# Rapid Air System Concept Exploration (RASCE)

***Overview***
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DRAFT

- **A physics-based, conceptual level, air system design and analysis modeling and simulation (M&S) system**
- **Originally developed as an educational tool to support student exploration of a wide range of unmanned air system (UAS) design and operational concepts during a single semester conceptual design course**
  - *Subsequently applied to government and industry projects*
- **Runs in real time on a standard laptop**
- **No laborious input data preparation and/or hand calculations**
  - Experienced users can go from initial concept to complete vehicle sized to standard mission rules in < 1 hour
- **Ideally suited for trade study concept exploration**
  - Configuration variables can be carefully and systematically controlled over a broad trade space

## *Overall approach*

**RASCE uses parametric geometry models in lieu of drawings to generate data for aero, weight and propulsion analysis and mission performance**

- Physically captures important design variables with minimum time and effort required to generate them

**Uses integrated full mission analysis from the beginning to determine design, requirement and technology drivers**

- Sizes for actual missions, reduces dependence on
  - (1) Configuration insensitive rule-of-thumb estimates
    - *Empty weight fraction, fuel fraction for climb, etc.*
  - (2) State-of-the-art technology insensitive models

**Quickly and systematically evaluate a wide range of concepts**

- Select preferred concepts and technologies based on data

# *Geometry models – why?*

**Drawing and analyzing airplanes takes time**

- Up front trade studies need to address a wide range of concepts and time is always at a premium

**And sometimes design teams fall in love with their initial concepts**

- Alternate concepts don't get much attention

**RASCE uses simple analytical geometry models for initial trade studies and concept screening**

- Physically capture the important design variables but minimize the time and effort required to assess them

**Use RASCE to develop a "best" configuration concept**

- Then draw and analyze it to confirm estimates

# RASCE methodology overview

**Physics based parametric design and analysis method systematically *and consistently* sizes/calculates performance for subsonic Battery Electric (BEProp), ICProp, TBProp or TBFan air vehicles**

- Aerodynamic lift and drag buildup methods capture critical wetted area and wing-body-tail geometry features (inc. interference and Rn effects)
- Standard atmosphere models capture no-wind altitude effects
- Generic propulsion models calculate thrust and fuel flow as a function of power setting, speed and altitude for (1) turboprop/fans [defined by bypass ratio, specific thrust, fuel-to-air ratio and thrust-to-weight] or (2) IC or electric motor propeller installations
- Mass property models capture key weight drivers using airframe wetted area/unit weights, installed propulsion thrust-to-weight and subsystem weight fraction methods and length fraction based c.g. calculations
- Geometry models capture key configuration design features, areas, volumes component locations and geometry interactions
- Sizing relationships iterate volume and stability available vs. required to generate and "draw" concepts that uniquely meet mission requirements

# RASCE problem definition

**Parametric designs are defined in absolute *and* relative terms**

- Payload weight, volume, number of engines are absolute values
- Fuselage diameter can be input as an absolute value or iterated to meet volume requirements
  - *Forebody, aftbody and length are defined relative to diameter*
- Aero and propulsion parameters [Oswald efficiency (e), fuel-to-air ratio (f/a), etc.] are defined as absolute values
- Everything else (wing, tails, engines, nacelles,etc.) is defined in relative terms (AR, W0/Sref, BHp0/W0, tail volume coefficients (TVC) , BHp0/Weng, unit weights, etc.)

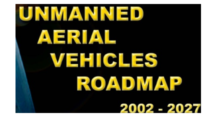
**Missions (taxi and takeoff times, operating radius, landing reserves, etc.) are described in absolute terms**

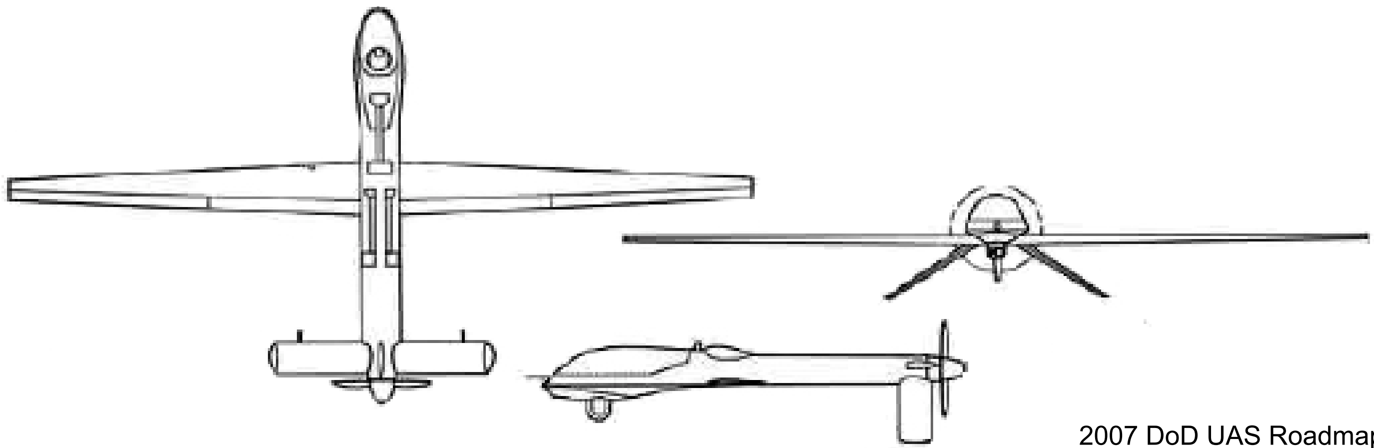
- One is a "design" mission, the other a "fall out"
  - *The UA is sized or (i.e. "scaled") to the design mission*
  - *The other mission is flown with a "fall out" air vehicle*
    - Payload, fuel and mission definition are the only variables

# RASCE example problem

**MQ-1 Predator/General Atomics/Air Force**

Weight: 2250 lb
Length: 28.7 ft
Wingspan: 48.7 ft
Payload: 450 lb
Ceiling: 25,000 ft
Radius: 400 nm
Endurance: 24+ hr



2007 DoD UAS Roadmap

**MQ-1 B**

| | | | |
|---|---|---|---|
| Length | 27 ft | Wing Span | 55 ft |
| Gross Weight | 2250 lb | Payload Capacity | 450 lb |
| Fuel Capacity | 640 lb | Fuel Type | AVGAS |
| Engine Make | Rotax 914F | Power | 115 hp |
| Endurance | 24+ hr clean<br>16 hr w/external stores | Maximum/Loiter Speeds | 118/70 kt |
| Ceiling | 25,000 ft | Radius | 500 nm |

# RASCE input notation

## Text type and fill color are used to identify inputs

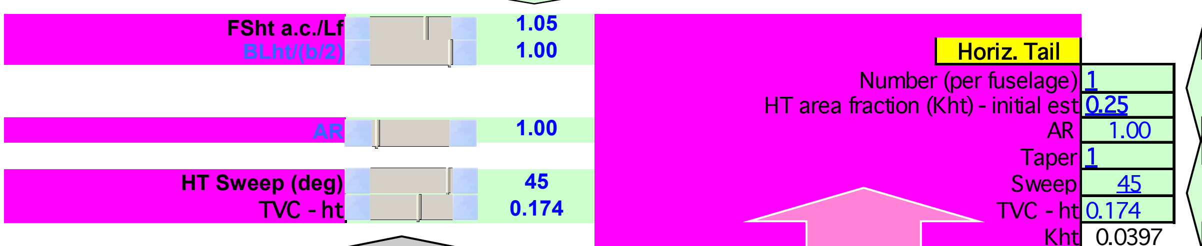
- Similar type/component input descriptions identified by fill color
- **Numerical input cells have light green fill and underlined bold text**
- **Slider bar input values shown in bold blue text with light green fill**

## Output values are in cells with no fill color

- **Sometimes bold** and sometimes mixed in with input values
  - When mixed with inputs, typically denote minima or maxima

Slider bar variable values shown in bold blue type with pale green fill

**Other input cells use bold green or blue underlined text with pale green fill**




Numerical inputs entered in cells with blue underlined text and pale green fill

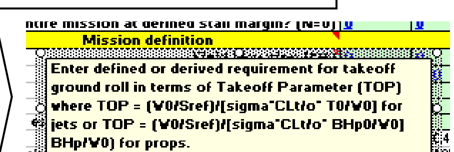
Slider values repeated in non-bold blue text, typing in these cells enters data and de-activates slider

**Slider bars used for inputs requiring frequent adjustment**

**Fill color used to identify similar component inputs**

**Calculated values output in cells with no fill**

Input cell comments expand definitions



# Methodology Overview

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**Overall problem definition**
- *Concepts of operation*
- *Requirements*
- *Engine type*
- *Initial estimates*
- *User inputs*

**Geometry**
- *Parametric Inputs*
- *Parametric Models*
  - *Fuselage(s)*
  - *Nacelle(s)*
  - *Wings*
  - *Tails*
  - *Pods*
- *Wetted area and volume*

**Mass Properties**
- *Input*
  - *Payload weight*
  - *Subsystem fractions*
  - *Airframe unit weights*
  - *Misc weights*
- *Weight convergence*
- *Parametric comparisons*

Geometry and mass models iterate together to achieve convergence

**Integrated Performance**
- *Mission convergence*
- *Requirement convergence*
- *Parametric comparisons*
- *Parametric adjustments*

**Converged solution**
- *System performance*
- *Trade Studies*
- *System optimization*

**Aerodynamics**
- *Input*
  - *CLmax (no flaps)*
  - *CLtakeoff*
  - *Trim drag factor*
  - *Laminar fractions*
- *Rn⇒Cfe⇒Drag Build-up*
- *Parabolic polar⇒CDi*
- *Parametric comparisons*

**Performance**
- *Input*
  - *Mission_definition*
- *Calculate*
  - *Takeoff*
  - *Climb*
  - *Turn*
  - *Accelerate*
  - *Cruise*
  - *Loiter*
  - *Land*
  - *Fuel req'd or remaining*
- *Parametric comparisons*

**Propulsion**
- *Input*
  - *Specific weight, density*
  - *Cycle parameters*
  - *Installation losses*
- *Speed and altitude effects*
- *Parametric comparisons*

# Worksheet Correlation

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* ICP = IC Piston Prop
BEP = Battery Electric Prop
TBP = Turboprop
TBF = Turbofan

* Duplicate versions for Fallout mission

**Overall problem definition**
- Concepts of operation
- Initial estimates
- User inputs

**- AVDef&Perf**

**Geometry**
- Parametric Inputs
- Parametric Models
  - Fuselage(s)
  - Tails
  - Pods
- Wetted area and volume

**-Geom(iter)**

**Mass Properties**
- Input
  - Payload weight
  - Misc weights
- Weight convergence
- Parametric comparisons

**- Wt(iter)**

**Integrated Performance**

**- AVDef&Perf**
**- PerfSum**
**- ConfigDataSum**

**Converged solution**

**Multiple SpreadSheet solutions**

**Aerodynamics**
- Input
  - CLmax (no flaps)
- Rn⇒Cfe⇒Drag Build-up
- Parabolic drag⇒CDi
- Parametric comparisons

**- Aero-Design***
**- Atmos-Design***

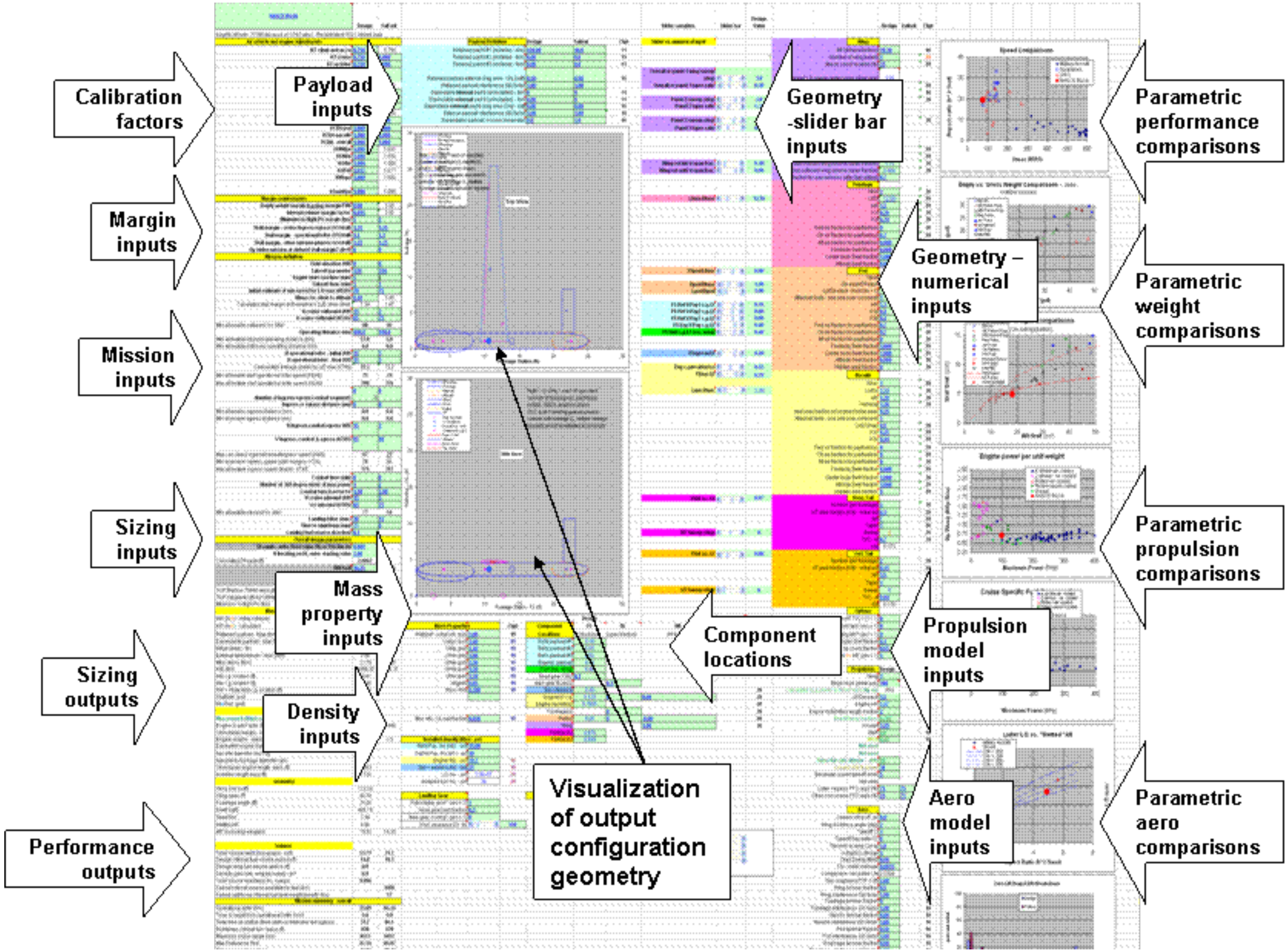
**Performance**
- Input
  - Mission_definition
- Calculate
  - Takeoff
  - Climb
  - Cruise
  - Loiter
  - Land
  - Fuel req'd or remaining
- Parametric comparisons

**- PerfCalc**

**Propulsion**
- Input
- Speed and altitude effects
- Parametric comparisons

**- ICP*, BEP*, TBP* or TBF***

# *Worksheet AVDef&Perf - RASCE user interface*



# *Mission performance*

**Performance calculations use simplified energy methods and a generic, unrefueled loiter mission model**

- Equal cruise out plus climb/cruise back distances and constant cruise speeds ($V_{cr}$) and loiter altitudes ($H_{lo}$)
- Equal ingress/egress distances at constant speed and altitude; multiple (*or no*) ingress/egress segments can be defined
- Climb-acceleration segments assumed between takeoff and cruise, cruise and loiter, loiter and ingress and egress and cruise back.
- Combat is assumed to follow ingress and is defined by minutes at maximum power setting or by a specified number of sustained turns
  - *Payload drop follows combat*

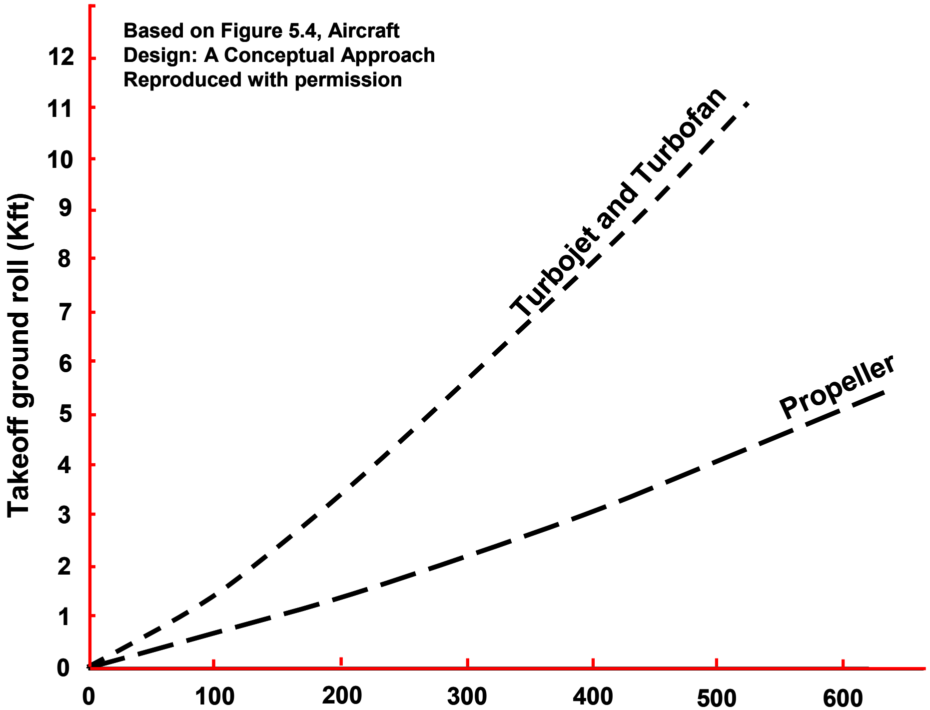
**Fuel remaining after cruise, ingress/egress, combat, landing loiter, etc., defines operational loiter time available**

- Negative values signify a fuel shortfall

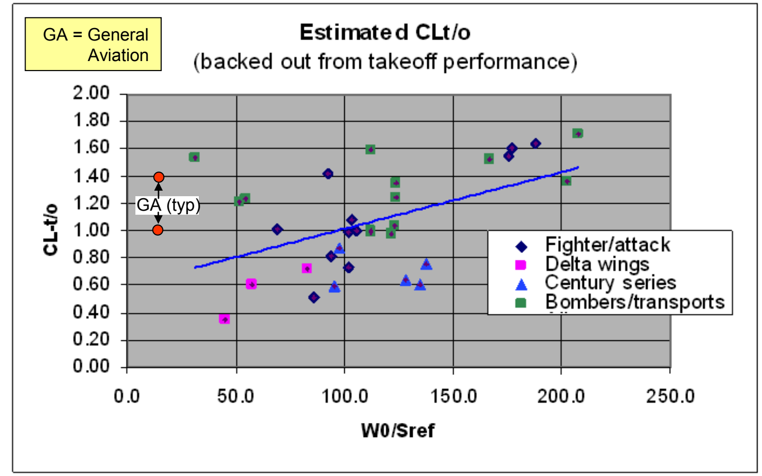
**Excess thrust is calculated for each mission segment**

- Excessive (or negative) values identify thrust mismatches that are corrected by refining the input values of $T_0/W_0$ or $BHp_0/W_0$

