Tandem Trainer Aircraft

Sizing model for a tandem trainer plane.

Mission

Variables	Value	Units	Description
$MTOW$		$[lbf]$	max take off weight
W_{cent}		$[lbf]$	aircraft center weight
$W_{fuel-tot}$		$[lbf]$	total fuel weight
R_{min}	400.000	$[nmi]$	minimum flight range

$$
\begin{array}{ll}
\text{minimize} & 1 \\
\text{subject to} & [' Mission']_{[0]} \\
& [' Mission']_{[0]} \\
& [' Mission']_{[0]} \\
& MTOW = W_{start} \\
& MTOW \geq W_{fuel-tot} + W_{zfw} \\
& W_{fuel-tot} \geq W_{fuel-fs} \\
& W_{end} \geq W_{zfw} \\
& W_{cent} \geq W_{fuel-tot} + W_{pay} + W_{Engine} \\
& \vec{R} \geq 0.2 R_{min} \\
& W_{Fuselage} \geq MTOW f
\end{array}
$$

Aircraft

Variables	Value	Units	Description
W_{pay}	700.000	$[lbf]$	payload
W_{zfw}		$[lbf]$	zero fuel weight

$$
\begin{array}{ll}
\text{minimize} & 1 \\
\text{subject to} & [' Mission',' Aircraft']_{[0,0]} \\
& [' Mission',' Aircraft']_{[0,0]} \\
& [' Mission',' Aircraft']_{[0,0]} \\
& W_{zfw} \geq W_{pay} + W_{Engine} + W_{Fuselage} + W_{Wing}
\end{array}
$$

FlightSegment

Variables	Value	Units	Description
W_{start}		$[lbf]$	vector-begin weight
W		$[lbf]$	aircraft weight during flight segment
W_{end}		$[lbf]$	vector-end weight
$W_{fuel-fs}$		$[lbf]$	flight segment fuel weight

minimize 1

subject to

$$['Mission']_{[0]}$$
$$['Mission','FlightSegment']_{[0,0]}$$
$$['Mission','FlightSegment']_{[0,0]}$$
$$['Mission','FlightSegment']_{[0,0]}$$
$$['Mission','FlightSegment']_{[0,0]}$$
$$W_{fuel-fs} \geq W_{fuel} + W_{fuel} + W_{fuel} + W_{fuel} + W_{fuel}$$
$$\vec{W} = \begin{bmatrix} W_{end}{}^{0.5} W_{start}{}^{0.5} \ [\mathrm{lbf}] & W_{end}{}^{0.5} W_{start}{}^{0.5} \ [\mathrm{lbf}] & W_{end}{}^{0.5} W_{start}{}^{0.5} \ [\mathrm{lbf}] & W_{end}{}^{0.5} W_{start}{}^{0.5}$$
$$\begin{bmatrix} W_{end} \ [\mathrm{lbf}] & W_{end} \ [\mathrm{lbf}] & W_{end} \ [\mathrm{lbf}] & W_{end} \ [\mathrm{lbf}] \end{bmatrix} \geq \begin{bmatrix} W_{start} \ [\mathrm{lbf}] & W_{start} \ [\mathrm{lbf}] & W_{start} \ [\mathrm{lbf}]$$

AircraftLoading

Variables	Value	Units	Description

minimize 1

subject to $['Mission','AircraftLoading']_{[0,0]}$

Wing

Variables	Value	Units	Description
b		$[ft]$	wing span
$\bar{c}$	1.111		normalized chord at mid element
λ	0.800		wing taper ratio
c_{MAC}		$[ft]$	mean aerodynamic chord
c_{ave}		$[ft]$	mid section chord
$\bar{c}_{ave}$	1.028		normalized mid section chord
W		$[lbf]$	weight
S		$[ft**2]$	surface area
AR			aspect ratio
τ	0.150		airfoil thickness ratio
m_{fac}	1.500		wing weight margin factor
c_{root}		$[ft]$	root chord

minimize 1
subject to $['Mission','Aircraft','Wing']_{[0,0,0]}$
$['Mission','Aircraft','Wing']_{[0,0,0]}$
$b^2 = ARS$
$\lambda = \lambda$
$\vec{\bar{c}} = \vec{\bar{c}}$
$\vec{c_{ave}} = \left[\frac{S\bar{c}_{ave}}{b} \text{ [ft]} \quad \frac{S\bar{c}_{ave}}{b} \text{ [ft]} \quad \frac{S\bar{c}_{ave}}{b} \text{ [ft]} \quad \frac{S\bar{c}_{ave}}{b} \text{ [ft]} \right]$
$c_{root} = 1.111\frac{S}{b}$
$c_{MAC} = \frac{S}{b}$
$\frac{W}{m_{fac}} \geq W_{CapSpar} + W_{WingSkin}$

Engine

Variables	Value	Units	Description
$W_{Rotax-912}$	152.600	$[lbf]$	Installed/Total DF70 engine weight
m_{fac}	1.000		Engine weight margin factor
P_{sl-max}	98.560	$[hp]$	Max shaft power at sea level
W		$[lbf]$	Installed/Total engine weight

minimize 1
subject to $W_{Rotax-912} \leq \frac{W}{m_{fac}}$
$P_{sl-max} = P_{sl-max}$

Fuselage

Variables	Value	Units	Description
f	0.300		fraction of total weight
W		$[lbf]$	fuselage weight

minimize 1
subject to $W = W$
$f = f$

FlightState

Variables	Value	Units	Description
ρ	0.771	$[kg/m**3]$	air density
V_{min}	10.000	$[m/s]$	minimum true airspeed

μ	0.000	$[N * s/m * *2]$	dynamic viscosity
V		$[m/s]$	true airspeed
h	15000.000	$[ft]$	flight altitude
h_{ref}	15000.000	$[ft]$	reference altitude

$$\begin{array}{ll} \text{minimize} & 1 \\ \text{subject to} & \vec{V} \geq \vec{V_{min}} \\ & \vec{\rho} = \vec{\rho} \\ & \vec{\mu} = \vec{\mu} \\ & \vec{h} = \vec{h} \\ & \vec{h_{ref}} = \vec{h_{ref}} \end{array}$$

