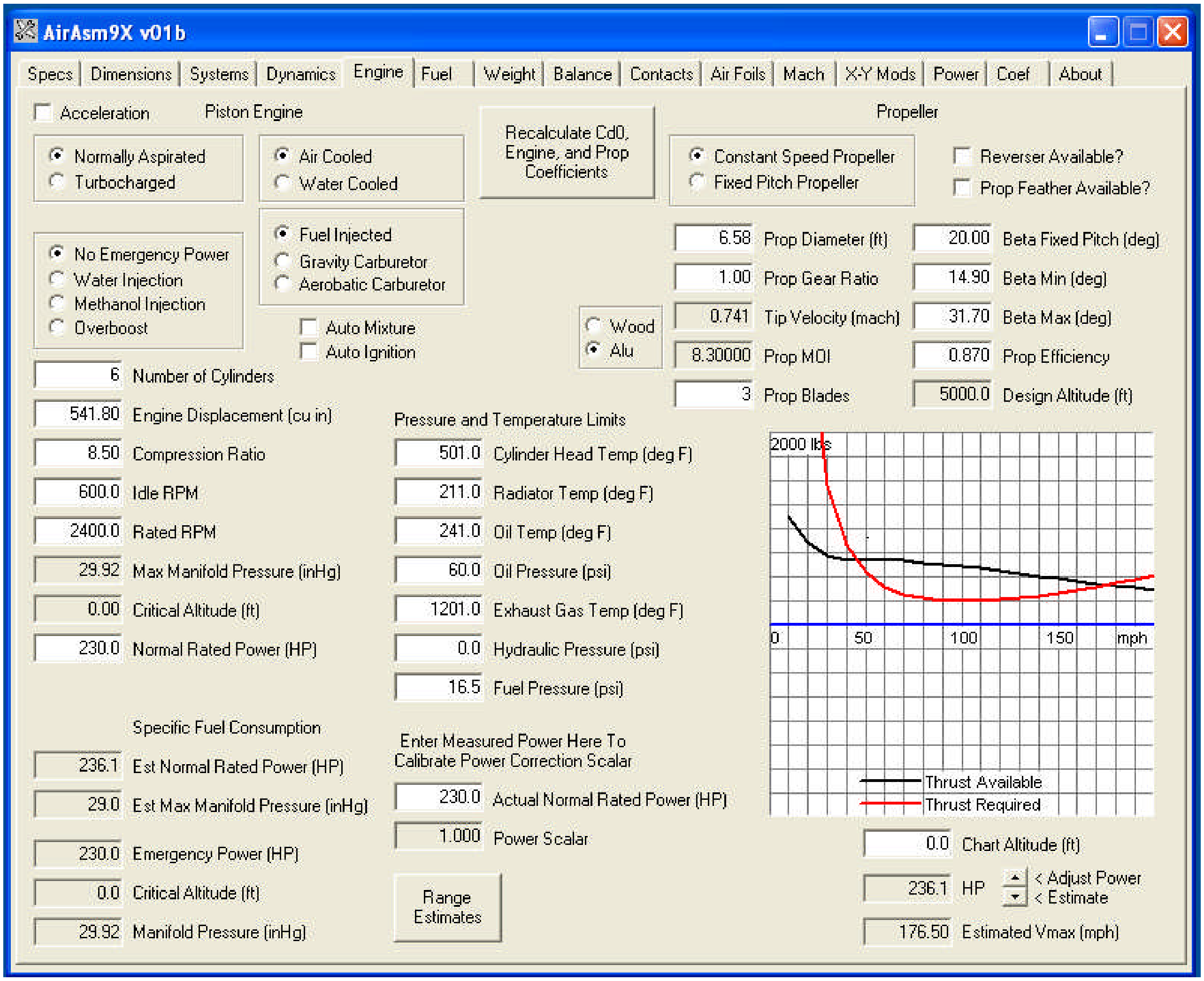
Calculate Roll Coefficients

The **Calculate Roll Coefficients** feature can be used to estimate the AIR file coefficients that control roll rates. The total aileron area and deflection angle limits are the critical parameters for roll performance. In order to match a specified roll rate, the critical aileron parameters have to be large enough to generate the desired roll response. If the aileron dimensions are insufficient to generate the desired roll response, AirWizEd will highlight the data entry cells that need to be updated to correct the problem.

Engine Setup

There are three different tabs for engine specifications: Piston, Jet, Turboprop. The engine tab displayed will match the engine type selected on the Dimensions tab.

Piston Engine Tab



☐ Acceleration

Piston Engine

● Normally Aspirated
○ Turbocharged

● Air Cooled
○ Water Cooled

● No Emergency Power
○ Water Injection
○ Methanol Injection
○ Overboost

● Fuel Injected
○ Gravity Carburetor
○ Aerobatic Carburetor

☐ Auto Mixture
☐ Auto Ignition

6 Number of Cylinders
541.80 Engine Displacement (cu in)
8.50 Compression Ratio
600.0 Idle RPM
2400.0 Rated RPM
29.92 Max Manifold Pressure (inHg)
0.00 Critical Altitude (ft)
230.0 Normal Rated Power (HP)

Specific Fuel Consumption
236.1 Est Normal Rated Power (HP)
29.0 Est Max Manifold Pressure (inHg)
230.0 Emergency Power (HP)
0.0 Critical Altitude (ft)
29.92 Manifold Pressure (inHg)

Pressure and Temperature Limits
501.0 Cylinder Head Temp (deg F)
211.0 Radiator Temp (deg F)
241.0 Oil Temp (deg F)
60.0 Oil Pressure (psi)
1201.0 Exhaust Gas Temp (deg F)
0.0 Hydraulic Pressure (psi)
16.5 Fuel Pressure (psi)

Enter Measured Power Here To Calibrate Power Correction Scalar
230.0 Actual Normal Rated Power (HP)
1.000 Power Scalar

Propeller

● Constant Speed Propeller
○ Fixed Pitch Propeller

☐ Reverser Available?
☐ Prop Feather Available?

○ Wood
● Alu

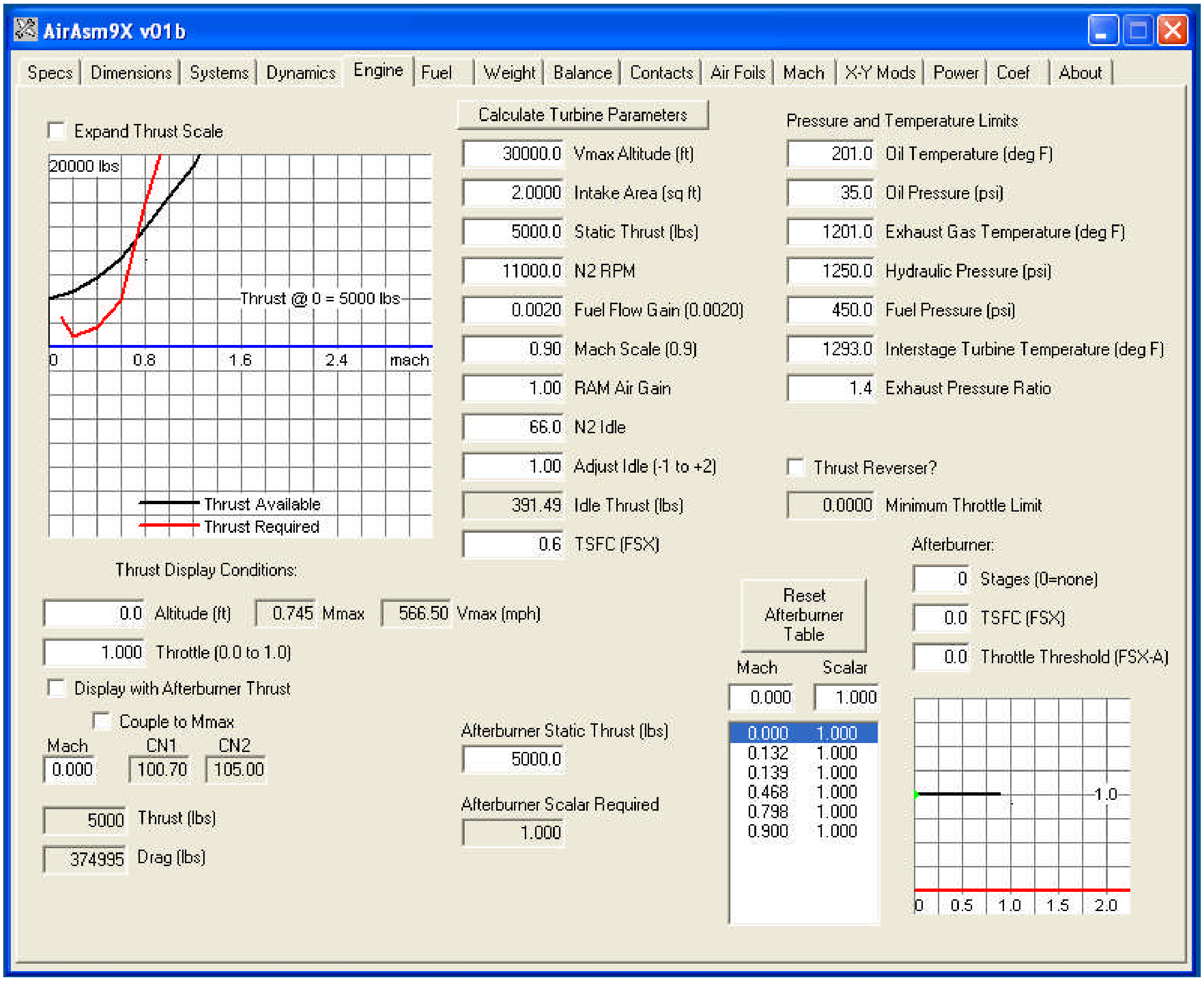
6.58 Prop Diameter (ft)
1.00 Prop Gear Ratio
0.741 Tip Velocity (mach)
8.30000 Prop MOI
3 Prop Blades

20.00 Beta Fixed Pitch (deg)
14.90 Beta Min (deg)
31.70 Beta Max (deg)
0.870 Prop Efficiency
5000.0 Design Altitude (ft)

0.0 Chart Altitude (ft)
236.1 HP < Adjust Power < Estimate
176.50 Estimated Vmax (mph)

The button labeled '**Recalculate Cd0, Engine, and Prop Coefficients**' will calculate AIR file coefficients necessary to match the current value of Vmax @ Sea-level entered on the 'Specs' tab. These calculations are based on the assumption that for a propeller driven aircraft in straight and level flight at maximum speed, the thrust produced by the propeller is equal to the drag produced by the airframe. See '**Drag coefficient calculation for a piston engine aircraft'** in the **'Introduction to Aerodynamics'** section.

Jet Engine Tab



☐ Expand Thrust Scale

30000.0 Vmax Altitude (ft)
2.0000 Intake Area (sq ft)
5000.0 Static Thrust (lbs)
11000.0 N2 RPM
0.0020 Fuel Flow Gain (0.0020)
0.90 Mach Scale (0.9)
1.00 RAM Air Gain
66.0 N2 Idle
1.00 Adjust Idle (-1 to +2)
391.49 Idle Thrust (lbs)
0.6 TSFC (FSX)

Pressure and Temperature Limits
201.0 Oil Temperature (deg F)
35.0 Oil Pressure (psi)
1201.0 Exhaust Gas Temperature (deg F)
1250.0 Hydraulic Pressure (psi)
450.0 Fuel Pressure (psi)
1293.0 Interstage Turbine Temperature (deg F)
1.4 Exhaust Pressure Ratio

☐ Thrust Reverser?
0.0000 Minimum Throttle Limit

Afterburner:
0 Stages (0=none)
0.0 TSFC (FSX)
0.0 Throttle Threshold (FSX-A)

Thrust Display Conditions:
0.0 Altitude (ft)
0.745 Mmax
566.50 Vmax (mph)
1.000 Throttle (0.0 to 1.0)
☐ Display with Afterburner Thrust
☐ Couple to Mmax

Mach	CN1	CN2
0.000	100.70	105.00

5000 Thrust (lbs)
374995 Drag (lbs)

Afterburner Static Thrust (lbs)
5000.0

Afterburner Scalar Required
1.000

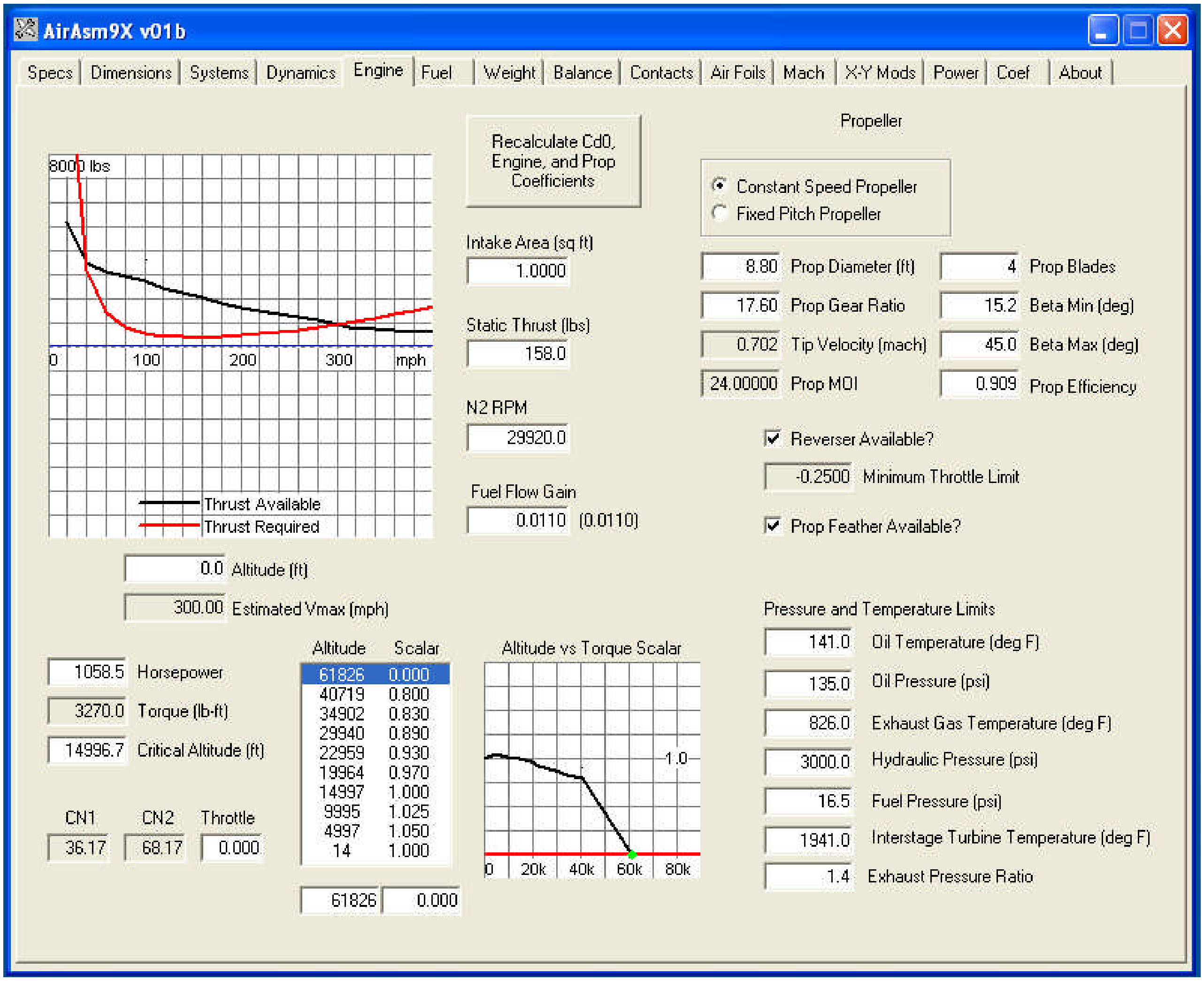
Mach	Scalar
0.000	1.000
0.000	1.000
0.132	1.000
0.139	1.000
0.468	1.000
0.798	1.000
0.900	1.000

Calculate Turbine Parameters

This feature can be used to repair unknown or incorrect jet engine parameters and performance specifications. This option will recommend alternate values if current settings are outside 'normal' values. The user has the option of accepting each recommended value or rejecting it in favor of the current parameter value.

This option works by assuming a jet powered aircraft will attain a maximum airspeed of mach 0.9 at an altitude of 30,000 ft. These values have been chosen to get the jet engine parameters and get the thrust required vs. thrust available performance 'in the ballpark'. The user is free to change maximum speeds and altitudes and accept or reject each value recommended by AirWizEd.

Turboprop Tab



Intake Area (sq ft) 1.0000

Static Thrust (lbs) 158.0

N2 RPM 29920.0

Fuel Flow Gain 0.0110 (0.0110)

0.0 Altitude (ft)

300.00 Estimated Vmax (mph)

1058.5 Horsepower

3270.0 Torque (lb-ft)

14996.7 Critical Altitude (ft)

CN1 36.17

CN2 68.17

Throttle 0.000

Altitude	Scalar
61826	0.000
40719	0.800
34902	0.830
29940	0.890
22959	0.930
19964	0.970
14997	1.000
9995	1.025
4997	1.050
14	1.000

61826 0.000

Propeller

● Constant Speed Propeller
○ Fixed Pitch Propeller

8.80 Prop Diameter (ft)
4 Prop Blades
17.60 Prop Gear Ratio
15.2 Beta Min (deg)
0.702 Tip Velocity (mach)
45.0 Beta Max (deg)
24.00000 Prop MOI
0.909 Prop Efficiency

☑ Reverser Available?

-0.2500 Minimum Throttle Limit

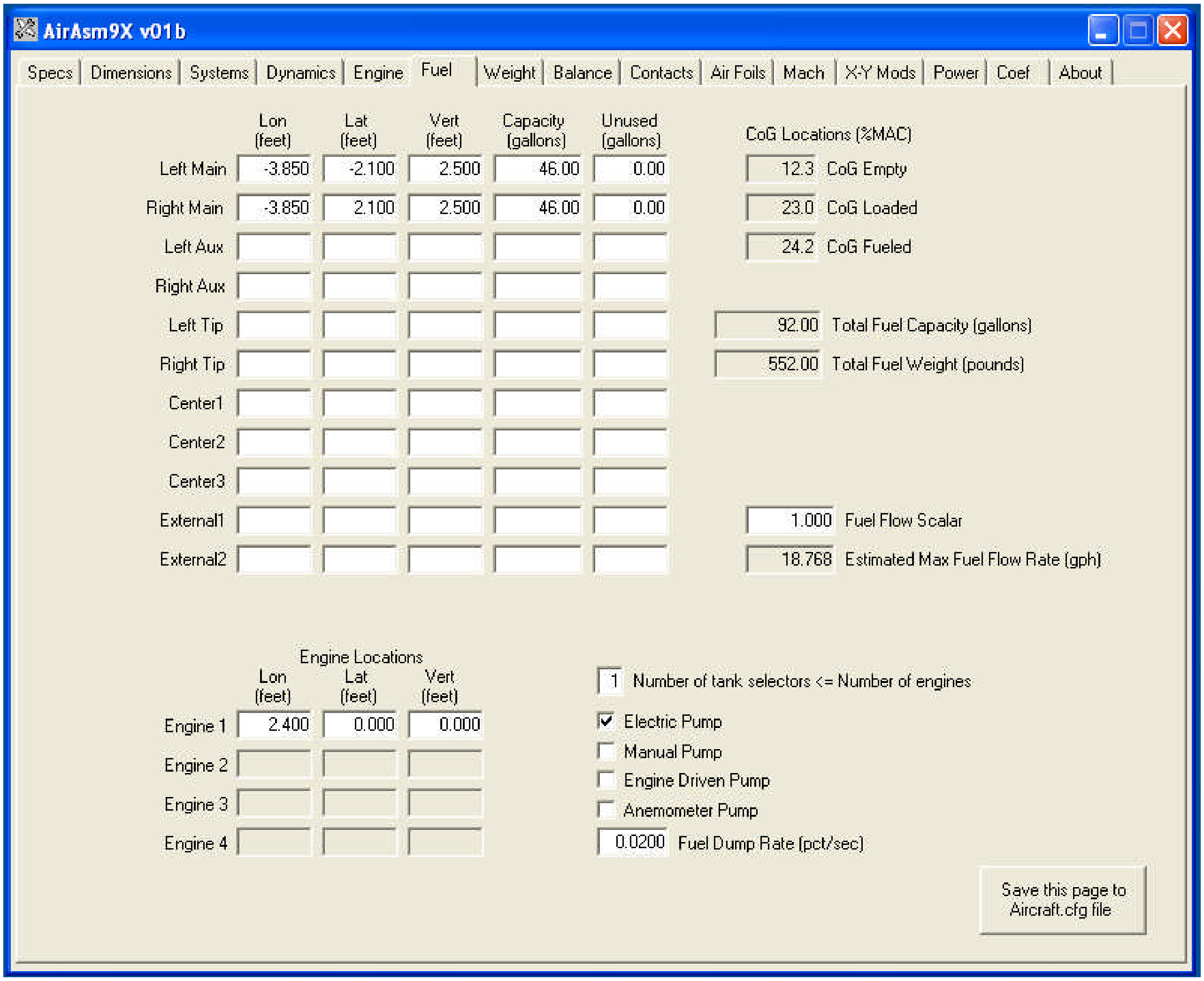
☑ Prop Feather Available?

Pressure and Temperature Limits

141.0 Oil Temperature (deg F)
135.0 Oil Pressure (psi)
826.0 Exhaust Gas Temperature (deg F)
3000.0 Hydraulic Pressure (psi)
16.5 Fuel Pressure (psi)
1941.0 Interstage Turbine Temperature (deg F)
1.4 Exhaust Pressure Ratio

The button labeled '**Recalculate Cd0, Engine, and Prop Coefficients**' will calculate AIR file coefficients necessary to match the current value of Vmax @ Sea-level entered on the 'Specs' tab. These calculations are based on the assumption that for a propeller driven aircraft in straight and level flight at maximum speed, the thrust produced by the propeller is equal to the drag produced by the airframe. See '**Drag coefficient calculation for a piston engine aircraft'** in the **'Introduction to Aerodynamics'** section.