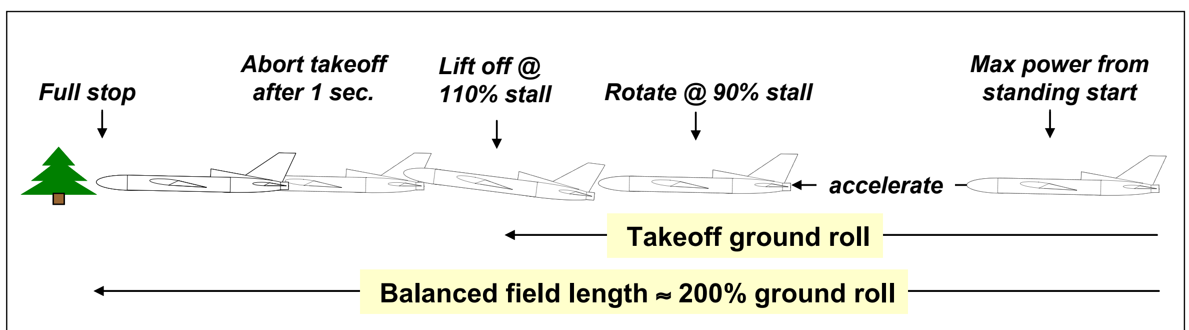
# Takeoff performance based on Takeoff Parameter (TOP)




Takeoff Parameter (TOP) = $[(W_0/S_{ref})/(BHp_0/W_0)]/[\sigma CL_{t/o}]$ *(prop)* or $[(W_0/S_{ref})/(T_0/W_0)]/[\sigma CL_{t/o}]$ *(jet)*

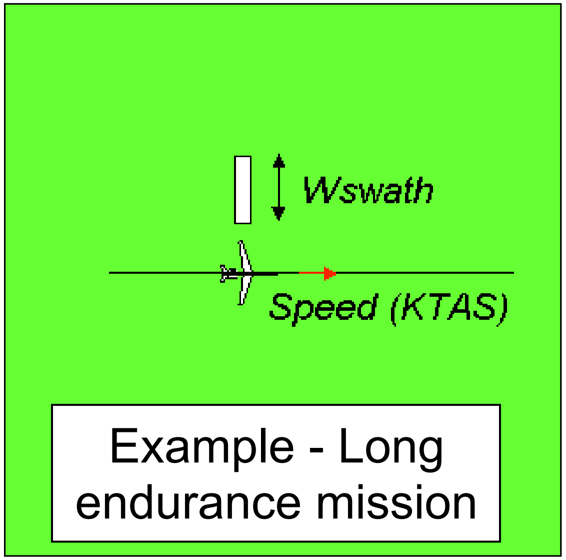


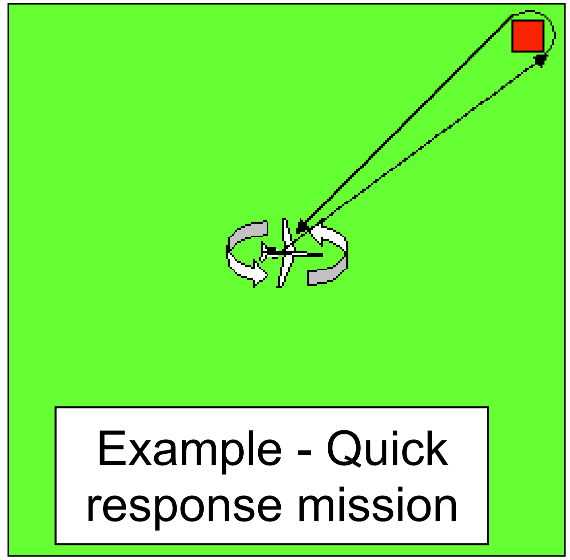

$W_0$ = Maximum takeoff weight (lbm)
$BHp_0$ = Sea level takeoff power (BHp)
$T_0$ = Sea level takeoff thrust (lbf)
$\sigma$ = air density relative to sea level ($\rho/\rho_0$)
$CL_{t/o}$ = takeoff lift coefficient

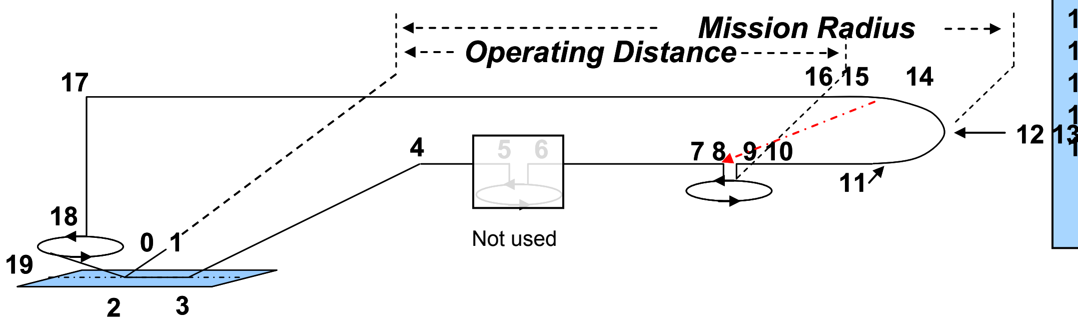


# Mission models – design and fallout

Unless otherwise specified, altitudes are given in Kft above mean sea level (MSL)




0 Engine start
1 Start taxi
2 Start takeoff
3 Start climb
4 End climb, start cruise
5 Start refuel
6 End refuel, start cruise
7 End cruise, start climb
8 End climb, start loiter
9 End loiter, start accel[1]
10 End accel, start ingress
11 End ingress
12 Sustained rate turn
13 Combat & weapon drop
14 Start egress (or climb[2])
15 End egress, start climb
16 End climb, start cruise
17 End cruise
18 Start hold
19 End hold, land

[1]accels can include climbs or descents [2] back to loiter

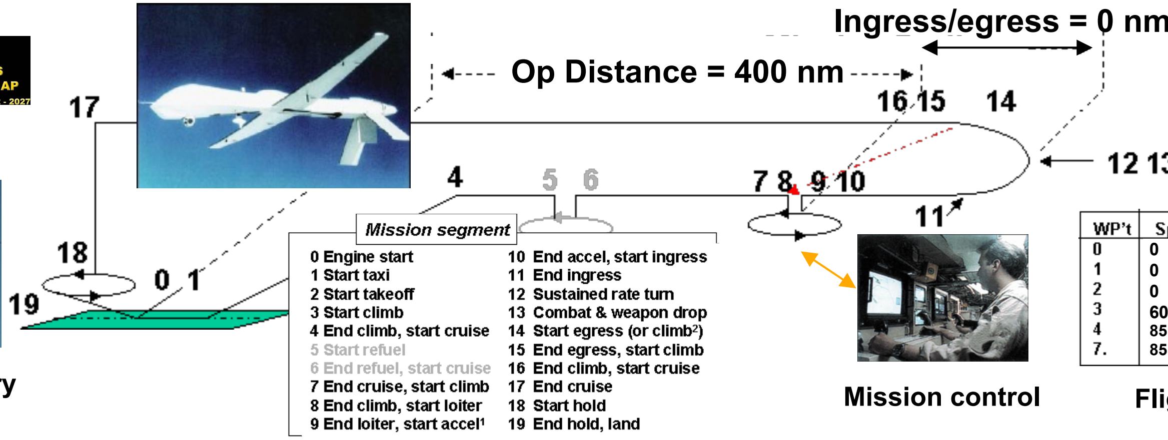
**RASCE air vehicles are sized to meet Design Mission requirements, air vehicle performance is calculated for Fallout Missions**

# *Mission definition example*

Photos from



Launch and recovery




Mission control

| WP't | Speed | Altitude |
|---|---|---|
| 0 | 0 | 0.0 |
| 1 | 0 | 0.0 |
| 2 | 0 | 0.0 |
| 3 | 60 KIAS | 0.0 |
| 4 | 85 KTAS | 15.0 |
| 7. | 85 KTAS | 15.0 |

Flight Plan

Numerical inputs in cells with blue underlined text with pale green fill

**Mission definition**

Estimate for ground roll = 3 Kft

| | |
|---|---|
| Field elevation (Kft) | 0 |
| Takeoff parameter | 413 |
| Engine start-taxi time (min) | 5 |
| Takeoff time (min) | 1 |
| Initial estimate of min speed for L/D max (KEAS) | 70 |
| **Mmax for climb to altitude** | 0.40 |
| Calculated stall margin at theoretical V (L/D )max climb | 1.06 |
| **H cruise outbound (Kft)** | 15 |
| **V cruise outbound (KTAS)** | 75 |
| Min allowable outbound Vcr (kts) | 94 |
| **Operating distance (nm)** | 400.0 |
| Min allowable inbound operating distance (nm) | 42.4 |
| Min allowable outbound operating distance (nm) | 0.0 |
| **H operational loiter - initial (Kft)** | 15 |
| **H operational loiter - final (Kft)** | 15 |
| Caalculated average speed for L/D max (KTAS) | 86.3 |
| Min allowable start operational loiter speed (KEAS) | 75 |
| Max allowable start operational loiter speed (KEAS) | 298 |

| | |
|---|---|
| **Number of ingress/egress/combat segments** | 0 |
| **Ingress or egress distance (nm)** | 0 |
| Min allowable ingress distance (nm) | 0.0 |
| Min allowable egress distance (nm) | 0.0 |
| **H ingress,combat,egress (Kft)** | 15 |
| **V ingress, combat & egress (KTAS)** | 85 |
| Max calculated ingress/combat/egress speed (KIAS) | 76 |
| Min allowable ingress speed (stall margin) - KTAS | 95 |
| Max allowable ingress speed (Mach) - KTAS | 376 |
| **Combat time (min)** | 0 |
| **Number of 360 degree turns at max power** | 0 |
| **Combat turn load factor** | 1.50 |
| **H cruise inbound (Kft)** | 15 |
| **Vcr inbound (KTAS)** | 85 |
| Min allowable inbound Vcr (kts) | 94 |
| Landing loiter (min ) | 30 |
| Time to shutdown (min) | 15 |
| Landing fuel reserve (fraction) | 0.1 |

Max climb Mach for prop ≈ 0.4

# *Performance margins*

**Design and performance margins are required, examples:**

- Empty weight growth margin fraction (no margin = 0.0)
- Internal volume margin factor (no margin = 1.0)
- Takeoff rotation speed margin (e.g. V/Vstall ≥ 1.1)
- Climb and cruise (e.g. V/Vstall ≥ 1.25)
- Loiter (e.g. V/Vstall ≥ 1.1)
- Specific excess power (e.g. Ps ≥ 5 fps)

## *Margin Input Example*

| Margin requirements | |
|---|---|
| Empty weight margin fraction (margin/EW) | 0.00 |
| Internal volume margin factor | 1.000 |
| Minimum in-flight Ps margin (fps) | 5 |
| Stall margin - cruise/ingress/egress (V/Vstall) | 1.25 |
| Stall margin - operational loiter (V/Vstall) | 1.1 |
| Stall margin - other mission phases (V/Vstall) | 1.25 |
| Fly entire mission at defined stall margin? (N=0) | 0 |

Numerical inputs in cells with blue underlined text with pale green fill

# *Overall sizing parameters - example air vehicle*

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**Primary design variables**

1. Fuel Fraction ($W_f/W_0$) = Fuel weight/Max gross weight
   - *Breguet range/endurance equation variable drives mission performance (range or time on station)*
2. Power or Thrust-to-weight ratio = $BHp_0/W_0$ or $T_0/W_0$
   - *Primary specific excess power variable drives takeoff and in-flight performance (rate of climb and acceleration)*
3. Takeoff wing loading = W0/Sref
   - *Primary trade study variable that drives wing area requirement*

**Input as overall RASCE design parameters –** *RQ-1 example*

| | |
|---|---|
| Df-equiv - enter fixed value (ft) or 0 to iterate | 0.000 |
| If iterating on Df, enter starting value | 2.00 |
| Calculated Df-equiv (ft) | 1.9997 |
| W0/Sref | 18.25 |
| Fuel fraction | 0.2840 |
| Bhp0/W0 or T0/W0 | 0.044 |
| TOP Bhp0 or T0/W0 req'd (BHp or lbf/lbm) | 0.0570 |
| TOP input/avail [(ft-lb)^2/BHp or lbf] | 0.77 |
| Minimum in-flight Ps (fps) | 4.3 |

Sizes wing to fuselage

Sizes fuel capacity for required range or endurance

Sizes engine to achieve required takeoff or climb performance

Input values based on DoD Roadmap data

# *Parametric geometry models*

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**Fuselage model**

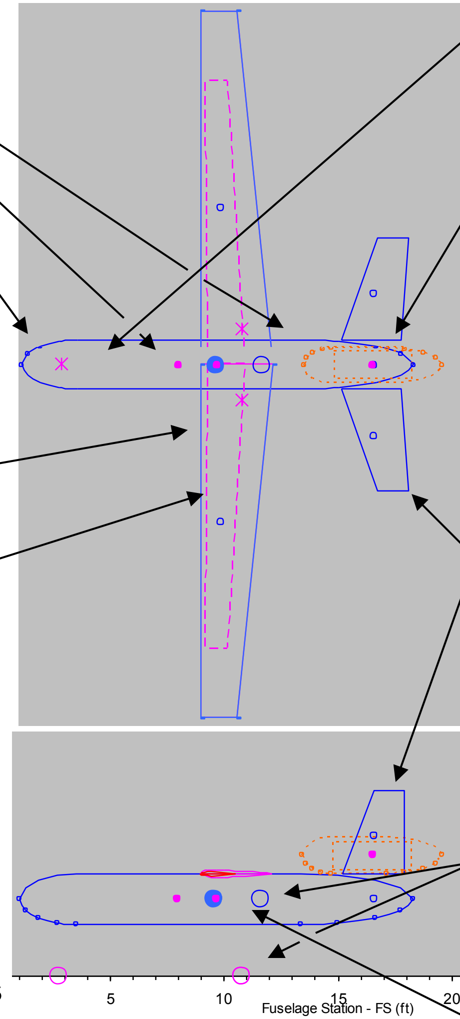
- Ellipsoid forebody
- Elliptical cylinder centerbody
- Ellipsoid aftbody
- Diameter sized to meet volume requirements less wing and nacelle
- Weight and balance based on wetted area

**Wing model**

- Multi-panel planform, constant taper (λ) & thickness-to-chord (t/c)
- Partial span and chord trapezoidal volume, constant λ & t/c
- Area sized by wing loading ($W_0$/Sref)
- Location based on balance
- Volume calculated
- Weight and balance based on exposed planform area

**Propulsion model**

- Sized by mission requirements
- Weight and volume from power-to-weight and density
- Performance from parametric cycle deck (V, h, %throttle)




**Payload model**

- Sized by mission requirements
- Location input parametrically

**Nacelle model**

- Ellipsoid forebody
- Elliptical cylinder centerbody
- Ellipsoid aftbody
- Inlet and exhaust sized by frontal area ratios
- Diameter sized by engine requirements
- Weight and balance based on wetted area

**Empennage models**

- Single panel planform, constant taper (λ) & thickness-to-chord (t/c)
- Exposed areas sized by tail volume coefficients
- Weight and balance based on exposed planform area

**Landing gear and systems**

- Volumes from density
- Weights from fractions
- Locations input parametrically

**Fuel**

- Sized by mission requirements

**Model captures key math and physics of overall air vehicle**

# *Wide range of configuration types can be modeled, e.g.*

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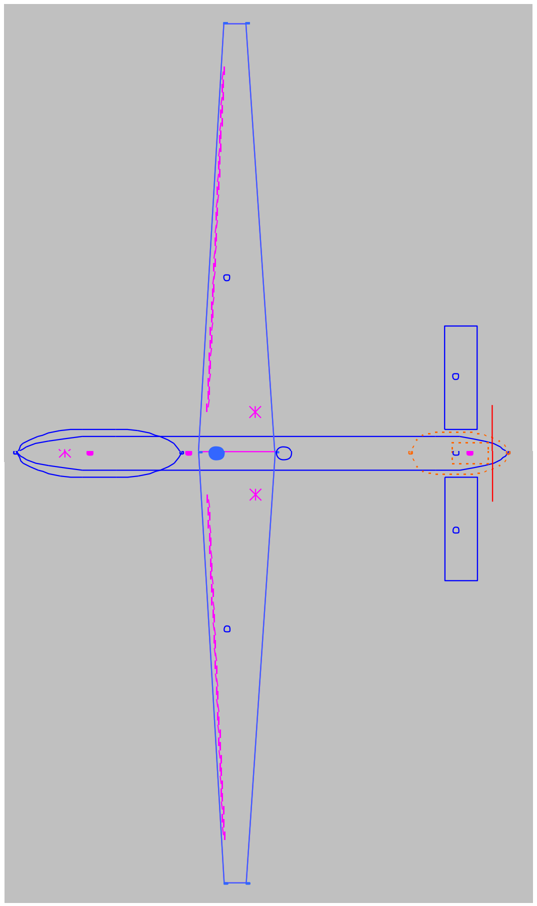
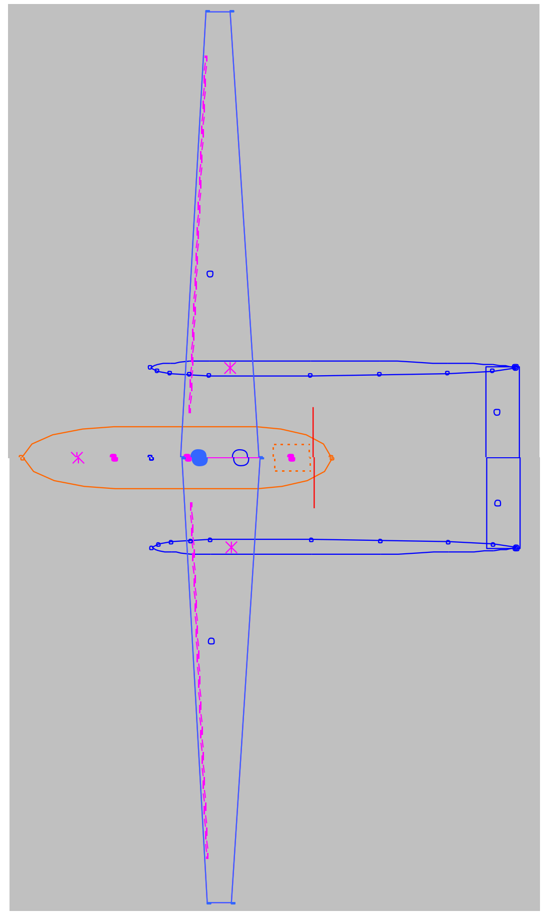
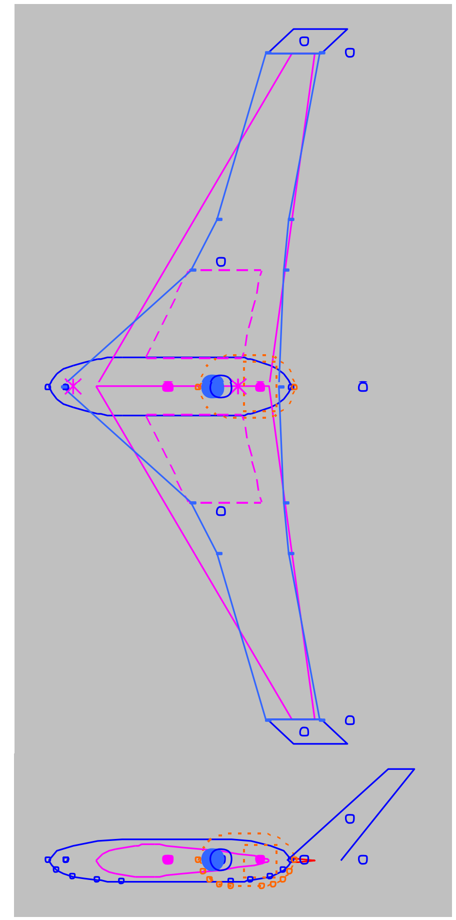