AircraftPerf

Variables	Value	Units	Description
η_{prop}	0.700		propulsive efficiency
C_D			aircraft drag coefficient
CDA_0	0.025		non-wing drag coefficient

$$\begin{array}{ll} \text{minimize} & 1 \\ \text{subject to} & \vec{C_D} \geq \begin{bmatrix} CDA_0 + C_d & CDA_0 + C_d & CDA_0 + C_d & CDA_0 + C_d & CDA_0 + C_d \end{bmatrix} \\ & \vec{\eta_{prop}} = \vec{\eta_{prop}} \\ & ['Mission',' FlightSegment',' AircraftPerf']_{[0,0,0]} \\ & ['Mission',' FlightSegment',' AircraftPerf']_{[0,0,0]} \end{array}$$

SteadyLevelFlight

Variables	Value	Units	Description
T		$[N]$	thrust

$$\begin{array}{ll} \text{minimize} & 1 \\ \text{subject to} & \vec{W} \leq \Big[0.5SC_LV^2\rho \left[\frac{\mathrm{ft}^2\cdot\mathrm{kg}}{(\mathrm{m}\cdot\mathrm{s}^2)}\right] \quad 0.5SC_LV^2\rho \left[\frac{\mathrm{ft}^2\cdot\mathrm{kg}}{(\mathrm{m}\cdot\mathrm{s}^2)}\right] \quad 0.5SC_LV^2\rho \left[\frac{\mathrm{ft}^2\cdot\mathrm{kg}}{(\mathrm{m}\cdot\mathrm{s}^2)}\right] \quad 0.5SC_LV^2\rho \left[\frac{\mathrm{ft}^2\cdot\mathrm{kg}}{(\mathrm{m}\cdot\mathrm{s}^2)}\right] \\ & \vec{T} \geq \Big[0.5SC_DV^2\rho \left[\frac{\mathrm{ft}^2\cdot\mathrm{kg}}{(\mathrm{m}\cdot\mathrm{s}^2)}\right] \quad 0.5SC_DV^2\rho \left[\frac{\mathrm{ft}^2\cdot\mathrm{kg}}{(\mathrm{m}\cdot\mathrm{s}^2)}\right] \quad 0.5SC_DV^2\rho \left[\frac{\mathrm{ft}^2\cdot\mathrm{kg}}{(\mathrm{m}\cdot\mathrm{s}^2)}\right] \quad 0.5SC_DV^2\rho \left[\frac{\mathrm{ft}^2\cdot\mathrm{kg}}{(\mathrm{m}\cdot\mathrm{s}^2)}\right] \\ & \vec{P_{shaft}} \geq \begin{bmatrix} \frac{TV}{\eta_{prop}} \left[\frac{\mathrm{N}\cdot\mathrm{m}}{\mathrm{s}}\right] & \frac{TV}{\eta_{prop}} \left[\frac{\mathrm{N}\cdot\mathrm{m}}{\mathrm{s}}\right] & \frac{TV}{\eta_{prop}} \left[\frac{\mathrm{N}\cdot\mathrm{m}}{\mathrm{s}}\right] & \frac{TV}{\eta_{prop}} \left[\frac{\mathrm{N}\cdot\mathrm{m}}{\mathrm{s}}\right] & \frac{TV}{\eta_{prop}} \left[\frac{\mathrm{N}\cdot\mathrm{m}}{\mathrm{s}}\right] \end{bmatrix} \end{array}$$

BreguetRange

Variables	Value	Units	Description
g	9.810	$[m/s**2]$	gravitational acceleration
W_{fuel}		$[lbf]$	segment-fuel weight
z_{bre}			Breguet coefficient
ρ_{JetA}	6.750	$[lb/gal]$	Jet A fuel density
R		$[nmi]$	range

$$\begin{array}{ll} \text{minimize} & 1 \\ \text{subject to} & \vec{z_{bre}} \geq \Big[0.01386\frac{R\dot{m}\rho_{JetA}g}{VW_{end}{}^{0.5}W_{start}{}^{0.5}} \quad 0.01386\frac{R\dot{m}\rho_{JetA}g}{VW_{end}{}^{0.5}W_{start}{}^{0.5}} \quad 0.01386\frac{R\dot{m}\rho_{JetA}g}{VW_{end}{}^{0.5}W_{start}{}^{0.5}} \quad 0.01386\frac{}{V} \\ & \begin{bmatrix}\frac{W_{fuel}}{W_{end}} & \frac{W_{fuel}}{W_{end}} & \frac{W_{fuel}}{W_{end}} & \frac{W_{fuel}}{W_{end}} & \frac{W_{fuel}}{W_{end}}\end{bmatrix} \geq \big[0.1667z_{bre}{}^3 + 0.5z_{bre}{}^2 + z_{bre} \quad 0.1667z_{bre}{}^3 + 0.5z_{bre}{}^2 \\ & \vec{W_{start}} \geq \big[W_{end} + W_{fuel} \ \text{[lbf]} \quad W_{end} + W_{fuel} \ \text{[lbf]} \quad W_{end} + W_{fuel} \ \text{[lbf]} \quad W_{end} + W_{fuel} \ \text{[lbf]} \end{array}$$

WingLoading

Variables	Value	Units	Description

$$\begin{array}{ll} \text{minimize} & 1 \\ \text{subject to} & ['Mission','AircraftLoading','WingLoading']_{[0,0,0]} \\ & ['Mission','AircraftLoading','WingLoading']_{[0,0,0]} \end{array}$$

