MDO!

Selecting Wing & Engine Size

- One level more detailed examination of sizing

- Directly examine the roles of:
  1. Advanced Technology
  2. Technology Integration (multidisciplinary optimization)

- Insight & methods to understand and interpret the results of giant codes
STATEMENT OF THE PROBLEM

MINIMIZE WEIGHT,
Subject to range and point performance requirements.

i.e. minimize $W = W_{\text{eng}} + W_{\text{wing}} + W_{\text{fuel}}$

- EXAMINE COMPONENT TECHNOLOGIES

Approach:
- USE RESULTS OF NICOLAI SIZING PROGRAM to provide nominal weight to start
- THINK in TERMS of WING AREA as the independent variable.
WING WEIGHT EQU. : STRUCTURAL TECHNOLOGY

from Nicolai, for fighters

+ $K_T =$ technology factor

$$W_{\text{WNG}} = 3.08 \cdot K_T \left( \frac{K_{\text{piv}} N \cdot W_{\text{TO}}}{t/c} \left[ \tan \Lambda_{\text{LE}} - \frac{2(1-N)}{AR(1+N)} \right]^2 + 1 \right) \times 10^{-6} \left[ (1+N) \tan \Lambda_{c/2} \right]^0.593 \left( 1 + \frac{\Lambda}{\Lambda_{c/2}} \right)^{0.89} \left( \frac{t/c}{S_{\text{w}}} \right)^{0.741}$$

regroup

$K_{\text{piv}} =$ variable sweep = 1.175 (1 otherwise)

$W_{\text{TO}} =$ TOGW

$N =$ ultimate load factor,

= 11. for fighters

(1.33 x 1.5)

+ Standard Variables = $t/c$, $\Lambda$, $\Lambda$, AR, $S_w$
\[ W_{\text{wang}} = 3.08 \, K_T \left( \frac{N \cdot W_{\text{to}}}{b/c} \right)^{0.6} \left( 1 + \tan \frac{\alpha}{\lambda_c/2} \times 10^{-6} \right)^{0.593} (1 + \lambda)^{0.89} b^{-0.199} S_w \]

**Drivers**

- Note
- \( \frac{1}{b/c} \)
- \( S_w^{0.741} \) for fixed AR
- \( S_w^{0.149} \) for fixed span
- \( (1 + \lambda)^{0.89} \)
- \( W_{\text{to}}^{0.6} \)

Low wing weight \( \Rightarrow \)
- Thick wings
- Low span
- High taper (\( \lambda \) small)
PROPULSION

\[ W_{\text{ENG}} = \frac{T_{\text{ENG REQ'D.}}}{(T/W)_{\text{ENG}}} \]

\((I/W)_{\text{ENG}}\) defines technology levels

- > 12 High Tech (Very)
- < 8 Low Tech
AERODYNAMICS

\[ C_D = C_{D0} + \frac{C_L^2}{\text{TARE}} \]

E - defines technology level

\[ C_{D0} - \text{Configuration Integration, Discipline} + \text{some technology} \]

\[ E = E(C_L, M) \]
To Solve

\[ W = W_{\text{ENG}} + W_{\text{WNG}} + W_{\text{FUEL}} \]

using \( S_w \),

\[ \frac{dW}{dS_w} = \frac{dW_{\text{ENG}}}{dS_w} + \frac{dW_{\text{WNG}}}{dS_w} + \frac{dW_{\text{FUEL}}}{dS_w} = 0 \]

Many variations of requirements possible starting with this statement.
The Classic Maneuver Dominated Fighter

- Assume the maneuver design point sizes the wing and engine.

- Neglect $dW_{fuel}/dS_w$ in analysis

- Specify $N_z$ at a given Mach, Altitude, called Maneuver Design Point or MDP.
An Example: the F-15 - Design Points

17 Design points
C - cruise ($\leq L/D_{max}$)
M - maneuvering ($> L/D_{max}$)

- (8) ◇ Maximum power $P_S$ points
- (5) □ Mil power $P_S$ points
- (1) ▲ Buffet onset G load
- (3) ○ Maximum mach points