**Wing-body-tail**



**Boom tail**



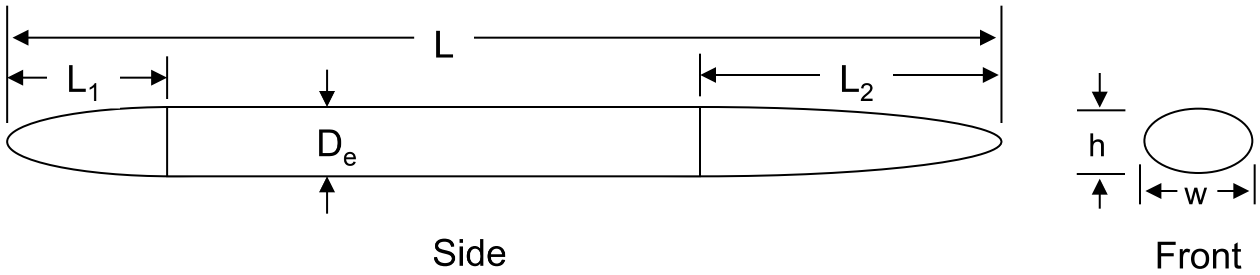
**Blended wing body**

….and many others

# *Model details*

**3-D components (fuselages, nacelles, pods, tanks) represented by generic 3 element geometry model:**

Half-ellipsoid fore body and aft body connected by elliptical cylinder




$Vol = (\pi/4)*[(L/D_e)*D_e\text{^}3]*[1-(k_1+k_2)/3]$

$Swet = [(\pi/2)*D_e^2]*\{1+(L/D_e)*[k_1*(f_{e1}-2)+ k_2*(f_{e2}-2)+2]\}*[(h/w+w/h)/2]^{0.5}$

*where*

$L$ = component length, $D_e$ = equivalent diameter = $(w*h)^{0.5}$

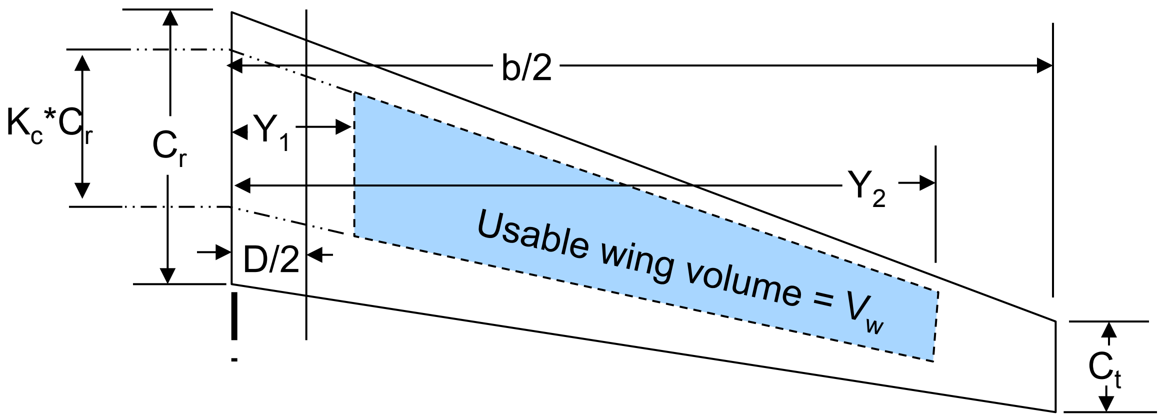
$k_1 = L_1/L$, $f_{e1} = \arcsin(\varepsilon_1)/\varepsilon_1$, $\varepsilon_1 = [1-(D_e/L)/(2*k_1))^2]^{0.5}$

$k_2 = L_2/L$, $f_{e2} = \arcsin(\varepsilon_2)/\varepsilon_2$, $\varepsilon_2 = [1-(D_e/L)/(2*K))^2]^{0.5}$

*Note* - arcsin($\varepsilon$) is expressed in radians

# *Model details cont'd*

**Lifting surfaces (wings, tails) represented by plane trapezoidal area or prismoid:**




Geometry definitions

- $t/c$ = const
- $\lambda = C_t/C_r$
- $\xi_1 = 2Y_1/b$
- $\xi_2 = 2Y_2/b$
- $C_r = 2Sref/[b(1+\lambda)]$
- $K_c$ = Wing volume chord ratio

**Wing area and volume**

$Sref_{exp} = Sref[1-(D/b)(2-(D/b)(1-\lambda)]/(1+\lambda))$ $\quad Swet_w = 2Sref_{exp}f(t/c)$

$V_w = (4/3)\{[(K_c(t/c)Sref^2]/[b(1-\lambda)(1+\lambda)^2]\}\{(1-\xi_1(1-\lambda))^3 - ((1-\xi_2(1-\lambda))^3\}$

**Exposed Tail area**

$S_{exp} = Cr(1+\lambda)b/2$ $\quad Swet_w \approx 2Sref_{exp}f(t/c)$

# *Fuselage sizing*

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**Fuselages are modeled using elliptical cylinder center section and ellipsoid fore and aft body geometry models**

- The fuselage is defined in absolute and relative terms
  - *Fuselage equivalent diameter ($D_e$) is absolute but can be iterated to assure volume required = available*
  - *Relative variables are length to diameter ratio ($Lf/D_e$), width-to-height (w/h) and forebody and aftbody length ratios ($K_{1f}$ and $K_{2f}$)*

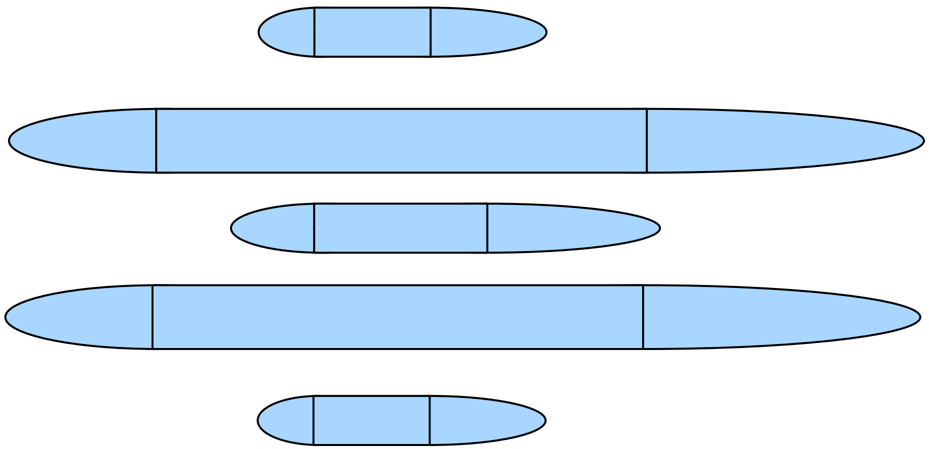
**$D_e$ required is iterated to meet payload, fuel and other volume requirements using input or calculated weights and densities**

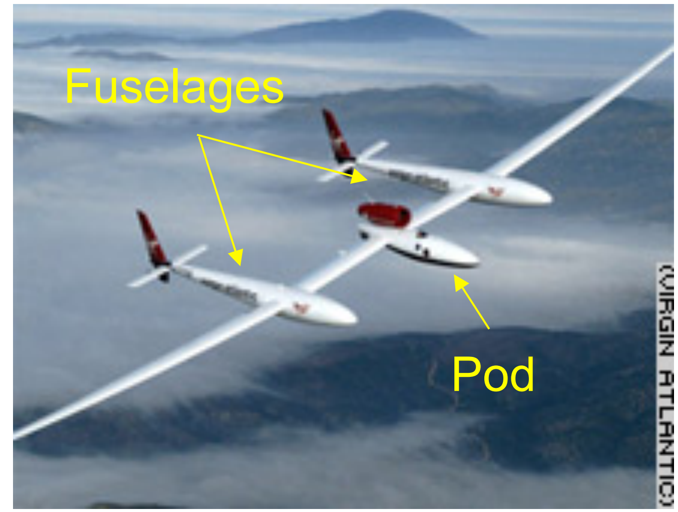
- Forebody, center body and aft body volumes available are allocated using component packing factors
  - *E.g., an aftbody might have a lower allocation than a forebody*
- Propulsion volume requirements are allocated

**As fuselage size required is iterated, length and wetted area are calculated and used for weight and volume calculations**

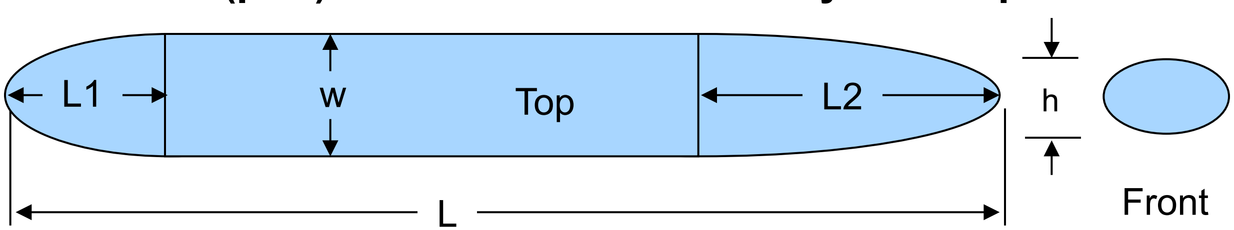
**By defintion, a RASCE "fuselage" has a tail. "Pods" are similar but have no tail.**
**Pod diameter is defined relative to fuselage diameter.**
**External "tanks" are similar to pods but are allocated only for fuel**

# *Pods, tanks and multi-fuselages*






- **Multi-fuselage and pod sizes/locations are relative:**
  - **Longitudinal location or fuselage station (FS) is given relative to the nose (FS=0)**
  - **Lateral location or butt line (BL) is given relative to wing span from the wing centerline (BL= 0)**
- **Pod diameters are defined relative to the fuselage**
- **Fuel tank (pod) diameters are defined by fuel req'd**

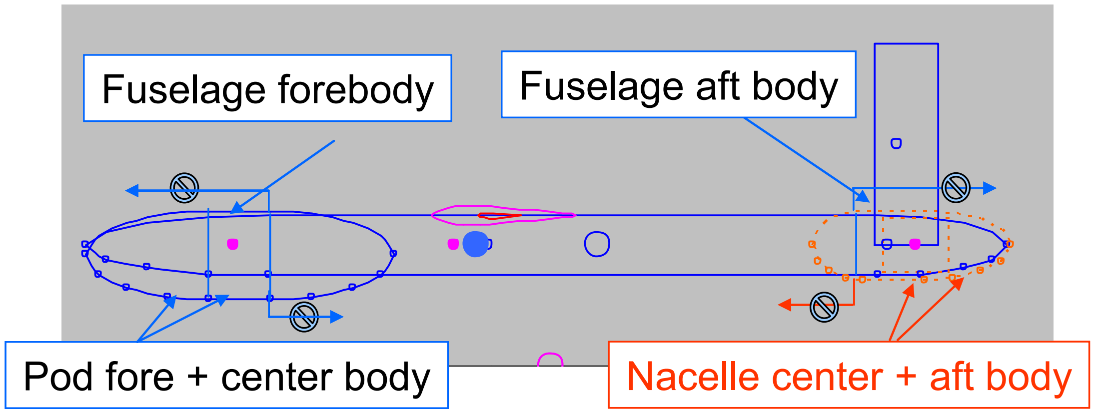




**Note – fore/center/aft body volumes and wetted areas can be "zeroed out" and replaced by other bodies**

# *Multi-body components*

**Example 1** - Replace fuselage fore body with larger diameter "pod"
**Approach** - "Zero-out fuselage fore body volume and wetted area
- Align fuselage fore body and pod aft body fuselage stations
- "Zero-out" pod aft body volume and wetted areas (*more precise adjustments can be made later to account for overlap)*




**Component fineness ratios calculated using component diameters but multi-body length**

**Example 2** - Replace fuselage aft body with nacelle
**Approach** - "Zero-out fuselage aft body volume and wetted area
- Align fuselage aft and nacelle fore body fuselage stations
- "Zero-out" nacelle fore body volume and wetted area
- Allocate nacelle volume to propulsion, i.e. no fuel and payload

# *Example pod, tank and fuselage inputs*

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| | |
|---|---|
| **Lfuse/Dfuse** | **12.50** |
| **FSpod/Lfuse** | **0.00** |
| **Dpod/Dfuse** | **1.40** |
| **Lpod/Dpod** | **3.00** |

**Slider bars used for inputs requiring visual adjustment**

| Fuselage | |
|---|---|
| Nfus | 1 |
| Lf/Df | 12.50 |
| w/h | 1.2 |
| K1f | 0.20 |
| K2f | 0.14 |
| Fwd vol fraction for pay/fuel/sys | 0 |
| Ctr vol fraction for pay/fuel/sys | 0.7 |
| Aft vol fraction for pay/fuel/sys | 0.000 |
| Forebody Swet fraction | 0.000 |
| Center body Swet fraction | 1.000 |
| Aftbody Swet fraction | 0.000 |

| Pod | |
|---|---|
| Npod | 1 |
| Dp-equiv/Df-equiv | 1.40 |
| Lp/Dp-equiv (must be > 1) | 3.00 |
| Attached body - one only (see comment) | 1 |
| w/h | 1.1 |
| K1p | 0.4 |
| K2p | 0.4 |
| Fwd vol fraction for pay/fuel/sys | 0.7 |
| Ctr vol fraction for pay/fuel/sys | 0.7 |
| Aft vol fraction for pay/fuel/sys | 0 |
| Forebody Swet fraction | 1.000 |
| Center body Swet fraction | 1.000 |
| Aftbody Swet fraction | 0.000 |
| Hidden area fraction | 0 |

| External fuel/store options | Design | Fallout |
|---|---|---|
| External fuel (%) | 0.00 | **0.00** |
| Number of external fuel tanks or stores | 0.00 | 0.00 |
| Tank diameter estimate or external store dia. (ft) | 0.00 | 0.00 |
| Tank or external store fineness ratio (Le/De) | 1.00 | 1.00 |

- **Useable volume fraction for systems and payload ≤ 0.7**
- **Useable volume fraction for fuel typically ≤ 0.8**

**Fuselage fore body “zeroed out” and replaced by 40% larger diameter “pod”, fuselage aft body is “zerroed out” to be replaced by nacelle**

# Nacelles

**Nacelles are modeled like fuselages**

- Elliptical center section, ellipsoid fore and aft bodies with individual volume and wetted area allocations
- Inlet and exhaust areas are subtracted based on input engine frontal area fractions

**Integration concept adjustments made using input wetted area fractions (Kswet)**

- 0.95 = typical podded commercial jet transport nacelle
- 0.90 = nacelle attached to fuselage (e.g. Global Hawk)
- 0.80 = engine buried in the fuselage (e.g. DarkStar)

**Planform area fractions (Kplan) are used to identify "covered" areas**

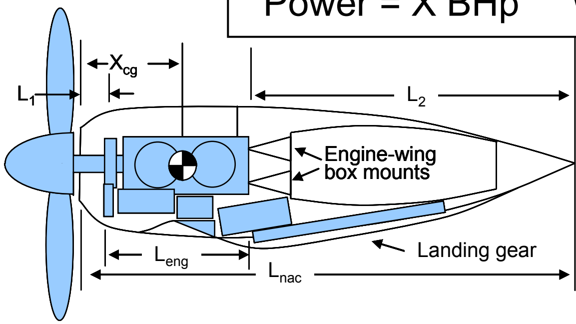
- For example, Global Hawk type, Kplan = 1.0 (100% of projected planform area covers upper fuselage)

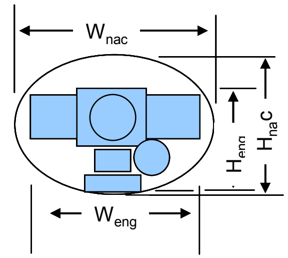
**Nacelles can be integrated with other bodies**

- E.g., aft fuselage nacelle can replace fuselage aftbody by zeroing out aft fuselage and nacelle forebody volume and wetted areas
  - *Geometry input includes definition of which bodies are separate and which are integrated*

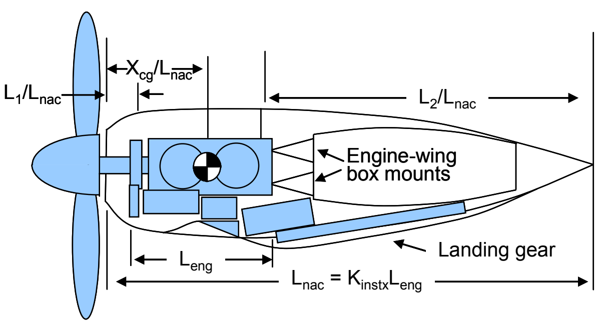
# *Nacelle example*

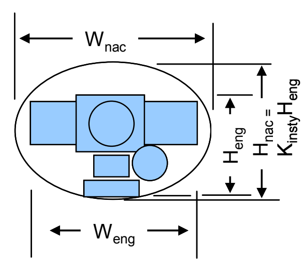
**Conventional Definition**
Power = X BHp Weng = Y lbm Dimensions as required to fit engine




**RASCE Definition**: Power loading ($W_0$/BHp), engine power-to-weight (BHp/$W_{eng}$), engine density ($W_{eng}/Vol_{eng}$), engine geometry ($L_{eng}/D_{eng}$, $W_{eng}/H_{eng}$), nacelle geometry ($L_{nac}/D_{nac}$, $W_{nac}/H_{nac}$, $H_{nac}/H_{eng}$, $L_{nac}/L_{eng}$, $X_{cg}/L_{nac}$)




**Parametric Volume Equations[1]**
Engine (cylinder model) :
$Vol_{eng}/D^3_{eng} = (\pi/4)L_{eng}/D_{eng}$, $D^2_{eng} = W_{eng}H_{eng}$
Nacelle (Cylinder+ 2 half ellipse model) :
$Vol_{nac} = (\pi/4)\,[(L_{eng}/D_{eng})\,D^3_{eng}][1-(L_1/L_{nac}+L_2/L_{nac})/3]$

[1] **Similar equations used for wetted area ($S_{wet}$)**

# *Nacelle input example*

**Nacelle volumes not required for propulsion can be allocated to fuel, payload or systems by appropriate definition of volume utilization factors**

| | |
|---|---|
| Eng c.g.location/Ln | 0.52 |
| FSnac/Lf | 0.79 |
| Lnac/Dnac | 2.33 |

**Slider bars used for inputs requiring visual adjustment**

| Nacelle | |
|---|---|
| Nnac | 1 |
| Ln/Dn | 2.330 |
| w/h | 1.20 |
| Hn/Heng | 1.255 |
| Inlet area fraction (of engine frontal area) | 0.25 |
| Attached body - one only (see comment) | 1 |
| Ln/Lf (max) | 0.9 |
| K1n | 0.25 |
| K2n | 0.438 |
| Fwd vol fraction for pay/fuel/sys | 0 |
| Ctr vol fraction for pay/fuel/sys | 0 |
| Aft vol fraction for pay/fuel/sys | 0 |
| Forebody Swet fraction | 0.000 |
| Center body Swet fraction | 1.000 |
| Aftbody Swet fraction | 1.000 |
| Hidden area fraction | 0 |

**Fuselage aft body replaced by nacelle (payload/fuel/system volume fraction = 0.0), nacelle volume allocated to propulsion only**

# *Wing sizing*

**Wings are sized separate from the fuselage**

- Based on input wing loading ($W_0/S_{ref}$), Aspect ratio (AR), taper ratios ($\lambda$), sweeps ($\Lambda$) and thickness-to-chord ratios (t/c)
  - *Up to 3 separate wing panels can be defined*
    - Internal to the program, multiple panels are reduced to a single equivalent trapezoidal planform for analysis purposes
  - *Thickness ratios are defined at root and tip*
    - Equivalent thickness is calculated using area-weighting

**Wing volume available is defined in terms of chord & span fraction**

- One chord fraction defines wing compartment forward location, second one defines chord length available, packing factor defines utilization
- Span fractions define inboard and outboard butt line (BL) limits
- Wing t/c defines compartment depth, resulting variable thickness trapezoid assumed available for fuel, landing gear, payload, etc.
  - *First priority assigned to fuel and landing gear, remaining volume is used for systems/avionics and payload*

