Aircraft Structural Mass Property Prediction Using Conceptual-Level Structural Analysis

Presentation to the 57th Annual Conference of the Society of Allied Weight Engineers

Wichita, Kansas

20 May, 1998

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Summary

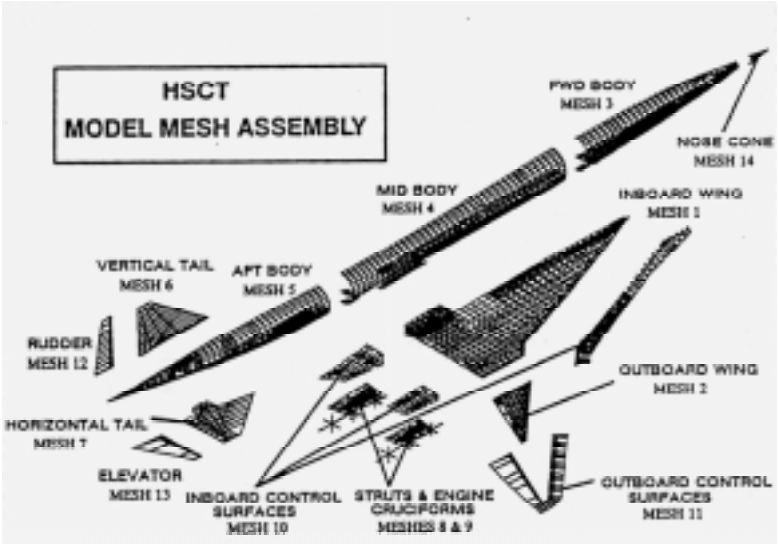
- ELAPS is a conceptual-level aircraft structural analysis tool uniquely situated between empirical methods and finite element analysis
- The ELAPS-based mass property analysis process enables a low cost, high fidelity multidisciplinary approach to conceptual design
- Stochastic analysis techniques provide a robust and efficient framework for managing uncertainty in conceptual design

Overview

- Structural mass property prediction
- ELAPS
- ELAPS structural models
- Non-optimal mass
- Stochastic analysis and design
- ELAPS stochastic mass property analysis
- Case study: ERAST Proof-of-Concept
- Summary & Conclusions

Structural Mass Property Prediction

$$Weight_{fuselage} = 1.35 \cdot \left[X_L \cdot \left(\frac{W_{fuselage} + D_{fuselage}}{2} \right) \right]^{1.28} \cdot \left(1.0 + 0.05 \cdot N_{engine_{fuselage}}\right) \cdot \left(1.0 + 0.38 \cdot W_{cargo_{fuselage}}\right) \cdot N_{fuselage}$$