Fuel – Tank and Engine Locations



	Lon (feet)	Lat (feet)	Vert (feet)	Capacity (gallons)	Unused (gallons)
Left Main	-3.850	-2.100	2.500	46.00	0.00
Right Main	-3.850	2.100	2.500	46.00	0.00
Left Aux					
Right Aux					
Left Tip					
Right Tip					
Center1					
Center2					
Center3					
External1					
External2					

CoG Locations (%MAC)

12.3 CoG Empty
23.0 CoG Loaded
24.2 CoG Fueled

92.00 Total Fuel Capacity (gallons)
552.00 Total Fuel Weight (pounds)

1.000 Fuel Flow Scalar
18.768 Estimated Max Fuel Flow Rate (gph)

Engine Locations

	Lon (feet)	Lat (feet)	Vert (feet)
Engine 1	2.400	0.000	0.000
Engine 2			
Engine 3			
Engine 4			

1 Number of tank selectors <= Number of engines

☑ Electric Pump
☐ Manual Pump
☐ Engine Driven Pump
☐ Anemometer Pump

0.0200 Fuel Dump Rate (pct/sec)

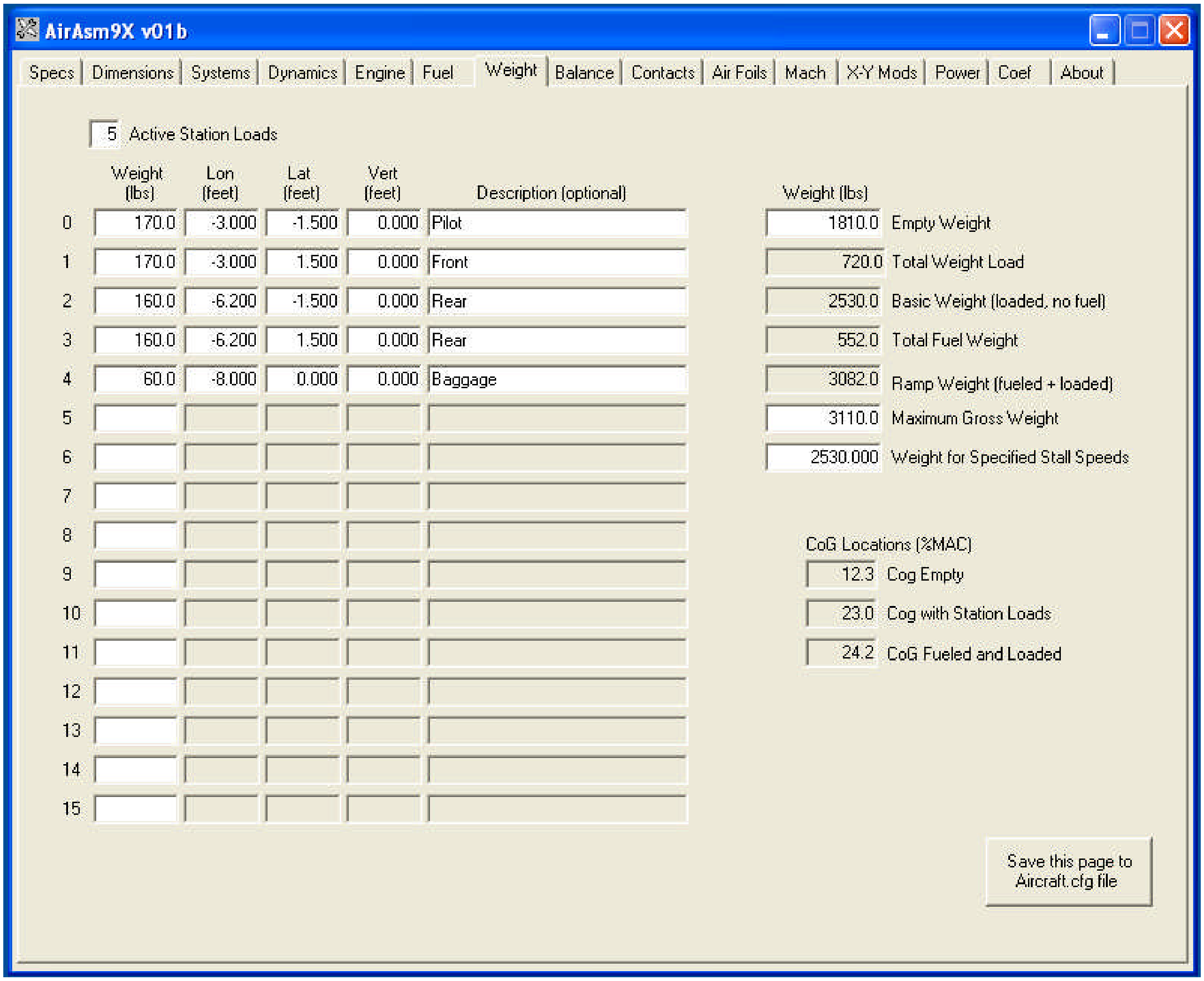
Tabulated display of all fuel tank locations and capacities
Tabulated display of all engine locations

The Fuel tab allows you to display and edit all the fuel tank locations and capacities for your flight model. This page allows you to adjust the effects of fuel on the center of gravity location without leaving AirWizEd.

The Fuel page also allows you to display and edit all the engine locations for your flight model. Since engine location can affect many aspects of flight model performance, it's important to review the engine locations to be sure they make sense.

All of the parameters on the Fuel page can be edited and saved without changing any other aspect of your flight model by using the button labeled 'Save this page to Aircraft.cfg file'.

Weight



5 Active Station Loads

	Weight (lbs)	Lon (feet)	Lat (feet)	Vert (feet)	Description (optional)
0	170.0	-3.000	-1.500	0.000	Pilot
1	170.0	-3.000	1.500	0.000	Front
2	160.0	-6.200	-1.500	0.000	Rear
3	160.0	-6.200	1.500	0.000	Rear
4	60.0	-8.000	0.000	0.000	Baggage
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					

Weight (lbs)	
1810.0	Empty Weight
720.0	Total Weight Load
2530.0	Basic Weight (loaded, no fuel)
552.0	Total Fuel Weight
3082.0	Ramp Weight (fueled + loaded)
3110.0	Maximum Gross Weight
2530.000	Weight for Specified Stall Speeds

CoG Locations (%MAC)	
12.3	Cog Empty
23.0	Cog with Station Loads
24.2	CoG Fueled and Loaded

Tabulated display of 16 station load weights and locations

The Weight page allows you to display and edit all the station load weights and locations for your flight model. This page allows you to adjust the effects of station loads on the location of the center of gravity.

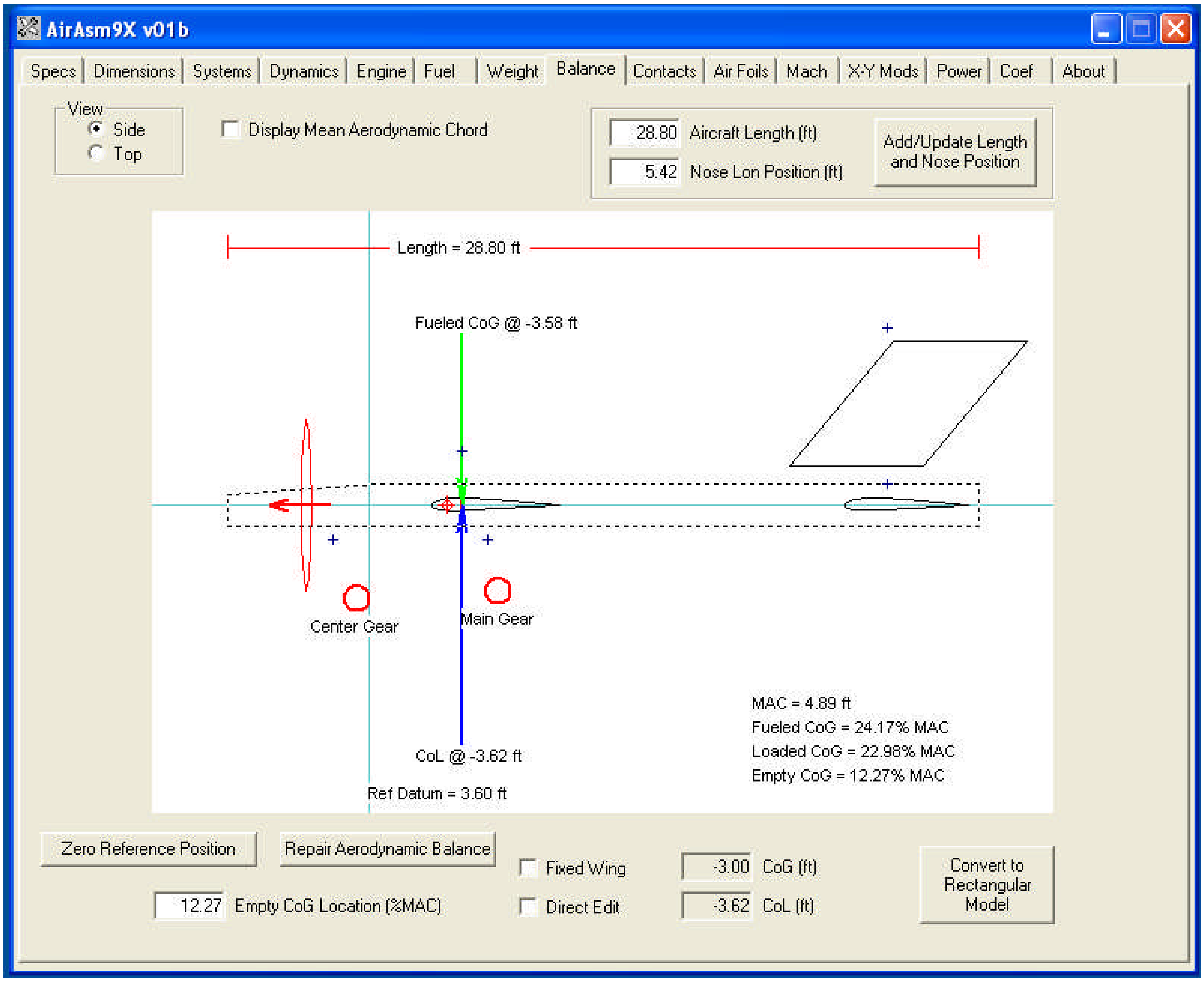
All of the parameters on the Weight page can be edited and saved without changing any other aspect of your flight model by using the button labeled 'Save this page to Aircraft.cfg file'.

Aerodynamic Balance

AirWizEd displays a pictograph of the model on the Balance tab. The aircraft outline is scaled to the proper length, but not the actual shape of the 3-D model. It is shown to give you an idea where the CoG, CoL, MAC, landing gear, and tail surfaces located.

Aerodynamic balance is extremely important in a flight model. The user has complete freedom to locate components anywhere; however, the parameters that affect aerodynamic balance may not be obvious, and establishing a balanced flight model can be a difficult and frustrating task.

Contact points and weight distribution are critical for modeling appropriate ground handling. Tricycle gear aircraft will not rotate properly on takeoff or may even fall on the tail if the center of gravity and landing gear contact points do not have appropriate geometric relations. Tail draggers are just as sensitive to the same geometric relations.



View
● Side
○ Top

☐ Display Mean Aerodynamic Chord

28.80 Aircraft Length (ft)
5.42 Nose Lon Position (ft)

MAC = 4.89 ft
Fueled CoG = 24.17% MAC
Loaded CoG = 22.98% MAC
Empty CoG = 12.27% MAC

12.27 Empty CoG Location (%MAC)
☐ Fixed Wing
☐ Direct Edit
-3.00 CoG (ft)
-3.62 CoL (ft)

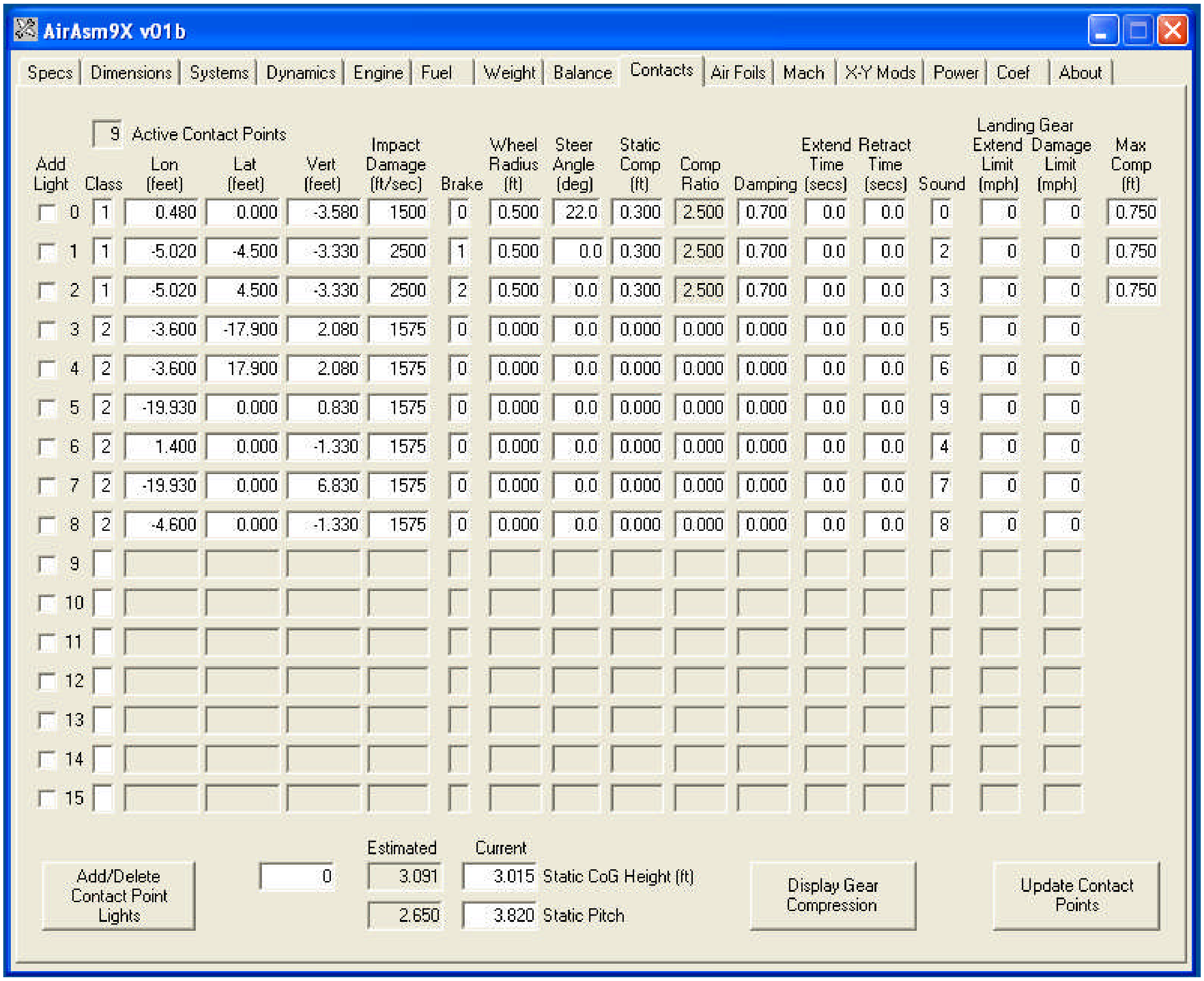
Contact point locations are shown as unlabeled '+' signs on the Balance tab display screen.

The **Repair Aerodynamic Balance** button located on the Balance tab may be used to automatically establish an aerodynamically balanced flight model. This option ensures that the weight and aerodynamic centers are collocated. Depending on their initial values, the following parameters may be changed:

Empty Weight Center of Gravity
Center of Lift
Nose Position
Horizontal stabilizer longitudinal position
Vertical stabilizer longitudinal position
Station load longitudinal positions
Fuel tank longitudinal positions
Landing gear longitudinal positions

Note: The 3D visual model and the flight model dimensions are independent, and use of the **Repair Aerodynamic Balance** option may cause misalignment of the landing gear with the visual model.

Contacts



9 Active Contact Points

Add Light		Class	Lon (feet)	Lat (feet)	Vert (feet)	Impact Damage (ft/sec)	Brake	Wheel Radius (ft)	Steer Angle (deg)	Static Comp (ft)	Comp Ratio	Damping	Extend Time (secs)	Retract Time (secs)	Sound	Landing Gear Extend Limit (mph)	Landing Gear Damage Limit (mph)	Max Comp (ft)
☐	0	1	0.480	0.000	-3.580	1500	0	0.500	22.0	0.300	2.500	0.700	0.0	0.0	0	0	0	0.750
☐	1	1	-5.020	-4.500	-3.330	2500	1	0.500	0.0	0.300	2.500	0.700	0.0	0.0	2	0	0	0.750
☐	2	1	-5.020	4.500	-3.330	2500	2	0.500	0.0	0.300	2.500	0.700	0.0	0.0	3	0	0	0.750
☐	3	2	-3.600	-17.900	2.080	1575	0	0.000	0.0	0.000	0.000	0.000	0.0	0.0	5	0	0	
☐	4	2	-3.600	17.900	2.080	1575	0	0.000	0.0	0.000	0.000	0.000	0.0	0.0	6	0	0	
☐	5	2	-19.930	0.000	0.830	1575	0	0.000	0.0	0.000	0.000	0.000	0.0	0.0	9	0	0	
☐	6	2	1.400	0.000	-1.330	1575	0	0.000	0.0	0.000	0.000	0.000	0.0	0.0	4	0	0	
☐	7	2	-19.930	0.000	6.830	1575	0	0.000	0.0	0.000	0.000	0.000	0.0	0.0	7	0	0	
☐	8	2	-4.600	0.000	-1.330	1575	0	0.000	0.0	0.000	0.000	0.000	0.0	0.0	8	0	0	
☐	9																	
☐	10																	
☐	11																	
☐	12																	
☐	13																	
☐	14																	
☐	15																	

	Estimated	Current	
0	3.091	3.015	Static CoG Height (ft)
	2.650	3.820	Static Pitch

The Contacts page allows you to display and edit up to 16 contact points for your flight model. The contact points can be edited and saved without changing any other aspect of your flight model by using the button labeled 'Save this page to Aircraft.cfg file'. This feature is very useful for fine tuning the in-game alignment of the landing gear with the ground.

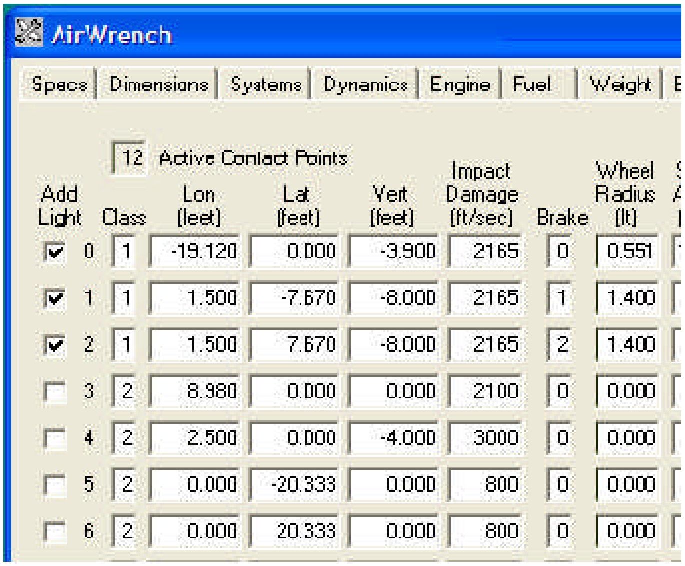
You may notice that AirWizEd does not allow direct edit of the landing gear compression ratio. AirWizEd calculates the landing gear compression ratio using the specified static compression and maximum compression values. See the section '**Landing Gear Compression in MSFS**' for further details on how these landing gear parameters work.

AirWizEd also estimates values for the static CoG height above the ground and the static pitch. The simulator uses these AIRCRAFT.CFG parameters to position the aircraft when it loads the model on the runway. Using accurate values for these parameters eliminates drops and bounces at the start of a new flight.

Contact point lights

With just a few mouse clicks, you can add and remove white navigation lights wherever you have a contact point. This shows you where your contact points are in-the-sim and helps you align the visual model with your flight model.

To add or remove a contact point light, just click the 'Add Light' box (the first column on the left) for the contact point row, then click the 'Add/Delete Contact Point Lights' button. If the box is checked a light is added, and if the box is clear any previous light for that point will be removed.

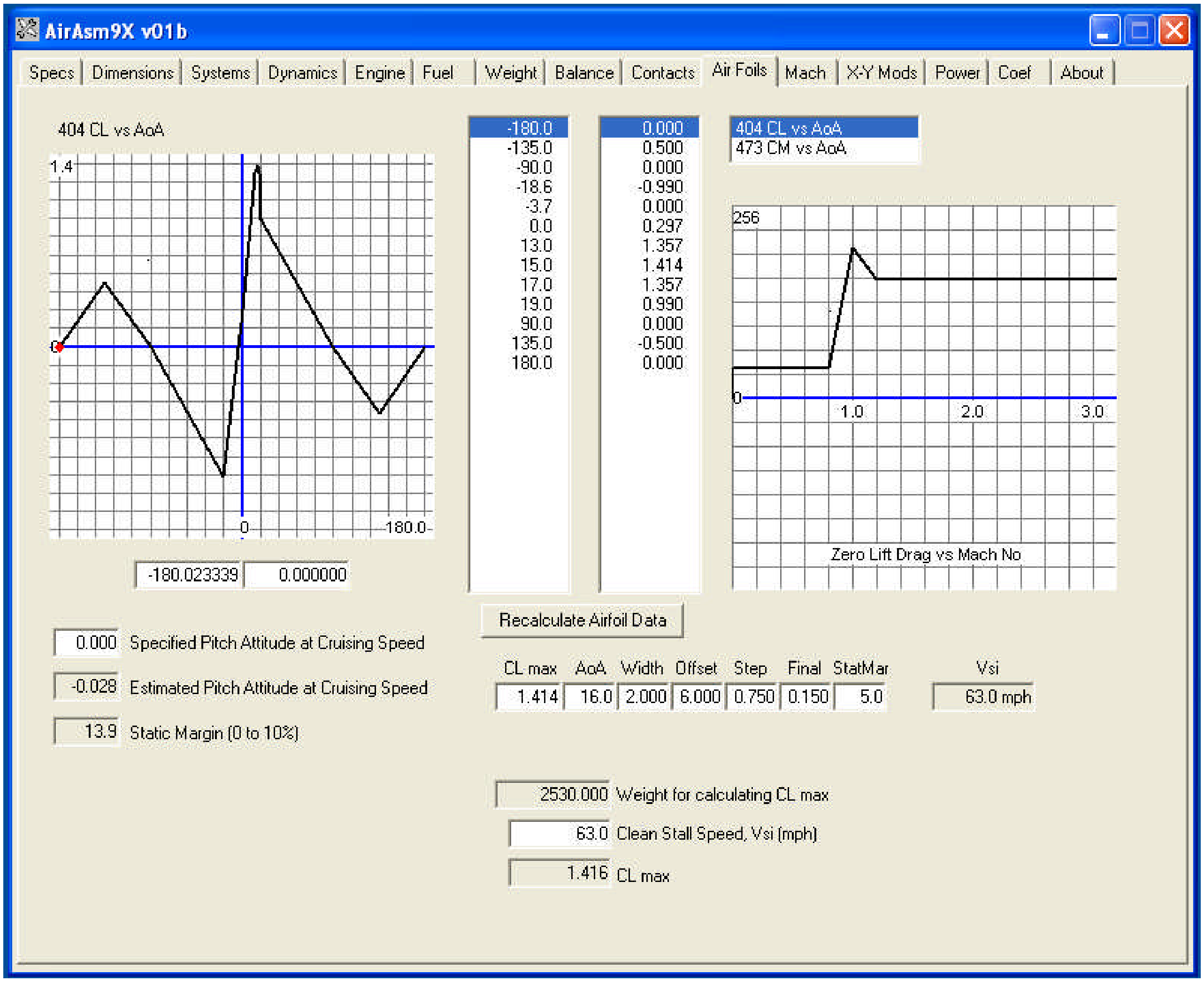


12 Active Contact Points

Add Light		Class	Lon (feet)	Lat (feet)	Vert (feet)	Impact Damage (ft/sec)	Brake	Wheel Radius (ft)
☑	0	1	-19.120	0.000	-3.900	2165	0	0.551
☑	1	1	1.500	-7.670	-8.000	2165	1	1.400
☑	2	1	1.500	7.670	-8.000	2165	2	1.400
☐	3	2	8.980	0.000	0.000	2100	0	0.000
☐	4	2	2.500	0.000	-4.000	3000	0	0.000
☐	5	2	0.000	-20.333	0.000	800	0	0.000
☐	6	2	0.000	20.333	0.000	800	0	0.000

Air Foil Data

This tab shows the air foil data in graphic format. Air foil table values can be edited by point, click and drag on the graph, or table values in the list may be selected and edited via key board entry.