**Wing location is defined by center-of-gravity (c.g.) vs. aerodynamic center (a.c.) relationship (i.e. design static margin)**

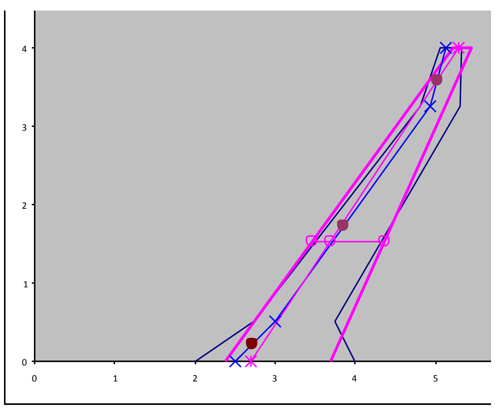
# *Blended wing body analysis currently based on surrogate trapezoidal wing*

## 1. Parametric inputs

| Surrogate test case | | Slider bar | Design Value |
|---|---|---|---|
| Sref | 6.20 | | |
| AR | 10.34 | | |
| Taper1 | 0.50 | | 0.50 |
| Sweep1 | 56.00 | | 56.0 |
| t/c1 | 0.13 | | |
| b1/b | 0.1250 | | |
| Taper2 | 0.250 | | 0.25 |
| Sweep2 | 37.00 | | 37.0 |
| t/c2 | 0.13 | | |
| b2/b | 0.8125 | | |
| Taper3 | 0.130 | | 0.13 |
| Sweep3 | 18.00 | | 18.0 |
| t/c3 | 0.13 | | |
| a.c. chord location | 0.25 | | |
| Max thickness chord location (fraction) | 0.35 | | |

## 2. BWB calculations

| | FS | BL | WL |
|---|---|---|---|
| Wing apex offset | 2.00 | 0.00 | 0.00 |
| 3Panel wing apex | 2.00 | 0.00 | 0.00 |
| LE Break1 | 2.74 | 0.50 | 0.00 |
| LE Break2 | 4.82 | 3.25 | 0.00 |
| LE Tip | 5.06 | 4.00 | 0.00 |
| TE Tip | 5.32 | 4.00 | 0.00 |
| TE Break2 | 5.32 | 3.25 | 0.00 |
| TE Break1 | 3.74 | 0.50 | 0.00 |
| TE root | 4.00 | 0.00 | 0.00 |
| a.c. 1 | 2.72 | 0.22 | 0.00 |
| a.c. 2 | 3.86 | 1.72 | 0.00 |
| a.c. 3 | 5.02 | 3.59 | 0.00 |
| a.c./chord at root | 2.50 | 0.00 | 0.00 |
| a.c./chord at break1 | 2.99 | 0.50 | 0.00 |
| a.c./chord at break2 | 4.94 | 3.25 | 0.00 |
| a.c./chord at tip | 5.12 | 4.00 | 0.00 |




## 4. Geometry visualization

| | | | |
|---|---|---|---|
| Surrogate panel wing apex | 2.37 | 0.00 | 0.00 |
| LE Tip | 5.23 | 4.00 | 0.00 |
| TE Tip | 5.45 | 4.00 | 0.00 |
| TE root | 3.69 | 0.00 | 0.00 |
| LE mac | 3.46 | 1.53 | 0.00 |
| ac | 3.69 | 1.53 | 0.00 |
| TE mac | 4.37 | 1.53 | 0.00 |
| a.c./chord at root | 2.70 | 0.00 | 0.00 |
| a.c./chord at tip | 5.28 | 4.00 | 0.00 |
| Sref' check | 6.20 | | |

## 3. Surrogate wing geometry

# *Wing input example*

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**Slider vs. numerical input**

**Slider bars used for inputs requiring visual adjustment**

1

| | |
|---|---|
| **Overall or panel 1 wing sweep (deg)** | **3.0** |
| **Overall or panel 1 taper ratio** | **0.300** |
| **Panel 2 sweep (deg)** | **3.0** |
| **Panel 2 taper ratio** | **0.300** |
| **Panel 3 sweep (deg)** | **3.0** |
| **Panel 3 taper ratio** | **0.300** |
| Design static margin req'd | 10.00 |
| Wing Apex/Lf | 0.3743 |
| **Wing vol inb'd span frac.** | **0.10** |
| **Wing vol outb'd span frac.** | **0.90** |

| Wing | |
|---|---|
| AR (dimensionless) | **19.300** |
| Number of wing panels | 1 |
| Max t/c chord location (%) | 35 |
| "Average" LE sweep (enter using slider only) | 3.00 |
| "Average" taper ratio (enter using slider only) | 0.30 |
| Panel 2 intersection span fraction | 1 |
| Panel 2 sweep (enter using slider only) | |
| Panel 2 taper ratio (enter using slider only) | |
| Panel 3 intersection span fraction | 1 |
| Panel 3 sweep (enter using slider only) | |
| Panel 3 taper ratio (enter using slider only) | |
| Root thickness/chord (t/c) | **0.150** |
| Tip thickness/chord (t/c) | 0.15 |
| Wing volume LE location (chord fraction) | 0.1 |
| Wing volume usable chord (fraction) | 0 |
| Start inboard wing volume (span fraction) | 0.10 |
| End outboard wing volume (span fraction) | 0.900 |
| Vol fraction for sys+avionics (after fuel added) | 0.7 |

**Wing volume available for fuel, payload and systems defined by fore and aft chord and inboard and outboard span fractions**
**No utilization of wing volume denoted by zero useable chord fraction**

# Tail sizing

**Primary objective is to define tail size, weight and drag**

- Current version does not include control force calculations*
  - *Trim drag estimated as percentage of induced drag*
- Historical data used to estimate initial horizontal and vertical tail size
- Horizontal and vertical tail volume coefficients are used to iterate final size required as function of calculated c.g. & tail moment arms

**Sizing approach assumes area outboard of mean aerodynamic chord (mac) can contribute to pitch stability**

- Provided as option and reduces (or eliminates) horizontal tail size

**Optional winglets are assumed to contribute to yaw stability**

- Winglets sized to input $S_{ref}$ area fraction and located at defined fraction of wing tip chord
- Residual vertical tail size required to meet $TVC_{VT}$ "drawn" at prescribed fuselage station (FS)

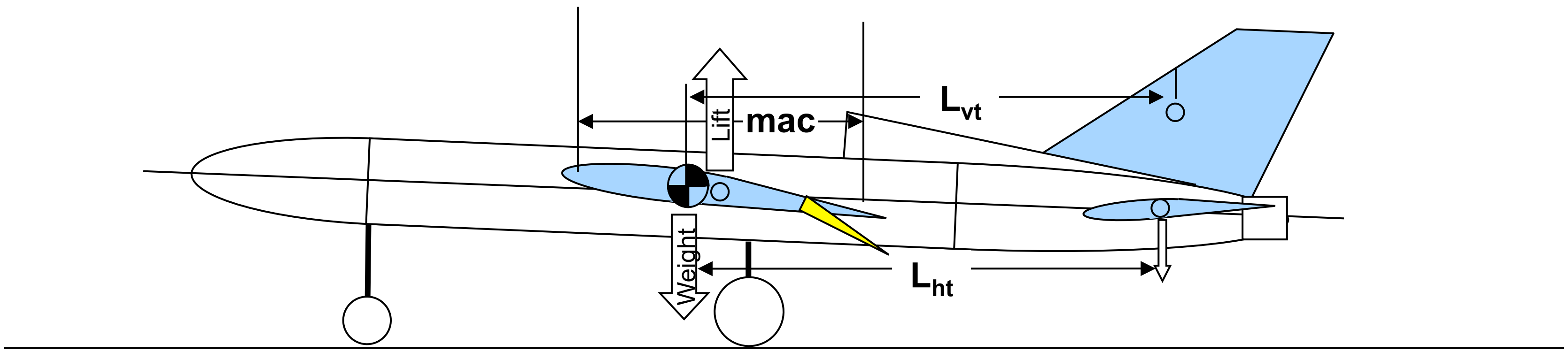
**Only gross horizontal and vertical tail areas are calculated**

- V-tail assumed to have same projected areas as conventional tail, otherwise tail type inputs limited to interference factors



** Control force upgrade currently under development*

# *Tail volume notation*




<u>Tail volume coefficient</u> (TVC)

$$TVC_{ht} = L_{ht}S_{ht}/[(mac)(Sref)] = Const \qquad TVC_{vt} = L_{vt}S_{vt}/[(b)(Sref)] = Const$$

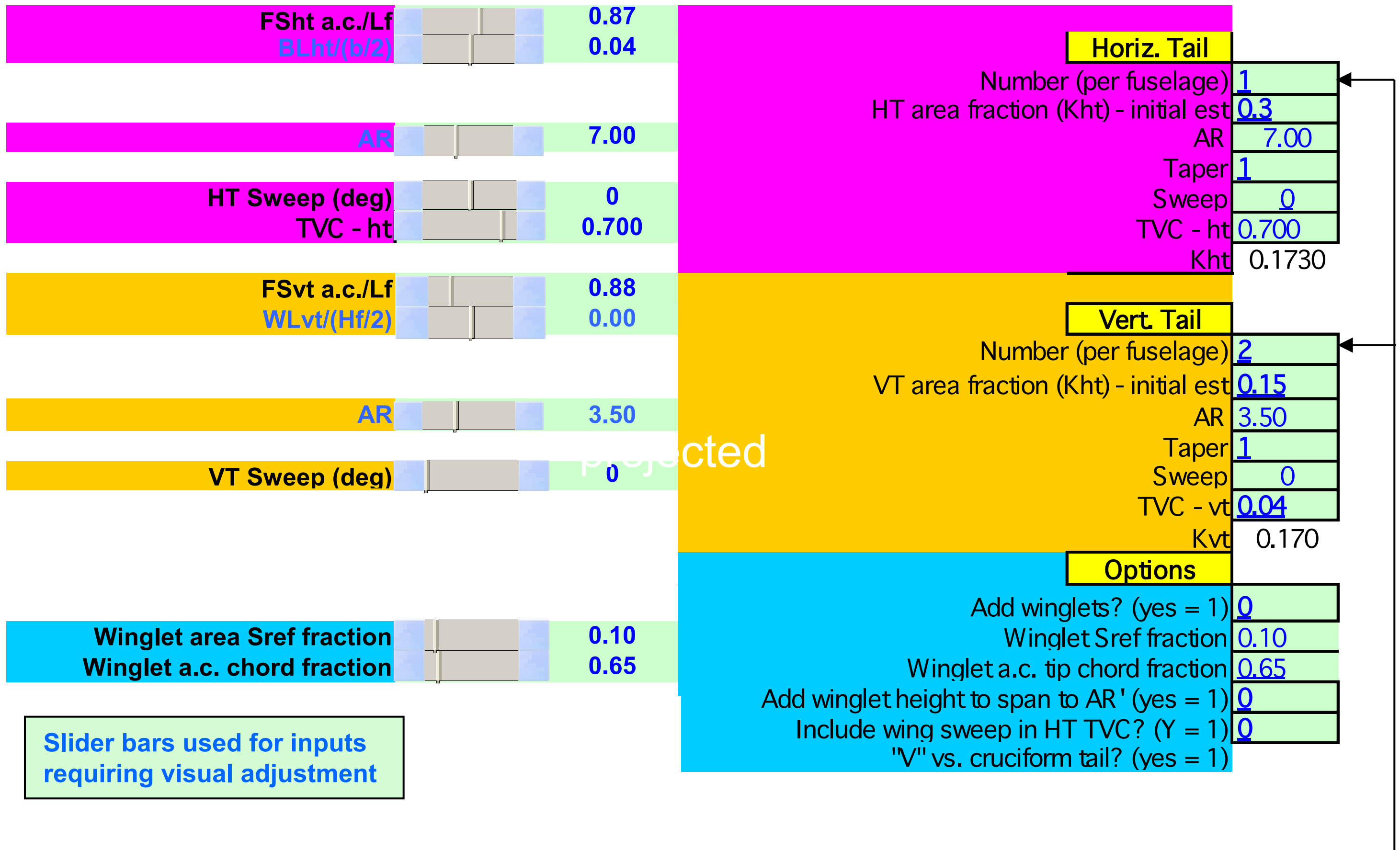
- Horizontal and vertical tail locations defined by aerodynamic centers (a.c.)
- Canard horizontal tail volume coefficient negative by definition
- Swept wing and winglets assumed to contribute to horizontal and vertical tail volume requirements
  - *Wing area outboard of m.a.c. included as surrogate horizontal tail for tail volume coefficient purposes, ditto for winglets and vertical tail volume coefficient*
  - *Winglet a.c. locations defined relative to wing tip chord*



** Control force upgrade currently under development*

# Tail input example






**Slider bars used for inputs requiring visual adjustment**

**"V" tails are approximated by 1 horizontal and 2 vertical tails with volume coefficients based on the sum of the projected horizontal and vertical plane areas**



** Control force upgrade currently under development*

# *Component locations*

**Most component axial locations are defined relative to fuselage station (FS) where FS = 0 is defined by the fuselage nose tip**

- An exception is an engine which is defined relative to nacelle length
- Components are located relative to their nose station, e.g. a pod at FS = 0.25 has it's nose located at 25% of the fuselage length
- Axial locations are used to calculate overall center of gravity

**Component lateral locations are defined relative to wing centerline or butt line (BL) relative to wing half span**

- E.g., a component located at the wing tip would input as 1.0, a component half way would be input as 0.5
- Lateral locations are currently used only for visualization purposes

**Component vertical locations or water line (WL) are defined in fuselage height fractions relative to fuselage centerline**

- E.g., a component located on top of a fuselage would be input as 1.0
- Vertical locations are currently used only for visualization purposes

# Component location example

| Component Locations | Design FS (Lf fraction) | BL (span fraction) | WL (Hf/2 fraction) | Fallout FS (Lf fraction) |
|---|---|---|---|---|
| Ret'd payload #1 | 0.16 | | | 0.16 |
| Ret'd payload #2 | 0.00 | | | 0.00 |
| Ret'd payload #3 | 0.00 | | | 0.00 |
| Expend. payload | 0.40 | | | 0.40 |
| Fuel (exc. wing) | 0.40 | | | 0.40 |
| Nose gear FS/Lf | 0.1 | | | |
| Main gear BL/(b/2) | | 0.1 | | |
| Sys.+Avionics | 0.40 | | | |
| Engine(s) c.g. | 0.520 | 0 | 0.00 | |
| Engine nacelle(s) | 0.7900 | | | |
| Fuselage(s) | | 0 | | |
| Pod(s) | 0.00 | 0 | -0.08 | |
| Wing | | | 1.00 | |

**Direct numerical inputs in cells with blue underlined text with pale green fill**

| Tail Locations | a.c. FS (Lf fraction) | Root BL (span fraction) | Root WL (Hf/2 fraction) |
|---|---|---|---|
| FSht(ac)/Lf | 0.870 | 0.04 | 0 |
| FSvt(ac)/Lf | 0.880 | 0 | 0.00 |

Slider bar inputs are transferred to numerical input cells and denoted by non-bold text with no underline

# *Mass property estimates*

**"Bottoms-up" weight estimates are iterated using multiple methods**

- Airframe weight estimates are based on input component unit weights (wing, fuselage, etc) and calculated wetted or planform areas
- Propulsion weight is based on $T_0/W_{eng}$ or $BHp_0/W_{eng}$
- Landing gear weight ($W_{lg}$) is based on an input gross weight ($W_0$) fraction where $W_{lg} = (W_{lg}/W_0)*W_0$
- "Other" system plus avionics weights ($W_{spa}$) use another input weight fraction where $W_{spa} = (W_{spa}/W_0)*W_0$
- Misc. weights (trapped fuel, etc) and weight growth margins are input as allocations

**Raymer Table 15.2 airframe unit weights and weight factors are used for initial weight estimates**

- Airframe weight per unit wing area ($W_{af}/S_{ref}$) parametric is used to adjust inputs for wing loading and type
- Statistical weight equations by air vehicle type can be used to adjust for other features (wing t/c, taper ratio, AR, etc.)

**Center of gravity is iterated based on input component locations**

# *Mass property input example*

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## Mass property inputs

| Margin requirements | |
|---|---|
| Empty weight margin fraction (margin/EW) | 0.00 |

| Mass Properties | |
|---|---|
| Waf/Sref - initial est. (psf) | 5.00 |
| Uwfpn (psf) | 1.40 |
| UWp (psf) | 1.40 |
| UWet (psf) | 1.00 |
| UWw (psf) | 2.50 |
| UWht (psf) | 1.50 |
| UWvt (psf) | 1.50 |
| Wlg/W0 | 0.05 |
| Wsys+/W0 | 0.100 |
| | |

| | |
|---|---|
| Misc wts - ULoad fraction | 0.020 |

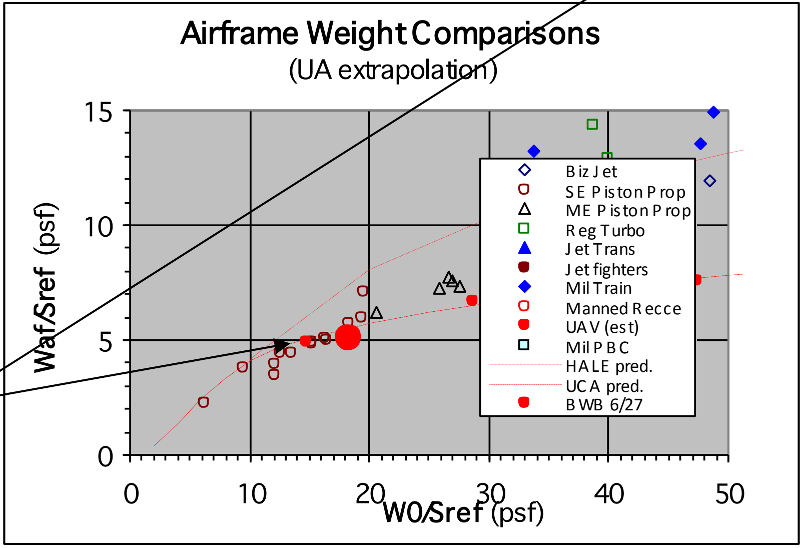
## Mass property adjustments

| Air vehicle and engine adjustments | |
|---|---|
| KAFwt | 1.063 |

**Airframe weight multiplier ($KAF_{wt}$) adjusted to converge results to satisfy parametric data**

## Mass property outputs

| Mass Properties | |
|---|---|
| W0 (lbm) - initial estimate | 2250 |
| W0 (lbm) - calculated | **2250.00** |
| Retained payload - total (lbm) | 450.00 |
| Expendable payload - total (lbm) | 0.00 |
| Wfuel (total) - lbs | 639.0 |
| External tanks/stores - total (lbm) | 0.00 |
| Misc items (lbm) | 22.22 |
| WE (lbs) | **1138.78** |
| W0 c.g. location (ft) | 10.62 |
| We c.g. location (ft) | 13.90 |
| C.g. shift (% mac) | (118.6) |
| We + Wpay ret'd c.g. location (ft) | 10.88 |
| C.g. shift (% mac) | (9.7) |
| Waf/Sref (psf) | **5.08** |
| We/Sref (psf) | **9.24** |



# *Volume estimates*

**Volume available and required is calculated while iterating bottoms-up weight and geometry**

- Fuel, payload, system and landing gear weights are used to estimate fuselage and pod (if any) volume required
  - *Fuel volume = fuel weight/( fuel density* PF ) = weight/40 pcf*
  - *Payload volume = Wpay/density*
  - *Landing gear volume = gear weight/25 pcf*[1]
  - *Other systems volume = other systems weight/25 pcf*[1]

**Volume available is calculated by the geometry model using input estimates of useable volume per component**

- Maximum value = 0.7 for fuselage and pods (if any)
- Nominal value for nacelles is a configuration variable

