

Lab 4 – Design Problem Formulation

Unified Engineering

4 Mar 06

Learning Objectives

- Measure and analyze prototype/baseline UE Competition airplane
- Formulate a suitable design space for a new wing
- Perform preliminary design and sizing studies. This will be a quantitative continuation of the exercise from Lab 1.

Plane Vanilla Measurements for Redesign Baseline (reverse engineering)

- Measure the prototype Plane Vanilla airplane in order to determine S , b , W , λ
- Note the component weights given
- Measure the thickness/chord ratio τ of the root airfoil
- For wing weight and deflection estimates, the pink foam's approximate properties are:

$$\rho \simeq 2.0 \text{ lbm/ft}^3 = 0.525 \text{ g/in}^3 = 32 \text{ kg/m}^3 \quad , \quad E \simeq 2800 \text{ psi} = 19.3 \text{ MPa}$$

The cross-sectional area of a typical airfoil is very nearly

$$A = 0.60 c t = 0.60 c^2 \tau$$

which allows estimation of the wing volume and hence the wing weight. The weight of the remainder of the airplane can be assumed to be fixed for now.

- The wing airfoil's profile drag is approximately

$$\begin{aligned} c_d &\simeq 0.028 \quad , \quad \text{for } c_\ell \simeq 0.8 \dots 1.0 \quad (\text{min power operation}) \\ c_d &\simeq 0.018 \quad , \quad \text{for } c_\ell \simeq 0.0 \dots 0.4 \quad (\text{max speed operation}) \end{aligned}$$

- Estimate the CDA_0 of the non-wing stuff via the frontal areas of the bluff objects seen by the flow. The tail's CDA_0 contribution is best estimated via its surface area, with $c_{d_{\text{tail}}} \simeq 0.03$
- Estimates for the maximum available power and the efficiencies are

$$P_{\text{max}} \simeq 25 W \quad , \quad \eta_p \simeq 0.65 \quad , \quad \eta_m \simeq 0.50$$

Design Space Formulation

- Pick a suitable set of wing design variables to define a design space, for the purpose of attaining the design objective of minimum electric flight power P_{ele} , and also of maximum speed V_{max} . This set should be as small as possible, so each variable in the set should have a strong influence on the objective.
- Express P_{ele} , V_{max} , and δ/b in terms of your design variables. These formulas will also involve “constants” which you have decided not treat as design variables, such as c_d , etc. Use the Plane Vanilla baseline values for these constants.

Suggestion: Do not try to write P_{ele} as one huge formula with everything written out. Instead, define auxilliary functions such as the wing weight first, and then include these in P_{ele} symbolically. For example, the two formulas

$$\begin{aligned} W_{\text{wing}} &= \dots AR \dots S \dots \\ P_{\text{ele}} &= \dots W_{\text{wing}}(AR, S) \dots \end{aligned}$$

are easier to work with than one big formula for P_{ele} alone. The numerical implementation should follow this same modular approach.

Simple Parameter Space Exploration

- Numerically implement the objective functions P_{ele} , V_{max} in terms of the design variables. You may use Excel, Matlab, Gnuplot, ADA code, etc.
- Also numerically implement the δ/b constraint function
- Perform a preliminary exploration of P_{ele} and V_{max} in the design space using the approach of your choice. You may use
 - the 2D-slices-with-contours approach (Figures 3,6 in notes), or
 - the 1D-slices-with-line-plots approach (Figure 7 in notes)

The minimum requirement is that each design variable should be sampled over its expected range in at least one plot (i.e. each direction in the design space is traversed at least once).

- Also display δ/b in the same variables as P_{ele} and V_{max} .
- Plots of P_{ele} and V_{max} should indicate where a constraint is violated.

Reporting

- Each team will turn in one activity report (or memo).
- Contents:
 - Title, team number, team member names, date
 - Table of S , b , W ... measured or given for Plane Vanilla (assume the reader doesn't know these)
 - List of chosen design space variables for a wing redesign for minimum flight power and maximum speed. Justify each chosen variable with one or two sentences.
 - Give the objective function expressions for P_{ele} , V_{max} , that you used. Auxilliary functions (e.g. wing weight) are best given separately.
 - Give the constraint function expression for δ/b that you used.
 - State any other constraints which you think will come into play.
 - Plots showing exploration of the design space, with brief discussions or extended plot captions.