Lab 7 – Design Problem Formulation
Unified Engineering
19 Mar 09

Learning Objectives

- 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 version of the exercise from Lab 1.

Plane Vanilla Analysis for Baseline (reverse engineering)

- Some Plane Vanilla parameters are below. Others can be estimated by carefully measuring the 3-view drawing.

$$\begin{aligned} CDA_0 &= 0.004\,\mathrm{m}^2 \\ \tau &= 0.10 \\ \varepsilon &= 0.03 \\ W_{\mathrm{fuse}} &= 2.5\,\mathrm{N} \end{aligned}$$

- For wing weight and deflection estimates, the foam's approximate properties are:

$$\rho_{\mathrm{foam}} \simeq 2.0\,\mathrm{lbm/ft}^3 = 0.525\,\mathrm{g/in}^3 = 32\,\mathrm{kg/m}^3 \qquad , \qquad E_{\mathrm{foam}} \simeq 2800\,\mathrm{psi} = 19.3\,\mathrm{MPa}$$

- 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 non-wing remainder of the airplane W_{fuse}, given above, will be assumed fixed here.

- The wing airfoil's profile drag is approximately

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

The airfoil also has a stall limit of $c_\ell \leq 1.0$. As usual, we will assume $C_L = c_\ell$.

- An estimate for the maximum available thrust from the motor/propeller combination is

$$T_{\mathrm{max}} \simeq 0.70\,\mathrm{N}$$

Design Space Formulation

- Pick a suitable set of wing design variables to define a design space, for the purpose of maximizing W_{pay}, and also separately maximizing 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 W_{pay}, V_{max}, and δ/b in terms of your design variables. These formulas will also involve "constants" which you have decided <u>not</u> treat as design variables, such as c_d, etc. Use the Plane Vanilla baseline values for these constants.

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

$$\begin{aligned} W_{\mathrm{wing}} &= \ldots AR \ldots S \ldots \\ W_{\mathrm{pay}} &= \ldots W_{\mathrm{wing}}(AR, S) \ldots \end{aligned}$$

are easier to work with than one big formula for $W_{\rm pay}$ alone. The numerical implementation should follow this same modular approach.

Programming and Checking

• Numerically implement the objective functions $W_{\rm pay}$ and $V_{\rm max}$ in terms of the design variables. You may use Matlab, Gnuplot, Maple, C++, etc.
• Also numerically implement the δ/b constraint function
• Compute maximum $W_{\rm pay}$ and corresponding δ/b for Plane Vanilla.
• For the no-payload case, i.e. $W = W_{\rm fuse} + W_{\rm wing}$, compute $V_{\rm max}$ and corresponding δ/b for Plane Vanilla.

Simple Parameter Space Exploration

• Perform a preliminary exploration of $W_{\rm pay}$ 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)