CapSpar

Variables	Value	Units	Description
w		$[in]$	spar width
ρ_{AI}	2.700	$[g/cm**3]$	density of aluminum
W		$[lbf]$	spar weight
E	70.000	$[GPa]$	Youngs modulus of aluminum
g	9.810	$[m/s**2]$	gravitational acceleration
S_y		$[m**3]$	section modulus
t		$[in]$	spar cap thickness
h_{in}		$[in]$	inner spar height
w_{lim}	0.150		spar width to chord ratio
I		$[m**4]$	spar x moment of inertia

minimize 1

subject to
$$I \leq 0.5h_{in}^2tw$$
$$W \geq \rho_{AI}bgtw$$
$$\begin{bmatrix} w_{lim}c_{ave} \text{ [ft]} & w_{lim}c_{ave} \text{ [ft]} & w_{lim}c_{ave} \text{ [ft]} & w_{lim}c_{ave} \text{ [ft]} \end{bmatrix} \geq w$$
$$\begin{bmatrix} \tau c_{ave} \text{ [ft]} & \tau c_{ave} \text{ [ft]} & \tau c_{ave} \text{ [ft]} & \tau c_{ave} \text{ [ft]} \end{bmatrix} \geq 2t + h_{in}$$
$$I \geq S_y h_{in} + S_y t$$

WingSkin

Variables	Value	Units	Description
t_{min}	0.050	$[in]$	minimum thickness
g	9.810	$[m/s**2]$	gravitational acceleration
W		$[lbf]$	wing skin weight
ρ_{AI}	2.700	$[g/cm**3]$	density of aluminum
t		$[in]$	wing skin thickness
$\bar{J}/t$	0.018	$[1/mm]$	torsional moment of inertia

minimize 1

subject to
$$W \geq 2S\rho_{AI}gt$$
$$\bar{J}/t = \bar{J}/t$$
$$t \geq t_{min}$$
$$b = b$$
$$c_{root} = c_{root}$$

NACA652Aero

Variables	Value	Units	Description
Re			Reynold's number
c_{dp}			wing profile drag coeff
C_L			lift coefficient
e	0.900		Oswald efficiency
C_d			wing drag coefficient

minimize 1

subject to
$$\vec{C_d} \geq \begin{bmatrix} 0.3183\frac{C_L{}^2}{ARe} + c_{dp} & 0.3183\frac{C_L{}^2}{ARe} + c_{dp} & 0.3183\frac{C_L{}^2}{ARe} + c_{dp} & 0.3183\frac{C_L{}^2}{ARe} + c_{dp} & 0.3183\frac{C_L{}^2}{ARe} + c_d \end{bmatrix}$$
$$\begin{bmatrix} c_{dp}{}^{18} & c_{dp}{}^{18} & c_{dp}{}^{18} & c_{dp}{}^{18} & c_{dp}{}^{18} \end{bmatrix} \geq \begin{bmatrix} 1.15 \times 10^{56}\frac{C_L{}^{93}}{Re^{14}} + 1.563 \times 10^{-10}\frac{C_L{}^{0.062}}{Re^{5.2}} + 2.443 \times 10^{-49}C \end{bmatrix}$$
$$\vec{Re} = \begin{bmatrix} 0.3048\frac{c_{MAC}V\rho}{\mu} & 0.3048\frac{c_{MAC}V\rho}{\mu} & 0.3048\frac{c_{MAC}V\rho}{\mu} & 0.3048\frac{c_{MAC}V\rho}{\mu} & 0.3048\frac{c_{MAC}V\rho}{\mu} \end{bmatrix}$$

EnginePerf

Variables	Value	Units	Description
$\eta_{alternator}$	0.800		alternator efficiency
P_{shaft}		$[hp]$	Shaft power
P_{total}		$[hp]$	Total power, avionics included
RPM		$[rpm]$	Engine operating RPM
RPM_{max}	5800.000	$[rpm]$	Maximum RPM
P_{avn}	40.000	$[W]$	Avionics power
$\dot{m}$		$[l/hr]$	fuel burn rate
L_{eng}	1.000		shaft power loss factor
$P_{shaft-max}$		$[hp]$	Max shaft power at altitude
$\dot{m}_{f-min}$	7.000	$[l/hr]$	minimum fuel burn rate

minimize 1

subject to

$$\left[\frac{P_{total}}{P_{shaft-max}} \quad \frac{P_{total}}{P_{shaft-max}} \quad \frac{P_{total}}{P_{shaft-max}} \quad \frac{P_{total}}{P_{shaft-max}} \quad \frac{P_{total}}{P_{shaft-max}}\right] = \Big[1.115\frac{RPM^{1.6}}{RPM_{max}{}^{1.6}} \quad 1.115\frac{RPM}{RPM_{m}}$$

$$\left[\frac{\dot{m}^{0.1}}{\dot{m}_{f-min}^{0.1}} \quad \frac{\dot{m}^{0.1}}{\dot{m}_{f-min}^{0.1}} \quad \frac{\dot{m}^{0.1}}{\dot{m}_{f-min}^{0.1}} \quad \frac{\dot{m}^{0.1}}{\dot{m}_{f-min}^{0.1}} \quad \frac{\dot{m}^{0.1}}{\dot{m}_{f-min}^{0.1}}\right] = \Big[1.152\frac{RPM^{0.23}}{RPM_{max}{}^{0.23}} \quad 1.152\frac{RPM^{0.23}}{RPM_{max}{}^{0.23}} \quad 1.152$$

$$\left[\frac{P_{shaft-max}}{P_{sl-max}} \quad \frac{P_{shaft-max}}{P_{sl-max}} \quad \frac{P_{shaft-max}}{P_{sl-max}} \quad \frac{P_{shaft-max}}{P_{sl-max}} \quad \frac{P_{shaft-max}}{P_{sl-max}}\right] = \vec{L_{eng}}$$

$$\vec{P_{shaft-max}} \geq \vec{P_{total}}$$

$$\vec{P_{total}} \geq \Big[0.001341\frac{P_{avn}}{\eta_{alternator}} + P_{shaft} \ [\mathrm{hp}] \quad 0.001341\frac{P_{avn}}{\eta_{alternator}} + P_{shaft} \ [\mathrm{hp}] \quad 0.001341\frac{P_{avn}}{\eta_{alternator}}$$