**Fuselage diameter ($D_{fe}$) is adjusted to equate volume available and volume required plus margin**

[1] *If actual density is unknown, 25 pcf is a reasonable estimate*

# Volume input example



| Margin requirements | |
|---|---|
| Internal volume margin factor | 1.000 |

Volume inputs

| Installed density (Rho) - pcf | |
|---|---|
| Ret'd Pay. rho (int.) - pcf | 17.68 |
| Exp'nd Pay. rho (int.) - pcf | 10 |
| Engine rho - pcf | 39.7 |
| Sys + avionics rho - pcf | 25 |
| LG rho - pcf | 2.5E+01 |
| Installed fuel rho - pcf | 36 |

Volume convergence is controlled by definition of fuselage diameter

- *A fixed fuselage diameter will be modeled as defined with no guarantee of volume convergence*
- *If fuselage diameter is input as a zero or blank, diameter required to satisfy volume criteria will be calculated*

In both cases a starting value is required

| Overall design parameters | |
|---|---|
| Df-equiv - enter fixed value (ft) or 0 to iterate | 0.000 |
| If iterating on Df, enter starting value | 2.00 |
| Calculated Df-equiv (ft) | 2.0069 |

Volume output

| Volume | |
|---|---|
| Volume margin fraction (excluding propulsion and internal fuel) | 1.000 |
| Total volume req'd (non-propul - cuft) | 53.73 |
| Design internal fuel volume req'd (cuft) | 14.8 |
| Design wing fuel volume avail (cuft) | 0.0 |
| Density (zero fuel, wing excluded) - pcf | 8.9 |

Volume converged

| Overall design parameters | |
|---|---|
| Df-equiv - enter fixed value (ft) or 0 to iterate | 2.000 |
| If iterating on Df, enter starting value | 2.00 |
| Calculated Df-equiv (ft) | 2.0000 |

Volume output

| Volume | |
|---|---|
| Volume margin fraction (excluding propulsion and internal fuel) | 0.991 |
| Total volume req'd (non-propul - cuft) | 53.68 |
| Design internal fuel volume req'd (cuft) | 14.7 |
| Design wing fuel volume avail (cuft) | 0.0 |
| Density (zero fuel, wing excluded) - pcf | 8.9 |

Volume not converged

# Component locations vs. volume

**Component c.g. locations vs. volume available and required must correlate to ensure locations and allocations are viable**

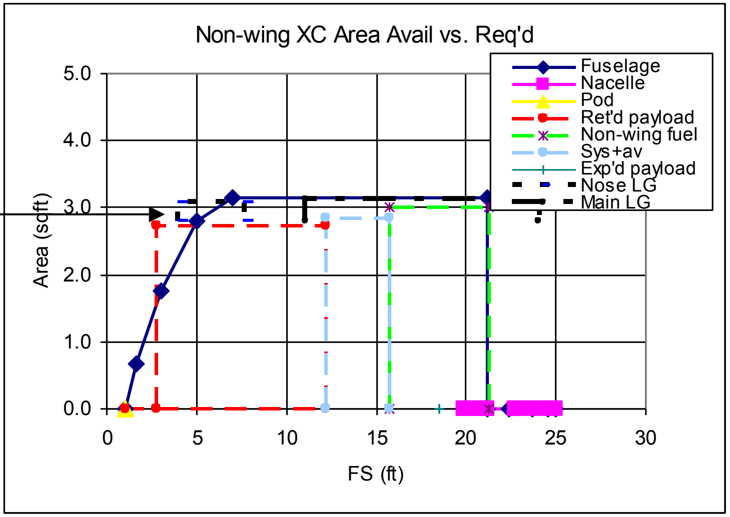
- Typically done in detail by subsystem integrators but integrated in overall sense by configuration designers

**RASCE outputs surrogate volume data in the form of cross sectional areas available vs. required based on input c.g. locations and FS innstallation length required**

- Graphical feedback is provided to facilitate adjustments
- Areas can be stacked by shifting component plot axis up and down

| Component Locations | Design FS (Lf fraction) | Installed length (Lf fraction) | Inc | Y axis shift |
|---|---|---|---|---|
| Ret'd payload #1 | 0.79 | 0.43 | 0.43 | |
| Ret'd payload #2 | 0.00 | 0.00 | 0.00 | |
| Ret'd payload #3 | 0.00 | 0.00 | 0.00 | |
| Expend. payload | 0.40 | 0.00 | 0.00 | |
| Fuel (exc. wing) | 0.44 | 0.24 | 0.24 | |
| Sys.+Avionics | 0.23 | 0.15 | 0.15 | 0 |
| Engine(s) c.g. | 0.380 | | | |
| Engine nacelle(s) | -0.0002 | | | |
| Fuselage(s) | | | | |
| Pod(s) | 0.00 | | | |
| Wing | | | | |
| FSht(ac)/Lf | 0.950 | | | |
| FSvt(ac)/Lf | 0.950 | | | |
| Landing Gear Location | | | | |
| Nose gear FS/Lf | 0.2 | 0.15 | 0.15 | 2.6 |
| Main gear BL/(b/2) | | 0.54 | 0.54 | 2.6 |

**LG volume req'd axis shifted up to ensure stacked areas fit**



# *Propulsion model*

**Propulsion models are simplified "cycle decks" that represent internal combustion engines (ICProp), turboprops (TBProp) or turbofans (TBFan)**

- Engines are scaled to meet parametric sea level static (h=0 and $V=V_0$ where $V_0$ is a non-zero reference speed) input values of thrust or power to gross weight required ($T_0/W_0$ or $BHp_0/W_0$)
- ICProp power available varies with altitude only using a simple air density parametric relationship
- TBProp and TBFan models estimate performance as a function of altitude and speed by assuming "corrected" power or thrust varies primarily with airflow ($Wdot_A$)
- Installation losses captured using thrust knock downs for jets and propulsion installation factors (including prop efficiency) for props
- Throttle effects captured using thrust/power and SFC factors by mission segment
- Secondary power and bleed air requirements are subtracted from thrust or power available (at speed and altitude) as appropriate

# *Internal Combustion (ICProp) Model*

**Maximum power = f(h) where h = altitude MSL**

- *$BHP = BHP_0*(8.55*\sigma -1)/7.55$*
  - $BHP_0$ = maximum power, SLS (sea level static)
  - $\sigma$ = air density ratio

**Thrust available (Ta) estimated from**

- *$Ta = 325.6*BHP*\eta_p/KTAS$*
  - Propulsion efficiency ($\eta_p$) assumed constant and includes propeller and installed propulsion losses *(nominal value = 0.7)*

**Fuel flow (WdotF) estimated from**

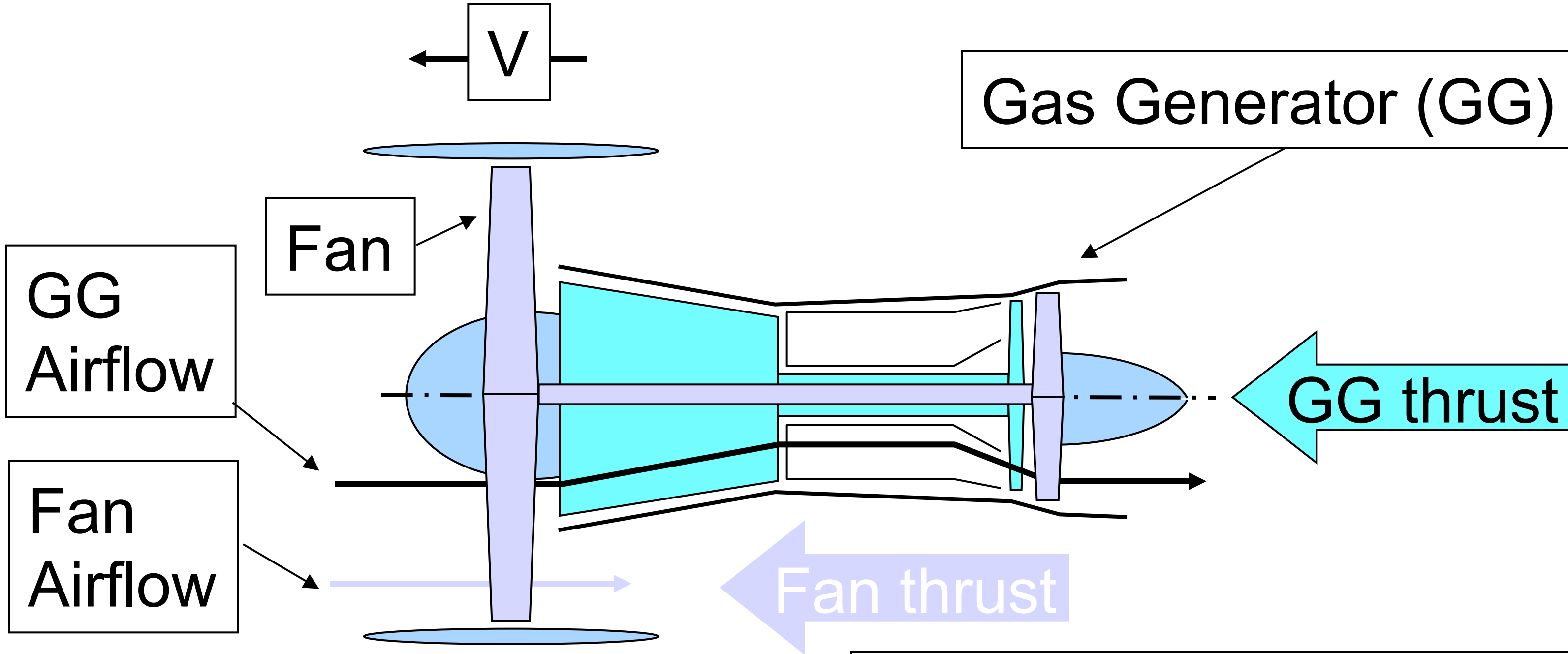
- *WdotF = SFC*BHP*
  - SFC (specific fuel consumption) assumed constant

**Engine weight ($W_{eng}$)**

- *Uninstalled $W_{eng}$ estimated using input $BHP0/W_{eng}$ parametric*
- *Installed $W_{eng}$ estimated using input installation factor ($K_{install}$)*
  - Nominal value = 1.25

# *Turbo Fan (TBF) and Turbo Prop (TBProp) Models*






**Bypass ratio (BPR)**

WdotAgg ≡ WdotA*1/(BPR+1)
WdotAfn ≡ WdotA*BPR/(BPR+1)

**Assumptions**

GG Fsp = constant = Fsp-gg
Fan Fsp = (V0/V)*Fsp-fn(SLS)
BPR = Constant

Turbojet BPR = 0, Turbofan BPR < 10; TurboProp BPR > 100

**Subsonic thrust available (Ta) is modeled as the sum of**

*(1) Core engine or "Gas generator" (gg)*

- Core engine thrust assumed to vary with core airflow (i.e. constant core specific thrust $Fsp_{gg}$)

*(2) "Fan" or fn (the fan or propeller) Specific Thrust ($Fsp_{fn}$) assumed to vary inversely with ($V_0/V$) where V = speed and $V_0$ (>0) = constant*

**Fan Bypass Ratio (BPR) assumed to remain constant**

- $WdotA_{fn} = WdotA\ [BPR/(1+BPR)]$

**Inlet temperature and pressure ratios ($\delta_i$ and $\theta_i$) assumed isentropic**

- or $\delta_i = \delta\ (1+.2M^2)^{3.5}$ and $\theta_i = \theta\ (1+.2M^2)$
- *($\delta$ and $\theta$) are standard atmosphere temperature and pressure ratios*

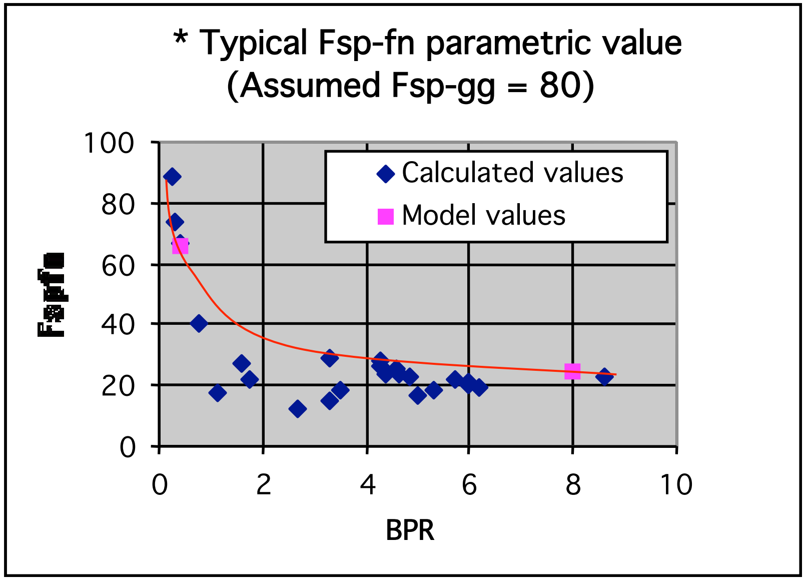
**All other engine parameters assumed to follow "corrected" engine performance relationships *where $_0$ denotes sea level static (SLS)***

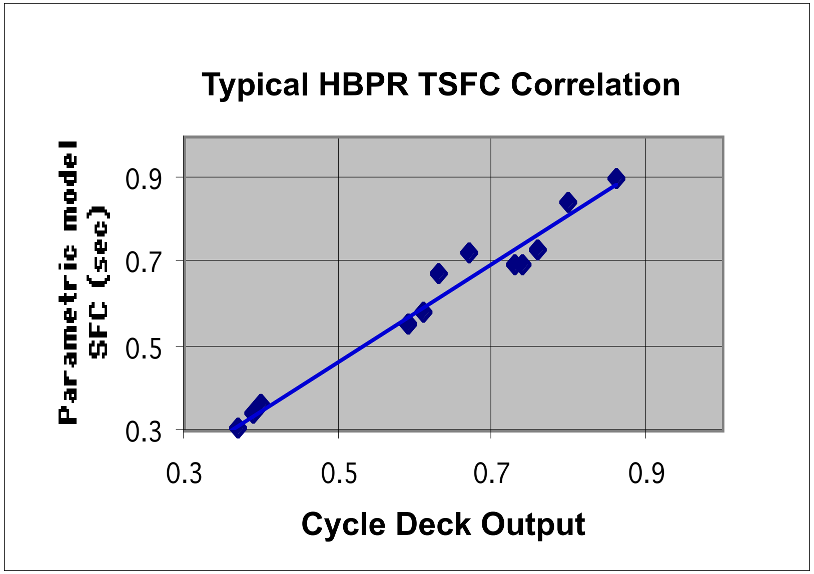
- *Thrust available (Ta) = $Ta_0\ \delta_i$*
- *Fuel flow (WdotF) = $WdotF_0\ \delta_i\ sqrt(\theta_i^k)$, $k \approx 0.5$)*
- *Thrust specific fuel consumption (TSFC) = $SFC_0 * sqrt(\theta_i^k)$*
- *Air Flow (WdotA) = $WdotA_0 * \delta_i / sqrt(\theta_i)$*
- *Fuel-to-air ratio (f/a) = $(f/a_0) * sqrt(\theta_i) * sqrt(\theta_i^k) \approx (f/a_0) * \theta_i^{0.75}$*

# Turbo Fan (TBF) and Turbo Prop (TBProp) Model Inputs

## *For typical Low and High Bypass Ratio (L/HBPR) and TBProp cycles*

| | LBPR | HBPR | TBProp |
|---|---|---|---|
| BPR | 0.4 | 8 | 135 |
| Core Fsp (sec) | 80 | 80 | 80 |
| Fan Fsp (sec)* | 66 | 25 | 5 |
| V0 (KTAS) | 100 | 100 | 50 |
| Fuel/air ratio (f/a) | 0.029 | 0.029 | 0.029 |



# Installation losses

**Installation losses are input as installation factors ($K_{install}$)**

- Assumed constant for any given slight segment but can be factored using multipliers for selected segments (i.e. climb vs. cruise)

**ICProp and TBProp**

- With the exception of secondary power, losses are captured by propulsion efficiency ($\eta_p$), most of which are propeller related
  - *Fixed pitch $\eta_p$ = 0.7, variable pitch $\eta_p$ = 0.8*
- Secondary power takeoff (PTO) is subtracted directly from power available

**TBFan and TBJet**

- Assumed to be a nominal thrust reduction across the flight regime (i.e. simple uninstalled thrust multiplier)
  - *Typical commercial transport wing pod nacelle $\eta_p$ = 0.95*
  - *Nacelle pod, disturbed flow $\eta_p$ = 0.9 (Global Hawk type)*
  - *Typical integrated fuselage fighter-type installation $\eta_p$ = 0.8*
- PTO is subtracted directly from power available for thrust
- Bleed air is subtracted from core engine airflow

# IC propulsion input example

| Propulsion | Design |
|---|---|
| Neng | 1 |
| BHp0 req'd (initial est,) | 100 |
| Calculated SLS power or thrust req'd (Hp ea) | 99.0 |
| Lth/De-equiv | 1.2 |
| Engine w/h | 0.87 |
| Engine installation length fraction | 2 |
| BHp0/Weng (Hp/lbm) | 0.707 |
| Kinstall | 1.25 |
| EtaP | 0.8 |
| SFC0 | 0.5 |
| Not used | |
| Not used | |
| Turbo flat rate altitude - (Kft) | 10 |
| Ground idle % power | 30 |
| Secondary power takeoff (KVA) | 5 |
| Not used | |
| Loiter->egress PTO req'd (%) | 75 |
| Other msn phase PTO req'd (%) | 25 |

**Height, width and installation length input to ensure proper nacelle fit**

- **Engine fineness ratio based on length and equivalent diameter ($D_e$) where $D_e$ = sqrt(width length)**
- **Turbocharger performance is based on input flat rated altitude**
- **Secondary power mission duty cycle for payload and systems is defined by % utilization of electrical capacity by mission segment**

# Aerodynamic model

**Traditional conceptual level lift and drag build-up method used**

✓ ***Lift curve slope calculated*** *($CL_\alpha$ = f(M,sweep)*

✓ ***Lift coefficient calculated*** *($CL = W/qS_{ref}$)*

- At takeoff to meet Balanced Field Length, at specified speeds and altitudes and at (L/D)max

- Adjusted to meet specified stall margins

✓ ***Drag coefficients*** *($CD_0$ and $CD_i$)*

- Drag buildup method for $CD_0$
  - Corrected for Reynolds Number (Rn)
    - *Based on input laminar flow fraction*
  - Form factor (calculated) and interference factor ($Q_i$) input
- Induced drag from parabolic polar assumption
  - Based on input Oswald efficiency "e"
- Trim drag estimated as induced drag factor (input ≈ 1.1)

✓ ***Horizontal and vertical tail "volume" determines tail size***

✓ ***Methodology valid for speeds < transonic drag rise ($M_{DD}$)***

✓ ***$L/D_{max}$ parametric output for validity check***

# *Aerodynamic input example*

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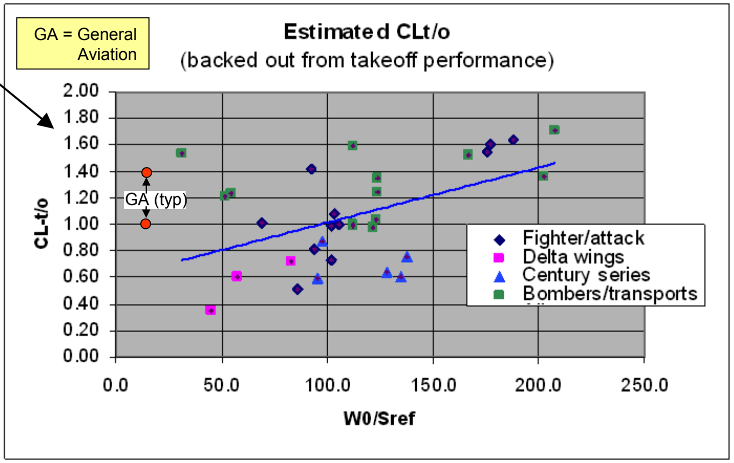
**$CL_{takeoff}$ used for Takeoff Parameter (TOP) calculation**

