Airplane/Glider Design Guidelines and Design Analysis Program

Ever have the urge to design your own plane but didn't feel secure enough with your usual TLAR (that looks about right) methods to invest all that building time for fear of ending up with an unstable or hard to maneuver design? Here are some simple design guidelines which guarantee success the first time out without trial or error and which work for gliders and for the fastest pattern planes.

The guidelines quantify relative flying surface areas, spatial relations between wing and tail surfaces, dihedral and polyhedral angles, and several other design parameters for aileron and polyhedral ships, for powered airplanes and for gliders. Yaw, pitch, and yaw to roll coupling parameters referred to in the table need to be evaluated first. If the numbers don't match or come close to the preferred guideline values in the table your design should be modified until they do.

My "design analysis" (da) program which runs on a PC under DOS will do the calculations for you. In addition to Ysf, Psf, and yaw to roll coupling parameter Rmf, it calculates W_Area, W_Span, Cavg, AR, C_Mom, P_Mom, and Y_Mom from your design data input file. Contact author for a copy of the "da" program and additional related files (minor charge for postage and diskette). The additional files include a text file which gives instructions on how to run the "da" program, a template for the design input file which specifics on your specific plane design, and an example of a real 2m glider design. The following are example printouts of a typical design file (input) and the printed results which are displayed on the screen (output) and are also appended to the bottom of the input design file. Following that is an analysis comparison of various (vintage) kits for which I happen to have detailed plans. Notice the last three parameters (Psf, Ysf, and Rmf) are scale independent and serve as a good overall summary analysis when comparing the kit designs against the design guidelines.

Guideline Parameter (symbol)	**Parameter Value Range**	**Comments**
Yaw stability (Ysf)	0.020-0.03	Plane configuration dependent (see Ysf definition).
Pitch stability (Psf)	0.4	Same for airplane or glider.
Yaw induced roll moment for polyhedral wing (Rmf)	0.220	For polyhedral glider or light powered airplane (Cl > 0.5) not equipped with ailerons.
Yaw induced roll moment for aileron wing (Rmf)	0.052	For airplane or glider equipped with ailerons.
Center of Gravity (CG)	30%	30% from leading edge of Cavg (average chord) is a good place to start for airplane or glider.

Cntrl surface throws: Rudder Ailerons Elevator	 ± 15° to ± 30° ± 10° to ± 20° ± 10° to ± 20°	Use small values for the start and increase as required. The smaller amounts for fast airplanes flying at low Cls (< 0.5) and more for slow airplanes or for gliders.
Glider Fuselage: Incidence Angle Decalage Angle	 4-6 degrees 2-3 degrees	Typical values and good place to start for glider or for light powered airplane (Cl > 0.5).
Airplane Fuselage: Incidence Angle Decalage Angle	 0-3 degrees 0-3 degrees	Typical values for airplane (Cl < 0.5). 0 for fast airplane (Cl < 0.2) and up to 3 for slower ones (0.2 < Cl < 0.5).
Aileron position/length	1/3 of outer wing	This should be considered a minimum length.
Cntrl surface widths: Rudder Ailerons Elevator	 25%-50% 20%-25% 20%-30%	Nominal widths.
Aspect Ratios: Wing Fin Stabilizer	 6-16 2-3 3-6	Typical values as follows Pattern plane: 6 2 m glider: 10 3 m glider: 16
Wing washout	0-3 degrees	Typically spread over outer 1/3 of wing. Slow flying planes typically use more washout than faster ones.

Input File:

