

Advanced Aircraft Analysis 3.2 Module Description

1 Weight Module

1.1 Weight Sizing

The purpose of the Weight Sizing submodule is to rapidly estimate the following weight components and/or sensitivity coefficients:

- Take-off weight, W_{TO}
- Empty weight, W_E
- Fuel weight, W_F
- Sensitivity of take-off weight to aerodynamic, propulsion and mission parameters

These parameters are estimated on the basis of the following input:

- A mission specification
- Statistical relations between empty weight and take-off weight of existing airplanes

The weight sizing module contains a plot feature which displays the weight iteration process. The methods are based on Chapter 2, Sections 2.1 to 2.5 and Section 2.7 of Airplane Design Part I.

Methods are included to establish a statistical relationship between empty weight and take-off weight for any type of airplane.

Different ranges can be plotted for varying payload.

1.2 Class I Weight

The purpose of this module is to estimate airplane component weights and to determine whether or not the center of gravity of the airplane is within the desirable range for different loading and unloading scenarios. The methods are based on Chapter 10 of Airplane Design Part II, and Chapter 2 of Airplane Design Part V.

This module also contains the moments of inertia calculation, based on Chapter 3 of Airplane Design Part V. This option allows the user to estimate the moments of inertia of the airplane with the radii of gyration method. The radii of gyration may be calculated from the moment of inertial data. The user can provide the data or the preloaded data base can be used. The user has the option to select data from comparable airplanes. By selecting a category, a choice can be made between several available airplanes appearing in a table. Because the Class I inertia estimation is based on the selected aircraft, the user should choose the most comparable aircraft.

1.3 Class II Weight

The purpose of this module is to present a Class II method for estimating airplane component weights. The Class II estimation methods used in this module are based on those described in Airplane Design Part V. These methods employ empirical equations, which relate component weights to airplane design characteristics. In the Class II weight estimate module, the weight estimation methods are identified as follows:

- Cessna method
- USAF method
- General Dynamics (GD) method
- Torenbeek method

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Because airplane component weight modeling in the software is a function of take-off weight, the Class II weight estimation is an iterative process.

Detailed moments of inertia based on component weights and component inertias can be calculated. Total center of gravity and empty weight center of gravity are calculated. Forward and aft center of gravity are determined based on minimum and maximum weights of passengers, fuel, baggage, cargo, weapons etc.

Detailed center of gravity calculations and effect of loading is included. A c.g. envelope is created from all possible loading scenarios showing most forward and aft center of gravity.

The empty weight components center of gravity are plotted together with a side view of the airplane.

1.4 Component Center of Gravity

This option allows the user to calculate the airplane center of gravity by entering weight components and their locations in a preformatted table. Tables are available for structure weight, fixed equipment weight, powerplant weight and total weight. Center of gravity of wing, canard, horizontal tail, V-Tail, tailbooms, nacelles and fuel tanks are calculated

2 Aerodynamics Module

2.1 Lift

The Lift submodule can be used for estimating the lifting characteristics of airplane lifting surfaces and high lift devices. Maximum lift coefficients for airfoils and wing, horizontal tail, vertical tail, v-tail and canard are calculated. The methods are based on Chapter 7 of Airplane Design Part II. The methodology used to determine the lifting surface spanwise lift distribution is based on lifting line theory.

The function of the flaps submodule is to determine the type and size of high lift devices needed to meet the maximum lift requirement for take-off and landing conditions. The user can select the flap type from plain flap, split flap, single slotted flap, double-slotted flap, fowler flap and triple slotted flaps. Flaps can be sized or flap lift can be calculated for a given flap configuration. Drooped ailerons are accounted for. The methods are based on Chapter 7 of Airplane Design Part II.

Ground effects on airplane lift are based on the methods in Chapter 8 of Airplane Design Part VI.

Lift as function of angle of attack, elevator (canardvator, ruddervator) and horizontal tail (canard, v-tail) incidence can be calculated.

The lift coefficient at zero-angle-of-attack can be used to determine the lift coefficients, downwash angle, and upwash angle at zero airplane angle of attack, and the zero lift angle of attack. This module includes flap effects. The flap maximum lift coefficient can be plotted as function of flap deflection and flap chord ratio. The methods are described in Chapter 8 of Airplane Design Part VI.