-180.0	0.000
-135.0	0.500
-90.0	0.000
-18.6	-0.990
-3.7	0.000
0.0	0.297
13.0	1.357
15.0	1.414
17.0	1.357
19.0	0.990
90.0	0.000
135.0	-0.500
180.0	0.000

404 CL vs AoA
473 CM vs AoA

-180.023339 0.000000

0.000 Specified Pitch Attitude at Cruising Speed
-0.028 Estimated Pitch Attitude at Cruising Speed
13.9 Static Margin (0 to 10%)

CL max	AoA	Width	Offset	Step	Final	StatMar	Vsi
1.414	16.0	2.000	6.000	0.750	0.150	5.0	63.0 mph

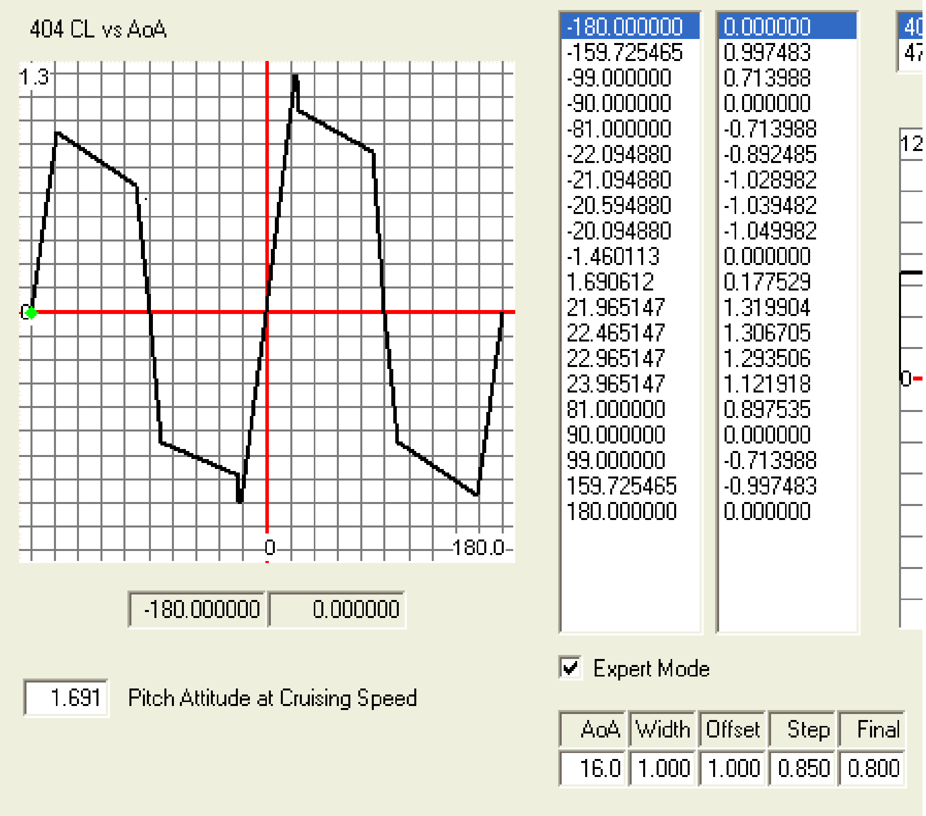
2530.000 Weight for calculating CL max
63.0 Clean Stall Speed, Vsi (mph)
1.416 CL max

When clicked, the **Recalculate Airfoil Data** button generates a new lift coefficient curve (CL vs AoA) based on the input parameters provided on the Airfoil tab. A convenient calculator is also provided to compute the maximum lift coefficient required (CL max) to obtain the specified Clean Stall Speed, given the current aircraft weight and wing surface area.

The lift coefficient curve parameters define the shape of the post-stall lift curve for the **Recalculate Airfoil Data** function. The purpose of each parameter is as follows:

CL max	maximum lift coefficient
AoA	nominal critical angle of attack
Width	number of degrees CL remains high post-stall
Offset	number of degrees CL takes to decrease post-stall
Step	initial value CL drops to post-stall
Final	final value CL drops to post-stall
Stat Mar	Static margin, determines slope of CM vs AoA curve

The following figure shows the lift curve generated using parameter values shown:



-180.000000	0.000000
-159.725465	0.997483
-99.000000	0.713988
-90.000000	0.000000
-81.000000	-0.713988
-22.094880	-0.892485
-21.094880	-1.028982
-20.594880	-1.039482
-20.094880	-1.049982
-1.460113	0.000000
1.690612	0.177529
21.965147	1.319904
22.465147	1.306705
22.965147	1.293506
23.965147	1.121918
81.000000	0.897535
90.000000	0.000000
99.000000	-0.713988
159.725465	-0.997483
180.000000	0.000000

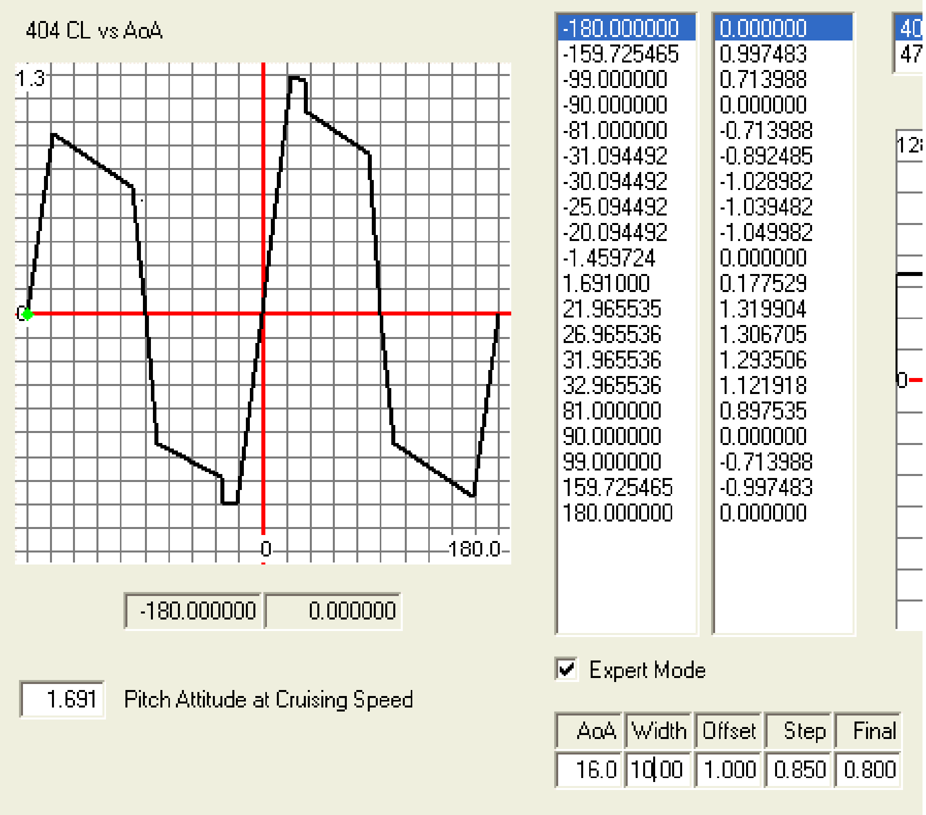
-180.000000 0.000000

1.691 Pitch Attitude at Cruising Speed

☑ Expert Mode

AoA	Width	Offset	Step	Final
16.0	1.000	1.000	0.850	0.800

The following figure shows the effect of increasing the width parameter to 10:



-180.000000	0.000000
-159.725465	0.997483
-99.000000	0.713988
-90.000000	0.000000
-81.000000	-0.713988
-31.094492	-0.892485
-30.094492	-1.028982
-25.094492	-1.039482
-20.094492	-1.049982
-1.459724	0.000000
1.691000	0.177529
21.965535	1.319904
26.965536	1.306705
31.965536	1.293506
32.965536	1.121918
81.000000	0.897535
90.000000	0.000000
99.000000	-0.713988
159.725465	-0.997483
180.000000	0.000000

-180.000000 0.000000

1.691 Pitch Attitude at Cruising Speed

☑ Expert Mode

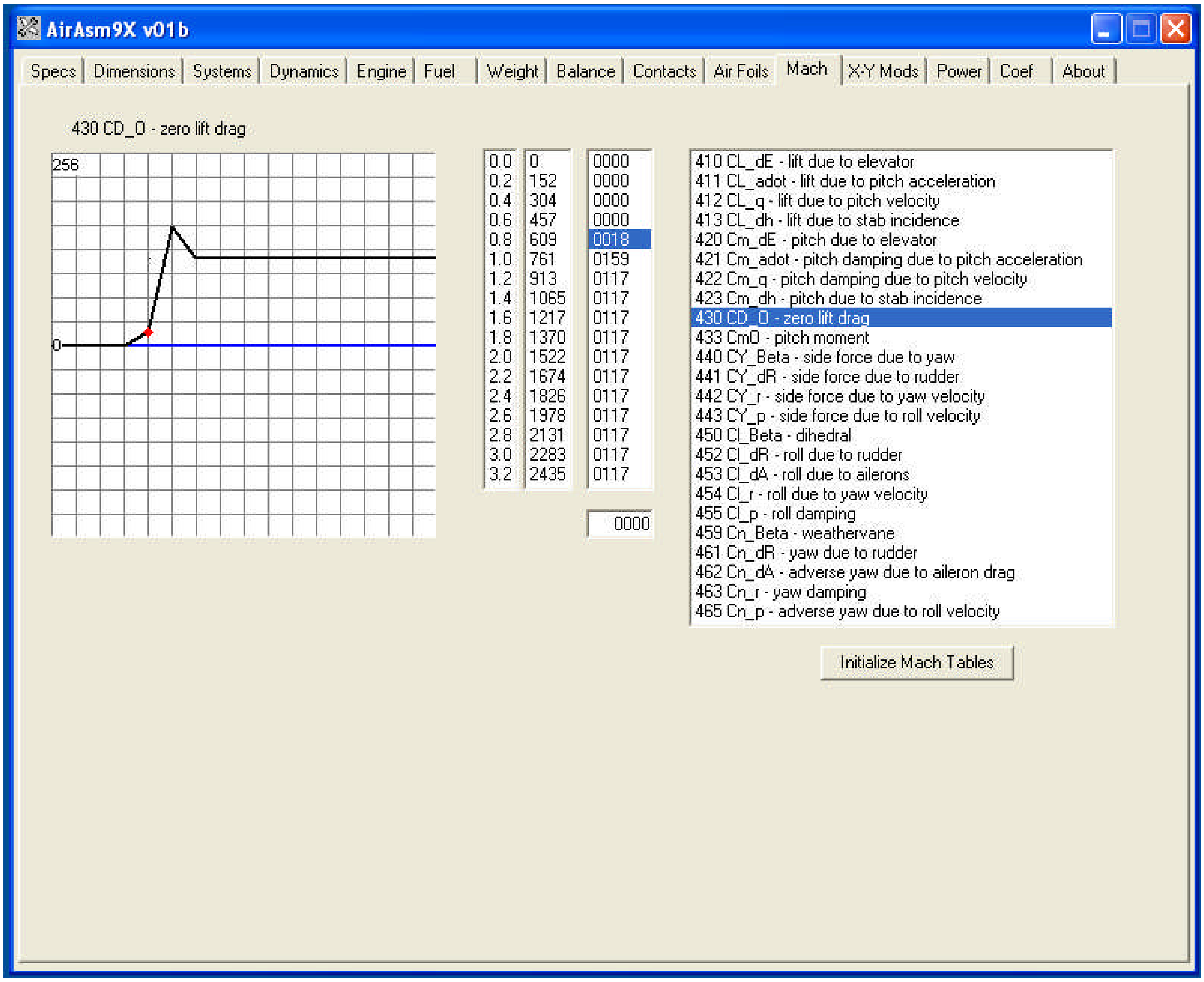
AoA	Width	Offset	Step	Final
16.0	10.00	1.000	0.850	0.800

The width of the lift coefficient peak, post-stall, is increased to 10 degrees.

Mach Table Editor

This tab presents a graph of the data found in the selected Mach modifier table, a list of the values contained in the table and a list of all available Mach modifier tables.

Table values can be edited by point, click and drag on the graph, or table values in the list may be selected and edited via key board entry.



430 CD_0 - zero lift drag

0.0	0	0000
0.2	152	0000
0.4	304	0000
0.6	457	0000
0.8	609	0018
1.0	761	0159
1.2	913	0117
1.4	1065	0117
1.6	1217	0117
1.8	1370	0117
2.0	1522	0117
2.2	1674	0117
2.4	1826	0117
2.6	1978	0117
2.8	2131	0117
3.0	2283	0117
3.2	2435	0117

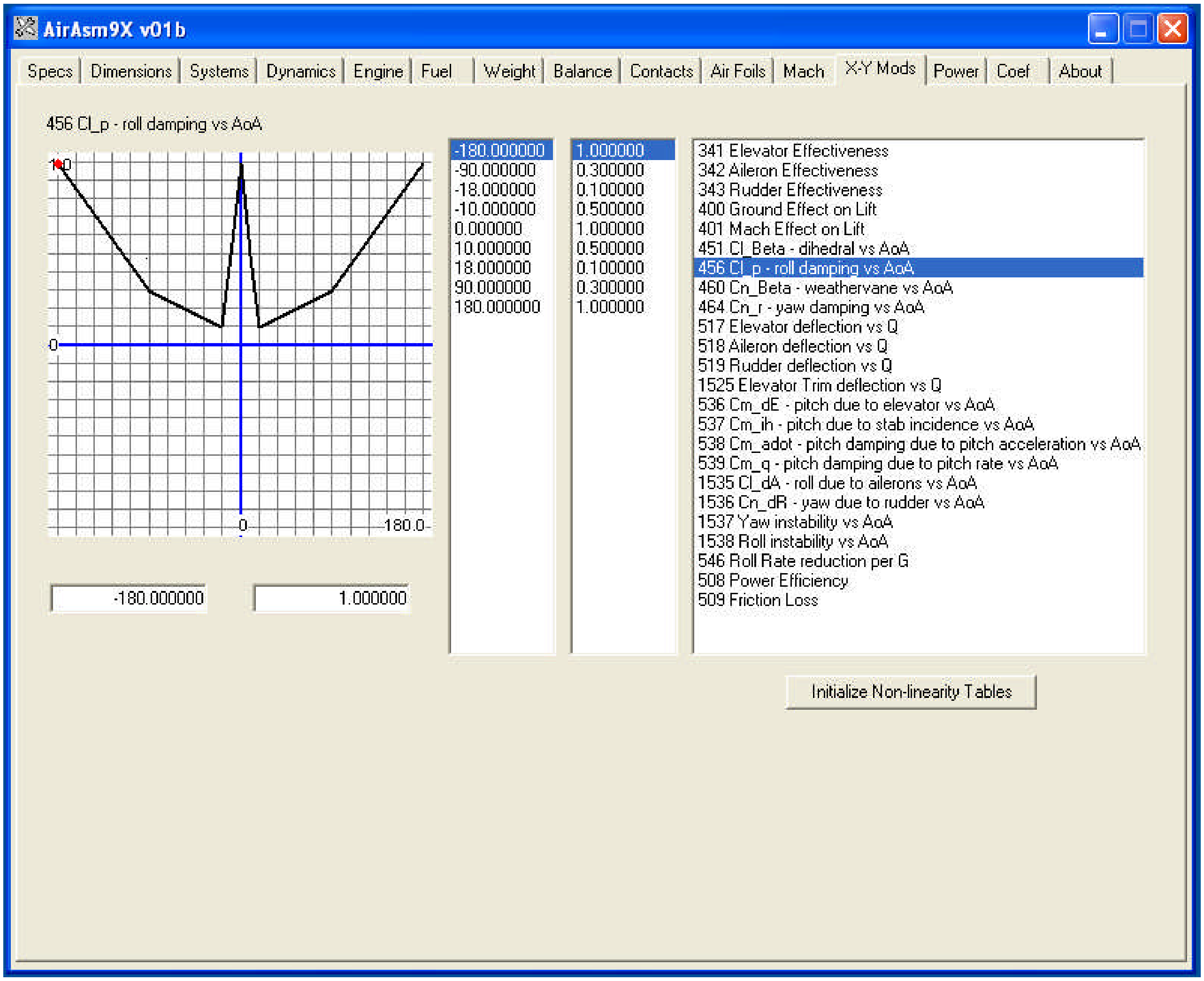
0000

410 CL_dE - lift due to elevator
411 CL_adot - lift due to pitch acceleration
412 CL_q - lift due to pitch velocity
413 CL_dh - lift due to stab incidence
420 Cm_dE - pitch due to elevator
421 Cm_adot - pitch damping due to pitch acceleration
422 Cm_q - pitch damping due to pitch velocity
423 Cm_dh - pitch due to stab incidence
430 CD_0 - zero lift drag
433 Cm0 - pitch moment
440 CY_Beta - side force due to yaw
441 CY_dR - side force due to rudder
442 CY_r - side force due to yaw velocity
443 CY_p - side force due to roll velocity
450 Cl_Beta - dihedral
452 Cl_dR - roll due to rudder
453 Cl_dA - roll due to ailerons
454 Cl_r - roll due to yaw velocity
455 Cl_p - roll damping
459 Cn_Beta - weathervane
461 Cn_dR - yaw due to rudder
462 Cn_dA - adverse yaw due to aileron drag
463 Cn_r - yaw damping
465 Cn_p - adverse yaw due to roll velocity

X-Y Modifier Table Editor

This tab presents a graph of the data found in the selected X-Y modifier tables, a list of the values contained in the table and a list of all available X-Y modifier tables.

Table values can be edited by point, click and drag on the graph, or table values in the list may be selected and edited via key board entry.



-180.000000 1.000000

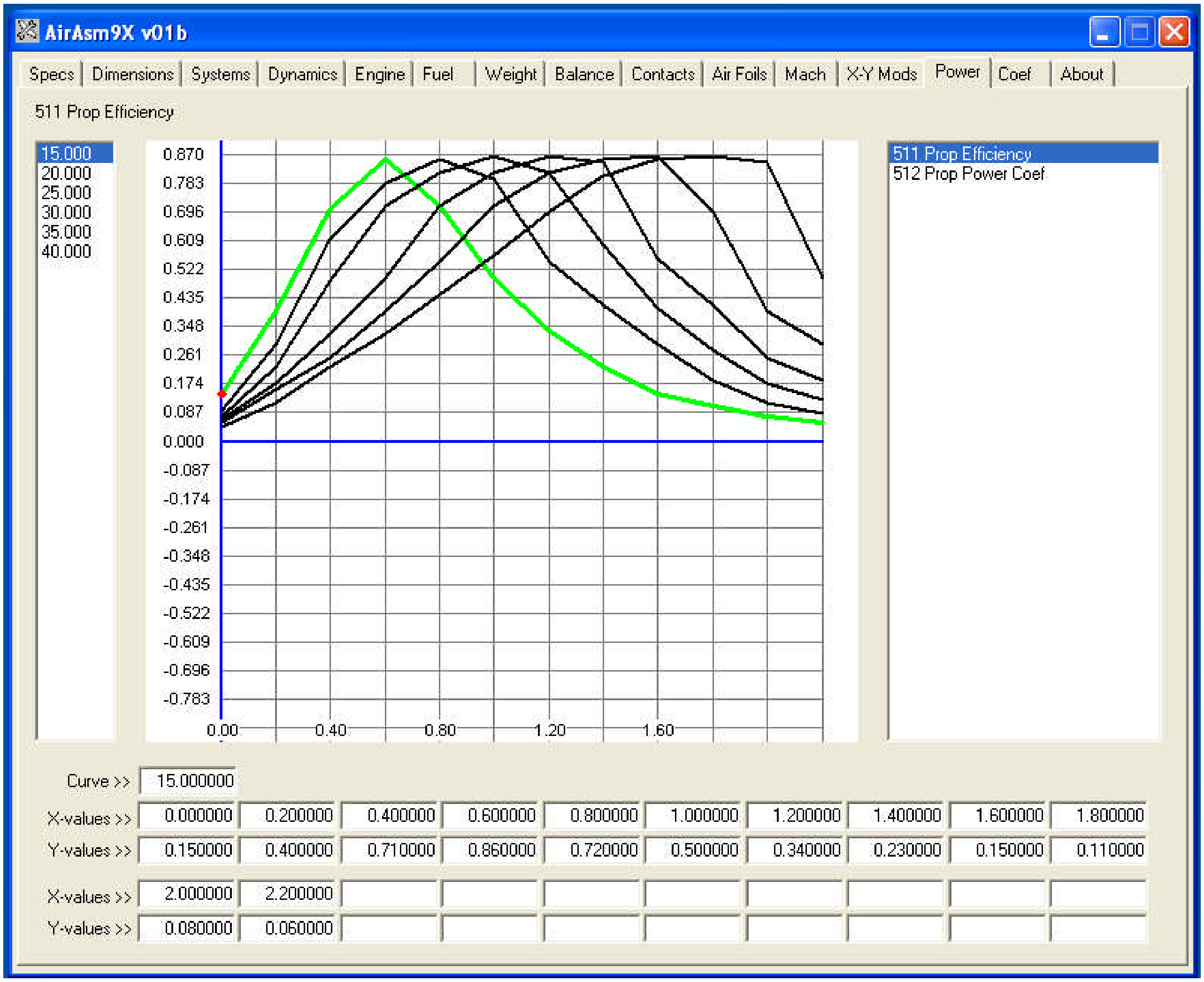
-180.000000	1.000000
-90.000000	0.300000
-18.000000	0.100000
-10.000000	0.500000
0.000000	1.000000
10.000000	0.500000
18.000000	0.100000
90.000000	0.300000
180.000000	1.000000

341 Elevator Effectiveness
342 Aileron Effectiveness
343 Rudder Effectiveness
400 Ground Effect on Lift
401 Mach Effect on Lift
451 Cl_Beta - dihedral vs AoA
456 Cl_p - roll damping vs AoA
460 Cn_Beta - weathervane vs AoA
464 Cn_r - yaw damping vs AoA
517 Elevator deflection vs Q
518 Aileron deflection vs Q
519 Rudder deflection vs Q
1525 Elevator Trim deflection vs Q
536 Cm_dE - pitch due to elevator vs AoA
537 Cm_ih - pitch due to stab incidence vs AoA
538 Cm_adot - pitch damping due to pitch acceleration vs AoA
539 Cm_q - pitch damping due to pitch rate vs AoA
1535 Cl_dA - roll due to ailerons vs AoA
1536 Cn_dR - yaw due to rudder vs AoA
1537 Yaw instability vs AoA
1538 Roll instability vs AoA
546 Roll Rate reduction per G
508 Power Efficiency
509 Friction Loss

Power System Coefficient Table Editor

This tab presents a graph of the data found in the selected power system coefficient table, a list of the values contained in one row of the table and a list of all available power system coefficient tables. The list of available power system coefficient tables varies depending on the engine type.

Table values can be edited by point, click and drag on the graph, or table values in the list may be selected and edited via key board entry.