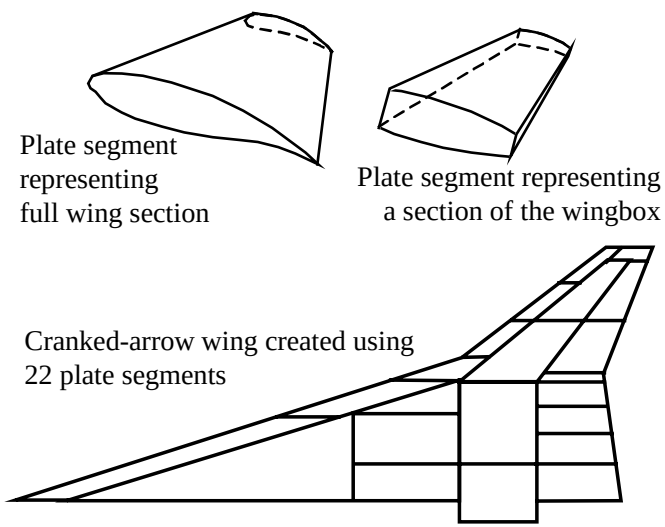


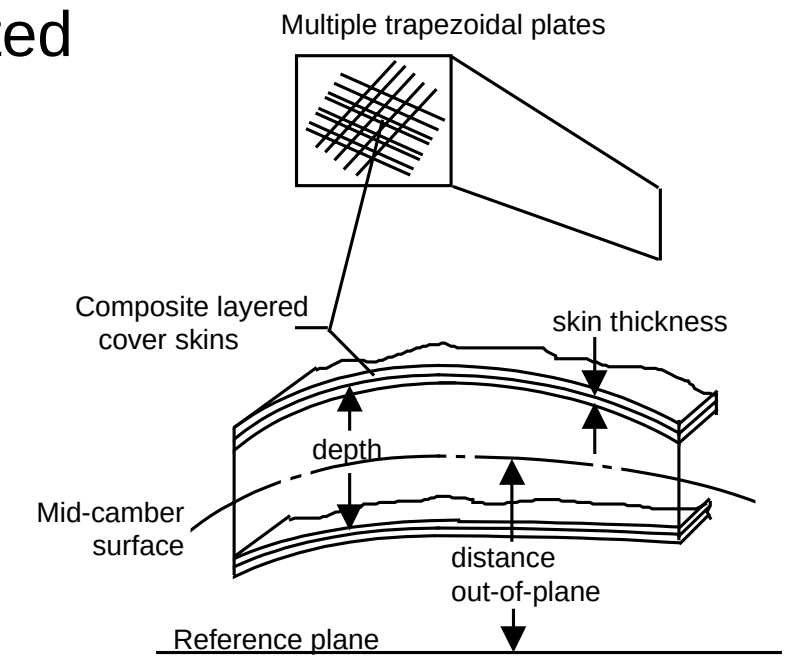
(from Mitchell, 1993)

- Empirical equations
- Empirically-augmented physical methods
- Finite Element Analysis (FEA)
- Algorithmic Mass Factoring Method (AM-FM, Boeing)
- Mock-ups & prototypes

ELAPS

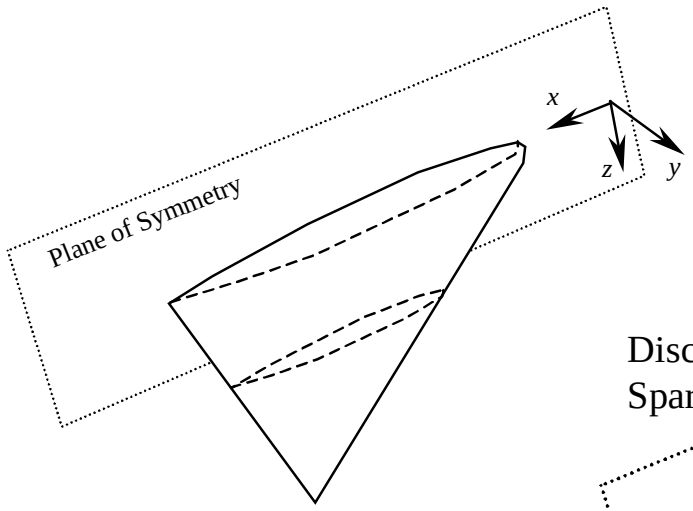
- ELAPS = Equivalent LAminated Plate Solution
- FEA → elements
- ELAPS → segments