Further, the effect of body width on lift curve slope may also be calculated.

Propeller power effects (prop wash) are accounted for.

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2.2 Class I Drag Polars

The Class I Drag submodule can be used for a first estimate of the airplane drag. The Class I Drag module has the following seven options:

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- flaps in take-off configuration with gear down
- flaps in take-off configuration with gear up
- no flap deflection and gear up
- flaps in landing configuration with gear up
- flaps in landing configuration with gear down
- one engine inoperative configuration
- current airplane flight condition

The program will check to see if the airplane has retractable or fixed landing gear. All drag polars may be displayed at once: Gear Up, Gear Down, Flaps Up, Flaps Down, One Engine Inoperative and Current Condition. The methodology used to calculate the drag polar can be found in Chapter 3 of Airplane Design Part I. The Class I Drag module relates the total airplane lift coefficient to the total airplane drag coefficient by a parabolic drag polar equation.

An iteration is built-in to calculate take-off weight based on L/D derived from the Class I drag polar.

2.3 Class II Drag Polars

The purpose of the Class II Drag submodule is to supply a Class II method for predicting drag polars of airplanes during the preliminary design phase. A detailed drag polar can be calculated for the subsonic, transonic and supersonic flow regimes. The following drag calculations can be performed:

- wing drag coefficient
- horizontal tail drag coefficient
- vertical tail drag coefficient
- v-tail drag coefficient
- canard drag coefficient
- fuselage drag coefficient
- nacelle drag coefficient
- trailing edge flap drag coefficient
- leading edge flap drag coefficient
- gear drag coefficient
- canopy drag coefficient
- windshield drag coefficient
- floats drag coefficient
- stores drag coefficient
- trim drag coefficient
- spoiler drag coefficient
- miscellaneous drag coefficient
- pylon drag coefficient
- drag coefficient due to windmilling
- total aircraft drag coefficients

The program will account for fuselage base area change as a function of inoperative engines. Changes in nacelle drag are also accounted for due to inoperative engines. Dihedral is accounted for in the wetted areas of lifting surfaces.

The methods are based on Chapter 4 of Airplane Design Part VI.

The drag coefficient can be plotted as a function of lift coefficient, Mach number, flap deflection and as a component build-up. Drag can also be plotted as a function of angle-of-attack for an untrimmed airplane. The drag can be approximated with a trendline.

2.4 Moment

The Moment submodule calculates the spanwise moment distribution on the wing, horizontal tail, vertical tail and canard. The ground effects on airplane moment are also determined. Methods are based on Airplane Design Part VI.

Moment as function of angle of attack, elevator (canard) and horizontal tail (canard) incidence can be calculated.

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This pitching moment at zero-angle-of-attack submodule can be used to determine the zero lift airplane pitching moment coefficients, and pitching moment coefficients at zero airplane angle of attack. This module includes flap effects. To account for each airplane component, the pitching moment coefficient components are calculated separately. The user can estimate the zero lift pitching moment coefficient, the effect of trailing and leading edge flaps on lift and pitching moment coefficients. The methods are described in Chapter 8 of Airplane Design Part VI.

2.5 Aerodynamic Center

The Aerodynamic Center submodule can be used to calculate aerodynamic center locations of individual airplane components, and the aerodynamic center shift due to components. The aerodynamic center methods described are found in Airplane Design Part VI.

The aerodynamic center and shift can be calculated for the following components:

- fuselage
- wing
- horizontal tail
- vertical tail
- v-tail
- canard
- nacelles
- floats
- stores
- tailbooms
- total airplane

2.6 Power Effects

The purpose of the Power Effects module is to calculate the effects of the operating propeller aerodynamic properties of the airplane. The effects of power are calculated for the following parameters:

- horizontal tail downwash angle
- v-tail downwash angle
- dynamic pressure ratio
- lift and pitching moment coefficients
- drag due to power

Power Effects can be applied to both single and multi-engine propeller driven aircraft.

2.7 Ground Effects

The Ground Effects module predicts the change in wing-fuselage lift coefficient, pitching moment coefficient and horizontal tail downwash angle due to the close proximity of the aircraft to the ground.