**$CL_{stall}$ without flaps (clean wing)**

**$M_{DD}$ defines upper limit of aero method validity, higher speeds will be ignored**

| | Aero |
|---|---|
| Oswald Wing eff. (e) | 0.8 |
| Wing incidence angle (deg) | 2 |
| Takeoff Cl | 1 |
| Takeoff flap delta-CL | 0 |
| Theoretical wing Clmax | 1.2 |
| In flight CLdesign | 1 |
| Drag Diverg.(Mdd) | 0.60 |
| Cfe - initial estimate | 0.0035 |
| Comparable calculated Cfe | 0.0039 |
| Skin roughness*10^-5 (ft) | 0.17 |
| Wing laminar fraction | 0.5 |
| Wing interference (Qi) factor | 1.00 |
| Fuselage laminar fraction | 0 |
| Fuselage interference (Qi) factor | 1.00 |
| Nacelle laminar fraction | 0.00 |
| Nacelle interference (Qi) factor | 1.00 |
| Pod laminar fraction | 0.00 |
| Pod interference (Qi) factor | 1.00 |
| Emp'nage laminar fraction | 0.00 |
| Emp'nage interference (Qi) factor | 1.04 |
| Vehicle flat plate drag area (sqft) | 0.000 |
| Additional "other drag" factor (included in overall Cfe definition) | 1.10 |
| Aircraft a.c. (% mac) | 35.00 |
| Design static margin (%) | 10.00 |
| Trim drag multiplier | 1.10 |



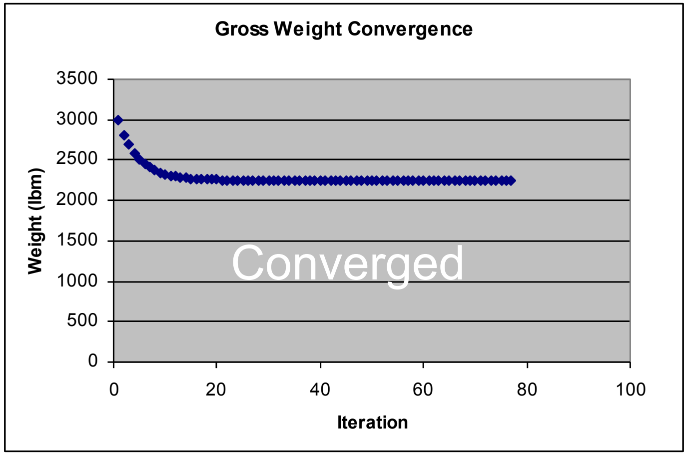

- **Equivalent skin friction coefficient is calculated but an input estimate is needed as a seed value for iteration**
- **Laminar fraction and interference factors are input for each component**
- **Overall air vehicle aerodynamic center is currently an input** (to be calculated later)

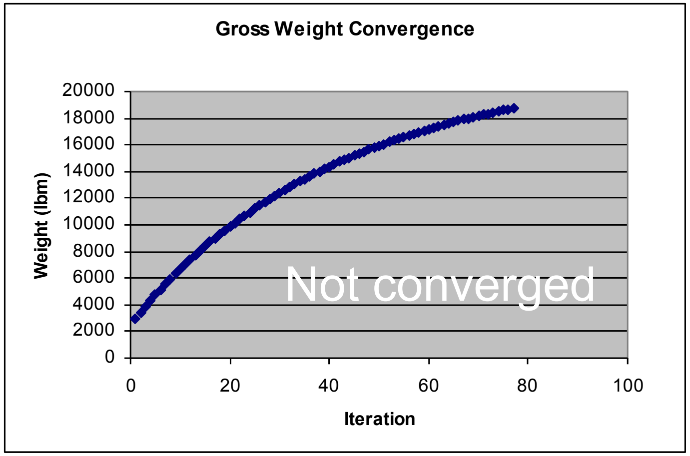
# *Model convergence*

**Mission convergence occurs in 2 steps**

Step1 is internal to RASCE and sizes/generates mission performance for the air vehicle ***model as input***.

- *Bottoms up weight, internal volume required vs. available and tail volume required vs. available are iterated to nominal convergence. Weight and volume margins and required fuel reserves are satisfied*
- *Output includes gross weight ($W_0$), empty weight ($W_e$) fuel weight ($W_f$) and mission performance (operational loiter capability, climb rates, fuel flow, specific excess power (Ps), etc.)*
- *Convergence is assumed to occur within 75 iterations but actual results must be monitored*



# Converged model example

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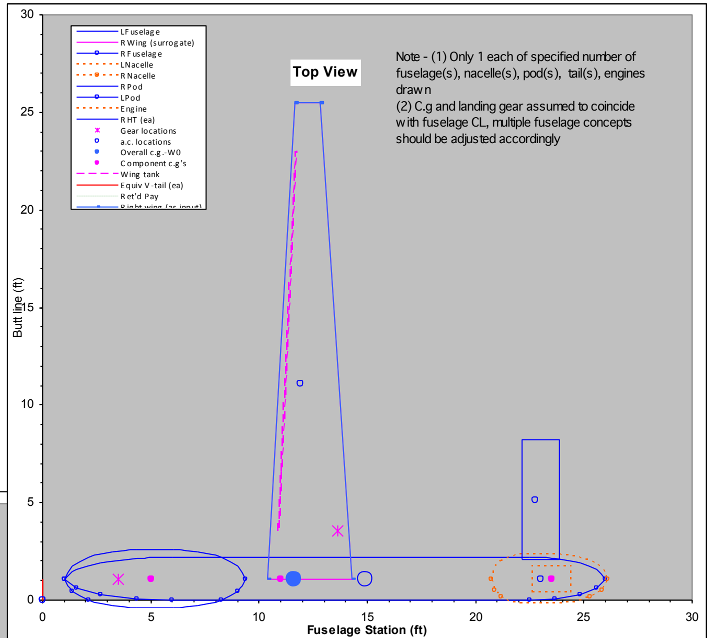
**Results for example air vehicle as input**

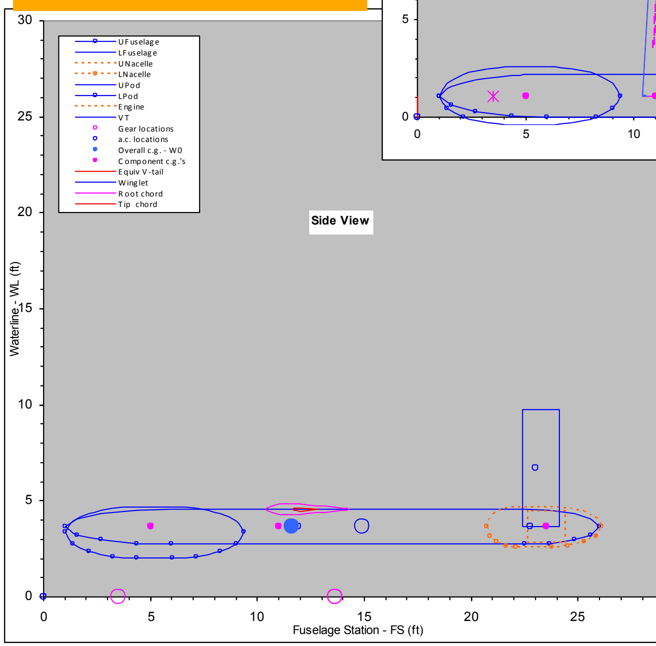
**Input**

$W_f/W_0 = 0.284$

$BHp_0/W_0 = 0.044$

etc.




**Output**

$D_{fe} = 2.0$

$W_0 = 2250$ lbm

$W_e = 1139$ lbm

$W_f = 639$ lbm

$BHp_0 = 99$

Minimum Ps = 4.3 fps

Op. loiter = 27.4 hrs

Max end. = 36.7 hrs

Max range = 3335 nm

etc.

| Overall design parameters | |
|---|---|
| Df-equiv - enter fixed value (ft) or 0 to iterate | 0.000 |
| If iterating on Df, enter starting value | 2.00 |
| Calculated Df-equiv (ft) | 1.9997 |
| W0/Sref | 18.25 |
| Fuel fraction | 0.2840 |
| Bhp0/W0 or T0/W0 | 0.044 |
| TOP Bhp0 or T0/W0 req'd (BHp or lbf/lbm) | 0.0570 |
| TOP input/avail [(ft-lb)^2/BHp or lbf] | 0.77 |
| Minimum in-flight Ps (fps) | 4.3 |
| **Mass Properties** | |
| W0 (lbm) - initial estimate | 3000 |
| W0 (lbm) - calculated | 2250.00 |
| Retained payload - total (lbm) | 450.00 |
| Expendable payload - total (lbm) | 0.00 |
| Wfuel (total) - lbs | 639.0 |
| External tanks/stores - total (lbm) | 0.00 |
| Misc items (lbm) | 22.22 |
| WE (lbs) | 1138.78 |
| W0 c.g. location (ft) | 10.62 |
| We c.g. location (ft) | 13.90 |
| C.g. shift (% mac) | (118.6) |
| We + Wpay ret'd c.g. location (ft) | 10.88 |
| C.g. shift (% mac) | (9.7) |
| Waf/Sref (psf) | 5.08 |
| We/Sref (psf) | 9.24 |
| **Propulsion** | |
| Max power0 (BHp0 each) | 99.0 |
| Engine Scale Factor (ESF) req'd | 0.990 |
| Uninstalled weight - each (lbm) | 140.0 |
| Engine volume - each cuft | 3.53 |
| Equivalent engine diameter - each (ft) | 1.55 |
| Nacelle diameter req'd (ft) | 2.29 |
| Nacelle-to-fuselage diameter ratio | 1.14 |
| Uninstalled engine length -each (ft) | 1.863 |
| Installed length req'd (ft) | 3.726 |
| **Geometry** | |
| Wing Sref (sqft) | 123.29 |
| Wing span (ft) | 48.78 |
| Fuselage length (ft) | 25.00 |
| Swet (sqft) | 484.87 |
| Swet/Sref | 3.93 |
| Wetted AR | 4.91 |
| AR' (including winglets) | 19.30 |
| Vol^2/3/Swet | 0.029 |
| **Volume** | |
| Volume margin fraction (excluding propulsion and internal fuel) | 1.000 |
| Total volume req'd (non-propul - cuft) | 53.16 |
| Design internal fuel volume req'd (cuft) | 14.2 |
| Design wing fuel volume avail (cuft) | 0.0 |
| Density (zero fuel, wing excluded) - pcf | 9.2 |
| Fallout internal volume available for fuel (lbs) | |
| Fallout additional internal fuel tank weight penalty (lbs) | |
| **Mission summary - overall** | |
| Operational loiter (hrs) | 27.51 |

Can't fly w/o payload or ballast

Stability issue

# *Step 2 Mission convergence*

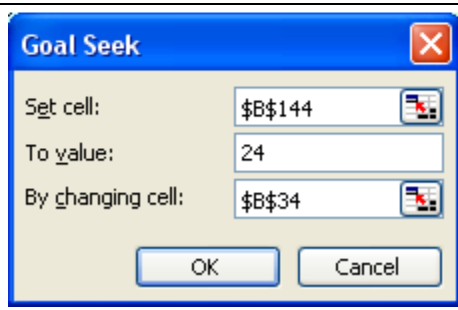


**RASCE uses standard excel tools (Solver or Goal Seek) to find solutions to meet mission and/or trade study requirements**

- *Goal seek provides a single independent variable numerical solution for a single goal value* ***(most useful for baseline model adjustment)***
  - E.g. solve for drag multiplier required to adjust model to meet known or demonstrated performance (e.g. 24 hour time on station)
- *Solver enables multi-variable solutions with multi-variable constraints*
  - E.g. solve for fuel fraction required for 24 hour loiter while satisfying power-to-weight requirements for takeoff *and minimum Ps req'd*

**Original solution**

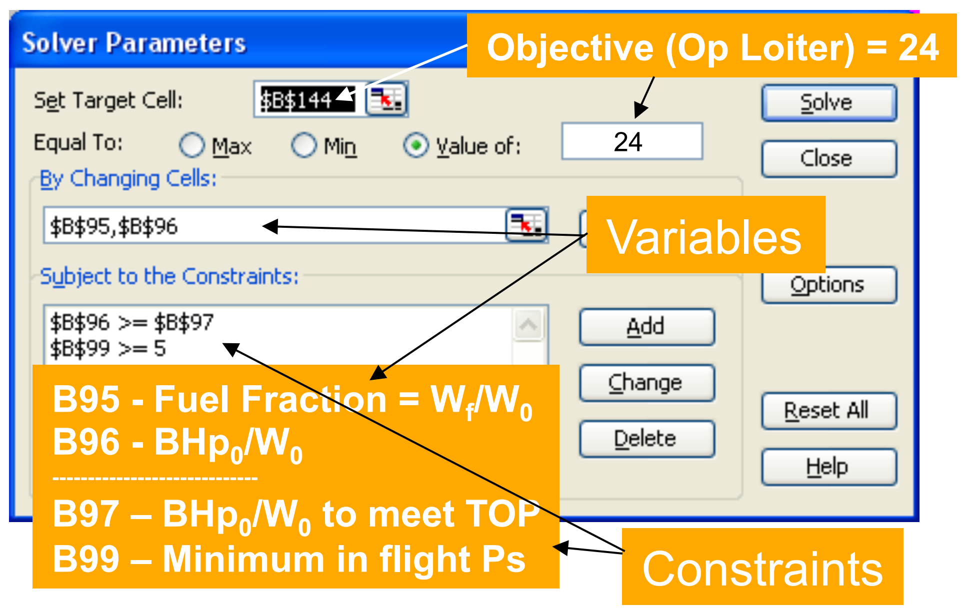
| | | Col B |
|---|---|---|
| Line 144 | Operational loiter (hrs) | **27.51** |
| Line 34 | **KCD0 - overall** | 1.000 |




**Goal Seek solution**

| | | Col B |
|---|---|---|
| Line 144 | Operational loiter (hrs) | **24.00** |
| Line 34 | **KCD0 - overall** | 1.192 |

**Multi-variable Solver solution**



# *Goal Seek example*

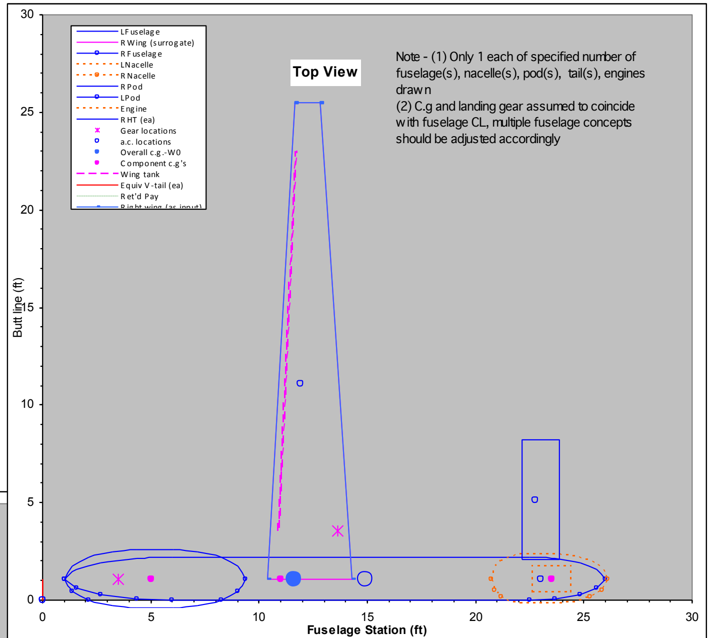
**Results for air vehicle example when $CD_0$ adjusted for Op Loiter = 24 hrs**

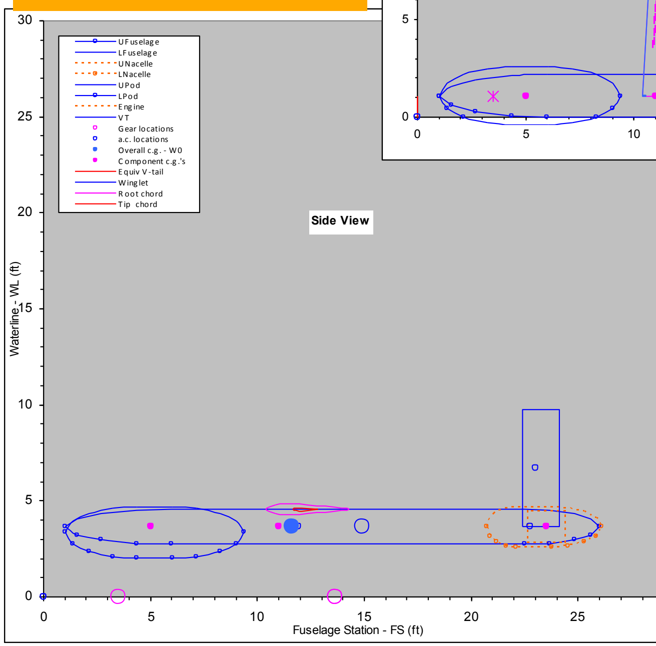
## Input

**$W_f/W_0$ = 0.284**

**$BHp_0/W_0$ = 0.444**

**etc.**




## Output

**$D_{fe}$ = 2.0**

**$W_0$ = 2250 lbm**

**$W_e$ = 1139 lbm**

**$W_f$ = 639 lbm**

**$BHp_0$ = 99**

**Minimum Ps = 3.4 fps**

**Op. loiter = 24 hrs**

**Max end. = 33.4 hrs**

**Max range = 2968 nm**

**etc.**

| Overall design parameters | |
|---|---|
| Df-equiv - enter fixed value (ft) or 0 to iterate | 0.000 |
| If iterating on Df, enter starting value | 2.00 |
| Calculated Df-equiv (ft) | 1.9997 |
| W0/Sref | 18.25 |
| Fuel fraction | 0.2840 |
| Bhp0/W0 or T0/W0 | 0.044 |
| TOP Bhp0 or T0/W0 req'd (BHp or lbf/lbm) | 0.0442 |
| TOP input/avail [(ft-lb)^2/BHp or lbf] | 1.00 |
| Minimum in-flight Ps (fps) | 3.4 |
| **Mass Properties** | |
| W0 (lbm) - initial estimate | 3000 |
| W0 (lbm) - calculated | 2250.00 |
| Retained payload - total (lbm) | 450.00 |
| Expendable payload - total (lbm) | 0.00 |
| Wfuel (total) - lbs | 639.0 |
| External tanks/stores - total (lbm) | 0.00 |
| Misc items (lbm) | 22.22 |
| WE (lbs) | 1138.77 |
| W0 c.g. location (ft) | 10.62 |
| We c.g. location (ft) | 13.90 |
| C.g. shift (% mac) | (118.6) |
| We + Wpay ret'd c.g. location (ft) | 10.88 |
| C.g. shift (% mac) | (9.7) |
| Waf/Sref (psf) | 5.08 |
| We/Sref (psf) | 9.24 |
| **Propulsion** | |
| Max power0 (BHp0 each) | 99.0 |
| Engine Scale Factor (ESF) req'd | 0.990 |
| Uninstalled weight - each (lbm) | 140.0 |
| Engine volume - each cuft | 3.53 |
| Equivalent engine diameter - each (ft) | 1.55 |
| Nacelle diameter req'd (ft) | 2.29 |
| Nacelle-to-fuselage diameter ratio | 1.14 |
| Uninstalled engine length -each (ft) | 1.863 |
| Installed length req'd (ft) | 3.726 |
| **Geometry** | |
| Wing Sref (sqft) | 123.29 |
| Wing span (ft) | 48.78 |
| Fuselage length (ft) | 25.00 |
| Swet (sqft) | 484.87 |
| Swet/Sref | 3.93 |
| Wetted AR | 4.91 |
| AR' (including winglets) | 19.30 |
| Vol^2/3/Swet | 0.029 |
| **Volume** | |
| Volume margin fraction (excluding propulsion and internal fuel) | 1.000 |
| Total volume req'd (non-propul - cuft) | 53.16 |
| Design internal fuel volume req'd (cuft) | 14.2 |
| Design wing fuel volume avail (cuft) | 0.0 |
| Density (zero fuel, wing excluded) - pcf | 9.2 |
| Fallout internal volume available for fuel (lbs) | |
| Fallout additional internal fuel tank weight penalty (lbs) | |
| **Mission summary - overall** | |
| Operational loiter (hrs) | 24.00 |