RELATE Thrust to Weight

\[ W_{ENG} = \frac{T_{SLS \text{ max AB}}}{(T/W)_{SLS \text{ max AB}}} \]

\[ T_{SLS \text{ max AB}} = \frac{T_{req'd}}{(T/T^*) \cdot (IF)} \]

\[ T_{req'd} = \text{VALUE REQUIRED AT SPECIFIED MACH, ALTITUDE} \]

\[ T/T^* = \text{RATIO AT ALTITUDE/MACH TO INSTALLED AT SL MAX AB} \]

\[ IF = \text{INSTALLATION FACTOR (\approx 0.9)} \]

\[ W_{ENG} = \frac{T_R}{A} \]

\[ A = (T/W)_{SLS \text{ max AB}} \cdot (T/T^*) \cdot IF \]
\[ W = W_{\text{ENG}} + W_{\text{WWNG}} \]

\[ W_{\text{ENG}} = \frac{T_r}{A} \]

\[ \frac{dW}{dS_w} = 0 = \frac{dW_{\text{ENG}}}{dS_w} + \frac{dW_{\text{WWNG}}}{dS_w} \]

\[ \frac{dW_{\text{WWNG}}}{dS_w} : \text{take simple derivative of wing weight eqn.} \]

\[ \frac{dW_{\text{ENG}}}{dS_w} = \frac{1}{A} \frac{dT_r}{dS_w} \]

WHERE \[ T_r = D_\text{MOP} = 8S_w \left[ C_{\text{Do}} + \frac{C^2}{\text{MOP}} \right] \]
Use given \( n_z \): \( L = n_z W = \frac{q}{g} S_w C_h \)

\[ C_h = \frac{n_z W}{q S_w} \]

\[ T_r = \frac{q}{g} S_w \left[ C_{D_0} \cdot \frac{S_F}{S_w} + 2 C_{f_e} F + \frac{1}{\pi A R E} \cdot \frac{n_z^2 W^2}{q^2 S_w^2} \right] \]

\[ C_{D_0} \]

\[ \frac{d T_r}{d S_w} = 2 C_{f_e} F q - \frac{1}{\pi A R E} \cdot \frac{n_z^2 W^2}{q} \left( \frac{1}{S_w^2} \right) \]

\[ = C_{D_{0w}} q - q K C_h^2 \]

where \( K = \frac{1}{\pi A R E} \)

\[ \frac{d T_r}{d S_w} = q \left[ C_{D_{0w}} - K C_h^2 \right] \]
Substituting into \( \frac{dW}{dS} = 0 \):

\[
\frac{dW_e}{dS_w} + \frac{dW_{wwn}}{dS_w} = 0 = \frac{1}{A} \frac{dTr}{dS_w} + \frac{dW_{wwn}}{dS_w}
\]

\[
= \frac{1}{A} q \left[ C_{Dow} - kC^2 \right] + \frac{dW_{wwn}}{dS_w}
\]

or

\[
0 = C_{Dow} - kC^2 + \frac{A}{q} \frac{dW_{wwn}}{dS_w}
\]

\text{solve for } C_L:

\[
C_L = \frac{1}{K} \left( \frac{C_{Dow} + \frac{dW_{wwn}}{dS_w}}{q \left( \frac{1}{A} \right)} \right)
\]

\[
\frac{1}{A} = \frac{1}{\frac{T(W)_{\text{sys}}}{\text{max}} \cdot (T_{4k})_{\text{IF}}} = \frac{dW_e}{dTr}
\]
\[ C_{\text{LMDP}} = \sqrt{\frac{1}{K} \left( C_{\text{DOW}} + \frac{dW\text{eng}/dSW}{g \frac{dW\text{eng}/dT}{T}} \right)} \]

- Aero
- Structures
- Propulsion

Originally: Herring, McDonnell Aircraft (F-15)
\[ S_w = ? \]

\[ L = h_z W = g S_{opt} C_{L_{MDP}} \]

\[ S_{WNS_{opt}} = \frac{h_z W}{4 g C_{L_{MDP}}} \]
Figure 1: Optimum wing size: Engine sized swing 500, 500, 1,200, 1,400. Min. Wt. based on maneuver alone 12,000. Min. Wt. + wing. Wing + Thrust 12,700.

<table>
<thead>
<tr>
<th>Min. Wt.</th>
<th>1.1</th>
<th>1.2</th>
<th>1.3</th>
<th>1.4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thrust</td>
<td>50</td>
<td>60</td>
<td>70</td>
<td>80</td>
</tr>
</tbody>
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N = 4.75, AR = 3.2, N = 57, E = 1.1
M = 9, h = 30 K

Min. Wt. + wing, minimum, maneuver solution.
Fig. 2. Effect of Maneuver Req't. on Wing Size & Lift Coefficient. Wing & Engine sized for Maneuver.

DECREASES!! with increasing $n_z$.

$T/W^*$

$W^*/S$

$C_{L_{MDP}}$

$C_{L_{MDP}}$

$S_w$

$AR=3; \lambda=2; \alpha=57^\circ; E=\frac{M=0.9, h=30K}{2}$
1st Variation on Classic Maneuver Problem

Question: What happens if engine is sized by the accel?
Figure 1. Optimum wing size: engine sized either for maneuver or accel.
Conclusion

• There is a rational method to find wing areas and engine size

• You should always be able to construct "back of the envelope" analysis along the lines given here to support ACSYN type code sizing work.