$$\vec{\dot{m}} \geq \vec{\dot{m}_{f-min}}$$

$$\vec{RPM} \leq \vec{RPM_{max}}$$

ChordSparL

Variables	Value	Units	Description
σ_{AI}	207.000	$[MPa]$	aluminum max stress
M_r		$[N * m]$	wing section root moment
κ	0.050		max tip deflection ratio
$\bar{q}$	1.333		normalized loading
N_{max}	5.000		max loading

minimize 1

subject to

$$['Mission','AircraftLoading','WingLoading','ChordSparL']_{[0,0,0,0]}$$

$$\vec{\vec{EI}} \leq 1.936 \times 10^{10} \frac{EI}{N_{max} W_{cent} b^2}$$

$$\vec{M_r} = \Big[0.25 N_{max} W_{cent} b\bar{M} \ [\mathrm{ft \cdot lbf}] \quad 0.25 N_{max} W_{cent} b\bar{M} \ [\mathrm{ft \cdot lbf}] \quad 0.25 N_{max} W_{cent} b\bar{M} \ [\mathrm{ft \cdot lbf}]$$

$$\left[\frac{M_r}{S_y} \ \left[\frac{\mathrm{N}}{\mathrm{m}^2}\right] \quad \frac{M_r}{S_y} \ \left[\frac{\mathrm{N}}{\mathrm{m}^2}\right] \quad \frac{M_r}{S_y} \ \left[\frac{\mathrm{N}}{\mathrm{m}^2}\right] \quad \frac{M_r}{S_y} \ \left[\frac{\mathrm{N}}{\mathrm{m}^2}\right]\right] \leq \sigma_{AI}$$

$$\vec{\delta} \leq \kappa$$

WingSkinL

Variables	Value	Units	Description
ρ_{sl}	1.225	$[kg/m**3]$	air density at sea level
C_{m_w}	0.121		negative wing moment coefficent
N_{max}	5.000		safety load factor
V_{NE}	150.000	$[m/s]$	never exceed vehicle speed
τ_{AI}	207.000	$[MPa]$	torsional stress limit

$$\begin{array}{ll} \text{minimize} & 1 \\ \text{subject to} & \tau_{AI} \geq 0.03937 \frac{C_{m_w} N_{max} S V_{NE}^2 \rho_{sl}}{\bar{J}/tc_{root}^2 t} \end{array}$$

Beam

Variables	Value	Units	Description
$\bar{\delta}$			normalized displacement
$\bar{S}$			normalized shear
θ			deflection slope
$\bar{M}$			normalized moment
$\bar{EI}$			normalized YM and moment of inertia
dx			normalized length of element
$\bar{S}_{tip}$	0.000		Tip loading
$\bar{M}_{tip}$	0.000		Tip moment
$\bar{\delta}_{root}$	0.000		Base deflection
θ_{root}	0.000		Base angle

$$\begin{array}{ll} \text{minimize} & 1 \\ \text{subject to} & \begin{bmatrix} \bar{S} & \bar{S} & \bar{S} & \bar{S} \end{bmatrix} \geq \begin{bmatrix} 0.5dx\bar{q} + 0.5dx\bar{q} + \bar{S} & 0.5dx\bar{q} + 0.5dx\bar{q} + \bar{S} & 0.5dx\bar{q} + 0.5dx\bar{q} + \bar{S} & 0.5dx\bar{q} + 0 \end{bmatrix} \\ & \bar{S} \geq \bar{S}_{tip} \\ & \begin{bmatrix} \bar{M} & \bar{M} & \bar{M} & \bar{M} \end{bmatrix} \geq \begin{bmatrix} 0.5dx\bar{S} + 0.5dx\bar{S} + \bar{M} & 0.5dx\bar{S} + 0.5dx\bar{S} + \bar{M} & 0.5dx\bar{S} + 0.5dx\bar{S} + \bar{M} & 0 \end{bmatrix} \\ & \bar{M} \geq \bar{M}_{tip} \\ & \theta \geq \theta_{root} \\ & \begin{bmatrix} \theta & \theta & \theta & \theta \end{bmatrix} \geq \begin{bmatrix} 0.5\frac{dx\bar{M}}{\bar{EI}} + 0.5\frac{dx\bar{M}}{\bar{EI}} + \theta & 0.5\frac{dx\bar{M}}{\bar{EI}} + 0.5\frac{dx\bar{M}}{\bar{EI}} + \theta & 0.5\frac{dx\bar{M}}{\bar{EI}} + 0.5\frac{dx\bar{M}}{\bar{EI}} + \theta & 0.5\frac{dx\bar{M}}{\bar{EI}} \end{bmatrix} \\ & \bar{\delta} \geq \bar{\delta}_{root} \\ & \begin{bmatrix} \bar{\delta} & \bar{\delta} & \bar{\delta} & \bar{\delta} \end{bmatrix} \geq \begin{bmatrix} 0.5dx\theta + 0.5dx\theta + \bar{\delta} & 0.5dx\theta + 0.5dx\theta + \bar{\delta} & 0.5dx\theta + 0.5dx\theta + \bar{\delta} & 0.5dx\theta + 0.5d \end{bmatrix} \\ & 4dx = 1 \end{array}$$