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File: da_templ.des


Effective_Stab_Area_(in^2)................. 86
Stab_Aerodynamic_Center_(AC)_coordinate... 30
Effective_Fin_Area_(in^2)................. 55
Fin_AC_coordinate......................... 35
Inside_wing_panel_1_root_LE_coordinate.... 0
Inside_wing_panel_1_root_TE_coordinate.... 9
Inside_wing_panel_1_span.................. 26
Inside_wing_panel_1_dihedral_angle_1...... 6.6
Inside_wing_panel_1_tip_LE_coordinate..... 1
Inside_wing_panel_1_tip_TE_coordinate..... 9
Next_wing_panel_2_span.................... 24
Next_wing_panel_2_dihedral_angle_2........ 8
Next_wing_panel_2_tip_LE_coordinate....... 4
Next_wing_panel_2_tip_TE_coordinate....... 9
Next_wing_panel_3_span.................... 0
Next_wing_panel_3_dihedral_angle_3........ 0
Next_wing_panel_3_tip_LE_coordinate....... 0
Next_wing_panel_3_tip_TE_coordinate....... 0
Next_wing_panel_4_span.................... 0
Next_wing_panel_4_dihedral_angle_3........ 0
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Next_wing_panel_4_tip_LE_coordinate....... 0
Next_wing_panel_4_tip_TE_coordinate....... 0
Next_wing_panel_5_span.................... 0
Next_wing_panel_5_dihedral_angle_3........ 0
Next_wing_panel_5_tip_LE_coordinate....... 0
Next_wing_panel_5_tip_TE_coordinate....... 0
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Output File:

```
File:  da_templ.des

Design Analysis Results:


W_Area =  741.187 = Projected Wing Area
W_Span =   98.105 = Projected Wing Span
Cavg   =    7.555 = Average Wing Chord
AR     =   12.985 = Wing Aspect Ratio
C_Mom  =    1.353 = Datum to Leading Edge of Cavg
P_Mom  =   26.381 = 30% Cavg to Stab AC
Y_Mom  =   31.381 = 30% Cavg to Fin AC
Psf    =    0.405 = Pitch Stability Factor (0.4 preferred)
Ysf    =    0.024 = Yaw Stability Factor
                    (0.020 for polydih. wing, 0.030 for aileron
wing)
Rmf    =    0.201 = Yaw to Roll Coupling Factor
                    (0.20 for polydih. wing, 0.052 for aileron
wing)
Pdf    =    1.022 = Pitch Damping Factor ( 1.000 preferred)
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Glider Kit Comparisons:

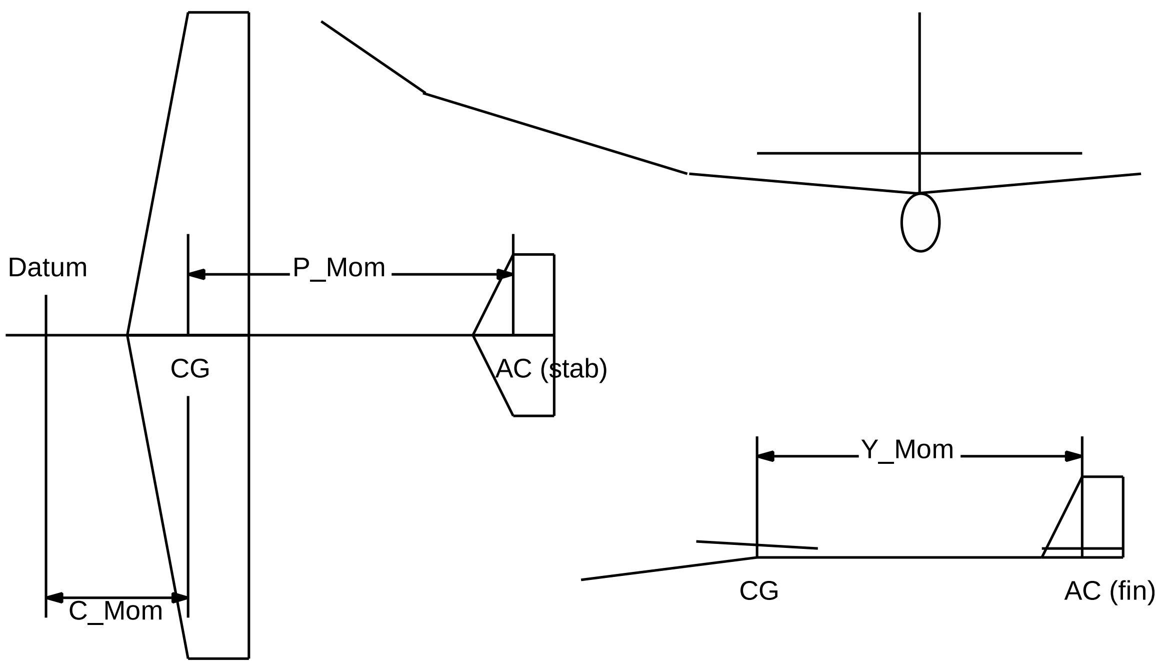
		Skeeter	G. Lady	Electra	Spirit	Aquila	BirdofT	Windsong
W_Area	=	324.998	638.658	647.270	655.064	829.490	1026.425	1075.802
W_Span	=	53.553	74.644	75.719	77.965	98.656	114.407	133.317
Cavg	=	6.069	8.556	8.548	8.402	8.408	8.972	8.070
AR	=	8.824	8.724	8.858	9.279	11.734	12.752	16.521
C_Mom	=	0.263	0.398	0.405	0.499	0.111	0.408	0.591
P_Mom	=	18.916	24.535	25.030	23.731	27.116	25.900	31.238
Y_Mom	=	19.916	23.535	24.280	21.981	28.366	29.400	31.738
Psf	=	0.364	0.427	0.434	0.407	0.462	0.349	0.461
Ysf	=	0.024	0.023	0.025	0.020	0.021	0.019	0.016
Rmf	=	0.219	0.208	0.203	0.184	0.135	0.173	0.052

Note: Wing spans indicated may be slightly less than actuals due to minor modeling simplifications made for this comparison analysis.

Definition of Terms

The remaining text is a definition of the following terms (symbols) which are referred to above.

Aerodynamic center (AC)
Average wing chord (Cavg)
Cavg moment arm (C_Mom)
Center of Gravity (CG)
Decalage
Incidence Angle
Lift coefficient (Cl)
Pitch moment arm (P_Mom)
Pitch stability (Psf)
Wing area (W_Area)
Wing aspect ratio (AR)
Wing loading (wl)
Wing span (W_Span)
Yaw moment arm (Y_Mom)
Yaw stability (Ysf)
Yaw induced roll moment (Rmf)
Pitch damping factor (Pdf)



Aerodynamic center (AC) - Generally 25% point of flying surface average chord.