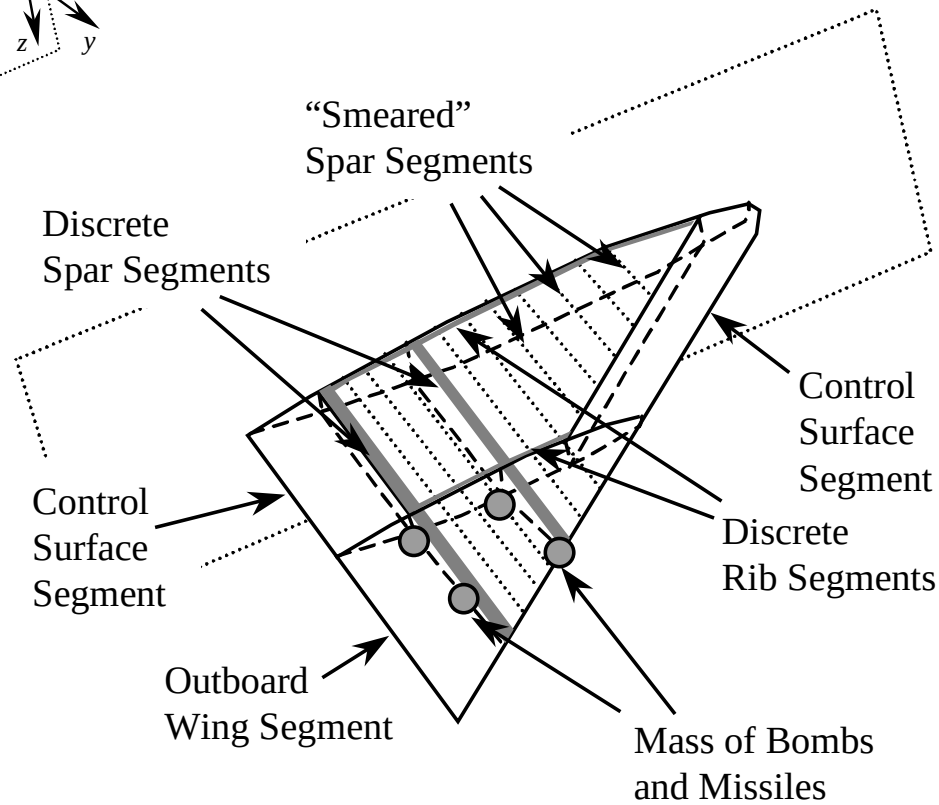




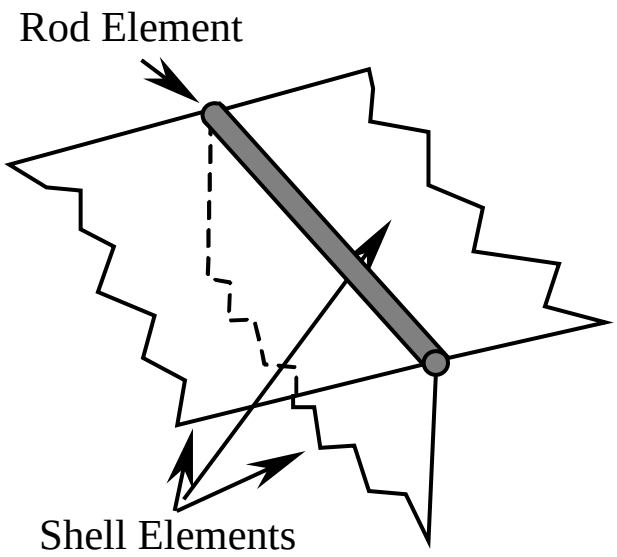
- Fast modeling
- Low computational cost