Fits

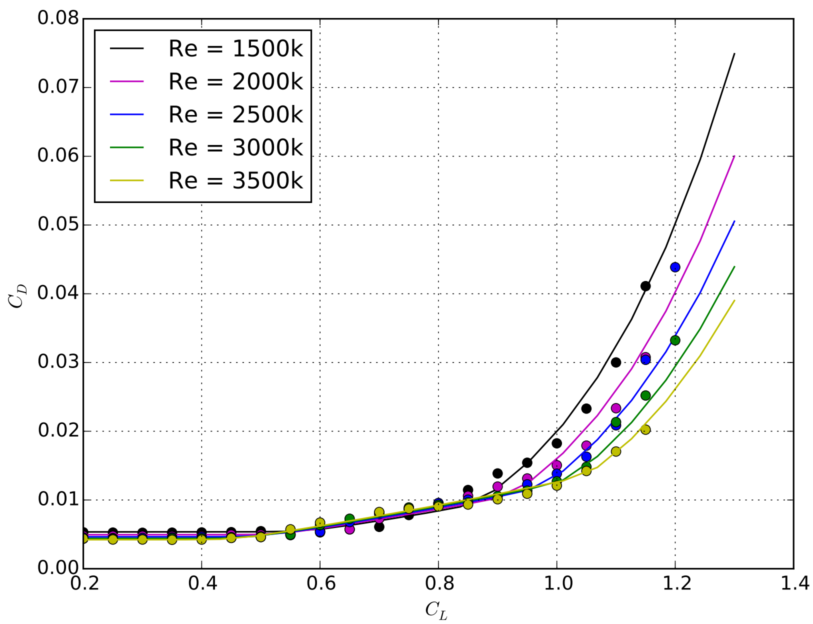
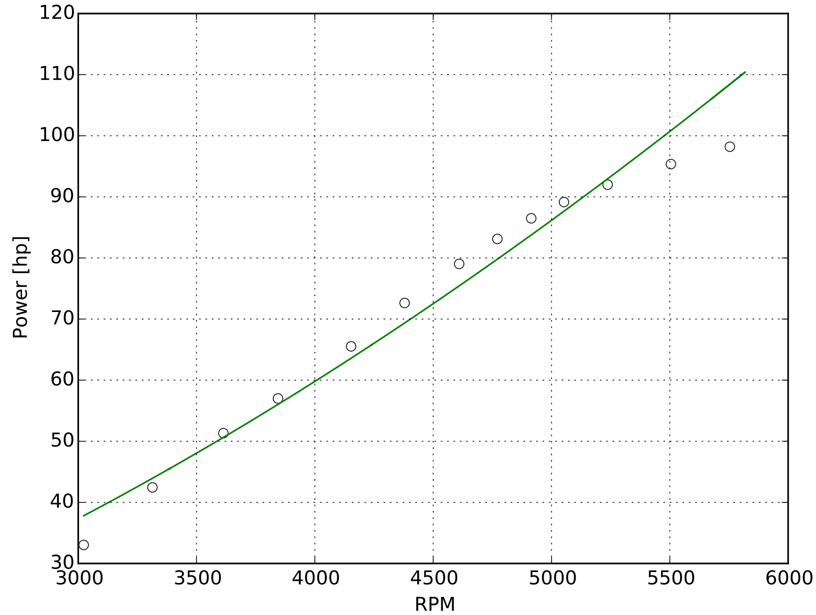
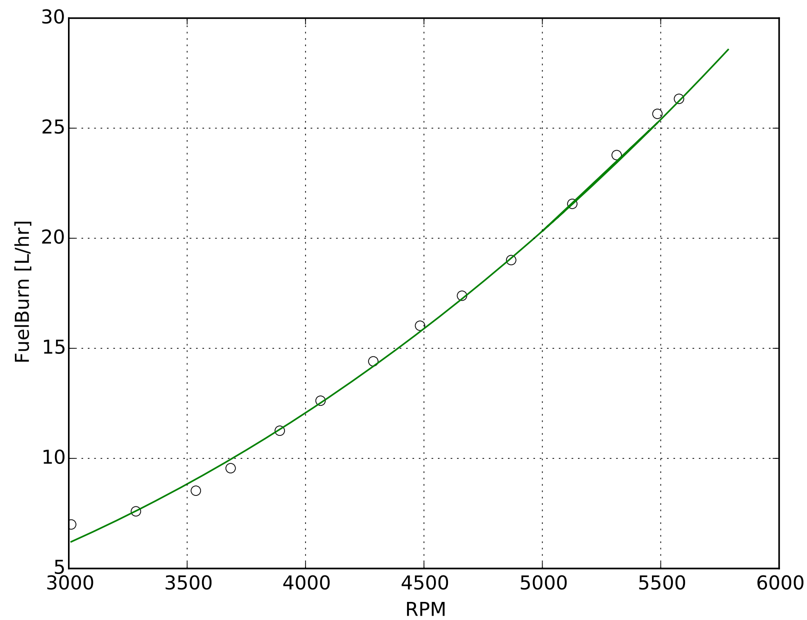


Figure 1: Fit of drag polar data from NACA 652-2412 airfoil


120
110
100
90
80
70
60
50
40
30
Power [hp]
3000
3500
4000
4500
5000
5500
6000
RPM


30
25
20
15
10
5
FuelBurn [L/hr]
3000
3500
4000
4500
5000
5500
6000
RPM

Solution

Minimizing the max take off weight we arrive at the solution.

Free Variables	Value	Units	Description
Mission			
$MTOW$	1562	lbf	max take off weight
W_{cent}	964.5	lbf	aircraft center weight
$W_{fuel-tot}$	111.9	lbf	total fuel weight
Mission/Aircraft			
W_{zfw}	1450	lbf	zero fuel weight
Mission/Aircraft/Engine			
W	152.6	lbf	Installed/Total engine weight
Mission/Aircraft/Fuselage			
W	468.5	lbf	fuselage weight
Mission/Aircraft/Wing			
AR	5.334		aspect ratio
S	37.58	ft^2	surface area
W	128.7	lbf	weight
b	14.16	ft	wing span
c_{MAC}	2.654	ft	mean aerodynamic chord
c_{root}	2.949	ft	root chord
c_{ave}	[2.88 2.73 2.58 2.43]	ft	mid section chord
Mission/Aircraft/Wing/CapSpar			
I	4.992e-06	m^4	spar x moment of inertia
S_y	5.008e-05	m^3	section modulus
W	33.03	lbf	spar weight
h_{in}	3.47	in	inner spar height
t	0.455	in	spar cap thickness
w	4.38	in	spar width
Mission/Aircraft/Wing/WingSkin			
W	52.8	lbf	wing skin weight
t	0.05	in	wing skin thickness
Mission/AircraftLoading/WingLoading/ChordSparL			
M_r	[1.04e+04 5.48e+03 2.29e+03 542]	$N \cdot m$	wing section root moment
Mission/AircraftLoading/WingLoading/ChordSparL/Beam			
dx	0.25		normalized length of element
$\bar{EI}$	[7 7 7 7]		normalized YM and moment of inertia
$\bar{M}$	[0.448 0.237 0.099 0.0234 ...]		normalized moment