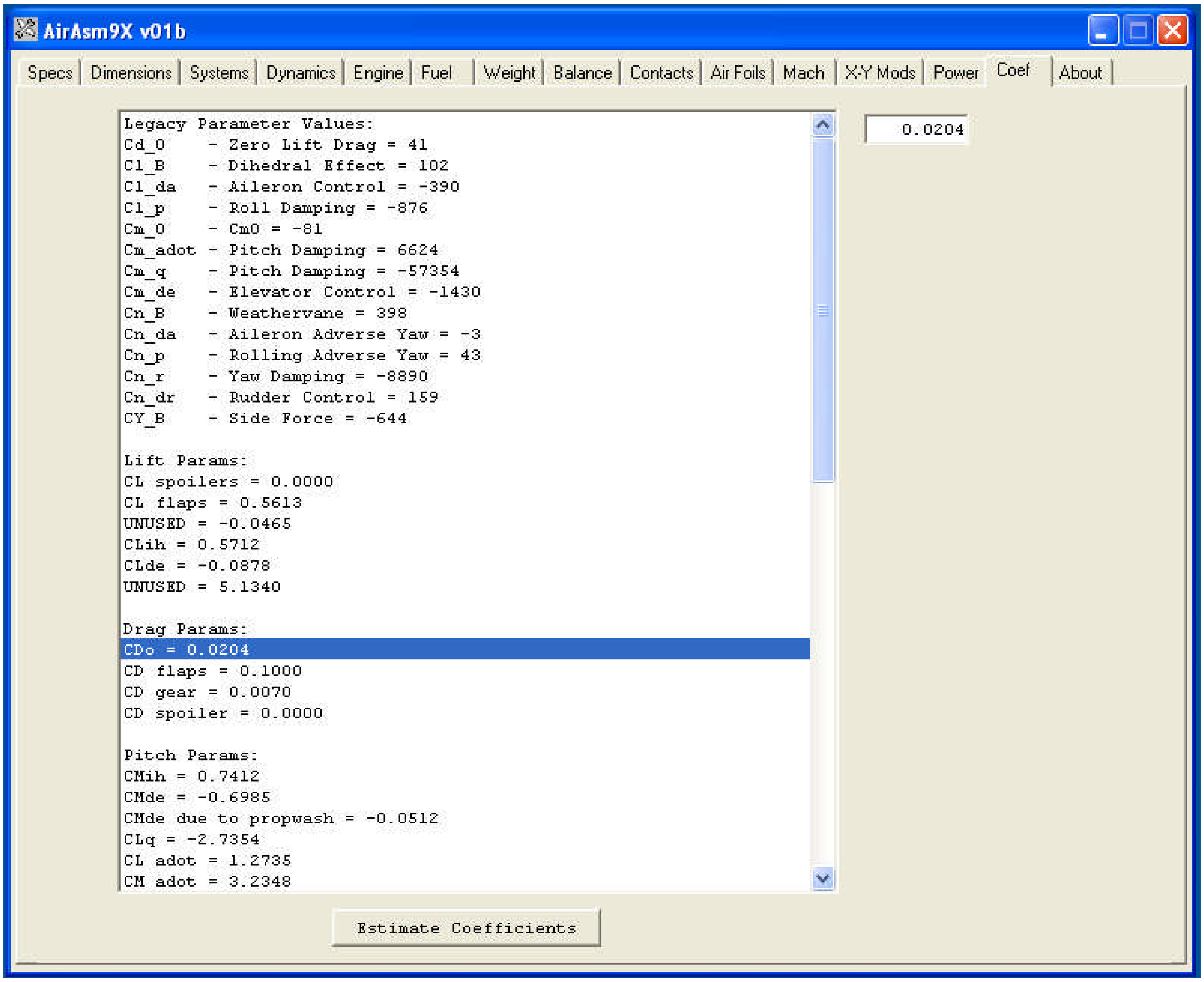
Curve >> 15.000000

X-values >>	0.000000	0.200000	0.400000	0.600000	0.800000	1.000000	1.200000	1.400000	1.600000	1.800000
Y-values >>	0.150000	0.400000	0.710000	0.860000	0.720000	0.500000	0.340000	0.230000	0.150000	0.110000
X-values >>	2.000000	2.200000								
Y-values >>	0.080000	0.060000								

Note: The AIR file sections in this figure are appropriate for a piston engine aircraft. The available sections will be different for turbine engines.

Stability Coefficients, Scalar Parameters, and Boolean flags

This tab presents a list of the baseline stability coefficients and their values. The stability coefficients are displayed as both real numbers and as fixed point binary numbers. Either format can be editied. Table values in the list may be selected and edited via key board entry.



```
0.0204
```

```
Legacy Parameter Values:
Cd_0     - Zero Lift Drag = 41
Cl_B     - Dihedral Effect = 102
Cl_da    - Aileron Control = -390
Cl_p     - Roll Damping = -876
Cm_0     - Cm0 = -81
Cm_adot  - Pitch Damping = 6624
Cm_q     - Pitch Damping = -57354
Cm_de    - Elevator Control = -1430
Cn_B     - Weathervane = 398
Cn_da    - Aileron Adverse Yaw = -3
Cn_p     - Rolling Adverse Yaw = 43
Cn_r     - Yaw Damping = -8890
Cn_dr    - Rudder Control = 159
CY_B     - Side Force = -644

Lift Params:
CL spoilers = 0.0000
CL flaps = 0.5613
UNUSED = -0.0465
CLih = 0.5712
CLde = -0.0878
UNUSED = 5.1340

Drag Params:
CDo = 0.0204
CD flaps = 0.1000
CD gear = 0.0070
CD spoiler = 0.0000

Pitch Params:
CMih = 0.7412
CMde = -0.6985
CMde due to propwash = -0.0512
CLq = -2.7354
CL adot = 1.2735
CM adot = 3.2348
```

AirWizEd will estimate values for all of the baseline stability coefficients when the '**Estimate Coefficients**' button is clicked.

An Introduction to Aerodynamics

In order to make full use of AirWizEd you will need some knowledge of aerodynamics and flight mechanics. The purpose of this section is to give you some of the information you will need to solve some of the aerodynamic problems you may encounter when developing flight dynamics for MSFS.

Flight simulation is a complex problem, and while the contents of this section may look a lot like an engineering text, the intent is to show the most important aerodynamic relationships using no more than high school level Algebra. If you can follow the theory you will better understand what it takes to make your airplane perform more realistically.

MSFS is implemented using classic linear flight equations that depend on a comprehensive set of aerodynamic coefficients to impart the flight characteristics of an aircraft. The fundamental linear equations are augmented with table-driven software to account for non-linear effects of angle of attack, elasticity, and mach number. MSFS also provides for detailed simulation of piston and turbine engines, accounts for aircraft interactions with the ground, and provides detailed modeling for instrumentation systems.

The Atmosphere in MSFS

The atmosphere in MSFS is generally representative of the 1976 US Standard Atmosphere. Density, pressure and temperature all vary with altitude and have significant effects on aircraft performance.

The table below gives the variation in density, pressure, and temperature with altitude for the US Standard Atmosphere. The speed of sound, which is directly related to the air temperature, and the ratio of true to indicated airspeed are also shown.

1976 US Standard Atmosphere

Altitude (feet)	Air Density	Pressure (in. Hg)	Temperature (Fahrenheit)	Mach 1 TAS (mph)	TAS/IAS
0	0.002378	29.92	59	760.9	1.000
5000	0.002049	24.89	41.2	747.7	1.077
10000	0.001756	20.58	23.4	734.3	1.164
15000	0.001496	16.88	5.5	720.6	1.261
20000	0.001267	13.75	-12.3	706.7	1.370
25000	0.001065	11.1	-30	692.5	1.494
30000	0.000889	8.88	-47.8	678.0	1.636
35000	0.000736	7.036	-65.6	663.2	1.797
40000	0.000582	5.541	-69.7	659.8	2.021
45000	0.000459	4.364	-69.7	659.8	2.276
50000	0.000361	3.436	-69.7	659.8	2.567
55000	0.00026	3	-69.7	659.8	3.024
60000	0.00019	2.7	-69.7	659.8	3.538

(Air density units = slugs per cu ft)

Dynamic Pressure

Dynamic Pressure is a difference between two special pressures that can be measured when an airplane moves through the air. The sum of the static pressure (ps) and the dynamic pressure (q) is called the total pressure (pt). The equation is simply: pt = ps + q.

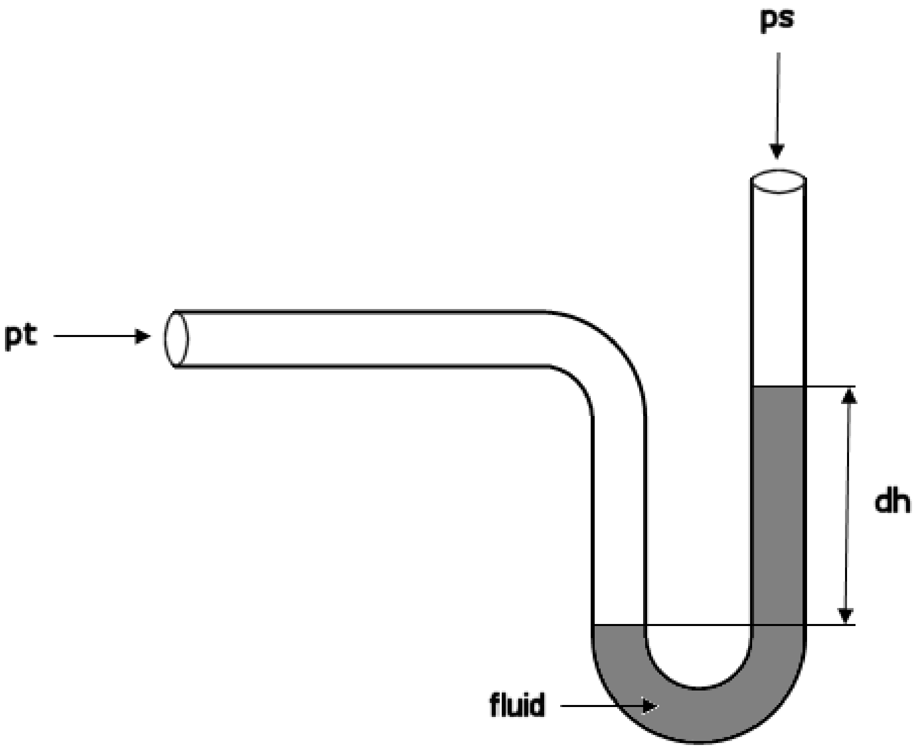
The definition of dynamic pressure from Bernoulli's equation is then:

$$q = \rho V^2 / 2$$

Where ρ (rho) = air density, and
V = air speed.

These pressure relationships provide a way of physically measuring airspeed. When a plane is moving through still air, the total pressure is the pressure ahead of the plane, while the static pressure is the pressure on the side of the plane.

A manometer is a simple instrument that can be used for measuring the difference between two air pressures. It consists of a U-shaped glass tube partly filled with liquid. The airspeed indicators used in aircraft today work on the same principle as the manometer shown in the figure below:



The total pressure can be obtained using a "pitot" tube that sticks forward into undisturbed air flow away from the body of the plane. Static pressure can be obtained from a tube mounted flush with the side of the aircraft in relatively clean air flow. These tubes are connected to an instrument with a diaphragm to measure the difference in pressures, which is the dynamic pressure. The instrument derives the airspeed from the measured dynamic pressure using the equation:

$$V = SQRT(2 q / \rho)$$

Air density is difficult to measure, so airspeed indicators are calibrated using the air density at sea level, and as a result, airspeed indicators display what is referred to as ‘indicated airspeed’ (IAS).
True airspeed (TAS) is the airspeed relative to the ground. Because air is less dense at higher altitudes, the effect of measuring airspeed using pressure differences is that, at altitudes above sea-level, indicated airspeed is always less than true airspeed.

The difference between true and indicated airspeed can be substantial. For example the maximum speed of the WWII P-51D is most often listed as 437 mph at 25,000 ft. This is the true airspeed; and at this altitude, the pilot would see an indicated airspeed of only 292 mph.

Indicated airspeed may not equate to speed over ground, but since it is based on a measurement of dynamic pressure, it is actually more useful to a pilot than true airspeed because all of the forces that keep an airplane flying are directly related to dynamic pressure. As a result, the indicated airspeeds for important aircraft operating speeds (stall speed for example) are constants for all altitudes.

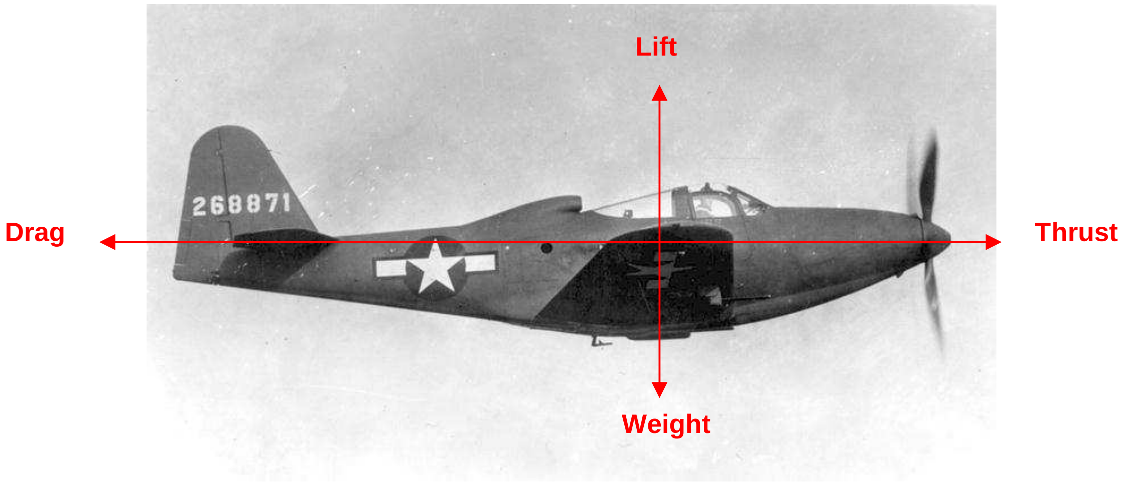
Aerodynamic Force Equations

The classic aerodynamic forces are defined as:

Lift = L = q CL S
Drag = D = q CD S
Side force = FY = q CY S

Where q = dynamic pressure and S = wing surface area.

The non-dimensional parameters CL, CD, CY in the above aerodynamic force equations are referred to as the lift coefficient, drag coefficient, and side force coefficient, respectively.



Forces acting on an aircraft in level flight

The two fundamental aerodynamic forces are lift and drag. Lift supports an aircraft's weight, while drag resists its motion through the air. Side force acts laterally to the plane's motion and is zero for all steady flying.

Equations of Motion

Flight simulators work by continuously computing aircraft speed, attitude, and location in response to control inputs, weather, and ground interaction. However, the calculus is far too complex to reduce all of the differential equations of motion into a single set of general equations to calculate the required simulation variables at any arbitrary point in time. This section will explain why the equations of motion for flight are a nearly impossible calculus problem and discuss the computation techniques used by simulation software to solve this extremely difficult math problem.

The equations for linear motion in flight are based on Newton’s law:

Force = mass* acceleration

To calculate an airplane’s speed and position, the equation is rearranged to solve for acceleration:

acceleration = Force / mass

The equation for velocity is obtained by integrating the acceleration over time, and the equation for position is likewise obtained by integrating the equation for velocity (calculus 101). What makes solving this problem extremely complex is that the aerodynamic forces in the equations depend on the air speed that the equations are intended to calculate, which creates a circular dependency.

A simulator solves the problem by taking advantage of its need to continuously compute force, acceleration, speed, and position. It doesn’t really need to compute these values at any arbitrary time, it really only needs to calculate them for ‘right now’ based on what they were a very short time ago. When the time interval between continuous ‘right now’ calculations is short enough, the computed values are for all practical purposes, equivalent to the values that would be obtained by integration over an arbitrary time interval.

When the simulation starts, all variable values are known. For example, if a plane is on the runway the acceleration and speed are zero, the attitude is determined by the geometry of the airplane, and the latitude, longitude, heading and altitude are set at the end of the runway. The engine is at idle, so the thrust is effectively zero.

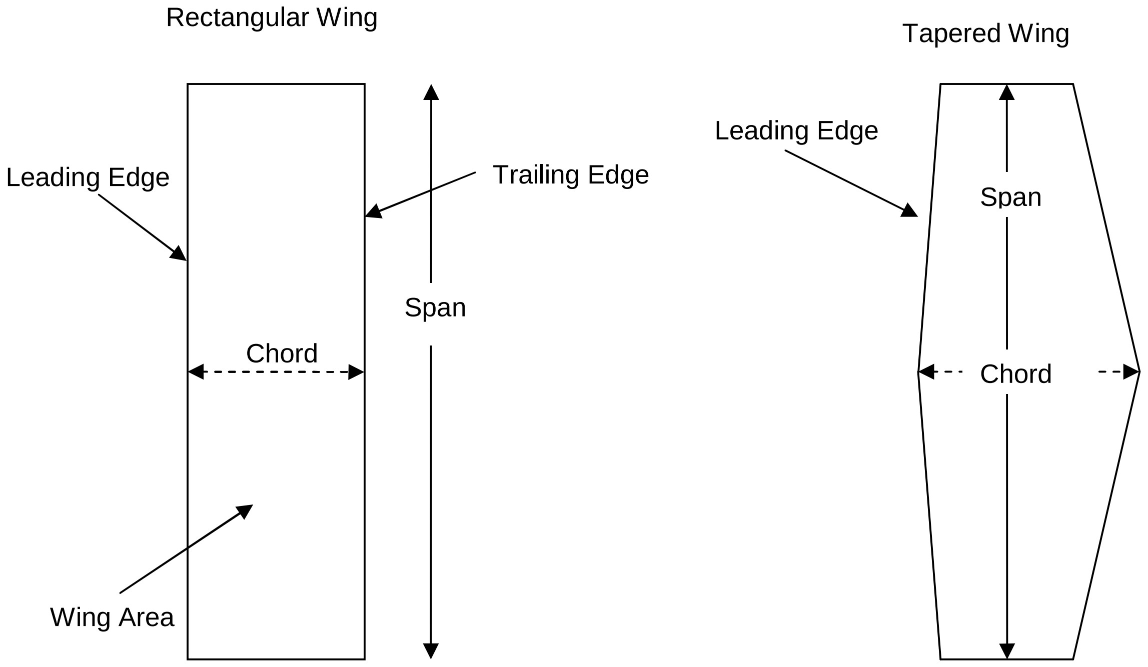
On the next time interval, the simulator finds that the throttle has been opened, so it can calculate a force for thrust and the resulting acceleration. Over the short time interval, the new velocity would be the previous velocity (zero) plus the acceleration multiplied by the time interval. This process assumes the acceleration has been constant for the entire time interval, but when the time interval is very small, the approximation is good enough. The new position is found in much the same way, with the average speed over the time interval ($0.5 * [V_{new} + V_{old}]$) multiplied by the time interval and added to the old position.

In subsequent time intervals, the previous value calculated for speed is used to compute all of the forces that depend on speed. The process works because when the intervals are short, the changes in speed from interval to interval are very small, and consequently the errors introduced in the force calculations are insignificant.

Wing geometry

The shape of a wing when viewed from above is called the planform. The following figure shows the planform of a simple rectangular wing on the left and a tapered wing on the right. Rectangular wings are commonly used on light general aviation aircraft, while tapered wings offer performance advantages for high speed aircraft.

Wing Planforms - Top View



The distance from the leading edge of the wing to the trailing edge is called the chord (*c)*. The distance from one wing tip to the other is called the span (*b)*. The wing area (*S)* is the total projected surface area of the wing and includes the area of the fuselage. For rectangular wings, the chord is constant for the entire span, but for tapered wings the chord length varies along the span.

The aspect ratio (AR) of a wing affects its drag characteristics and is defined to be the square of the span divided by the wing surface area:

$$\mathbf{AR = b^2 / S}$$

Where:
AR = aspect ratio
b = wing span
S = wing surface area

Aspect ratio is an indication of how long and narrow a wing is. High-aspect-ratio wings are long and slender, and because the drag characteristics are lower, high-aspect ratio wings are used in high-performance gliders.

Aerodynamic Coefficients of Lift and Drag

It should be noted that there is no theoretical method that will calculate precise values for the lift and drag coefficients, CD and CL. Estimates can be based on wind tunnel measurements of similar shapes or obtained from virtual wind tunnel software, but for any given airplane, the values of CD and CL must always be determined by test and measurement. Fortunately, for simulating an existing airplane, we don't usually need to estimate CD and CL. We can use the existing airplane performance measurements to calculate very precise values of CD and CL to use in the flight simulator.

We previously found that dynamic pressure is related to speed and air density by the following equation:

$$q = 0.5\ \rho\ V^2$$

Substituting air density (rho) and air speed for dynamic pressure and rearranging the classic aerodynamic force equation to solve for lift coefficient (CL) results in the lift equation:

$$CL = L / (1/2\ \rho\ V^2\ S)$$

Where:

L = lifting force (pounds)
ρ (rho) = air density (slugs per ft^3)
V = velocity (feet per second)
S = wing surface area

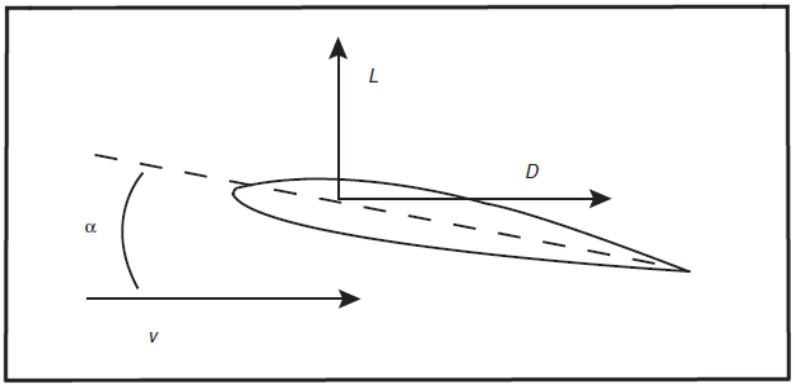
Similarly, the drag coefficient (CD) is defined by the drag equation:

$$CD = D / (1/2\ \rho\ V^2\ S)$$

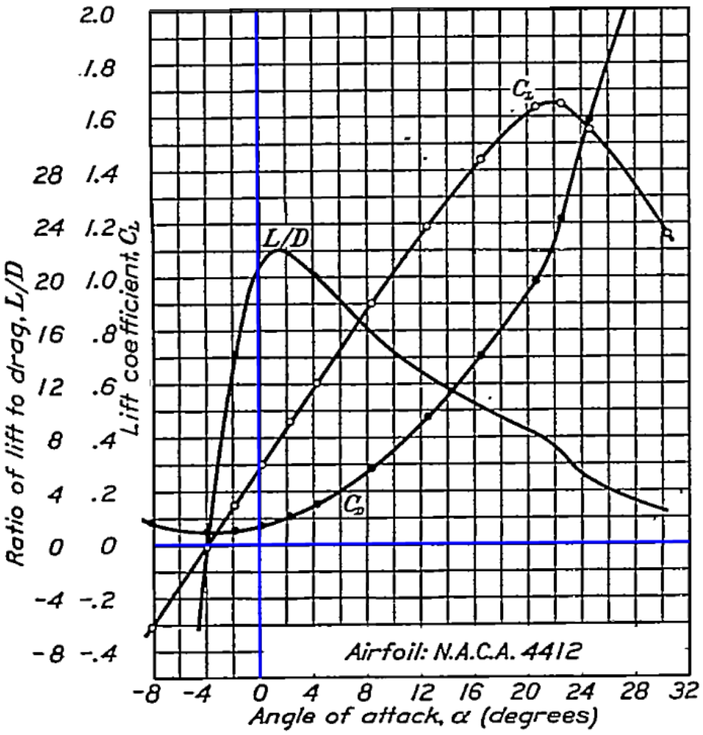
Where,

D = drag force (pounds)
ρ (rho) = air density (slugs per ft^3)
V = velocity (feet per second)
S = wing surface area

The angle of attack (α) is the angle formed between a line drawn through the wing from the leading edge to the trailing edge and the air flowing around the wing as shown in the following force diagram.