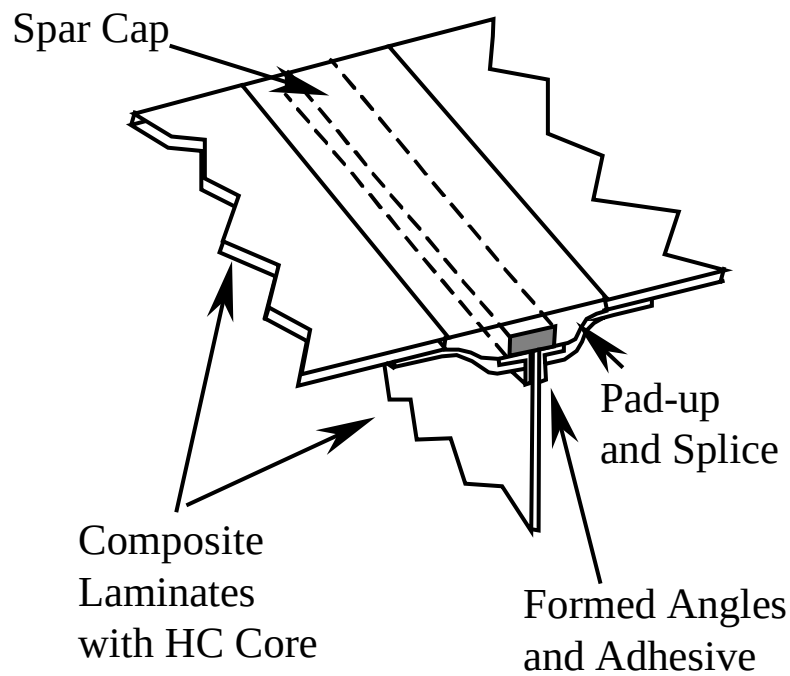
ELAPS Structural Models





Non-Optimal Mass

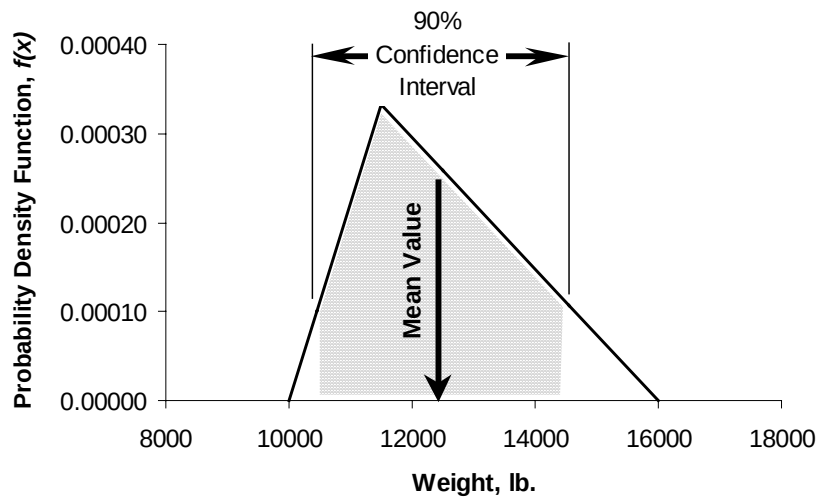




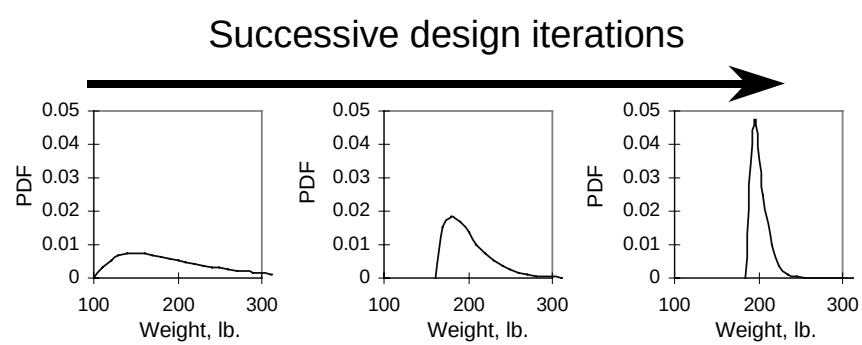
$$NOMF = \frac{as-built \quad mass}{ideal \quad mass}$$

Stochastic Analysis and Design

- Management of uncertainty



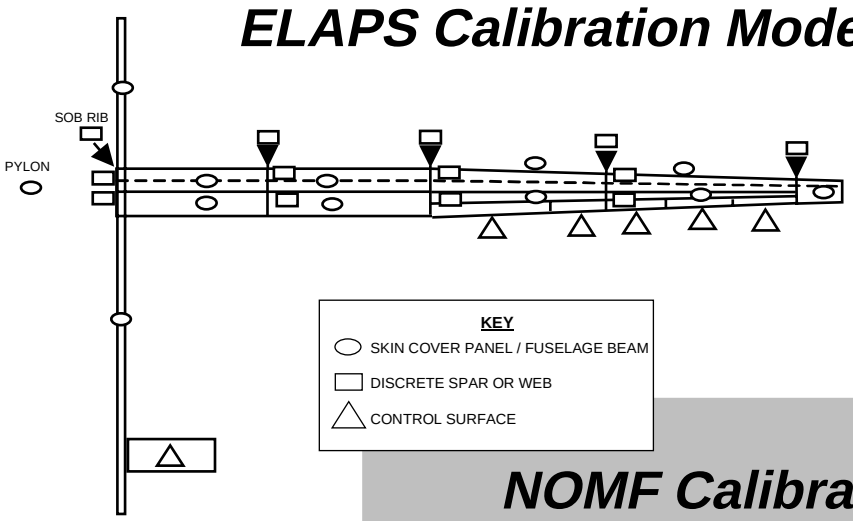
- Robustness
- Risk Assessment
- Learning