$\bar{S}$	[1 0.687 0.417 0.188 ...]		normalized shear
$\bar{\delta}$	[1e-10 0.00317 0.0139 0.0292 ...]		normalized displacement
θ	[1e-10 0.0149 0.0271 0.0391 ...]		deflection slope
Mission/FlightSegment			
$W_{fuel-fs}$	111.9	lbf	flight segment fuel weight
W	[1.55e+03 1.53e+03 1.5e+03 1.48e+03 ...]	lbf	aircraft weight during flight segment
W_{end}	[1.54e+03 1.51e+03 1.49e+03 1.47e+03 ...]	lbf	vector-end weight
W_{start}	[1.56e+03 1.54e+03 1.51e+03 1.49e+03 ...]	lbf	vector-begin weight
Mission/FlightSegment/AircraftPerf			
C_D	[0.0934 0.0778 0.0699 0.0648 ...]		aircraft drag coefficient
Mission/FlightSegment/AircraftPerf/EnginePerf			
$P_{shaft-max}$	[98.6 98.6 98.6 98.6 ...]	hp	Max shaft power at altitude
P_{shaft}	[98.5 98.5 98.5 98.4 ...]	hp	Shaft power
P_{total}	[98.6 98.6 98.6 98.4 ...]	hp	Total power, avionics included
RPM	[5.43e+03 5.43e+03 5.43e+03 5.42e+03 ...]	rpm	Engine operating RPM
$\dot{m}$	[24.6 24.6 24.6 24.6 ...]	$\frac{\mathrm{l}}{\mathrm{hr}}$	fuel burn rate
Mission/FlightSegment/AircraftPerf/NACA652Aero			
C_L	[0.93 0.81 0.743 0.698 ...]		lift coefficient
C_d	[0.0684 0.0528 0.0449 0.0398 ...]		wing drag coefficient
Re	[2.82e+06 3e+06 3.1e+06 3.18e+06 ...]		Reynold's number
c_{dp}	[0.0111 0.00925 0.00824 0.00757 ...]		wing profile drag coeff
Mission/FlightSegment/BreguetRange			
R	[80 80 80 80 ...]	nmi	range
W_{fuel}	[24.3 22.9 22.1 21.5 ...]	lbf	segment-fuel weight
z_{bre}	[0.0157 0.015 0.0147 0.0145 ...]		Breguet coefficient
Mission/FlightSegment/FlightState			
V	[74.2 78.9 81.8 83.8 ...]	$\frac{\mathrm{m}}{\mathrm{s}}$	true airspeed
Mission/FlightSegment/SteadyLevelFlight			
T	[693 652 629 613 ...]	N	thrust

Constants	Value	Units	Description
Mission			
R_{min}	400	nmi	minimum flight range
Mission/Aircraft			
W_{pay}	700	lbf	payload
Mission/Aircraft/Engine			

P_{sl-max}	98.56	hp	Max shaft power at sea level
$W_{Rotax-912}$	152.6	lbf	Installed/Total DF70 engine weight
m_{fac}	1		Engine weight margin factor

Mission/Aircraft/Fuselage

f	0.3		fraction of total weight

Mission/Aircraft/Wing

λ	0.8		wing taper ratio
τ	0.15		airfoil thickness ratio
m_{fac}	1.5		wing weight margin factor
$\bar{c}$	[1.11 1.06 1 0.944 ...]		normalized chord at mid element
$\bar{c}_{ave}$	[1.08 1.03 0.972 0.917]		normalized mid section chord

Mission/Aircraft/Wing/CapSpar

E	70	GPa	Youngs modulus of aluminum
ρ_{AI}	2.7	$\frac{\mathrm{g}}{\mathrm{cm}^3}$	density of aluminum
g	9.81	$\frac{\mathrm{m}}{\mathrm{s}^2}$	gravitational acceleration
w_{lim}	0.15		spar width to chord ratio

Mission/Aircraft/Wing/WingSkin

$\bar{J}/t$	0.01823	$\frac{1}{\mathrm{mm}}$	torsional moment of inertia
ρ_{AI}	2.7	$\frac{\mathrm{g}}{\mathrm{cm}^3}$	density of aluminum
g	9.81	$\frac{\mathrm{m}}{\mathrm{s}^2}$	gravitational acceleration
t_{min}	0.05	in	minimum thickness

Mission/AircraftLoading/WingLoading/ChordSparL

N_{max}	5		max loading
κ	0.05		max tip deflection ratio
σ_{AI}	207	MPa	aluminum max stress
$\bar{q}$	[1.33 1.17 1 0.833 ...]		normalized loading

Mission/AircraftLoading/WingLoading/ChordSparL/Beam

$\bar{M}_{tip}$	1e-10		Tip moment
$\bar{S}_{tip}$	1e-10		Tip loading
$\bar{\delta}_{root}$	1e-10		Base deflection
θ_{root}	1e-10		Base angle

Mission/AircraftLoading/WingLoading/WingSkinL

C_{m_w}	0.121		negative wing moment coefficent
N_{max}	5		safety load factor
V_{NE}	150	$\frac{\mathrm{m}}{\mathrm{s}}$	never exceed vehicle speed
ρ_{sl}	1.225	$\frac{\mathrm{kg}}{\mathrm{m}^3}$	air density at sea level
τ_{AI}	207	MPa	torsional stress limit