# *Solver example*

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**Results for air vehicle example when $W_f/W_0$ and $BHp_0/W_0$ solved for $Ps_{min}$ = 5 fps**

**Input**

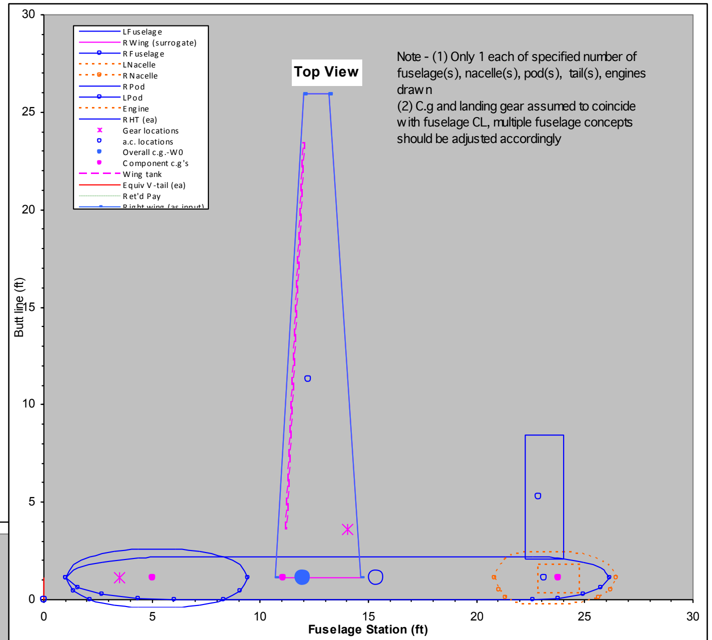
**$W_f/W_0$ = 0.284**

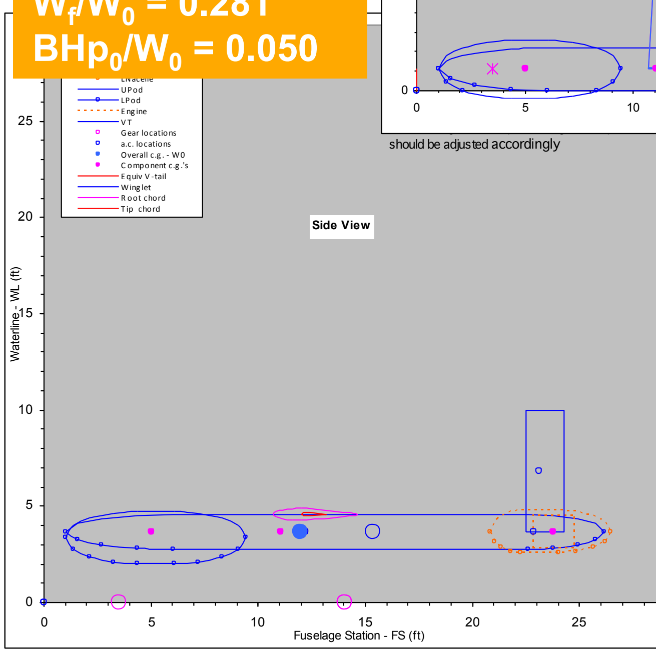
**$BHp_0/W_0$ = 0.044**

**Output**

**$W_f/W_0$ = 0.281**

**$BHp_0/W_0$ = 0.050**




**Output**

**$D_{fe}$ = 2.01**

**$W_0$ = 2332 lbm**

**$W_e$ = 1204 lbm**

**$W_f$ = 655 lbm**

**$BHp_0$ = 116**

**Minimum Ps = 5 fps**

**Op. loiter = 24 hrs**

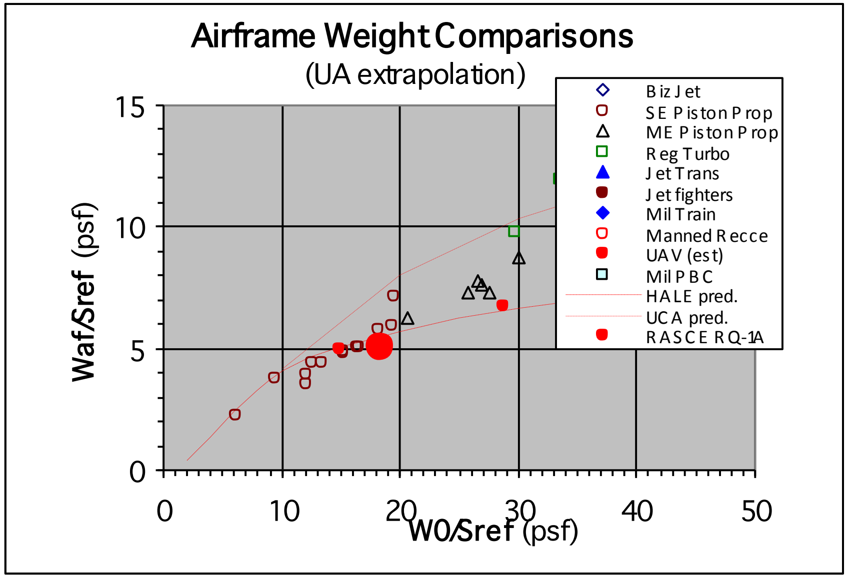
**Max end. = 33.4 hrs**

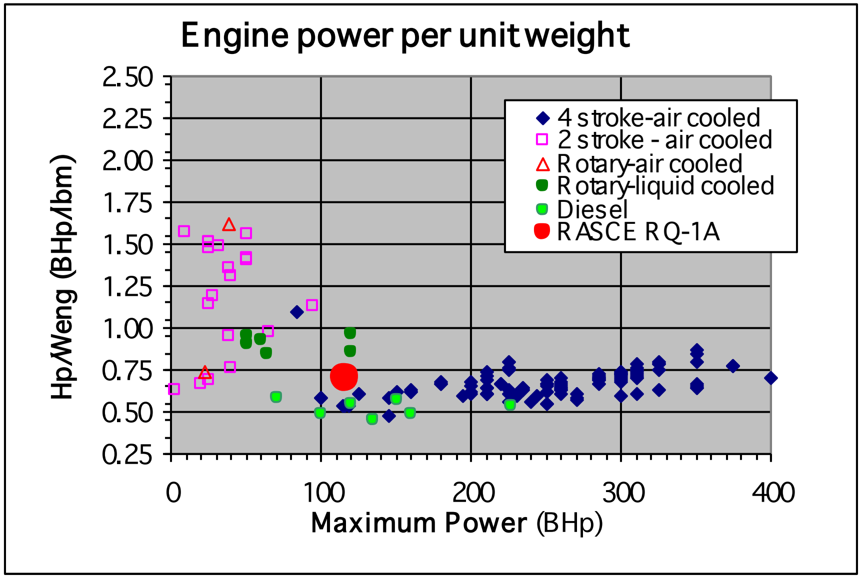
**Max range = 2956 nm etc.**

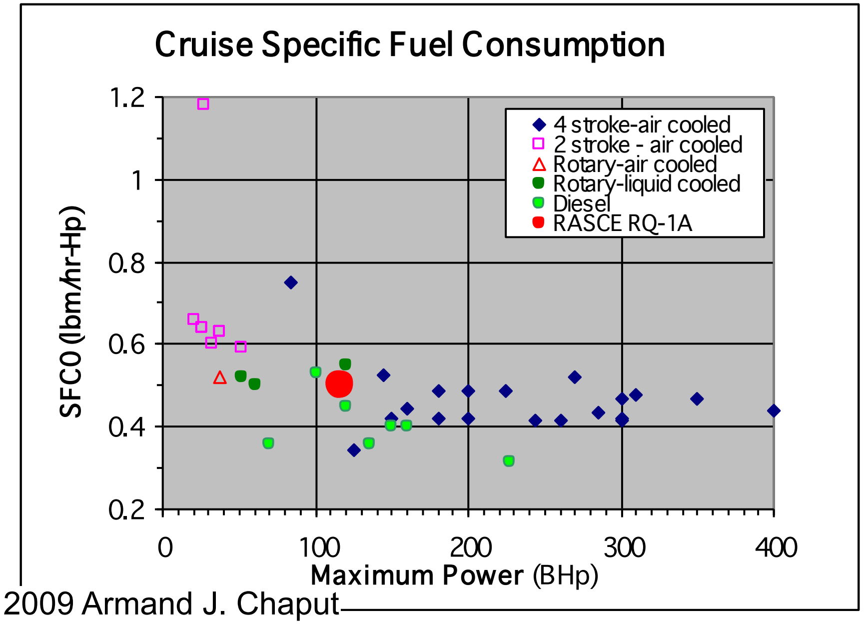
| | |
|---|---|
| **Overall design parameters** | |
| **Df-equiv - enter fixed value (ft) or 0 to iterate** | **0.000** |
| **If iterating on Df, enter starting value** | **2.00** |
| Calculated Df-equiv (ft) | **2.0102** |
| **W0/Sref** | 18.25 |
| **Fuel fraction** | 0.2808 |
| **Bhp0/W0 or T0/W0** | 0.050 |
| TOP Bhp0 or T0/W0 req'd (BHp or lbf/lbm) | **0.0442** |
| TOP input/avail [(ft-lb)^2/BHp or lbf] | 1.13 |
| Minimum in-flight Ps (fps) | 5.0 |
| **Mass Properties** | |
| W0 (lbm) - initial estimate | 3000 |
| W0 (lbm) - calculated | **2331.82** |
| Retained payload - total (lbm) | 450.00 |
| Expendable payload - total (lbm) | 0.00 |
| Wfuel (total) - lbs | 654.9 |
| External tanks/stores - total (lbm) | 0.00 |
| Misc items (lbm) | 22.55 |
| WE (lbs) | **1204.39** |
| W0 c.g. location (ft) | 10.94 |
| We c.g. location (ft) | 14.34 |
| C.g. shift (% mac) | (120.5) |
| We + Wpay ret'd c.g. location (ft) | 11.32 |
| C.g. shift (% mac) | (13.5) |
| Waf/Sref (psf) | **5.08** |
| We/Sref (psf) | **9.43** |
| **Propulsion** | |
| **Max power0 (BHp0 each)** | **116.1** |
| Engine Scale Factor (ESF) req'd | 1.161 |
| Uninstalled weight - each (lbm) | **164.3** |
| Engine volume - each cuft | 4.14 |
| Equivalent engine diameter - each (ft) | **1.64** |
| Nacelle diameter req'd (ft) | 2.41 |
| Nacelle-to-fuselage diameter ratio | 1.20 |
| Uninstalled engine length -each (ft) | 1.965 |
| Installed length req'd (ft) | 3.930 |
| **Geometry** | |
| Wing Sref (sqft) | 127.77 |
| Wing span (ft) | 49.66 |
| Fuselage length (ft) | 25.13 |
| Swet (sqft) | 504.24 |
| Swet/Sref | 3.95 |
| Wetted AR | 4.89 |
| AR' (including winglets) | 19.30 |
| Vol^2/3/Swet | 0.028 |
| **Volume** | |
| Volume margin fraction (excluding propulsion and internal fuel) | **1.000** |
| Total volume req'd (non-propul - cuft) | **54.00** |
| Design internal fuel volume req'd (cuft) | **14.6** |
| Design wing fuel volume avail (cuft) | **0.0** |
| Density (zero fuel, wing excluded) - pcf | **9.3** |
| Fallout internal volume available for fuel (lbs) | |
| Fallout additional internal fuel tank weight penalty (lbs) | |
| **Mission summary - overall** | |
| Operational loiter (hrs) | **24.00** |

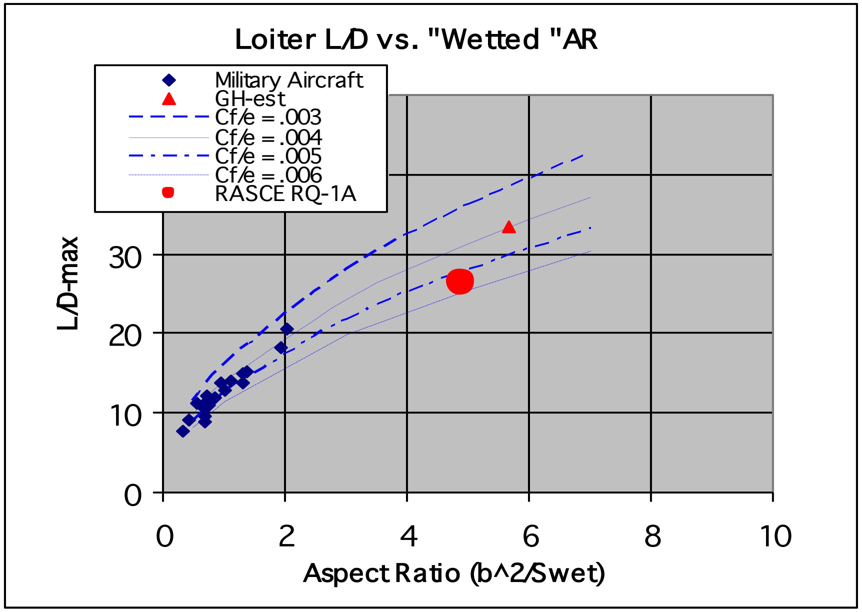
Landing stability issue getting worse

# Output parametric comparison data used to see if results reasonable

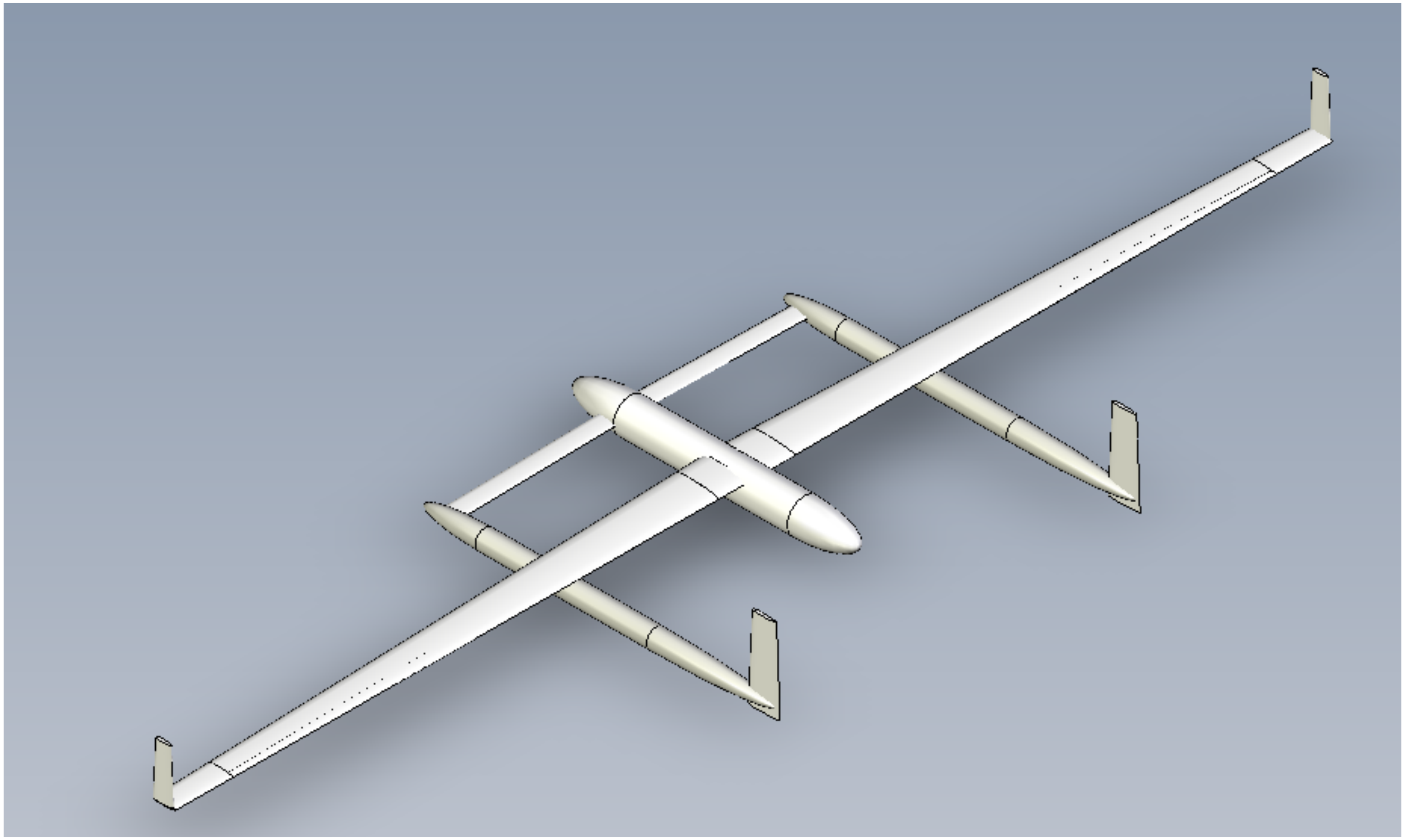


# 3D model output rendered by SolidWorks



**3D Rendering of Aircraft Configuration Designs**

James R. Carlson[1]
*University of Texas, Austin, Texas, 78712*

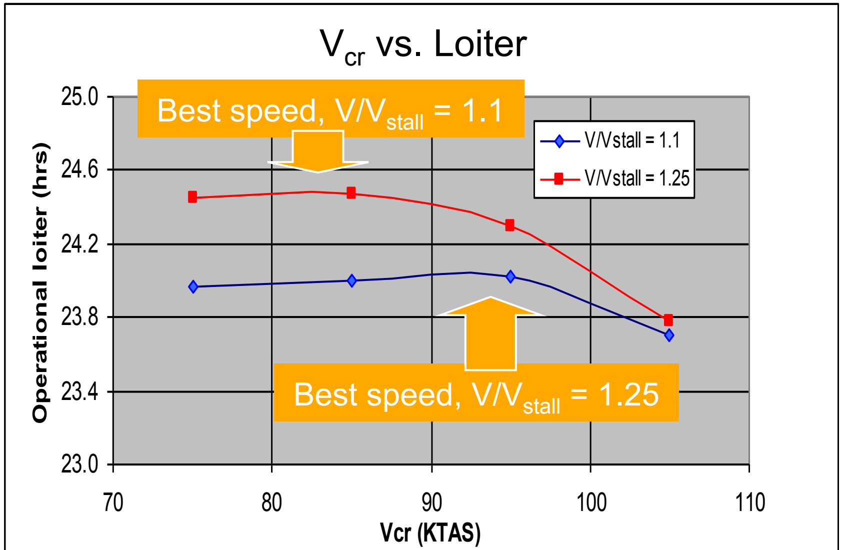
# RASCE Trade Study approach

THE UNIVERSITY OF TEXAS AT AUSTIN
Cockrell School of Engineering
AEROSPACE ENGINEERING & ENGINEERING MECHANICS

## Trade studies can be conducted manually (single variables with single variable impact) or by using Solver (multi-variable trades)

**Manual solutions – used for un-coupled single variable trades, e.g. determine cruise speed that maximizes operational loiter time**