The lift increases linearly with angle of attack until the wing reaches a point called the *critical angle of attack*. When the angle of attack exceeds the critical angle, lift stops increasing and the aircraft stalls. The following chart shows the variation of lift and drat with angle of attack measured in a wind tunnel.



NACA 2212 airfoil section lift and drag (NACA Report 460)

The stall characteristics of the aircraft depend on the geometry of the aircraft and the non-linear post stall lift characteristics of the wing.

Drag has many sources in an aircraft. In MSFS a single drag coefficient, Cd0, represents the sum of the parasitic drag for the combined wing, body, and tail of the aircraft. (FS provides independent drag coefficients to account drag added by flaps, landing gear, and spoilers.)

Total airframe drag is the sum of parasitic and induced drag components:

$$CD = CDo + CDi$$

The induced drag coefficient is proportional to the lift coefficient squared:

$$CDi = CL^2 / (\pi \, eAR)$$

Where,

e = Oswald efficiency factor and
AR = Aspect ratio.

Aerodynamic Efficiency

The ratio of lift to drag (L/D) is sometimes referred to as “aerodynamic efficiency”. Since lift and drag both vary with angle of attack, the ratio L/D also varies with angle of attack. For a gliding aircraft, analysis shows that the maximum value of L/D equals the glide ratio, i.e. the ratio of horizontal distance flown divided by the altitude lost. For example, without any wind present, a small aircraft with a glide ratio of 10 to 1 can glide nearly 10 miles from an altitude of 5000 ft.

AIR File Format

AIR files are machine-readable binary files that specify the aerodynamic coefficients FSX uses when simulating the behavior of an aircraft. An air file is basically a list of variable length binary records that are generally referred to as AIR file ‘sections’.

Each AIR file record starts with a 32-bit integer that identifies the section. This is the ‘section number’, and it’s usually displayed in hexadecimal format. The section number is followed by a second 32-bit integer that specifies the length of the record in bytes. The record length includes the 8 bytes used for the section number and length. The record length is then followed by the actual data for the section.

An AIR file (for example, PA28_180.air) originates as a human-readable text-based assembler file (PA28_180.asm) that can be compiled with an assembler like MASM, or the asm2air tool provided in the ESP Software Development Kit, or by AirWizEd. The following sections describe the format of the ASM file and its relationship to an AIR file.

ASM File Layout

An ASM file essentially contains the same data as an AIR file, but in text-based file format. An ASM file is divided into named token blocks, where each token block corresponds to an AIR file section. An example drag parameter token block from an ASM file is shown below:

```
TOKEN_BEGIN    AIR_80_DRAG_PARAMS
    REAL8      0.051       ; CDo
    REAL8      0.080000    ; CD flaps
    REAL8      0.007000    ; CD gear
    REAL8      0.130000    ; CD spoiler
TOKEN_END
```

Each ASM token block begins with a "TOKEN_BEGIN" statement and ends with a "TOKEN_END" statement. The "TOKEN_BEGIN" statement identifies the corresponding AIR file section using the token names defined by Microsoft in the FSX/ESP Software Development Kit (SDK). In the following paragraphs, the AIR file section number for each token block is also provided.

The data directives contained between each pair of begin and end statements define the aerodynamic coefficients for the corresponding AIR file section. The format of each AIR file section depends on the number and type of data directives found between the begin and end statements in each token block, so the number of elements, the order of the elements, and the element data types should not be altered. Token blocks within an ASM file, and sections within an AIR file, do not have to be arranged in any particular order.

Required Air File Sections

The base aerodynamic stability and control coefficients are used to scale the effectiveness of the wings, stabilizers, and control surfaces relative to the span, area and chord of the main wing. Before FSX loads flight dynamics files, the values of all base aerodynamic coefficients are set to zero; therefore the data for these coefficients must be defined in the AIR file to avoid abnormal flight behavior.

Prior to FS2002, the base aerodynamic coefficients were defined in a single Aerodynamic Coefficients section (1101). FS2002 introduced six additional aerodynamic coefficient sections that can also be used to define the same aerodynamic coefficients. These new sections did not add any new coefficients; they simply change the binary format and location of the coefficients.

The six FS2002 aerodynamic coefficient sections are as follows:

AIR_80_LIFT_PARAMS (1539)
AIR_80_DRAG_PARAMS (1540)
AIR_80_PITCH_PARAMS (1541)
AIR_80_SIDE_FORCE_PARAMS (1542)
AIR_80_ROLL_PARAMS (1543)
AIR_80_YAW_PARAMS (1544)

(FS2002 is FS version 8.0, hence the prefix 'AIR_80' in the token names.)

The lift and pitch moment coefficients are defined in two angle of attack look-up tables:

AIR_CL_ALPHA (404)
AIR_CM_ALPHA (473)

Internally, AirWizEd organizes and maintains the base aerodynamic coefficients using the AIR_80 aerodynamic coefficient formats. However, AIR files containing both the original Aerodynamic Coefficients section (1101) and any of the AIR_80 aerodynamic coefficient sections can be confusing because the rules of precedence are not explicitly stated. To eliminate confusion over which coefficient has precedence, AirWizEd reformats the aerodynamic coefficients and outputs just the Aerodynamic Coefficients section (1101) in AIR files. At the same time an AIR file is written, a corresponding ASM file is written that contains all of the base aerodynamic coefficients in AIR_80 token blocks.

When AirWizEd reads an AIR file, if both the original Aerodynamic Coefficients section and AIR_80 coefficient sections are present, the AIR_80 coefficient values take precedence.

The AirWizEd coefficient editor tab groups the base aerodynamic stability and control coefficients in AIR_80 token block order. The coefficient values are displayed as both real numbers and as legacy fixed binary point integers. The program will accept edit inputs in either format.

Optional Air File Sections

The following AIR file sections modify the base aerodynamic stability and control coefficients. They are used to model the non-linear variation of the base aerodynamic stability and control coefficients due to distance above ground, control linkage, airframe elasticity, load factor, angle of attack, and mach number. The ground effect, control input parameter, and angle of attack modifiers are scalar multipliers, while the mach effect modifiers are additive. Since FSX initializes the scalar multipliers to 1 and the mach effect modifiers to 0, these AIR file sections are optional.

Ground effect modifiers

AIR_GROUND_EFFECT (400)

Control input parameter modifiers

AIR_ELEVATOR_SCALING (341)
AIR_AILERON_SCALING (342)
AIR_RUDDER_SCALING (343)
AIR_61S_AIL_RUD_TRIM_CONSTANTS (516)
AIR_61S_ELEVATOR_ELASTICITY (517)
AIR_70_ELEVATOR_TRIM_ELASTICITY (1525)
AIR_61S_AILERON_ELASTICITY (518)
AIR_61S_RUDDER_ELASTICITY (519)
AIR_61S_AILERON_LOAD_FACTOR_EFF (546)

Angle of Attack modifiers

AIR_ALPHA_ON_CL_BETA (451)
AIR_ALPHA_ON_CLP (456)
AIR_ALPHA_ON_CN_BETA (460)
AIR_ALPHA_ON_CNR (464)
AIR_61S_ALPHA_ON_CMDE (536)
AIR_61S_ALPHA_ON_CMIH (537)
AIR_61S_ALPHA_ON_CMADOT (538)
AIR_61S_ALPHA_ON_CMQ (539)
AIR_70S_ALPHA_ON_CLDA (1535)
AIR_70S_ALPHA_ON_CNDR (1536)
AIR_70S_CN_ALPHA_YAW (1537)
AIR_70S_Cl_ALPHA_ROLL (1538)

Mach table modifiers

AIR_CL_MACH (401)
AIR_CL_DELTAE (410)
AIR_CL_ADOT (411)
AIR_CL_Q (412)
AIR_CL_IH (413)
AIR_CM_DELTAE (420)
AIR_CM_ADOT (421)
AIR_CM_Q (422)
AIR_CM_IH (423)
AIR_CDO (430)
AIR_CMO (433)
AIR_CY_BETA (440)
AIR_CY_DELTAR (441)
AIR_CY_R (442)
AIR_CY_P (443)
AIR_CL_BETA (450)
AIR_CL_DELTAR (452)
AIR_CL_DELTAA (453)
AIR_CL_R (454)
AIR_CL_P (455)
AIR_CN_BETA (459)
AIR_CN_DELTAR (461)
AIR_CN_DELTAA (462)
AIR_CN_R (463)
AIR_CN_P (465)

Autopilot PID Controllers

The autopilot section, AIR_AP_PID_CONTROLLERSF (1199), is only used by FSX to assist in handling AI-controlled airplanes. This AIR file section is divided up into 15 subsections, where each subsection defines a set of Proportional-Derivative-Integral (PID) control parameters for the autopilot. The PID control parameters are arranged in the following order:

1) UNUSED
2) Heading Hold
3) UNUSED
4) UNUSED
5) UNUSED
6) UNUSED
7) UNUSED
8) UNUSED
9) UNUSED
10) UNUSED
11) UNUSED
12) UNUSED
13) Airspeed Hold
14) UNUSED
15) UNUSED

Engine Parameters

Piston engine aircraft use the following engine and propeller tuning sections:

AIR_61S_ENG_MECHANICAL_EFFICIENCY (508)
AIR_61S_ENGINE_FRICTION (509)
AIR_61S_PROP_EFFICIENCY (511)
AIR_61S_PROP_PWR_CF (512)
AIR_61S_EGT (540)
AIR_61S_CHT (541)
AIR_61S_RADIATOR_TEMPERATURE (542)
AIR_61S_OIL_TEMPERATURE (543)
AIR_61S_OIL_PRESSURE (544)
AIR_61S_FUEL_PRESSURE (545)

Jet engine aircraft use the following engine tuning sections:

AIR_70_N2_TO_N1_TABLE (1502)
AIR_70_MACH_0_CORRECTED_COMMANDED_NE (1503)
AIR_70_MACH_HI_CORRECTED_COMMANDED_NE (1504)
AIR_70_CORRECTED_N2_FROM_FF (1505)
AIR_70_N1_AND_MACH_ON_THRUST (1506)
AIR_70_CORRECTED_AIRFLOW (1507)
AIR_70_PRIMARY_NOZZLE (1521)
AIR_70_REVERSER_NOZZLE (1522)
AIR_70_AFTERBURNER_ON_THRUST_TABLE (1524)
AIR_70_ITT (1526)
AIR_70_EPR (1532)
AIR_61S_EGT (540)
AIR_61S_OIL_TEMPERATURE (543)
AIR_61S_OIL_PRESSURE (544)
AIR_10XPACK_N1_MACH_ON_NOZZLE (1549)

Turboprop engine aircraft use the following engine and propeller tuning sections:

AIR_70_MACH_0_CORRECTED_COMMANDED_NE (1503)
AIR_70_MACH_HI_CORRECTED_COMMANDED_NE (1504)
AIR_70_N1_AND_MACH_ON_THRUST (1506)
AIR_70_CORRECTED_AIRFLOW (1507)
AIR_70_N1_TO_SHAFT_TORQUE (1508)
AIR_80_DENSITY_ON_TP_TORQUE (1548)
AIR_70_ITT (1526)
AIR_70_EPR (1532)
AIR_61S_EGT (540)
AIR_61S_OIL_TEMPERATURE (543)
AIR_61S_OIL_PRESSURE (544)
AIR_61S_ENGINE_FRICTION (509)
AIR_61S_PROP_EFFICIENCY (511)
AIR_61S_PROP_PWR_CF (512)

Helicopter tuning parameters

Helicopters require different sets of AIR file sections, depending on the type of the helicopter. FSX supports two primary helicopter types, piston engine helicopters and turbine engine helicopters. For the two primary helicopter types, the engine tuning parameters are defined in the AIR file, and all other parameters are defined in the .cfg file.

Piston engine helicopters use the following engine tuning sections:

AIR_61S_ENG_MECHANICAL_EFFICIENCY (508)
AIR_61S_ENGINE_FRICTION (509)
AIR_61S_EGT (540)
AIR_61S_CHT (541)
AIR_61S_RADIATOR_TEMPERATURE (542)
AIR_61S_OIL_TEMPERATURE (543)
AIR_61S_OIL_PRESSURE (544)
AIR_61S_FUEL_PRESSURE (545)

Turbine engine helicopters use the following engine tuning sections:

AIR_70_MACH_0_CORRECTED_COMMANDED_NE (1503)
AIR_70_MACH_HI_CORRECTED_COMMANDED_NE (1504)
AIR_70_N1_AND_MACH_ON_THRUST (1506)
AIR_70_CORRECTED_AIRFLOW (1507)
AIR_70_N1_TO_SHAFT_TORQUE (1508)
AIR_80_DENSITY_ON_TP_TORQUE (1548)
AIR_70_ITT (1526)
AIR_70_EPR (1532)
AIR_61S_EGT (540)
AIR_61S_OIL_TEMPERATURE (543)
AIR_61S_OIL_PRESSURE (544)
AIR_61S_ENGINE_FRICTION (509)

FSX also supports an older turbine helicopter format (Bell 206B) with very limited engine configuration options. The geometry for this older type is defined primarily in the ASM file using the following AIR file sections:

AIR_HELI_VERTICAL_TAIL (1400)
AIR_HELI_HORIZONTAL_TAIL (1401)
AIR_HELI_MAIN_ROTOR (1402)
AIR_HELI_TAIL_ROTOR (1403)
AIR_HELI_MISCELLANOUS (1404)

Data Conventions

FSX uses an orthogonal left hand system with the following conventions:

Longitudinal - positive forward
Lateral - positive right
Vertical - positive up
Pitch - positive nose down
Bank - positive left
Yaw - positive right
Elevator - positive up
Aileron - positive right
Rudder - positive right

ASM File Data Types

- 16-bit integers - declared as **dw** (signed) or **UINT16** (unsigned).
- 32-bit integers - declared as **dd** (signed) or **UINT32** (unsigned).
- 64-bit Floating point data - declared as **REAL8**, **DQ**, or **FLOAT64**.

Coefficient Table Format

FSX uses coefficient tables for several different simulation functions, such as engine tuning and non-linear aerodynamic effects caused by angle of attack, airframe elasticity, and g-force loading. Each coefficient table contains one or two integers that specify the number of elements found in the table, followed by the coefficient data formatted as 64-bit floating point numbers.

FSX uses linear interpolation to calculate the actual value from a table lookup; therefore, coefficient table values should be defined in ascending order.

FSX does not extrapolate table lookups from the endpoints. If a table lookup exceeds the range of values defined in a coefficient table, the value returned from the lookup operation will be limited to the minimum or maximum values defined in the table.

Some coefficient tables are two dimensional, which means two values are required to perform a lookup operation. When a coefficient table has two input dimensions, one input is used to determine the correct row of the table, and the second input is used to determine the correct row. For example, in the AIR_61S_PROP_EFFICIENCY table, the first input is advance ratio (column) and the second input is propeller beta angle (row).

Aerodynamic Coefficient Token Blocks

The aerodynamic coefficients determine the dynamic performance and stability of the flight model. These coefficients are used by FSX to calculate the linear and rotational acceleration, velocity and position of the model.

A number of the aerodynamic coefficients used by FSX are 'stability derivatives'. Stability derivatives are simply numbers used to scale the effectiveness of the horizontal and vertical stabilizers relative to the span, area and chord of the main wing.

The aerodynamic coefficient symbols used by FSX are derived from the following definitions:

CL	lift coefficient (lift/qS)
Cd	drag coefficient (drag/qS)
Cm	pitching-moment coefficient about the quarter-chord point of the MAC
Cl	rolling-moment coefficient
Cn	yawing-moment coefficient
q	pitch rate, deg/sec or rad/sec
P	roll rate, deg/sec or rad/sec
R	yaw rate, deg/sec or rad/sec
A (alpha)	angle of attack, deg or rad
adot	angle of attack change rate, deg/sec or rad/sec
B (beta)	angle of sideslip, deg or rad
ih	horizontal stabilizer incidence, deg or rad
da	aileron deflection, deg or rad
de	elevator deflection, deg or rad
dr	rudder deflection, deg or rad
df	flap deflection, deg or rad
dg	gear deflection, deg or rad
ds	spoiler deflection, deg or rad

AIR_80_LIFT_PARAMS (1539) Token Block

The AIR_80_LIFT_PARAMS token block is a list of six REAL8 aerodynamic lift coefficients defined as follows:

CL spoilers	Coefficient of lift for spoiler deflection, per radian of deflection.
CL flaps	Coefficient of lift for flap deflection, per radian of deflection.
UNUSED	
CLih	Coefficient of lift due to horizontal stabilizer incidence. CLih is multiplied by horizontal stabilizer incidence; lift will be zero if stabilizer incidence is zero.
CLde	Coefficient of lift due to elevator deflection, per radian of deflection.
UNUSED	

AIR_80_DRAG_PARAMS (1540) Token Block

The AIR_80_DRAG_PARAMS token block is a list of four REAL8 aerodynamic drag coefficients defined as follows:

CDo	Parasitic drag for total airframe.
CD flaps	Parasitic drag for flaps deflection, per radian of deflection.
CD gear	Parasitic drag for landing gear in the down position.
CD spoilers	Parasitic drag for spoiler deflection, per radian of deflection.

AIR_80_PITCH_PARAMS (1541) Token Block

The AIR_80_PITCH_PARAMS token block is a list of thirteen REAL8 aerodynamic pitch coefficients defined as follows:

CMih	Pitching moment due to horizontal stabilizer incidence. CMih is multiplied by horizontal stabilizer incidence; moment will be zero if stabilizer incidence is zero.
CMde	Pitch moment due to elevator deflection, per radian of deflection. Determines how much leverage the elevator has to pitch the aircraft up and down.
CMde due to propeller wash	Effect of propeller wash on Elevator Control. Determines how much elevator leverage is increased when propeller wash increases.
CLq	Lift due to pitch velocity. A lift coefficient that controls transient lift changes in proportion to pitch velocity.
CL adot	Lift due to pitch acceleration. A lift coefficient that controls transient lift changes in proportion to pitch acceleration.
CM adot	Pitch moment due to pitch acceleration. Pitch damping coefficient that controls resistance to pitching motions in proportion to pitch acceleration. Resists pitching motions in either direction, and adds to the stability of the aircraft.
CMq	Pitch moment due to pitch velocity. Pitch damping coefficient that controls resistance to pitching motions in proportion to pitch velocity. Resists pitching motions in either direction, and adds to the stability of the aircraft.
CMq due to propeller wash	Pitch damping due to propeller wash. Pitch damping coefficient that controls resistance to pitching motions in proportion to propeller wash. Resists pitching motions in either direction, and adds to the stability of the aircraft.
CMo	Reference moment at zero angle of attack. Pitching-moment coefficient at zero lift. Positive values cause nose to pitch up.
CM flaps	Pitching moment due to flap extension, per radian of deflection.
CM delta trim	Pitching moment due to pitch trim, per radian of trim deflection.
CM gear	Pitching moment due to landing gear extension in the down position.
CM spoilers	Pitching moment due to spoiler deflection, per radian of deflection.

AIR_80_SIDE_FORCE_PARAMS (1542) Token Block

The AIR_80_SIDE_FORCE _PARAMS token block is a list of four REAL8 aerodynamic side force coefficients defined as follows:

CyB	Side force due to yaw angle. Determines how much the aircraft sideslips in proportion to yaw angle.
CyP	Side force due to roll velocity. A side force coefficient that controls transient changes in side force in proportion to roll velocity.
CyR	Side force due to yaw velocity. A side force coefficient that controls transient changes in side force in proportion to yaw velocity.
Cy Delta Rudder	Side force due to rudder deflection. Determines how much the aircraft sideslips in proportion to rudder deflection, per radian of deflection.

AIR_80_ROLL_PARAMS (1543) Token Block

The AIR_80_ROLL _PARAMS token block is a list of six REAL8 aerodynamic roll coefficients defined as follows:

ClB	Roll moment due to yaw angle. Dihedral effect - the tendency of the aircraft to roll level in proportion to the yaw angle.
ClP	Roll moment due to roll velocity. Roll damping coefficient that controls resistance to rolling motions in proportion to roll velocity. Resists rolling motions in either direction, and adds to the stability of the aircraft.
ClR	Roll due to yaw velocity. A roll moment coefficient that controls transient changes in roll force in proportion to yaw velocity. Opposes the dihedral effect.
Cl Delta Spoiler	Roll moment due to spoiler deflection. Determines how much leverage the spoilers have to roll the aircraft, per radian of deflection.
Cl Delta Aileron	Roll moment due to aileron deflection. Determines how much leverage the ailerons have to roll the aircraft, per radian of deflection.
Cl Delta Rudder	Roll moment due to rudder deflection. Determines how much leverage the rudder has to roll the aircraft, per radian of deflection.

AIR_80_YAW_PARAMS (1544) Token Block

The AIR_80_YAW _PARAMS token block is a list of nine REAL8 aerodynamic yaw coefficients defined as follows:

CnB	Yaw moment due to yaw angle. Weathervane effect - the tendency of the aircraft to yaw in proportion to the yaw angle.
CnP	Yawing moment due to roll velocity. Adverse yaw caused by wing to wing lift differences when rolling.
CnR	Yaw moment due to yaw velocity. Yaw damping coefficient that controls resistance to yawing motions in proportion to yaw velocity. Resists yawing motions in either direction, and adds to the stability of the aircraft.
CnR due to propeller wash	Yaw damping due to propeller wash. Yaw damping coefficient that controls resistance to yawing motions in proportion to propeller wash. Resists yawing motions in either direction.
UNUSED	
UNUSED	
Cn Delta Aileron	Yaw moment due to aileron deflection. Adverse yaw caused by aileron drag.
Cn Delta Rudder	Rudder Control coefficient. Determines how much leverage the rudder has to yaw the aircraft, per radian of deflection.
Cn Delta Rudder due to propeller wash	Rudder Control due to propeller wash. Determines how much rudder leverage is increased due to propeller wash.

Section 1101 Aerodynamic Coefficients

This air file section contains the base stability derivatives and control coefficients, as well as a number of miscellaneous parameters. This section is present in most MSFS default AIR files and contains essentially the same parameters defined in the 'AIR_80' Base Aerodynamic Coefficients token blocks.