Mission/FlightSegment/AircraftPerf

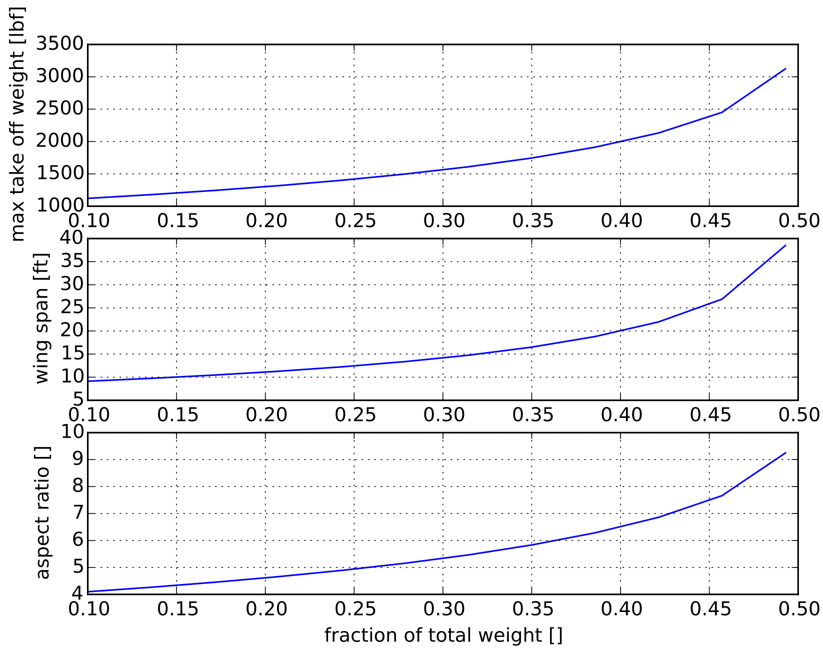
CDA_0	[0.025 0.025 0.025 0.025 ...]		non-wing drag coefficient
η_{prop}	[0.7 0.7 0.7 0.7 ...]		propulsive efficiency

Mission/FlightSegment/AircraftPerf/EnginePerf			
L_{eng}	[1 1 1 1 ...]		shaft power loss factor
P_{avn}	[40 40 40 40 ...]	W	Avionics power
RPM_{max}	[5.8e+03 5.8e+03 5.8e+03 5.8e+03 ...]	rpm	Maximum RPM
$\dot{m}_{f-min}$	[7 7 7 7 ...]	$\frac{\mathrm{l}}{\mathrm{hr}}$	minimum fuel burn rate
$\eta_{alternator}$	[0.8 0.8 0.8 0.8 ...]		alternator efficiency
Mission/FlightSegment/AircraftPerf/NACA652Aero			
e	[0.9 0.9 0.9 0.9 ...]		Oswald efficiency
Mission/FlightSegment/BreguetRange			
ρ_{JetA}	[6.75 6.75 6.75 6.75 ...]	$\frac{\mathrm{lb}}{\mathrm{gal}}$	Jet A fuel density
g	[9.81 9.81 9.81 9.81 ...]	$\frac{\mathrm{m}}{\mathrm{s}^2}$	gravitational acceleration
Mission/FlightSegment/FlightState			
V_{min}	[10 10 10 10 ...]	$\frac{\mathrm{m}}{\mathrm{s}}$	minimum true airspeed
μ	[1.64e-05 1.64e-05 1.64e-05 1.64e-05 ...]	$\frac{\mathrm{N \cdot s}}{\mathrm{m}^2}$	dynamic viscosity
ρ	[0.771 0.771 0.771 0.771 ...]	$\frac{\mathrm{kg}}{\mathrm{m}^3}$	air density
h	[1.5e+04 1.5e+04 1.5e+04 1.5e+04 ...]	ft	flight altitude
h_{ref}	[1.5e+04 1.5e+04 1.5e+04 1.5e+04 ...]	ft	reference altitude

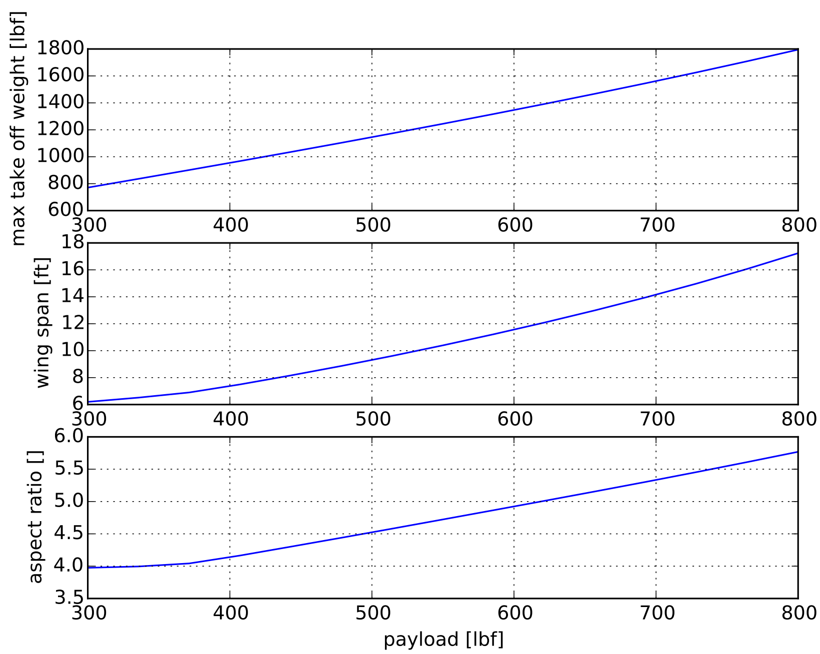
Sensitivities	Value	Units	Description
Mission/FlightSegment/FlightState			
ρ	[-0.0496 -0.0179 -0.00991 -0.00604 ...]	$\frac{\mathrm{kg}}{\mathrm{m}^3}$	air density
Mission/FlightSegment/BreguetRange			
g	[0.0294 0.0296 0.0297 0.0297 ...]	$\frac{\mathrm{m}}{\mathrm{s}^2}$	gravitational acceleration
ρ_{JetA}	[0.0294 0.0296 0.0297 0.0297 ...]	$\frac{\mathrm{lb}}{\mathrm{gal}}$	Jet A fuel density
Mission/FlightSegment/AircraftPerf/NACA652Aero			
e	[-0.08 -0.0371 -0.0263 -0.0211 ...]		Oswald efficiency
Mission/FlightSegment/AircraftPerf/EnginePerf			
$\dot{m}_{f-min}$	[0.0294 0.0296 0.0297 0.0297 ...]	$\frac{\mathrm{l}}{\mathrm{hr}}$	minimum fuel burn rate
L_{eng}	[-0.13 -0.0663 -0.0502 -0.0423 ...]		shaft power loss factor
Mission/FlightSegment/AircraftPerf			
CDA_0	[0.0349 0.0213 0.0179 0.0163 ...]		non-wing drag coefficient
η_{prop}	[-0.13 -0.0663 -0.0502 -0.0423 ...]		propulsive efficiency
Mission/AircraftLoading/WingLoading/ChordSparL			
N_{max}	0.1101		max loading
$\bar{q}$	[0.00512 0.0179 0.0307 0.0384 ...]		normalized loading
σ_{AI}	-0.1101	MPa	aluminum max stress