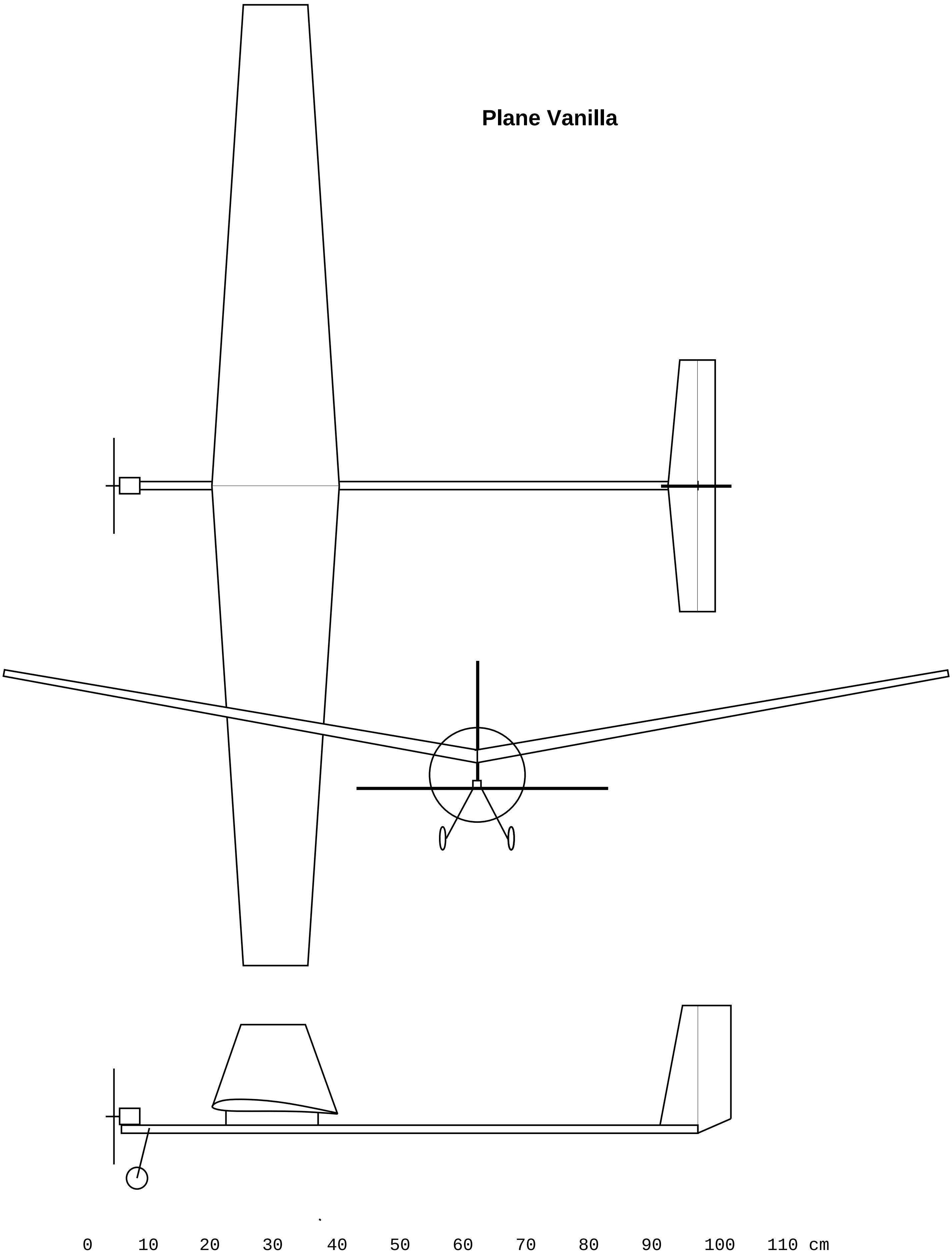
The minimum requirement is that each design variable should be sampled over its expected range in at least one plot (i.e. each direction in the design space is traversed at least once).
• Also display δ/b on your plots.
• Plots of $W_{\rm pay}$ and $V_{\rm max}$ should indicate where a constraint is violated.
• If possible, indicate the Plane Vanilla point in your design space.

Reporting

• Each team will turn in one technical memo.

• Contents:
— Title, team number, team member names, date
— Table of S, b, ...that you used for Plane Vanilla (assume the reader doesn't know these)
— Include maximum $W_{\rm pay}$ and corresponding δ/b for Plane Vanilla in the table
— Include $V_{\rm max}$ and corresponding δ/b for Plane Vanilla in the table
— List of chosen design space variables for a wing redesign for maximizing $W_{\rm pay}$ and/or $V_{\rm max}$. Justify each chosen variable with one or two sentences.
— Give the objective function expressions for $W_{\rm pay}$ and $V_{\rm max}$ that you used. Auxilliary functions (e.g. $W_{\rm wing}$) 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 for $W_{\rm pay}$, with brief discussions or extended plot captions.
— Plots showing exploration of the design space for $V_{\rm max}$, with brief discussions or extended plot captions.

Note: For this lab, you will treat the $W_{\rm pay}$ and $V_{\rm max}$ optimization as two separate problems, resulting in a different optimum airplane for each. For subsequent labs, and for the UE Flight Competition scoring, these will be combined into a single objective function which measures the overall payload + speed performance of the airplane.


Plane Vanilla
0 10 20 30 40 50 60 70 80 90 100 110 cm