Average wing chord (Cavg) - Wing area (as defined above) divided by the wing span.

Cavg moment arm (C_Mom) - Datum to Leading Edge of Cavg.

Center of Gravity (CG) - Center of mass of plane through and on which all resultant forces act. Typically placed at a position 30% back from leading edge of Cavg. Determining the exact location of the average chord can be a little tricky for tapered wings and is discussed in the next section.

Decalage - Angle between wing chord and stabilizer chord lines.

Incidence Angle - Angle between fuselage entry forward of CG (fuselage centerline) and wing chord line (stabilizer chord line is generally kept parallel with fuselage centerline). This angle is typically equal to trim wing angle of attack.

Lift coefficient (Cl) - Dimensionless number which is a measure of the amount of lift the wing produces (i.e. counter force of gravity of plane). The relationship between airspeed (v - feet/sec or mph), wing loading (wl - pounds/square foot), and Cl at sea level is as follows.

$$v = 29\sqrt{wl / Cl} \text{ ft/sec} = 19.773\sqrt{wl / Cl} \text{ mph}$$

Pitch moment arm (P_Mom) - Distance from CG (30% point of Cavg nominal) to Stab AC.

Pitch stability (Psf) - Stability about the lateral axis or the tendency for the plane to return to the longitudinal or pitch trim attitude. The horizontal stabilizer generally provides pitch stability for conventional non-flying airplanes and gliders (flying wings generally have pitch-stable wing configurations without need for additional stabilizers). Similar to the fin, the larger the stab or the farther away from the CG, the more stable the configuration.

Wing area (W_Area) - Area of wing when projected onto the horizontal plane.

Wing aspect ratio (AR) - Wingspan divided by average wing chord. A more formal definition is wingspan squared divided by wing area.

Wing loading (wl) - Plane weight distribution in pounds per square foot of wing area.

Wingspan (W_Span) - Straight line distance from one wing tip to the opposite wing tip independent of dihedral shape or magnitude.

Yaw moment arm (Y_Mom) - Distance from CG (30% point of Cavg nominal) to Fin AC.

Yaw stability (Ysf) - Stability about the vertical axis or the plane to return to a heading into the relative airflow. This form of stability is generally provided with the use of a fin and sometimes a fin in combination with a rudder. It is typically 0.02 for aileron coupled rudder type, 0.025 for non-aileron/rudder type (typical polyhedral), and 0.03 for aileron/no-rudder type plane configuration. Generally for a fixed distance between CG and fin, a larger fin area will provide more yaw stability than a smaller fin area. For a fixed fin area a longer moment arm (distance) between CG and fin provides greater yaw stability than a shorter moment arm. A properly proportioned fin design promotes a comfortable "groovy" flight without annoying slips or skids.

Yaw induced roll moment (Rmf) - The means by which the non-aileron plane can be made to roll (or is banked into a turn). More dihedral generally provides greater yaw to roll coupling and larger roll rates for a given rudder deflection. Yaw to roll coupling is generally not desirable for planes equipped with ailerons but is tolerated to counter spiral instabilities.

Pitch damping factor (Pdf) – A pitch axis damping measure derived from overall planform (typically close to 1.0).