Mission/Aircraft/Wing/WingSkin			
g	0.1041	$\frac{\mathrm{m}}{\mathrm{s}^2}$	gravitational acceleration
ρ_{AI}	0.1041	$\frac{\mathrm{g}}{\mathrm{cm}^3}$	density of aluminum
t_{min}	0.1041	in	minimum thickness
Mission/Aircraft/Wing/CapSpar			
g	0.06513	$\frac{\mathrm{m}}{\mathrm{s}^2}$	gravitational acceleration
ρ_{AI}	0.06513	$\frac{\mathrm{g}}{\mathrm{cm}^3}$	density of aluminum
w_{lim}	-0.04499		spar width to chord ratio
Mission/Aircraft/Wing			
m_{fac}	0.1692		wing weight margin factor
$\bar{c}_{ave}$	[-2.3e-10 -3.37e-10 -6.62e-10 -0.2]		normalized mid section chord
τ	-0.1551		airfoil thickness ratio
Mission/Aircraft/Fuselage			
f	0.6159		fraction of total weight
Mission/Aircraft/Engine			
m_{fac}	0.218		Engine weight margin factor
$W_{Rotax-912}$	0.218	lbf	Installed/Total DF70 engine weight
P_{sl-max}	-0.3316	hp	Max shaft power at sea level
Mission/Aircraft			
W_{pay}	1	lbf	payload
Mission			
R_{min}	0.148	nmi	minimum flight range

Sweeps



max take off weight [lbf]
wing span [ft]
aspect ratio []
fraction of total weight []



max take off weight [lbf]
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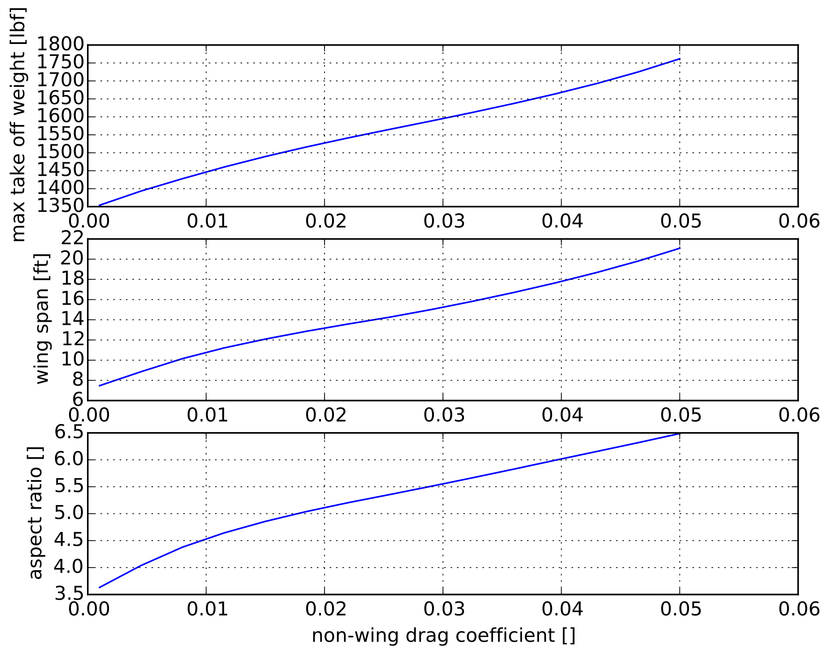
payload [lbf]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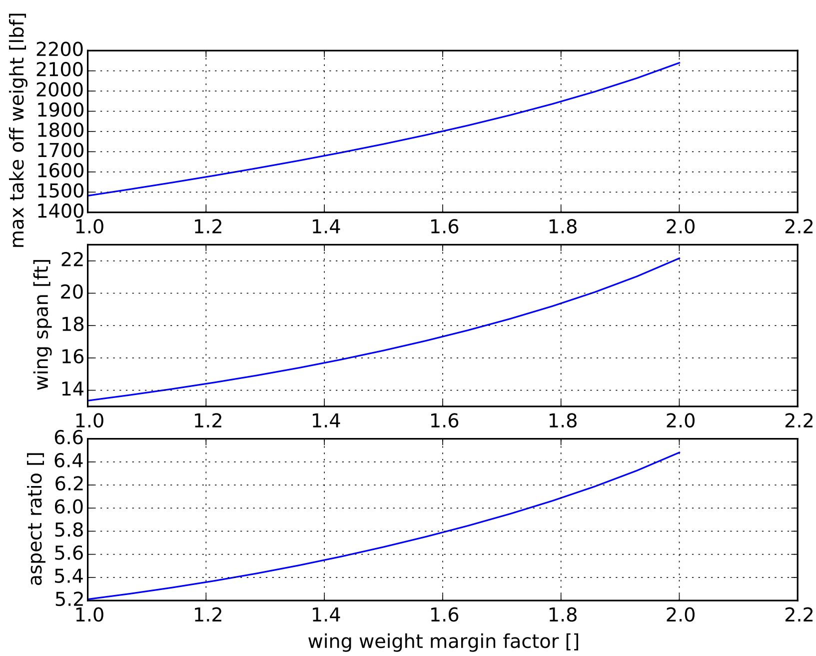
non-wing drag coefficient []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wing weight margin factor []