*a. Run multiple cruise speeds*
*b. Copy results into worksheet*
*c. Plot results*




| | | | | |
|---|---|---|---|---|
| **Margin requirements** | | | | |
| Empty weight margin fraction (margin/EW) | 0.00 | 0.00 | 0.00 | 0.00 |
| Internal volume margin factor | 1.000 | 1.000 | 1.000 | 1.000 |
| Minimum in-flight Ps margin (fps) | 5 | 5 | 5 | 5 |
| Stall margin - cruise/ingress/egress (V/Vstall) | 1.25 | 1.25 | 1.25 | 1.25 |
| Stall margin - operational loiter (V/Vstall) | 1.1 | 1.1 | [illegible] | 1.1 |
| Stall margin - other mission phases (V/Vstall) | 1.25 | 1.25 | [illegible] | 1.25 |
| Fly entire mission at defined stall margin? (N= | [illegible] | [illegible] | [illegible] | [illegible] |
| **Mission definition** | | | | |
| Field elevation (K | [illegible] | [illegible] | [illegible] | [illegible] |
| Takeoff parameter | 413 | 413 | 413 | 413 |
| Engine start-taxi time (min) | 5 | 5 | 5 | 5 |
| Takeoff time (min) | 1 | 1 | 1 | 1 |
| Initial estimate of min speed for L/D max (KEAS) | 70 | 70 | 70 | 70 |
| **Mmax for climb to altitude** | 0.40 | 0.40 | 0.40 | 0.40 |
| Calculated stall margin at theoretical V (L/D )max climb | 1.06 | 1.06 | 1.06 | 1.06 |
| **H cruise outbound (Kft)** | 15 | 15 | 15 | 15 |
| **V cruise outbound (KTAS)** | 75 | 85 | 95 | 105 |
| Min allowable outbound Vcr (kts) | 107 | [illegible] | 107 | 107 |
| **Operating distance (nm)** | 400.0 | 400. | 0.0 | 400.0 |
| Min allowable inbound operating distance (nm) | [illegible] | [illegible] | [illegible] | [illegible] |
| Min allowable outbound operating distance (nm) | [illegible] | [illegible] | [illegible] | [illegible] |
| **H operational loi** | [illegible] | [illegible] | [illegible] | [illegible] |
| **H operational loiter - final (Kft)** | 15 | 15 | 15 | 15 |
| Caalculated average speed for L/D max (KTAS) | 86.2 | 86.2 | 86.3 | 86.3 |
| Min allowable start operational loiter speed (KEAS) | 74 | 74 | 74 | 74 |
| Max allowable start operational loiter speed (KEAS) | 298 | 298 | 298 | 298 |
| **Number of ingress/egress/combat segments** | 0 | 0 | 0 | 0 |
| **Ingress or egress distance (nm)** | 0 | 0 | 0 | 0 |
| Min allowable ingress distance (nm) | 0.0 | 0.0 | 0.0 | 0.0 |
| Min allowable egress distance (nm) | 0.0 | 0.0 | 0.0 | 0.0 |
| Fallout additional internal fuel tank weight penalty (lbs) | | | | |
| **Mission summary - overall** | | | | |
| Operational loiter (hrs) | 23.97 | 24.00 | 24.03 | 23.71 |
| Time to target from operational loiter (min) | 0.0 | 0.0 | 0.0 | 0.0 |
| Total time on station (from start op loiter-end last egress) | 24.0 | 24. | 24.0 | 23.7 |
| Sustained combat turn radius (ft) | [illegible] | [illegible] | [illegible] | [illegible] |
| Maximum cruise range (nm) | [illegible] | [illegible] | [illegible] | [illegible] |
| Max Endurance (hrs) | [illegible] | [illegible] | [illegible] | [illegible] |
| Total mission time (hrs) | 32.86 | 32.87 | 32.86 | 32.15 |
| Total flight time (hrs) | 32.51 | 32.52 | 32.51 | 31.80 |
| Cruise +climb&accel time (hrs) | 8.0 | 8.0 | 8.0 | 7.6 |
| Cruise +climb&accel block speed (KTAS) | 99 | 100 | 100 | 105 |
| Max KEAS (both missions) | 93 | 93 | 93 | 93 |

$V/V_{stall}$ = 1.1 and 1.25

75 KTAS ≤ $V_{cr}$ ≤ 105 KTAS

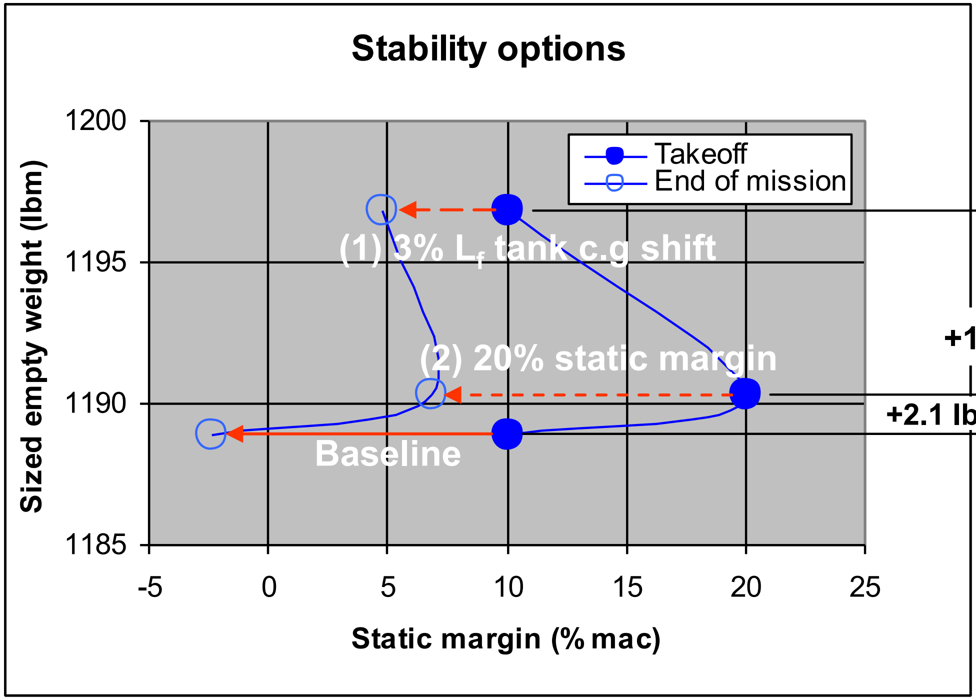
Operational loiter

# Another single-variable trade - *Options for improved static margin*

**Issue - Example baseline fuselage fuel tank c.g. location** *(probably incorrect)* **results in negative (-2.3%) static margin at landing**

**Two options exist to resolve issue (1) shift assumed tank location aft 3% $L_f$** *or* **(2) increase takeoff static margin** *(to 20% mac)*

**Trade study approach – assess both options and identify which has minimum impact** *(based on empty weight)*




**RASCE trade study results**

- ***Increased takeoff static margin (10%⇒ 20%) results in larger HT tail area required of 0.1 sqft ($\Delta W_e$ = 2.1 lbm), shifting fuel tank aft increased tail area by 0.6 sqft ($\Delta W_e$ = 10.1 lbm)***

**Conclusion – trade study indicates 10% increase in static margin has lightest way to get 5% minimum static margin at landing weight**

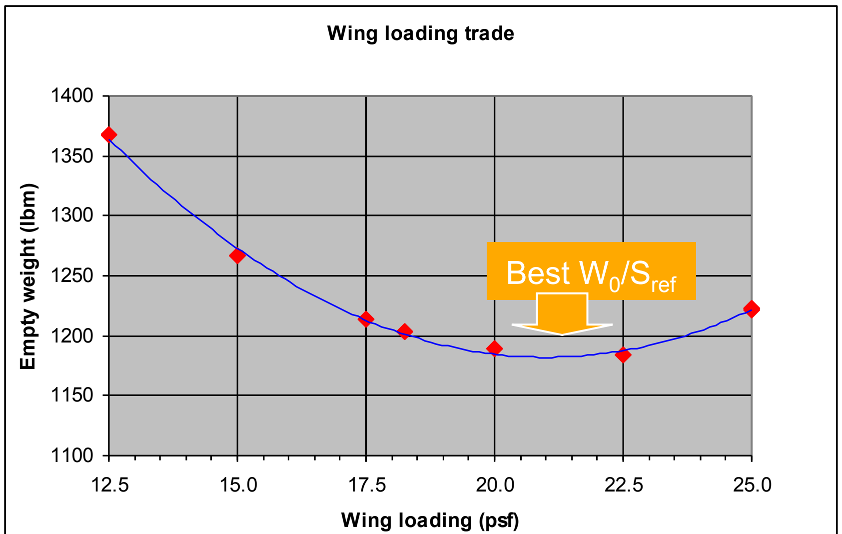
# RASCE Trade Study approach – *cont'd*

## - *Multi-variable trades (using Solver)*

**Trade studies** can be conducted manually (single variables with single variable impact) or by **using Solver (multi-variable trades)**

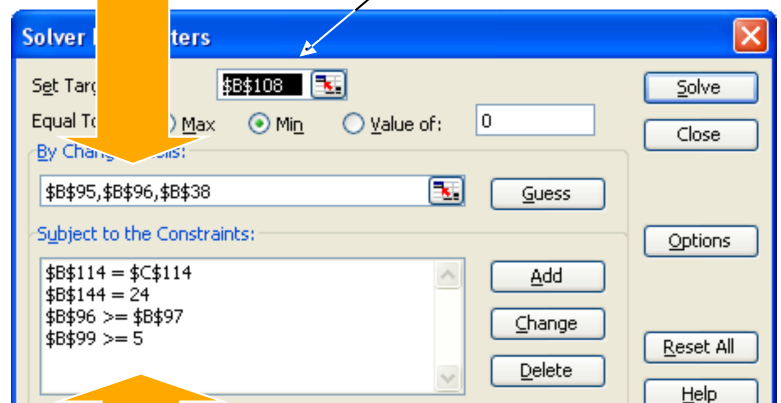
**Solver solutions – used for most trades, e.g. wing loading for constant performance at minimum $W_{empty}$**

a. *Estimate $W_{af}/S_{ref}$ = 2.125 ln($W_0/S_{ref}$) – 1.098 (fit to parametric data)*
b. *Run multiple wing loading solutions*
c. *Copy results into worksheet*
d. *Plot results*




**Objective – minimize empty weight**

**Variables**
- $W_f/W_0$ (B95)
- $BHp_0/W_0$ (B96)
- $KAF_{wt}$ (B38)




**Constraints**
- **Waf/Sref (B114)= *2.125 ln($W_0/S_{ref}$) – 1.098* *(computed in C114)***
- **Op loiter (B96) = 24**
- **$BHp_0/W_0 \geq BHp_0/W_0$ to meet TOP (B97)**
- **B99 (Minimum in flight Ps) ≥ 5 fps**

# RASCE Trade Study approach – *cont'd*

*- Requirements trades (using Solver)*

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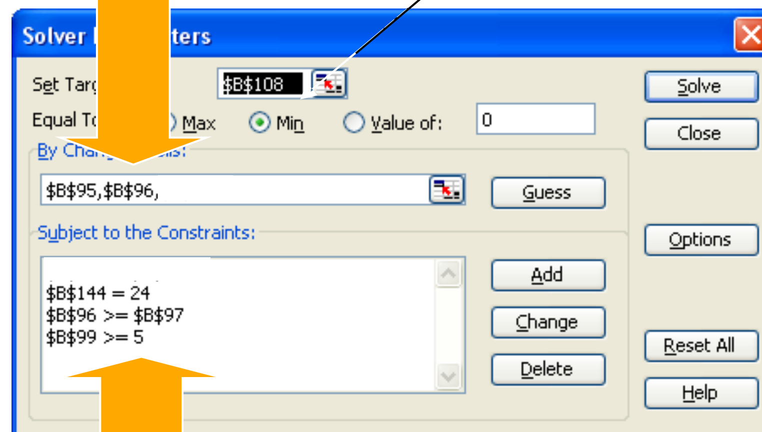
## Solver trade study to assess operational loiter requirement impact

**Solution approach – Same as previous example except wing loading constant and operational loiter input varied**

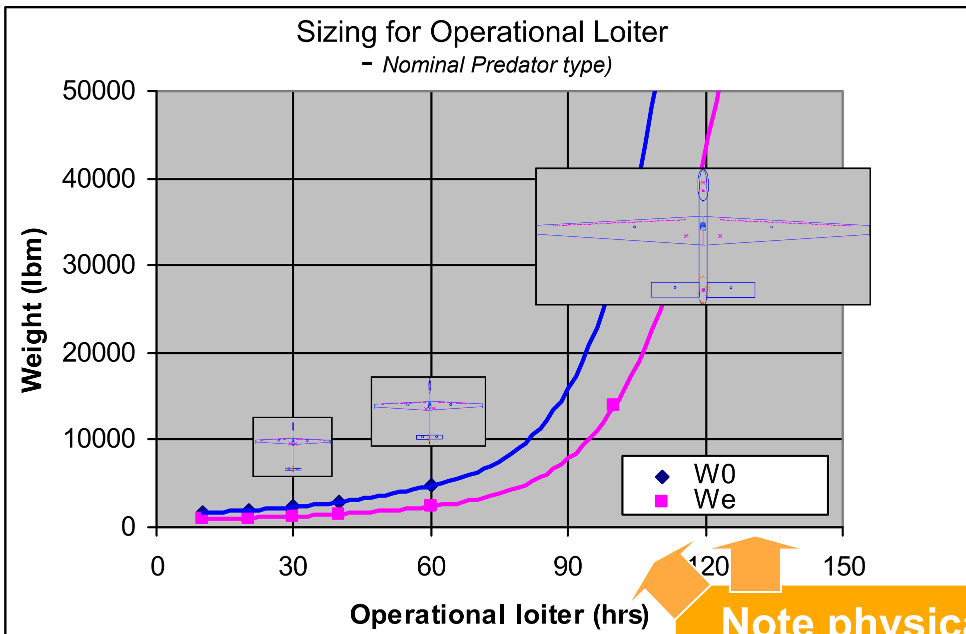
*a. Run multiple loiter solutions*
*a. Copy results into worksheet*
*b. Plot results*
*c. Copy and paste selected graphics*

**Objective – minimize empty weight**

**Variables**
- **$W_f/W_0$ (B95)**
- **$BHp_0/W_0$ (B96)**

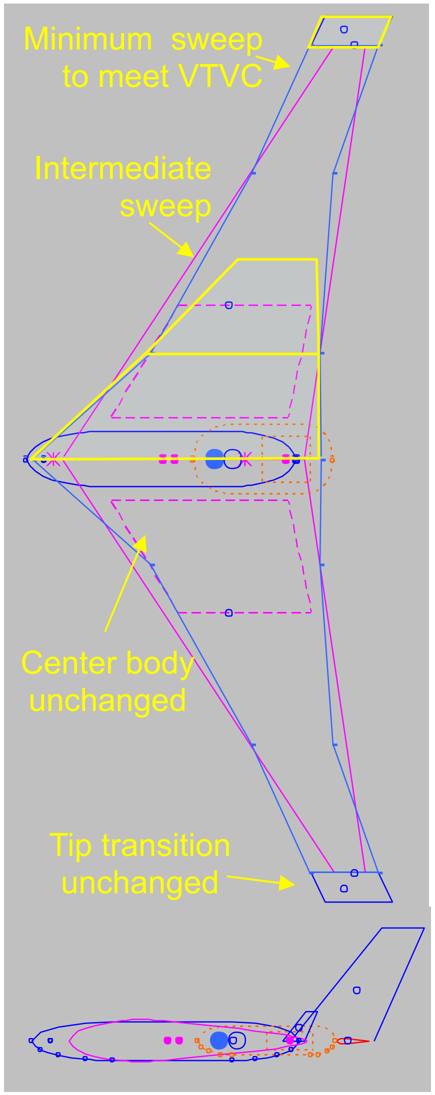



**Constraints**
- **Op loiter (B96) = 6 ⇒ 120 hours**
- **$BHp_0/W_0 \geq BHp_0/W_0$ to meet TOP (B97)**
- **B99 (Minimum in flight Ps) ≥ 5 fps**

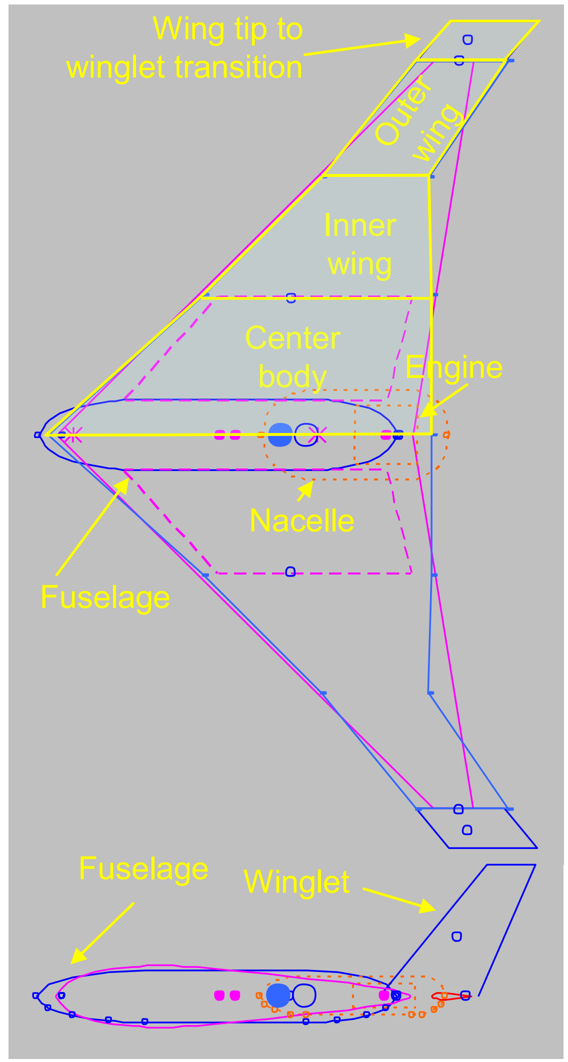



**Note physical changes as geometry model adjusts to meet requirements**

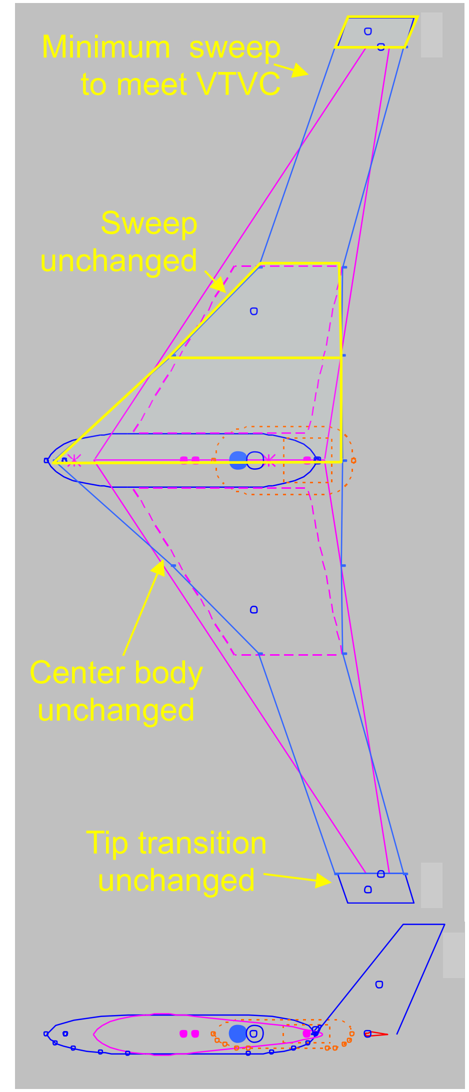
# RASCE Trade Study example – *Blended wing body growth options*




**Spanwise stretch**




**Baseline**




**Outboard panel stretch**

# Summary

**RASCE - a physics-based, conceptual level, air system design and analysis M&S environment developed to provide students with hands-on experience in air system design including real world design drivers not typically taught**

- *In continuous use since 2003 on student design projects*
- *Also applied to government and industry concept studies*

**RASCE is particularly well suited for concept screening and quantitative design and technology trade studies**

- *Configuration features and trade offs can be carefully and systematically controlled over a broad trade space*

**RASCE runs in real time on a standard laptop**

- *No laborious input data preparation and/or hand calculations*

**Experienced users can go from initial concept to complete air system sized to standard mission rules in < 1 hour**