2.8 Dynamic Pressure Ratio

The Dynamic Pressure Ratio module allows the user to predict the horizontal tail, V-tail and vertical tail dynamic pressure ratio as a variation of angle of attack. The wake effects are also accounted for in these calculations.

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3 Performance Module

3.1 Performance Sizing

The purpose of the Performance Sizing module is to allow for a rapid estimation of those airplane design parameters, which have a major impact on airplane performance. Airplanes are usually required to meet performance objectives in different categories depending on the mission profile. Meeting these performance objectives normally results in the determination of a range of values for:

- wing loading (W/S)
- thrust loading (T/W) or power loading (W/P)
- airplane maximum lift coefficients

The variables listed above are plotted in the form of a performance-matching plot. These plots depend on the type of airplane, the applicable specification and the applicable regulation(s). With the help of such a plot, the combination of the highest possible wing loading and the smallest possible thrust (or highest power) loading, which meets all performance requirements, can be determined. The methodology used for performance sizing can be found in Airplane Design Part I.

3.2 Performance Analysis

The purpose of the Analysis submodule is to provide the user with Class II analysis methods for predicting the performance characteristics of an airplane. The methodology used to analyze the performance characteristics can be found in Chapter 5 of Airplane Design Part VII and Airplane Aerodynamics and Performance.

The performance characteristics consists of :

- Stall speed
- Take-off distance
- Climb
- Cruise
- Dive and Descent
- Maneuver
- Glide
- Landing Distance

The engine performance data such as thrust or power can be entered as function of speed.

4 Geometry Module

The purpose of the geometry module is to help the user determine the geometry of the fuselage, wing, horizontal tail, vertical tail, v-tail and canard and calculate related parameters. The methodology used to calculate the airplane component geometries is described in Airplane Design Part II. Two-dimensional geometry can be defined for straight and cranked lifting surfaces. For the horizontal tail, vertical tail, v-tail and canard the volume coefficient method is available in the Stability & Control module.

The fuselage module shows all cross-sections of the fuselage and is used to determine fuselage camber, inclination angles of each segment and cross-sectional area distribution.

The control surfaces on each lifting surface can be plotted. The chord length at a specified surface chord station can be determined.

Fuel volume in the wing is calculated using Class I and Class II methods. Fuel in cranked wings is accounted for.

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The airplane geometry can be exported to CAD programs that use AeroPack (Shark and Shark FX).

The lateral tip-over option allows the user to calculate the lateral angle between the airplane center of gravity and the landing gear. This angle is useful in determining the risk of lateral tip-over on the ground.

The pitch angle allows the user to calculate the angle between the landing gear rotation point and the tail, thus determining the probability of a tail strike on rotation.

All geometric parameters may be scaled. For instance to make a wind tunnel model.

A three-view module shows top view, side view and front view of the airplane.

5 Propulsion Module

In this module the installed power and thrust of airplanes can be calculated. In addition to the installed power/thrust estimation, this module also provides options for inlet and nozzle sizing, estimation of inlet pressure recovery. Power extraction is also accounted for. Calculations in this module are based on the methodologies outlined in Chapter 6 of Airplane Design Part VI.

The methods are valid for piston engines, jet engines, turboprop and propfan engines. Installed thrust or power can be calculated from uninstalled engine performance.

6 Stability & Control Module

6.1 Stability & Control Derivatives

The purpose of the Derivatives submodule is to compute the non-dimensional aerodynamic stability and control derivatives for a rigid airplane in a given flight condition (i.e., for a given weight, altitude, and speed and c.g location). The derivatives module consists of longitudinal stability derivatives, lateral-directional stability derivatives, longitudinal control derivatives and lateral-directional control derivatives. The derivatives can be calculated for tail aft, canard and three-surface configurations.