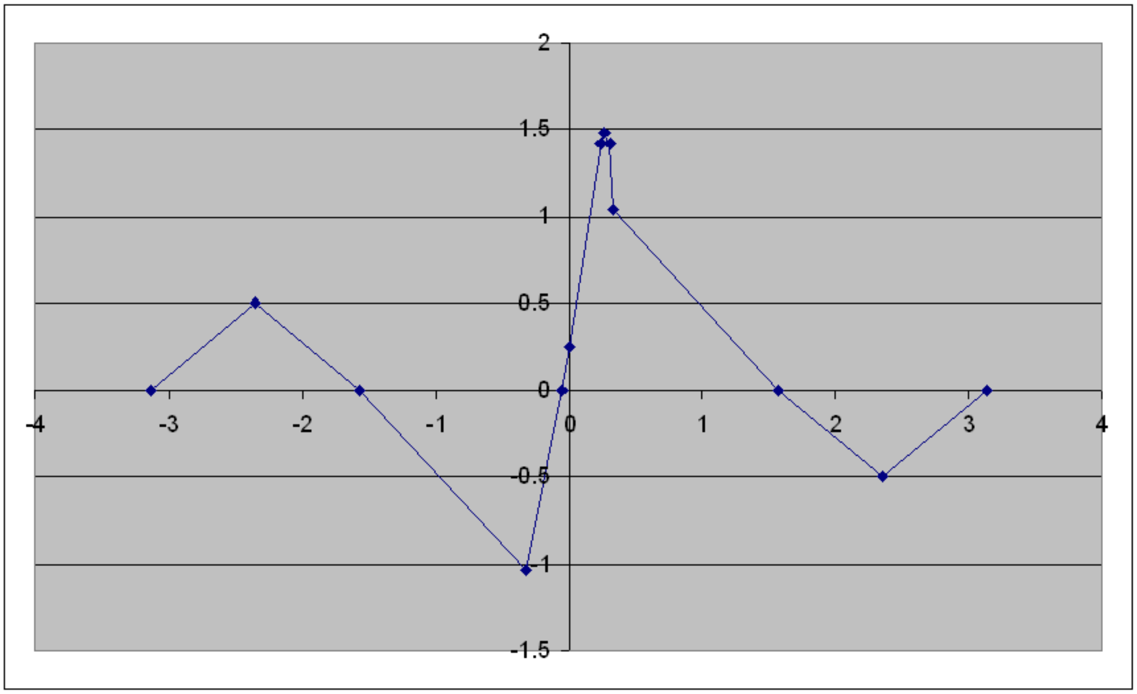
Offset (hex)	Data Type	Identity	Comments	Scale Factor
0	int8	Sim ID	cfs1 = 54 (36h) cfs2 = 56 (38h) cfs3 = 58 (40h) fs7/fs2000 = 55 (37h) fs8/fs2002 = 57 (39h) fs9/fs2004 = 97 (61h) fsx = 98 (62h) fsx acceleration = 99 (63h) (not used)	1
1	int8	Airframe ID	Generally not used. Only FS2000/Concorde (23) has any noted effect.	1
2	int16	Stick Shaker Stall Speed	Triggers FFB stick shaker if airspeed drops below this value.	1
4	aspd	Vmo	Maximum aircraft operating velocity in knots. Triggers on-screen over-speed warning message. (Replaced by aircraft.cfg parameters)	128
8	int16	Indicated Airspeed Offset	A value added to displayed IAS. Used to model low IAS at low speeds due to Pitot Tube effects. (Replaced by aircraft.cfg parameters)	1
0A	int16	Indicated Airspeed Scalar	IAS scalar. Range: -1 to +1	32768
0C	double	Flaps Cycle Time	Time it takes to fully extend or retract the flaps in seconds. (Replaced by aircraft.cfg parameters)	1
14	double	Spoiler Cycle Time	Time it takes to fully extend or retract the spoilers in seconds. (Replaced by aircraft.cfg parameters)	1
1C	int32	Aircraft weight	The empty weight of the airplane. (Replaced by aircraft.cfg parameters)	1
20	int16	Stall Warning Angle of Attack	Sets the value used by the simulator to trigger the stall horn. (section 404 used by FS2004 and FSX)	182
22	int32	Scalar	Can affect propwash (not used by FSX)	1
26	int16	Braking Strength	Landing gear brake force scalar. Range: 0 to 1 (Replaced by aircraft.cfg parameters)	65536
28	int16	Positive G Limit	Structural force limit in positive direction - clean aircraft. (Replaced by aircraft.cfg parameters)	1024
2A	int16	Negative G Limit	Structural force limit in negative direction - clean aircraft. (Replaced by aircraft.cfg parameters)	1024

Offset (hex)	Data Type	Identity	Comments	Scale Factor
2C	int16	Positive G Limit with flaps	Structural force limit in positive direction - flaps extended. (Replaced by aircraft.cfg parameters)	1024
2E	int16	Negative G Limit with flaps	Structural force limit in negative direction - flaps extended. (Replaced by aircraft.cfg parameters)	1024
30	int16	Cd0 - Zero Lift Drag	Zero lift drag coefficient. Parasitic drag of airframe.	2048
32	int16	Cd_df - Flaps Drag	Flaps drag coefficient. Parasitic drag of flaps per radian of deflection.	2048
34	int16	Cd_dg - Landing Gear Drag	Landing gear drag coefficient. Parasitic drag of landing gear in the down position.	2048
36	int16	Cd_ds - Spoiler Drag	Spoiler drag coefficient. Parasitic drag of spoilers per radian of deflection.	2048
38	double	Unused	Unused 64-bit floating point value	-
40	double	Unused	Unused 64-bit floating point value	-
48	double	Unused	Unused 64-bit floating point value	-
50	int16	Zero lift angle of attack	Minimum lift induced drag occurs at this angle of attack. (not used in FS2004 or FSX)	182
52	int32	CL_adot - Lift due to AoA acceleration	Lift coefficient increase induced by angle of attack acceleration.	2048
56	int32	CL_q - Lift due to pitch velocity	Lift coefficient increase induced by pitch velocity.	2048
5A	int16	CL_de - Lift due to elevator deflection	Lift coefficient increase induced by elevator deflection.	2048
5C	int16	CL_dh - Lift due to horizontal stabilizer	Lift coefficient increase due to horizontal stabilizer incidence. (No effect if horizontal stabilizer incidence is zero.)	2048
5E	double	CL_df - Lift due to flap deflection	Flap lift coefficient. Lift coefficient increase due to flaps, per radian of deflection.	1
66	double	CL_ds - Lift due to spoiler deflection	Spoiler lift coefficient. Lift coefficient increase due to spoilers, per radian of deflection.	1
6E	int16	Cl_Beta - Dihedral effect	Roll due to yaw angle. The tendency of the aircraft to roll level when yawed.	2048
70	int16	Cl_da - Aileron control coefficient	Roll moment coefficient, per radian of aileron deflection. Determines how much leverage the ailerons have to roll the aircraft.	2048
72	int32	Cl_dr - Roll due to rudder deflection	Determines how much leverage the rudder has to roll the aircraft.	2048
76	int32	Cl_p - Roll damping	Roll due to roll velocity. Resists rolling motions in either direction. Adds to the stability of the aircraft.	2048
7A	int32	Cl_r - Roll due to yaw velocity	Opposes dihedral.	2048
7E	double	Cl_adot - Roll due to AoA acceleration	Roll induced by angle of attack acceleration.	1
86	int32	Cm0 - CM at zero AoA	Pitch moment coefficient when angle of attack is zero. Positive values cause pitch up.	2048
8A	int32	Cm_adot - Pitch damping due to AoA acceleration	Resists pitching motions in either direction. Adds to the stability of the aircraft.	2048
8E	int32	Cm_de - Elevator control coefficient	Pitch moment coefficient, per radian of elevator deflection. Determines how much leverage the elevator has to pitch the aircraft up and down.	2048

Offset (hex)	Data Type	Identity	Comments	Scale Factor
92	int32	Cm_ih - CM added by Hstab	Pitch effect caused by horizontal stabilizer incidence. Coefficient is multiplied by angle of horizontal stabilizer incidence, so effect will be zero if stabilizer angle is zero.	2048
96	int32	Cm_q - Pitch damping due to pitch velocity	Resists pitching motions in either direction. Adds to the stability of the aircraft.	2048
9A	double	Cm_de_prop - Effect of propwash on elevator control	Increases elevator effectiveness due to propwash.	1
A2	double	Cm_q_prop - Effect of propwash on pitch damping	Increases pitch damping due to propwash.	1
AA	double	Cm_dt - CM due to trim	Pitch effect caused by trim deflection, per radian of pitch trim. Each 'click' of keyboard pitch trim is 1/1024 of trim range.	1
B2	double	Cm_df – Pitch due to flaps	Pitch effect caused by flap extension.	1
BA	double	Cm_dg - Pitch due to landing gear	Pitch effect caused by landing gear extension.	1
C2	double	Cm_ds - Pitch due to - spoilers	Pitch effect caused by spoiler extension.	1
CA	int32	Cn_Beta - Weathervane effect	Yaw moment due to yaw angle. Controls the directional stability of the aircraft.	2048
CE	int16	Cn_da - Adverse yaw due to aileron drag	Adverse yaw coefficient for aileron deflection. When the ailerons are deflected, drag on the down aileron side increases while drag on the up aileron side decreases. Net effect is adverse yaw.	2048
D0	int32	Cn_dr – Rudder control coefficient	Yaw moment coefficient, per radian of rudder deflection. Determines how much leverage the rudder has to yaw the aircraft.	2048
D4	double	Cn_dr_prop - Effect of propwash on rudder control	Increases rudder effectiveness due to propwash.	1
DC	double	Cn_r_prop - Effect of propwash on yaw damping	Increases yaw damping due to propwash.	1
E4	int32	Cn_p - Adverse yaw due to rolling	Adverse yaw caused by side to side differences in lift vector inclination when rolling, proportional to roll velocity.	2048
E8	int16	Cn_r - Yaw damping	Resists pitching motions in either direction. Adds to the stability of the aircraft.	2048
EA	int32	Unused	Unused 32-bit integer value	2048
EE	int16	CY_beta - Side force due to yaw angle	Determines how much the aircraft sideslips when yawed.	2048
F0	int16	CY_dr - Side force due to rudder deflection	Determines how much the aircraft sideslips due to rudder deflection.	2048
F2	int32	CY_p - Side force due to roll velocity	Determines how much the aircraft sideslips when the aircraft is rolling.	2048
F6	int32	CY_r - Side force due to yaw velocity	Determines how much the aircraft sideslips when the aircraft is yawing.	2048

AIR_CL_ALPHA (404) Token Block

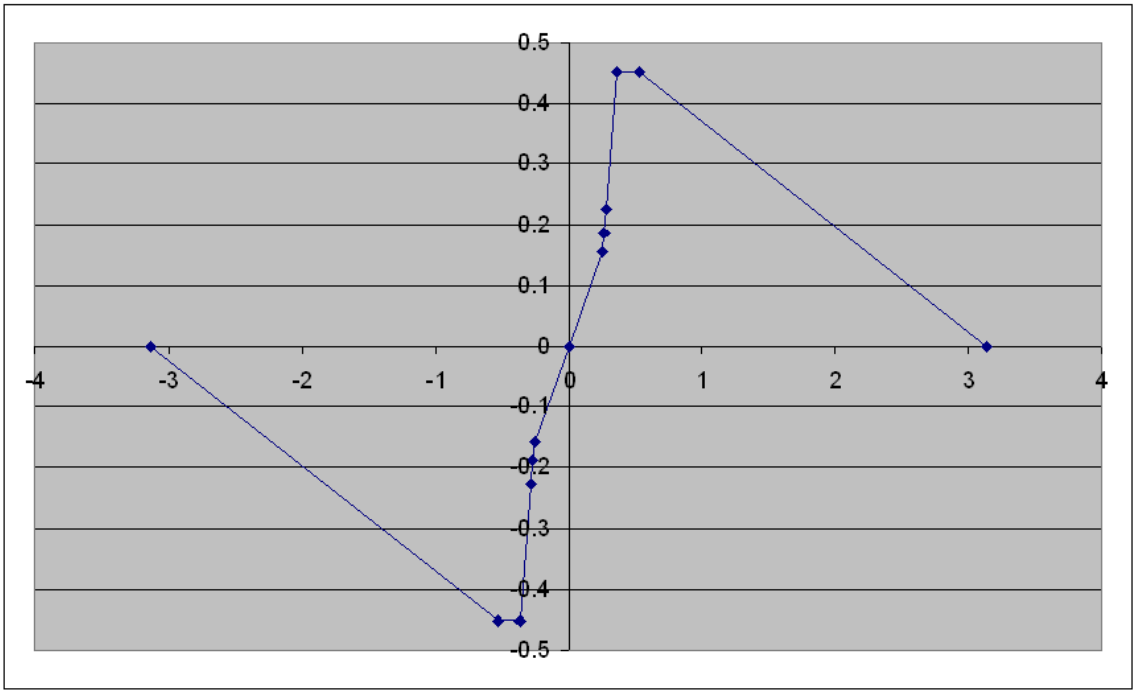
The AIR_CL_ALPHA token block contains a coefficient table that defines the aircraft's lift coefficient (CL) as a function of angle of attack (radians). The table defines a 360 degree range of coefficient values, in ascending order from -180 to +180 degrees, and may use a maximum of 47 data points. To convert an angle of attack in degrees to radians for use in this token block, multiply the angle in degrees by pi/180. The following graph shows an example AIR file lift coefficient curve with the angle of attack shown on the X-axis.



Example AIR_CL_ALPHA Data

AIR_CM_ALPHA (473) Token Block

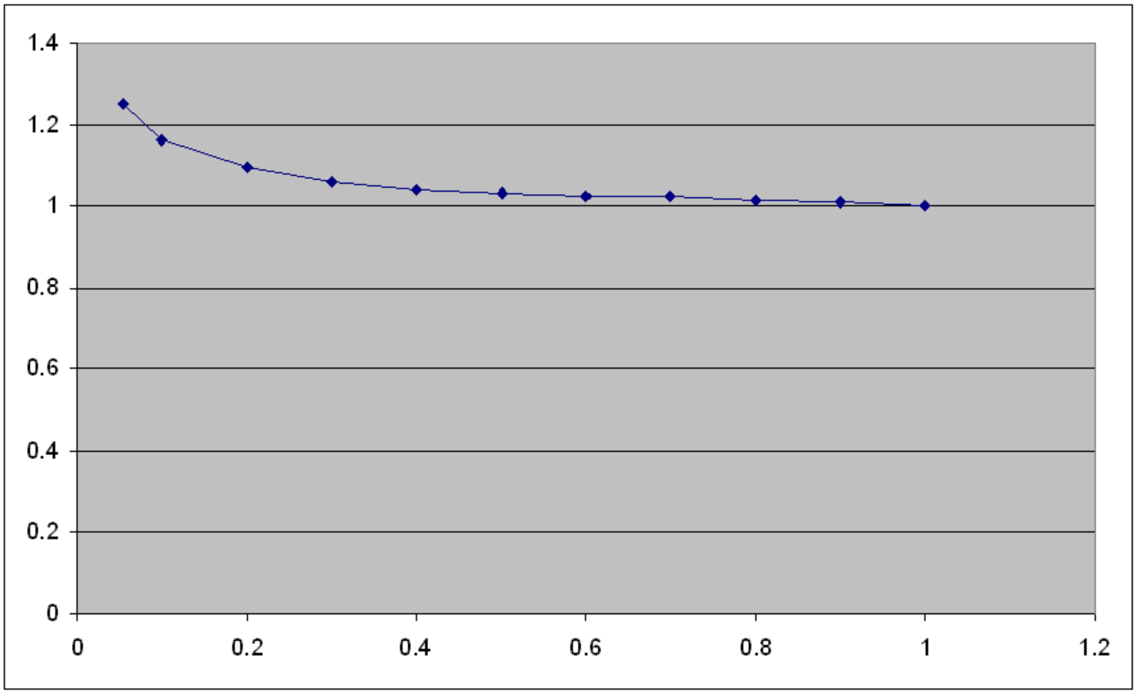
The AIR_CM_ALPHA token block contains a coefficient table that defines the aircraft's moment coefficient (CM) as a function of angle of attack (radians). The table defines a 360 degree range of coefficient values, in ascending order from -180 to +180 degrees, and may use a maximum of 47 data points. To convert an angle of attack in degrees to radians for use in this token block, multiply the angle in degrees by pi/180. The following graph shows an example AIR file moment coefficient curve with the angle of attack plotted on the X-axis.



Example AIR_CM_ALPHA Data

AIR_GROUND_EFFECT (400) Token Block

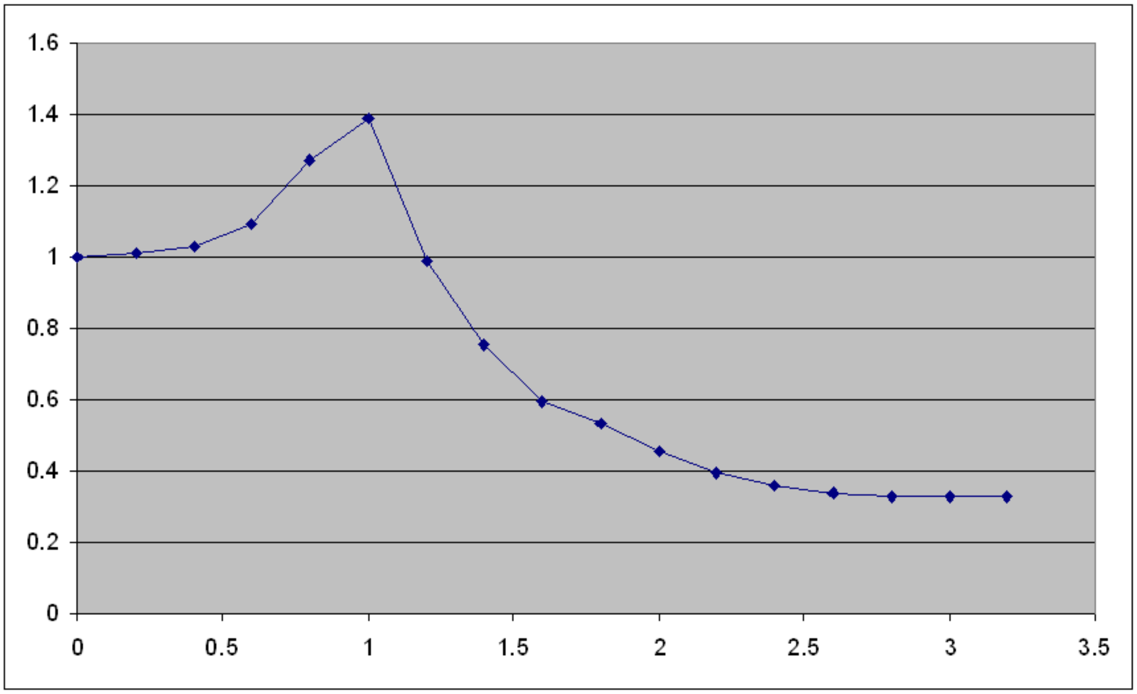
The AIR_GROUND_EFFECT token block contains a coefficient table used to model the effect of ground proximity on the lift coefficient. The data defined in this token block is used to scale the lift coefficient by multiplication. The table covers a range of 0 to 1, which represents the ratio of the altitude above ground to the wingspan of the aircraft, and may use a maximum of 11 data points. The following graph shows an example AIR file ground effect curve with the altitude/wingspan ratio plotted on the X-axis.



Example AIR_GROUND_EFFECT Data

AIR_CL_MACH (401) Token Block

The AIR_CL_MACH token block contains a coefficient table used to model the non-linear effect of mach air compression on the lift coefficient. The data defined in this token block is used to scale the lift coefficient by multiplication. The table typically covers a range of 0 to 3.2 mach and may use a maximum of 17 data points. The following graph shows an example AIR file ground effect curve with the altitude/wingspan ratio plotted on the X-axis.



Example AIR_CL_MACH Data

Mach Integer Token Blocks

Most of the required base aerodynamic coefficients have a corresponding lookup table based on mach number. FSX uses these tables to model the non-linear effects of mach air compression on the base aerodynamic coefficient. The following token blocks are mach integer tables:

Token Block	Mach effect on
AIR_CL_DELTAE (410)	Lift due to elevator deflection
AIR_CL_ADOT (411)	Lift due to pitch acceleration
AIR_CL_Q (412)	Lift due to pitch velocity
AIR_CL_IH (413)	Lift due to horizontal stabilizer incidence
AIR_CM_DELTAE (420)	Elevator control leverage
AIR_CM_ADOT (421)	Pitch damping due to pitch acceleration
AIR_CM_Q (422)	Pitch damping due to pitch velocity
AIR_CM_IH (423)	Pitching moment due to horizontal stabilizer
AIR_CDO (430)	Drag
AIR_CMO (433)	Reference pitching moment
AIR_CY_BETA (440)	Side force due to yaw angle
AIR_CY_DELTAR (441)	Side force due to rudder deflection
AIR_CY_R (442)	Side force due to yaw velocity
AIR_CY_P (443)	Side force due to roll velocity
AIR_CL_BETA (450)	Dihedral effect
AIR_CL_DELTAR (452)	Roll due to rudder deflection
AIR_CL_DELTAA (453)	Aileron control leverage
AIR_CL_R (454)	Roll due to yaw velocity
AIR_CL_P (455)	Roll damping
AIR_CN_BETA (459)	Weathervane effect
AIR_CN_DELTAR (461)	Rudder control leverage
AIR_CN_DELTAA (462)	Adverse yaw due to aileron drag
AIR_CN_R (463)	Yaw damping
AIR_CN_P (465)	Adverse yaw due to roll velocity

Each integer mach table has a fixed size (17 entries) and a fixed interval (0.2 mach), which results in a range of 0 to 3.2 mach. The first entry in each table represents the modification due to mach 0, the second entry is the modifier at mach 0.2, etc. Modifiers for intermediate mach numbers are interpolated.

Each modifier is a 16-bit fixed point binary integer equal to the real number multiplied by 2048. For example a real value of 0.25 would be entered as 512 in an integer mach table (512 = 0.25 * 2048). The range of decimal values is therefore -16.0 to +16.0, with an accuracy of 1/2048.

The base aerodynamic coefficients are modified by addition, i.e. the mach table modifier is added to, or subtracted from, the base aerodynamic coefficient.