For longitudinal stability derivatives the following options are available:

- steady state lift, drag, moment and thrust coefficients
- speed derivatives
- angle-of-attack derivatives
- rate of angle-of-attack derivatives
- pitch rate derivatives

For lateral-directional stability derivatives the following options are available:

- angle-of-sideslip derivatives
- rate of angle-of-sideslip derivatives
- roll rate derivatives
- yaw rate derivatives

For longitudinal control derivatives the following options are available:

- stabilizer control derivatives
- elevator control derivatives
- ruddervator control derivatives
- canard control derivatives

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- canardvator control derivatives
- elevon control derivatives
- elevator tab control derivatives
- ruddervator tab control derivatives
- canardvator tab control derivatives
- elevon tab-control derivatives

For lateral-directional control derivatives the following options are available:

- aileron derivatives
- spoiler derivatives
- differential stabilizer derivatives
- rudder derivatives
- rudder tab derivatives
- aileron tab derivatives

6.2 Hingemoment Derivatives

The hingemoment submodule is used to determine the hingemoment coefficient derivatives of the elevator, rudder, aileron, canardvator, elevator tab, rudder tab, aileron tab and canardvator tab. The control surfaces can have unshielded, fully shielded and partially shielded horn balances. The methodology for the hingemoment calculations is found in Airplane Design Part VI.

6.3 Class I Stability and Control/Emppennage Sizing Analysis

The methodology used to analyze the Stability and Control characteristics can be found in Chapter 11 of Airplane Design Part II. This module includes longitudinal stability and empennage sizing, directional stability and empennage sizing and minimum control speed with one engine inoperative stability/empennage sizing.

For Inputs are simplified and choice is given between geometric volume coefficient or volume coefficient based on C.G. and A.C.

6.4 Class II Stability and Control/Emppennage Sizing Analysis

The methodology used to analyze the longitudinal and lateral-directional trim characteristics can be found in Chapter 5 of Flight Dynamics Part I.

The Class II methods consist of trim diagram, longitudinal trim and lateral-directional trim. The elevator stick (or control wheel) forces, aileron stick (or control wheel) forces and rudder pedal forces can be calculated. The trim diagram determines control deflections and angles of attack for different center of gravity locations to trim the airplane longitudinally. Trim diagrams include propeller power effects.

Other important stability and control characteristics such as take-off rotation and a variety of dynamic stability considerations are calculated that are not covered by the Class I method.

Variation of wing location on stability and center of gravity range.

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7 Dynamics Module

7.1 Dynamics

The purpose of the dynamics module is to help the user analyze the open loop dynamic characteristics of the airplane in a given flight condition. The methodology used to analyze open loop dynamic characteristics can be found in Airplane Flight Dynamics Part I.

Dynamics is divided into estimation of the longitudinal and lateral-directional dynamic characteristics. Airplane transfer functions are determined. Flying qualities are checked against civil and military requirements. The effect of roll-pitch yaw coupling effect on the dynamic analysis is also determined. Sensitivity of various stability and control derivatives on flying qualities is also established. Phugoid and short period are determined. Spiral, Dutch roll and roll performance are investigated.

The Routh-Hurwitz stability requirements are calculated.

7.2 Control

The purpose of the Control module is to help the user analyze single and double loop feedback control systems of the airplane. If the open loop dynamic characteristics of the airplane are known, root locus analyses may be performed in the S-plane. The control analysis submodule can also be used to analyze a system open loop transfer function in the frequency domain (Bode diagram). The methodology used to analyze feedback control systems can be found in Airplane Flight Dynamics Part II.

The transfer functions can be selected from the standard airplane transfer functions or defined by the user. If the longitudinal and lateral-directional stability derivatives of the airplane are known, the user may use the Dynamics module prior to using the Control analysis module to generate the longitudinal and lateral-directional dynamic transfer functions of the airplane. These transfer functions are transferred into the Control analysis module, and can only be generated in the Dynamics module.

The transfer functions are:

- Speed-to-Elevator
- Angle-of-Attack-to-Elevator
- Pitch-Angle-to-Elevator
- Speed-to-Ruddervator
- Angle-of-Attack-to- Ruddervator
- Pitch-Angle-to- Ruddervator
- Speed-to-Stabilizer
- Angle-of-Attack-to-Stabilizer
- Pitch-Angle-to-Stabilizer
- Speed-to-V-Tail
- Angle-of-Attack-to-V-Tail
- Pitch-Angle-to-V-Tail
- Speed-to-Elevon
- Angle-of-Attack-to-Elevon
- Pitch-Angle-to-Elevon
- Speed-to-Canardvator
- Angle-of-Attack-to-Canardvator
- Pitch-Angle-to-Canardvator
- Speed-to-Canard
- Angle-of-Attack-to-Canard
- Pitch-Angle-to-Canard
- Angle-of-Attack-to-Canardvator
- Human Pilot
- Sideslip-Angle-to-Aileron
- Bank-Angle-to-Aileron
- Heading-Angle-to-Aileron
- Sideslip-Angle-to-Rudder
- Bank-Angle-to-Rudder
- Heading-Angle-to-Rudder
- Defined by the user

The following control systems can be analyzed:

- single loop feedback
- double loop control systems with the inner loop gain in the forward path
- double loop control systems with the inner loop gain in the feedback path
- gyro tilt angle effect

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The human pilot calculation can be used to estimate a human pilot transfer function for use in the open loop control system analysis. The human pilot module can be used to model pilots of differing abilities, reaction times and physical fitness. This module can even be used to show the dangers of a drunken pilot in the loop. The methodology used to analyze a human pilot transfer function can be found in Chapter 10 of Airplane Flight Dynamics Part II.

8 Loads Module

The purpose of this module is to estimate loads placed on airplane components and to determine important information for structural design and sizing. The Loads module consists of two submodules: V-n Diagram and Structural Loads. The purpose of the V-n Diagram submodule is to determine load factors and their corresponding speeds. The purpose of the Structural Loads submodule is to calculate the internal forces and moments in the structural components of an airplane. Use of the Loads module options will be described in the following sections.

8.1 V-n Diagram

In this submodule, velocity vs. load factor (V-n) diagrams can be constructed for the following types of airplanes: FAR 23 certified, FAR 25 certified and MIL-A-8861(ASG) certified airplanes.

8.2 Structural Loads

In this submodule the total internal loads for each structural component can be calculated in any combination that the user desires.

The following options are available to calculate the loads acting on a structural component:

- structural loads on the fuselage
- structural loads on the wing
- structural loads on the horizontal tail
- structural loads on the canard
- structural loads on the vertical tail
- estimation of the accelerations and rates acting on the airplane. Before the total internal loads for any structural component can be calculated, the linear accelerations, angular accelerations and angular rates must be calculated using this option

9 Structures Module

9.1 Class I Sizing

The purpose of this module is to estimate the size and weight of the structural components. This is done using material properties and the results of the calculation of the total internal loads for the component from the loads module.

9.2 Materials

In this submodule material properties that are not listed in the available materials table may be added and have their characteristics defined. These materials will be added to the user defined category of the available materials table.

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10 Cost Analysis Module

The purpose of this module is to estimate various costs of airplane design programs. The estimation methods are presented in such a manner that they can be applied to civil and military airplanes of all types. The cost escalation factor (CEF) used in this module accounts for inflation. The various cost definitions and cost estimation methods used for this module are as discussed in Chapter 1 through 7 of Airplane Design Part VIII.

After invoking the cost module, seven options are displayed:

- AMPR Weight For estimation of the Aeronautical Manufacturers Planning Report (AMPR) weight. This weight parameter is needed for estimation of the various costs in an airplane program.
- R.D.T.E. Cost For estimation of the research, development, test and evaluation cost.
- Prototype Cost For estimation of the cost of development, manufacturing and flight testing of the prototypes. This submodule is to be used only for those airplane programs that are not intended for eventual production.
- Acquisition Cost For estimation of the manufacturing and acquisition costs. The difference between these costs is the profit made by the manufacturer.
- Operating Cost (military) For estimation of the military airplane operating costs.
- Operating Cost (civil) For estimation of the civil airplane operating costs.
- Life Cycle Cost For estimation of the life cycle cost of an airplane program. The life cycle cost is defined as the sum of R.D.T.E. cost, acquisition cost, operating cost and disposal cost
- Price Data For estimation of the engine price, propeller price and airplane price as well as a rapid method for estimating prices of future designs.

11 Atmosphere

The purpose of the Atmosphere module is to calculate the properties of the standard atmosphere at a given altitude and temperature offset. Air density, pressure, temperature, speed of sound and acceleration of gravity are calculated as a function of altitude. For a given speed the Mach number is calculated.

12 Flight Condition

The purpose of the Flight Condition window is to set and define each flight condition to be included in the analysis. An airplane project can have one or more flight conditions defined. All parameters depending on speed, weight, flap deflection and center of gravity can be stored separately per flight condition. Flight conditions can be edited, moved, copied and deleted from the project.