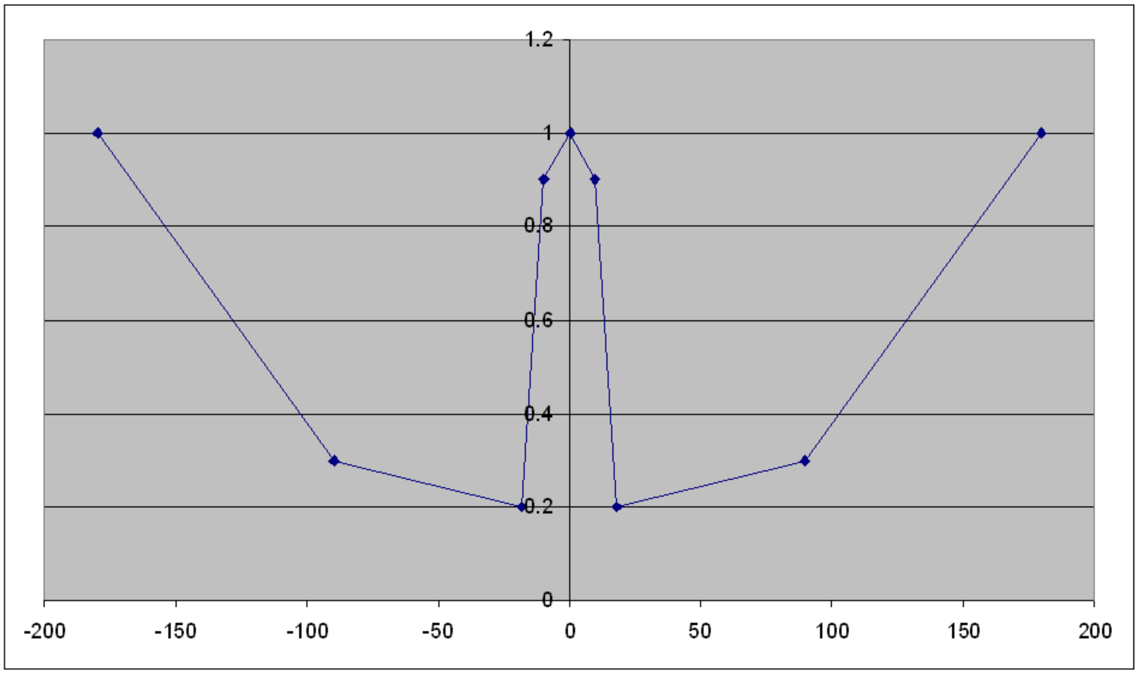
Angle of Attack Token Blocks

FSX uses the data tables defined in the angle of attack token blocks to model the non-linear effects of angle of attack on the associated base aerodynamic coefficient. The angle of attack token blocks are listed in the following table:

Token Block	Angle of attack effect on	Maximum Entries
AIR_ALPHA_ON_CL_BETA (451)	Dihedral effect	9
AIR_ALPHA_ON_CLP (456)	Roll damping	9
AIR_ALPHA_ON_CN_BETA (460)	Weathervane effect	9
AIR_ALPHA_ON_CNR (464)	Yaw damping	9
AIR_61S_ALPHA_ON_CMDE (536)	Elevator control leverage	5
AIR_61S_ALPHA_ON_CMIH (537)	Pitching moment due to horizontal stab	5
AIR_61S_ALPHA_ON_CMADOT (538)	Pitch damping due to pitch acceleration	5
AIR_61S_ALPHA_ON_CMQ (539)	Pitch damping due to pitch velocity	5
AIR_70S_ALPHA_ON_CLDA (1535)	Aileron control leverage	5
AIR_70S_ALPHA_ON_CNDR (1536)	Rudder control leverage	5
AIR_70S_CN_ALPHA_YAW (1537)	Yaw induced by angle of attack	7
AIR_70S_Cl_ALPHA_ROLL (1538)	Roll induced by angle of attack	7

The angle of attack tables usually define a 360 degree range, with data points arranged in ascending order from -180 to +180 degrees. The angles of attack in these token blocks are entered directly in degrees.

The following chart shows an example of the non-linear effects of angle of attack on roll damping:



Example AIR_ALPHA_ON_CLP Data

Elasticity Token Blocks

FSX uses the data tables defined in the elasticity token blocks to model the non-linear effects of structural deformation caused by dynamic pressure on the associated aerodynamic control coefficient. The elasticity token blocks are listed in the following table:

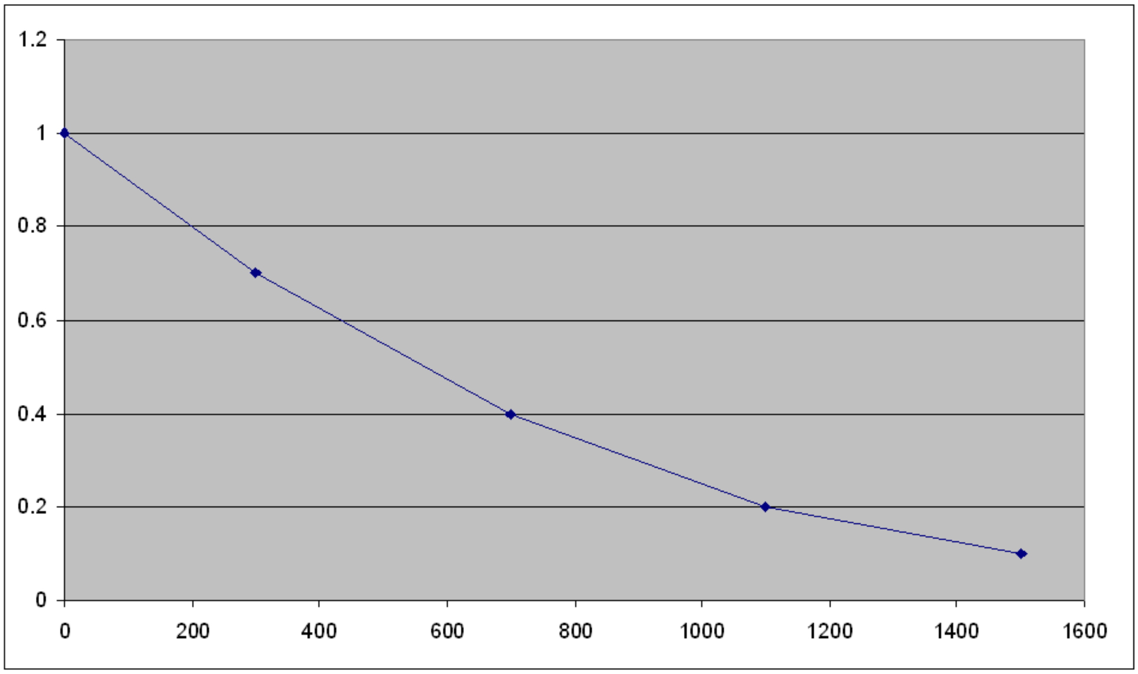
Token Block	Elasticity effect on
AIR_61S_ELEVATOR_ELASTICITY (517)	Elevator control leverage
AIR_70_ELEVATOR_TRIM_ELASTICITY (1525)	Elevator trim control leverage
AIR_61S_AILERON_ELASTICITY (518)	Aileron control leverage
AIR_61S_RUDDER_ELASTICITY (519)	Rudder control leverage

The elasticity tables are indexed by dynamic pressure, in pounds per square foot (psf), as defined in the following equation:

Dynamic pressure = (1/2 Rho * V^2) (pounds per square foot)

The data points in these tables are arranged in ascending order, and typically have a range of 0 to 1500 psf. A maximum of five data points can be defined in each elasticity token block.

The following chart shows an example of the non-linear effects of structural deformation on roll aileron control leverage:



Example AIR_61S_AILERON_ELASTICITY Data

AIR_AP_PID_CONTROLLERSF (1199) Token Block

The AIR_AP_PID_CONTROLLERSF token block defines the autopilot Proportional-Derivative-Integral (PID) control parameters FSX uses to assist in handling AI-controlled airplanes. Each AIR_AP_PID_CONTROLLERSF token block entry defines the following seven control factors:

```
p, i, i2, d, i_boundary, i2_boundary, d_boundary
```

A Proportional-Derivative-Integral controller is a feedback controller that computes an error for a controlled parameter and simultaneously outputs a correction value to the aircraft control system. On an airspeed controller, the error is the difference between the desired airspeed and the current airspeed, and the output is a control signal for the aircraft throttle system. The output is determined by the sum of three factors computed from the error and the P, I, and D control parameters.

The "P" factor is proportional to the error:

"P factor" = P * error

The "I" (integral) factor is an accumulated value scaled by the error:

"Accumulated I factor" = "Accumulated I factor" + (I * error * deltaTime)

This is simply an integral, where the error has to reverse its sign to drive the accumulated factor to 0. This will cause the error to oscillate, but will eventually drive the error to zero.

The "D" (derivative) factor is a value based on the rate of change of the error:

"D factor" = D * error/deltaTime.

As the error gets smaller, the output will be driven asymptotically towards the desired value.

Piston Engine Tuning Parameters

AIR_61S_ENG_MECHANICAL_EFFICIENCY (508) Token Block

This section controls gross engine power as a function of RPM. The first column of the table is engine RPM and the second column is mechanical efficiency. The table can contain a maximum of five entries ordered by ascending RPM, typically with a range of zero to the maximum rated RPM of the engine. The following table shows typical values for an AIR file:

```
0     0.53
700   0.53
2000  0.56
2200  0.56
3000  0.56
```

AIR_61S_ENGINE_FRICTION (509) Token Block

For a reciprocating piston engine, this section controls torque loss per cylinder as a function of engine rpm. It's used to model the effects of engine friction. The first column of the table is engine RPM and the second column is a friction coefficient. The table can contain a maximum of four entries ordered by ascending RPM, typically with a range of negative idle RPM to the maximum rated RPM of the engine. The following table shows typical values for an AIR file:

```
-300.0   -41.0
300.0    41.0
900      40.0
3000     95.0
```

For a piston engine, the horsepower lost at max RPM due to torque loss can be calculated as follows:

HP_{loss} = Num_cylinders * friction_coefficient * RPM / 5252

Note: 5252 = 550 ft-lb/sec * 60 sec/min / 2*PI

For a turbo prop engine, this section controls the percentage of torque lost to friction as a function of turbine N1 rpm. The horsepower of a turbo prop engine is as follows:

HP = Torque * friction_coefficient / (Reduction Gear Ratio * 5252 / Rated N2 RPM)

Note: 5252 = 550 ft-lb/sec * 60 sec/min / 2*PI

Estimating Piston Engine Horsepower Output

The approximate power output can be calculated using the following equations:

efficiency = AIR_61S_ENG_MECHANICAL_EFFICIENCY table lookup
(To estimate maximum power, use the table entry at maximum RPM)

friction = AIR_61S_ENGINE_FRICTION table lookup
(To estimate maximum power, use the table entry at maximum RPM)

friction_loss = number_of_cylinders * friction * rpm / 5252.0

volume_flow = 0.5 * displacement * rpm / (1728.0 * 60.0)

compression = 2.0325 + 4.7 * (1-compression_ratio^0.1665)

gross_hp = efficiency * mp * volume_flow * compression

net_hp = gross_hp - friction_loss

where:
CR = compression ratio

MP = maximum manifold pressure

Propeller Tuning Parameters

The blade of a propeller is twisted at an angle that may be called the propeller pitch, blade angle, or beta angle. Simple propellers that are not able to change the blade angle in flight are referred to as ‘fixed pitch propellers’. Propellers that can mechanically change the blade angle in flight have been referred to as ‘variable pitch propellers’ or ‘constant speed propellers’. While the term ‘variable pitch propeller’ is arguably more descriptive, ‘constant speed propeller’ is the term that has stuck. A flight model can simulate either a fixed pitch propeller or a constant speed propeller, depending on the value of propeller_type in the AIRCRAFT.CFG file.

Piston aircraft engines are most efficient when run at a constant engine speed, while the efficiency of a propeller depends on the speed of the aircraft and the blade angle. When the constant speed propeller type is selected, FSX automatically varies the propeller pitch to select the optimum propeller blade angle for the current aircraft speed.

Propeller thrust

Propeller thrust output depends on a number of constants and runtime variables including propeller diameter, propeller blade angle, propeller gear ratio, propeller efficiency, engine RPM, engine horsepower output and current airspeed. To simplify propeller thrust calculations, look-up tables are used to determine the power required to spin the propeller and the efficiency of the propeller for the current airspeed and propeller blade angle.

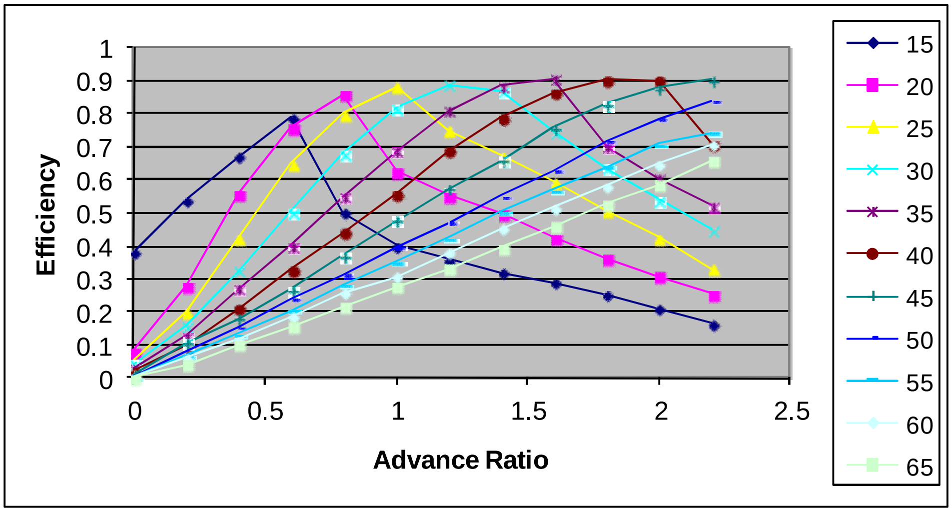
An intermediate parameter called the propeller ‘advance ratio’ (or ‘J’) is calculated from the propeller diameter, propeller gear ratio, engine RPM and airspeed. The advance ratio is then used as an input to lookup propeller power and efficiency coefficients. Advance ratio is calculated using the following formula:

$$\mathbf{J = \text{Advance Ratio} = \frac{\text{Prop Gear Ratio * Airspeed (mph) * 88}}{\text{Prop Diameter (ft) * Engine RPM}}}$$

AIR_61S_PROP_EFFICIENCY (511) Token Block

Propeller Efficiency Coefficients

The **AIR_61S_PROP_EFFICIENCY** token block contains a table of propeller efficiency coefficients. The inputs for table lookup are advance ratio and propeller blade angle. The following chart shows typical propeller efficiency coefficient data for FSX. The X-axis is advance ratio, and each of the individual curves is the propeller efficiency data for a particular propeller blade angle.



Example Propeller Efficiency Coefficients

Propeller Thrust

FSX changes the way it calculates thrust in the low speed range. At speeds above low_speed_theory_limit (value set in the AIRCRAFT.CFG file), FSX calculates thrust using a propeller efficiency table lookup, the current horsepower output of the engine, and the current aircraft velocity:

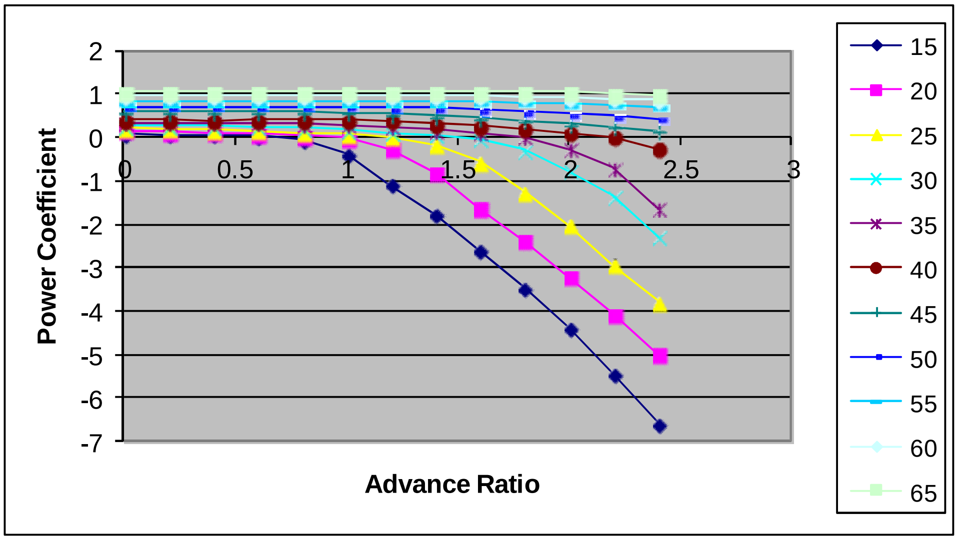
Thrust (lbs) = Efficiency * Horsepower * 375 / Velocity (mph)

Below low_speed_theory_limit, FSX uses an alternate formula to calculate thrust to avoid division by zero and over estimating low speed thrust.

AIR_61S_PROP_PWR_CF (512) Token Block

Propeller Power Coefficients

The **AIR_61S_PROP_PWR_CF** token block contains a table of propeller power coefficients. The inputs for table lookup are advance ratio and propeller blade angle. The following chart shows typical propeller power coefficient data for FSX. The X-axis is advance ratio, and each of the individual curves is the propeller power coefficient data for a particular propeller blade angle.



Example Propeller Power Coefficients

Propeller Power Coefficient and Efficiency Table Usage

FSX apparently calculates engine power and advance ratio, then determines the optimum propeller blade angle using the power coefficient table. The propeller blade angle and advance ratio are then used to look up the propeller efficiency, which is then used to calculate propeller thrust.

The propeller power coefficients are calculated using the following equation:

$$Cp = 550 * hp / (rho * rps^3 * diam^5)$$

Where:

rho = air density (0.002378 at sea-level)
hp = horsepower
rps = propeller revolutions per second
diam = propeller diameter in feet

Jet Engine Tuning Parameters

AIR_70_MACH_0_CORRECTED_COMMANDED_NE (1503)
AIR_70_MACH_HI_CORRECTED_COMMANDED_NE (1504)

The relationships between throttle setting, compressor rpm (CN2), and mach number are defined by the data tables contained in these two token blocks. The runtime values of throttle setting and mach number are used to look-up a value for CN2.

Both of these tables are two dimensional arrays that are indexed by throttle percentage and Inverse Air Pressure Ratio (IAP), where:

IAP = Pressure at sea-level / Pressure at altitude

These tables are each used to look up a value of CN2 given input values of throttle setting and air pressure. Entries in these tables must be ordered by increasing IAP values.

The final value of CN2 is found by interpolating the between values obtained from the two tables by mach number. (The mach numbers used for interpolating CN2 are located at index 0, 0 in these two tables.)

AIR_70_N2_TO_N1_TABLE (1502) Token Block

This table is a two dimensional array used to look up a value for CN1 (turbine rpm) given CN2 (compressor rpm) and mach number. It is indexed by CN2 and mach number.

AIR_70_CORRECTED_N2_FROM_FF (1505) Token Block

This table is a single dimension array of N2 (corrected) vs. fuel flow constant, where the fuel flow constant is a normalized ratio of actual fuel flow parameter to static thrust.

AIR_70_N1_AND_MACH_ON_THRUST (1506) Token Block

This table is a two dimensional array used to look up a thrust coefficient given CN1 and mach number, where:

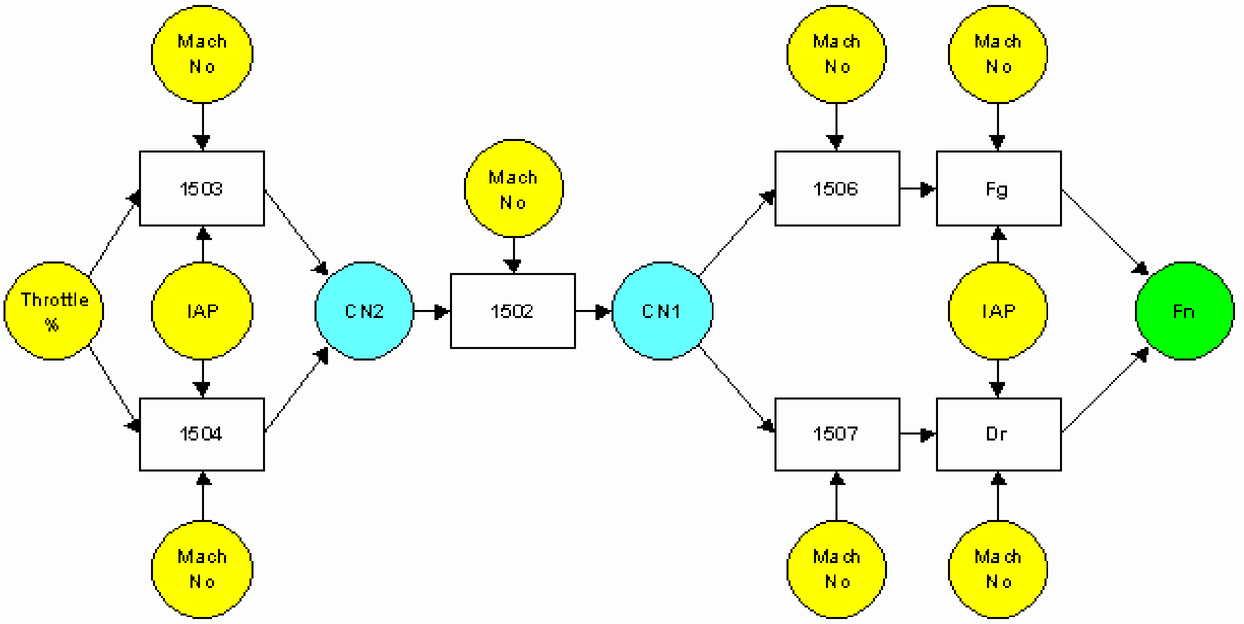
Thrust coefficient = Gross thrust / Static thrust

The table is indexed by CN1 and mach number. The thrust coefficient is used in the calculation of gross thrust.

AIR_70_CORRECTED_AIRFLOW (1507) Token Block

This table a two dimensional array indexed by CN1 and mach number used to look up the normalized airflow, which is used to calculate mass airflow rate and ram drag.

The following figure summarizes the data flow through the token blocks used in the turbojet engine simulation.



Jet Turbine Thrust Calculation

The following equations can be used to calculate the net thrust output of the simulation given mach number, altitude and flight dynamics file parameters:

theta = (288.15 – 0.00198 * altitude) / 288.15

delta = theta$^{5.256}$

delta2 = delta * (1 + M^2/5)$^{3.5}$

theta2 = theta*(1 + M^2/5)

Gross Thrust = Static Thrust * [TBL 1506] * delta2

Ram Drag = (V/g) * Intake_Area * [TBL 1507] * delta2 / theta2$^{0.5}$

Net Thrust = Gross Thrust – Ram Drag

AIR_70_AFTERBURNER_ON_THRUST_TABLE (1524) Token Block

This table a two dimensional array indexed by CN1 and mach number. The data in this table is used to calculate the additional thrust output when the afterburner is engaged.

FSX Model Centers

The 3D visual model and the flight dynamics model are defined by two independent sets of unrelated files. The appearance of an airplane is defined by the 3D visual model, while the location and orientation of the 3D model in the virtual world are determined by the flight model.

The flight model rotates on all axes (pitch, bank and yaw) around the center of gravity, while the visual model rotates around the center of the 3D model. Therefore, the center of the 3D model has to be aligned with the center of gravity in the flight model in order for the display of the simulated aircraft to look realistic.

The recommended center point for FS 3D visual models coincides with the center of gravity location on a normal airplane: on the centerline of the fuselage, ¼ chord aft of the leading edge of the wing. If this recommendation is followed, the 3D visual model and the flight dynamics are aligned automatically.

However, if the center of the 3D model is located elsewhere, the AIR file token block **AIR_70_AERODYNAMIC_CENTER** should be used to align the center of the 3D model with the normal center of gravity location, i.e. on the centerline of the fuselage, ¼ chord aft of the leading edge of the wing.

Center of Gravity Location

The location of the flight model's center of gravity is specified in the AIRCRAFT.CFG file using the parameters **reference_datum_position** and **empty_weight_CG_position**. These parameters are defined as follows:

reference_datum_position	The offset (in feet) of the aircraft's reference datum from the standard FS 3D model center point. (Setting the Reference Datum Position allows using the manufacturer's actual aircraft loading data directly; however, it is often less confusing to set this parameter to 0, 0, 0)
empty_weight_CG_position	The offset (in feet) of the center of gravity of the basic empty aircraft (no fuel, passengers, or baggage) from the Reference Datum Position.

The sign convention for these AIRCRAFT.CFG parameters is positive equals longitudinally forward, laterally to the right, and vertically upward.

Station loads and fuel tank locations affect the location of the center of gravity (CoG), so the CoG at runtime is not necessarily the same as specified by the **empty_weight_CG_position**. The center of gravity may also change during flight as the fuel tanks empty.

Mean Aerodynamic Chord Position

Most aircraft are designed so that the aircraft's center of lift is close to the center of gravity (CoG) in order to minimize the amount of trim required over the widest possible range of operating conditions. The default location of the center of lift is zero relative to the center of the visual model; but this location can be changed in the **AIR_70_AERODYNAMIC_CENTER** AIR file section to accommodate non-standard 3D models or unusual aircraft designs.

The CoG location is not static. For example, if the fuel tanks are located fore or aft of the center of the aircraft, fuel usage will change the center of gravity and consequently change the stability of the aircraft.

The CoG location relative to the MAC can be displayed on a gauge in MSFS. Since the output is a percentage of the MAC, with zero being the leading edge of the MAC and 100% being the trailing edge, it is necessary to know how to set the location of the MAC in the flight model in order to make use of the output from this gauge.

The AIRCRAFT.CFG parameter **wing_pos_apex_lon** sets the location of the MAC. For the following discussion, **reference_datum_position** is assumed to be **0, 0, 0**.

For a straight tapered wing with no leading edge sweep, **wing_pos_apex_lon** is:

wing_pos_apex_lon = CoG_pct * MAC + empty_weight_CG_position_lon

Conversely, to calculate the CoG location relative to the mean aerodynamic chord:

CoG_pct = (wing_pos_apex_lon - empty_weight_CG_position_lon) / MAC

When the leading edge of the wing is swept back, the leading edge of the mean aerodynamic chord moves aft, and the equation to set wing_pos_apex_lon with non-zero wing sweep is then:

wing_pos_apex_lon =
sweep_offset + CoG_pct * MAC + empty_weight_CG_position_lon

To calculate CoG relative to MAC for a swept wing the equation becomes:

CoG_pct =
(wing_pos_apex_lon - empty_weight_CG_position_lon - sweep_offset) / MAC

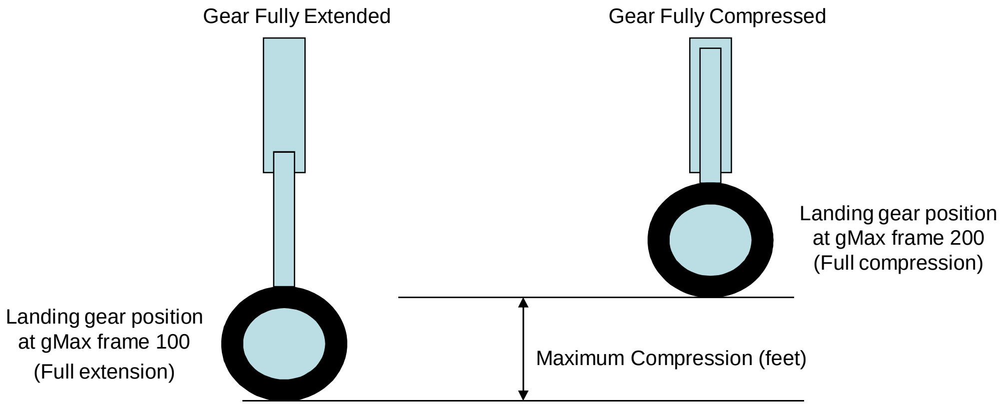
The following equations can be used to calculate sweep_offset, the distance from the leading edge of the root chord to the leading edge of the mean aerodynamic chord:

taper_ratio = (2 * wing_area / wing_span - wing_root_chord) / wing_root_chord

MAC = 2/3 * wing_root_chord * (1 + taper_ratio + taper_ratio^2**) / (1 + taper_ratio)**

sweep_offset =
(wing_span/6) * ((1 + 2 * taper_ratio) / (1 + taper_ratio)) * tan (wing_sweep)

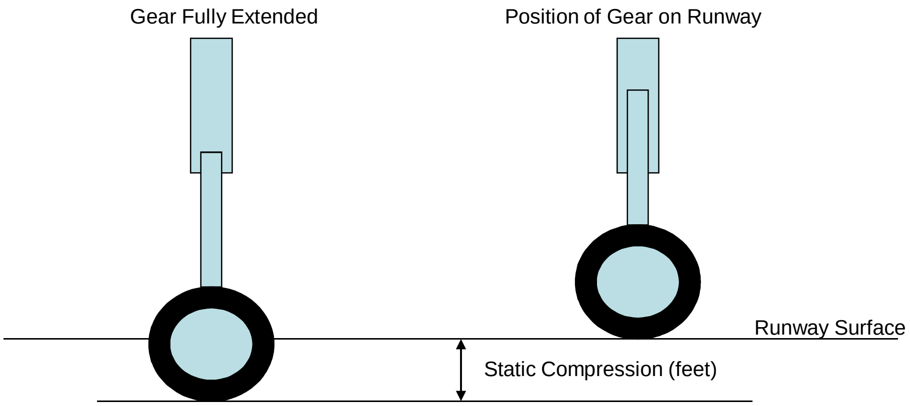
Landing Gear Compression in MSFS


Maximum Compression

Maximum Compression is the total distance the wheel can travel from fully extended to fully compressed. This distance is determined by the animation frames in the visual model.

The fully extended position is visible when the wheels are down in the air, but the fully compressed position will almost never be visible.

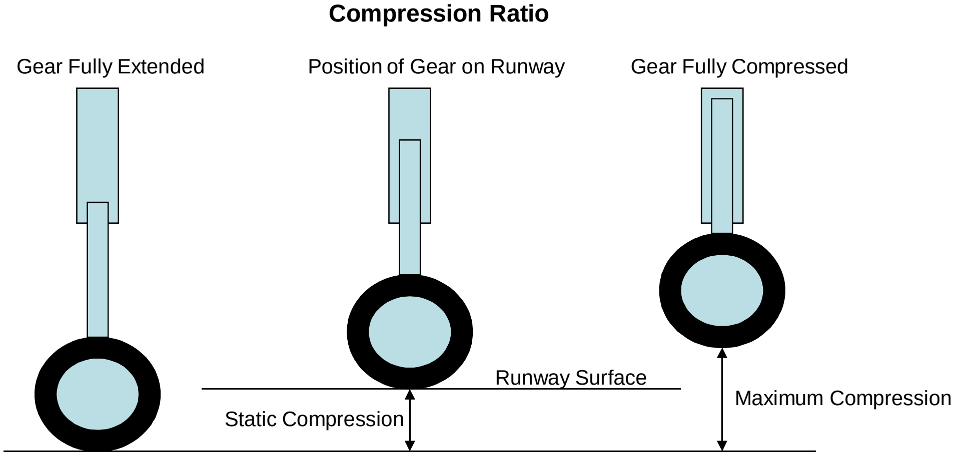
Static Compression



When an aircraft is loaded, it is positioned on the runway with the landing gear compressed by an amount specified by the Static Compression parameter for each contact point.

Static Compression should be set to a value less than Maximum Compression.

At run time FS calculates a spring constant for each landing gear using Static Compression and the weight supported by the gear. The lower the value of Static Compression, the stiffer the spring.



Static Compression and Compression Ratio values are required for each landing gear contact point in the aircraft configuration file. Static Compression can be set to any value less than Maximum Compression, and the Compression Ratio can be calculated using the following formula:

Compression Ratio = Maximum Compression / Static Compression

Note: If Static Compression is changed, Compression Ratio must be recalculated.

If the values of Static Compression and Compression Ratio for a model are correct, Maximum Compression can be found using the following formula:

Maximum Compression = Static Compression * Compression Ratio

Notes

The following sections are a collection of notes on an assortment of problems commonly encountered in developing flight dynamics for FS.

Drag coefficient calculation for a piston engine aircraft

For a piston engine aircraft in straight and level flight at maximum speed, the thrust produced by the propeller is equal to the drag produced by the airframe. The propeller thrust equation is:

$$\mathrm{Thrust} = \eta * HP * 375 / V$$

Where,
η = propeller efficiency,
HP = engine horsepower at altitude,
V = velocity (mph)

Because thrust is equal to drag at maximum speed, the thrust equation can be substituted for drag in the drag coefficient equation, and the drag coefficient can then be calculated from the power required for straight and level flight at maximum speed. Assuming the engine is performing at maximum power at altitude, the drag coefficient is then:

$$CD = 550\, \eta\, HP / (1/2\, \rho\, V^3\, S)$$

Where,
η = propeller efficiency,
HP = engine horsepower at altitude,
ρ = air density at altitude,
V = velocity (mph)
S = wing area (sq ft)

Estimating maximum lift coefficient

If the stall speed is known, the lift equation may be used to find the maximum lift coefficient, CL_{max}:

$$CL_{max} = 391\, W / (1/2\, \rho\, V^2\, S)$$

Where,
W = aircraft weight (lbs),
ρ = air density,
V = velocity (mph)
S = wing area (sq ft)

Estimating clean stall speed

Conversely, an estimated maximum lift coefficient can be used to estimate the stall speed:

$$V_{stall} = \text{sqrt} (2\ W / \rho\ S\ CL_{max})$$

Where,
W = aircraft weight (lbs),
ρ = air density,
V = velocity (mph)
S = wing area (sq ft)

Stability and Control Coefficients

Stability and control coefficients are dimensionless values used to quantify the effectiveness of the stabilizers and control surfaces on the aircraft's motion. The following sections examine a few of these stability coefficients and describe how they affect the performance of an aircraft.

Dihedral Effect (ClB)

A secondary result of an aircraft rolling is that gravity induces a sideslip, which then produces a yaw due to the Weathervane Effect (CnB). Simultaneously, a roll moment results from the yaw due to the dihedral angle of the wing because the angle of attack increases on one wing and decreases on the other. A wing-to-wing difference in lift results, creating a rolling moment that tends to level the wings. The tendency for the wings to roll level is referred to as positive dihedral. (Negative dihedral is referred to as anhedral.)

The dihedral effect increases with dihedral angle, but is also influenced by the position of the wing on the fuselage. Given the same dihedral angle, the dihedral effect will be significantly higher on a high-wing aircraft than it will be on a low-wing aircraft. Low wing aircraft with zero dihedral may exhibit anhedral behavior.

The dihedral effect is a cross-effect, i.e. a yawing motion causes a rolling motion. Note that yaw caused by the rudder will also cause a simultaneous tendency to roll due to the dihedral effect. For positive dihedral, applying the rudder will cause the aircraft to roll into the turn initiated by the rudder.

Roll due to yaw velocity (ClR)

'Roll due to yaw velocity' is a transient cross-effect caused by yaw velocity that creates a simultaneous roll moment due to the speed difference between the left and right wings when the aircraft is yawing.

When the nose of the aircraft yaws to the right, lift on the left wing increases and lift on the right wing decreases due to the difference in wing-to-wing velocity. A nose right yaw will produce a rolling moment to the right.

Yaw moment due to yaw angle (CnB)

This aerodynamic coefficient is also known as the weathervane effect, and it determines the directional stability of the aircraft. This coefficient affects the amount of side slip i.e. how much the plane will slide away when banked. It may be helpful to think of this as the strength of a spring that returns the aircraft to its original heading when knocked off course.

Adverse Yaw

Adverse yaw in a rolling maneuver results from the combined effects of asymmetric aileron drag (Cn Delta Aileron) and inclination of the lift vectors (CnP).

Adverse yaw due to aileron drag (Cn Delta Aileron)

When the ailerons are deflected, the drag on the downgoing aileron's side is increased and the drag on the upgoing aileron is decreased. The effect of the difference in drag is the yawing moment due to the ailerons.

Yawing moment due to roll velocity (Cnp)

When an airplane rolls, the lift vectors on the downgoing wing are inclined forward and those on the upgoing wing are inclined backward. The yawing moment introduced by the inclined lift vectors is the yawing moment due to rolling.

While both yawing moments tend to swing the nose of the airplane in the opposite direction from that desired, the effect of lift vector inclination is of considerably greater magnitude than the effect of the drag.

Frise ailerons diminish or eliminate adverse yaw by increasing the drag on the side of the upgoing aileron. This is achieved by shaping the aileron nose and by the choice of hinge location. When deflected upward, the gap between the aileron and the wing increases, and the sharp nose protrudes into the air stream. Both of these geometric factors increase drag.

Helix Angle and Roll Rates

When an airplane rolls, the geometric figure produced by the wing tip is a helix (a coil spring is a helix). The angle between the fuselage (nose to tail) and the line drawn by the motion of the wing tip (think of a wing tip contrail) is called the "helix angle".

The roll rate is determined by the speed of the aircraft, the helix angle, and the wing span as given by the following formula:

roll rate (radians/sec) = 2 * speed (fps) * Helix angle (radians) / wing span (ft)

The roll rate varies with airspeed, so the faster the aircraft is moving, the faster the potential roll rate.

Helix angle is directly related to the aerodynamic coefficients ClP (roll damping) and Cl Delta Aileron (aileron control leverage) as shown in the following equation:

Helix angle = Cl Delta Aileron / ClP

Using helix angle to set roll coefficients Cl Delta Aileron & ClP

In aerodynamic texts helix angle is often abbreviated '**pb/2V**'. This abbreviation is actually the formula for calculating the helix angle:

Helix angle = p * b / (2 * V)

Where,
P = roll rate (radians/second),
B = wing span (feet),
V = air speed (feet/second)

The helix angle can be calculated from available (or estimated) performance data. For example, a WWII fighter having a wing span of 37 ft has a roll rate of 100 degrees/sec at 275 mph. The helix angle for this particular fighter would be:

100/57.7 * 37 / (2 * 275 * 5280/3600) = 0.079 (radians)

NACA Report 635 (p 459) contains a graph of ClP vs aspect ratio and taper ratio. For an aspect ratio of 6 and a taper ratio of 0.5, the corresponding value for the roll damping coefficient is 0.46.

The relationship between helix angle, roll damping coefficient (ClP), and roll moment due to ailerons (Cl Delta Aileron) can be rewritten:

Cl Delta Aileron = ClP * Helix angle

The roll moment due to ailerons is then:

Cl Delta Aileron = 0.46 * 0.079 = 0.03634

Note that Cl Delta Aileron in MSFS is has units of 'per radian of aileron deflection'. To account for this, the scalar value used in an AIR file for Cl Delta Aileron needs to be divided by the maximum deflection angle of the ailerons in radians.

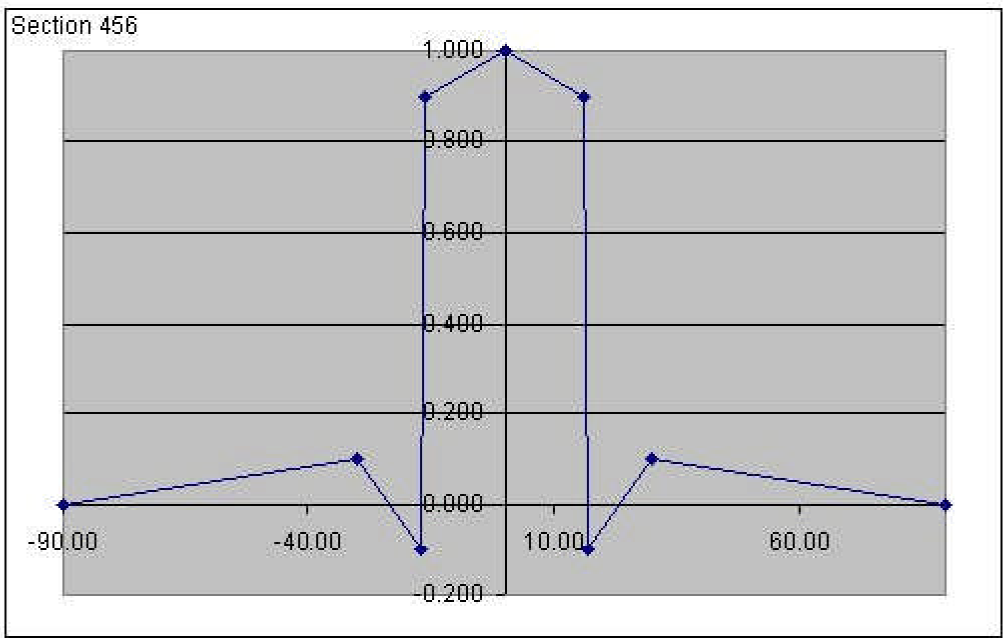
Stalls

First, the reason an aircraft spins is that either one wing stalls and the other doesn't, or that both wings stall and one wing stalls more than the other. What you end up with is both a rolling motion due to wing to wing differences in lift, and a yawing motion due to wing to wing differences in drag. The severity of the spin depends on how much of difference there is in stall from one side to the other. Also, because the wing is stalled, the ailerons usually aren't very effective in stopping a spin.

Now you could say that there is only one wing in MSFS, so how could you possibly model a spin? Well 'one wing' is correct with respect to some things like lift and drag. But these are linear forces, and what we need for a spin are rotational forces. Rotational forces in MSFS are determined by other stability coefficients, not lift and drag coefficients.

In order to model a spin in MSFS, you need to know what stability coefficients determine the roll and yaw forces and what happens to them when one wing stalls and the other doesn't.

One thing that can happen to the roll damping stability coefficient (Cl_p in 1101 and section 456 Cl_p vs AoA) is it can rapidly change signs when the wing stalls. The effect is that, instead of providing a resistance to rolling, it provides autorotation. Here's an example of what section 456 might look like in this case:



The aileron control section (1535) would also need to reflect the fact that the ailerons are ineffective after the wing stalls.

The values show in section 456 would also tend to produce a tendency to snap roll.

You'll also need to consider what to do with section 0460 Cn_beta (weathervane effect) vs AoA and 0464 Cn_r (yaw damping) vs AoA for yawing forces in a spin.

Also, since the roll and yaw motions are factors of AoA, pitch stability affects AoA and therefore plays a large part in ease or difficulty of stall initiation and recovery.

All other things being equal MOI affects how fast spins occur and how long a recovery takes. This is also true of station loads and fuel tank locations (and how full the tanks are).

Given the same flight model, spins work better and are more convincing in some versions of MSFS than others. FS9 can be really bad with some flight models when severely stalled. Any stalled aircraft should eventually fall to earth, but some FS9 models continue to gain altitude as long as the model is stalled. In general, moderate seems to work better than extreme.

High Performance Jet Fighters

Lets start with the assumption that for all supersonic jet fighters, the maximum advertised air speed requires full afterburners.

Every modern high-performance fighter is capable of supersonic speeds, but very few can go supersonic without afterburners. Those that can are usually advertised as having ‘super-cruise’ abilities.

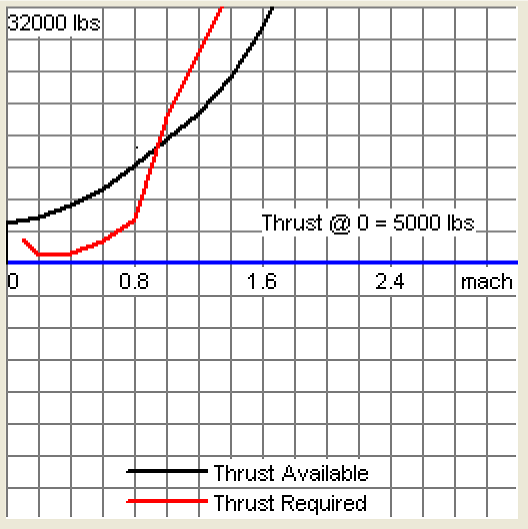
As far as the flight model is concerned, it doesn’t really matter if the aircraft has super-cruise abilities or not. The point to bear in mind is that there is a difference in performance with afterburners on and afterburners off, and we need to model both conditions.

Start flight model development for jet fighters using the performance figures for afterburners off and ignore the mach 2.2 specs until later. Start with estimating a high altitude Vmax with afterburners off.

If the aircraft in question isn’t advertised as having ‘super-cruise’ abilities, then it follows that its maximum speed without afterburners is subsonic. For most high-performance jet aircraft, anywhere around 0.95 mach would be a reasonable assumption for Vmax without afterburners. If the aircraft is capable of super-cruise, then Vmax will be somewhat more than mach 1.

After setting a reasonable value for Vmax on the Specs tab, go to the Engine tab and review the engine parameters. If you have trouble setting up the engine parameters, consider using the ‘Easy’ button – its labeled ‘Repair Jet Engine’.

Here’s an example of how the Thrust Available/Thrust Required’ chart might look without afterburners. The Thrust Available curve crosses the Thrust Required curve at about mach 0.95.

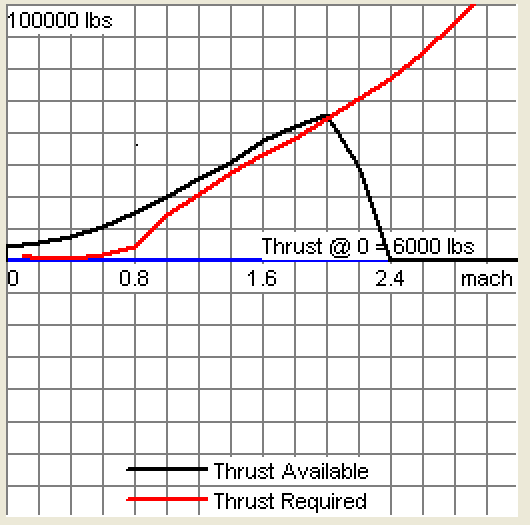


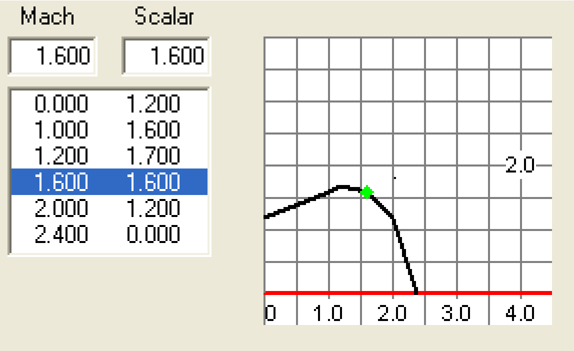
Thrust Available/Thrust Required’ without afterburner

The final step is setting up the afterburner table to achieve maximum airspeed with afterburners. First, make sure the Afterburner Static Thrust data is correct, then click the' Reset Afterburner Table' button and make sure the number of Afterburner Stages is at least one.

Now put a check mark in the Display with Afterburner Thrust box, located just below the 'Thrust Available/Thrust Required' chart. Now adjust the values in the Afterburner Table until the Thrust Available curve crosses the Thrust Required curve at the correct max Mach number.

Here's an example of how the Thrust Available/Thrust Required' chart and Afterburner Table can look with afterburners. The Thrust Available curve crosses the Thrust Required curve at about mach 2.0, which will be the maximum airspeed. In this case, it would be relatively easy to increase or decrease max mach by adjusting the values in the Afterburner Table.





Mach	Scalar
1.600	1.600
0.000	1.200
1.000	1.600
1.200	1.700
1.600	1.600
2.000	1.200
2.400	0.000

Altitude is a variable in both the FS thrust and drag equations. Jet engine thrust decreases more with altitude than drag; so in general, the maximum attainable TAS will decrease with altitude in FS. When measured by mach number, maximum attainable speeds for jet aircraft do not vary much with altitude from sea-level to service ceiling.

Some high performance aircraft manufacturers have advertised questionable high altitude performance specifications. Avoid the temptation to set the Vmax altitude too high. Maximum attainable mach speeds for jet aircraft do not vary much with altitude from sea-level to service ceiling. Avoid using extreme altitudes for Vmax altitude; be conservative and use a reasonable altitude well below the service ceiling.

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