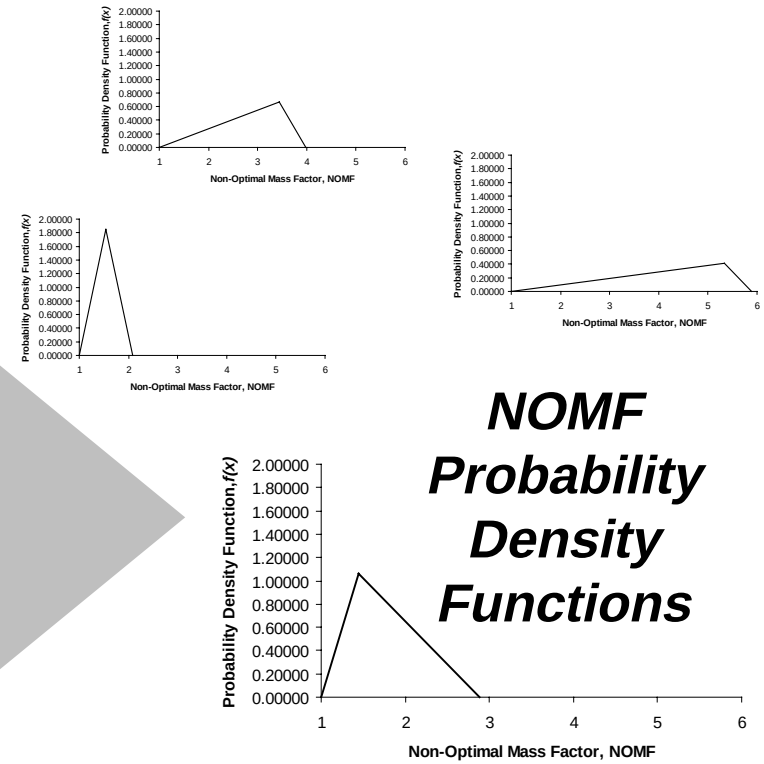
ELAPS Stochastic Mass Property Analysis

NOMF Uncertainty

ELAPS Calibration Model



NOMF Calibration

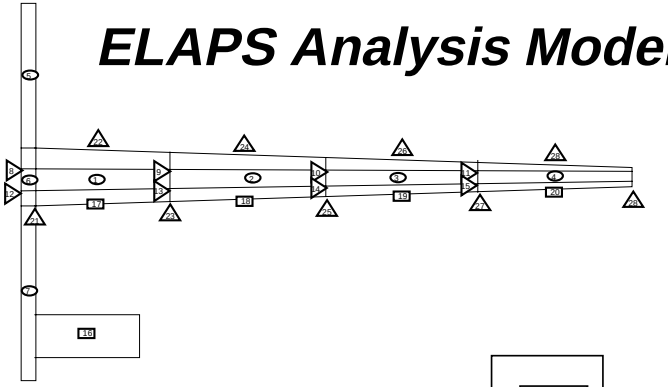


NOMF Probability Density Functions

ELAPS Stochastic Mass Property Analysis

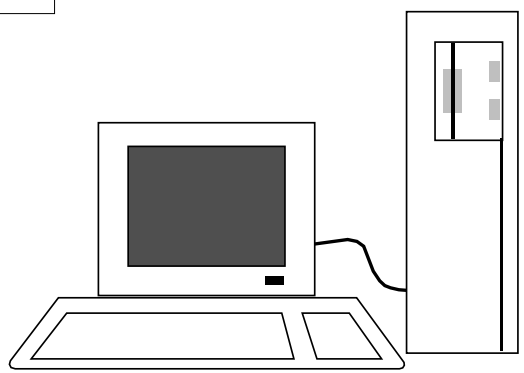
Monte Carlo Simulation

ELAPS Analysis Model



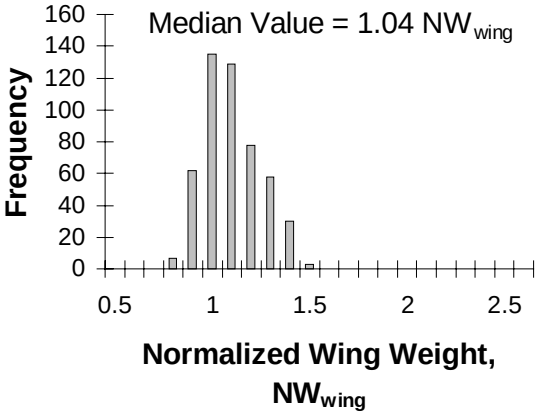
Configuration Roll-up

$$W_{as-built} = \sum_{i=1}^{Wing\_Skin\_Components} W_{Ideal\,i} \cdot NOMF_i + \sum_{i=1}^{Wing\_Spar\_Components} W_{Ideal\,i} \cdot NOMF_i + \sum_{i=1}^{Wing\_Rib\_Components} W_{Ideal\,i} \cdot NOMF_i + \ldots$$



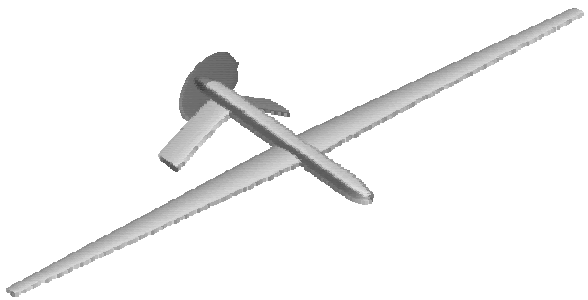
Monte Carlo Simulation

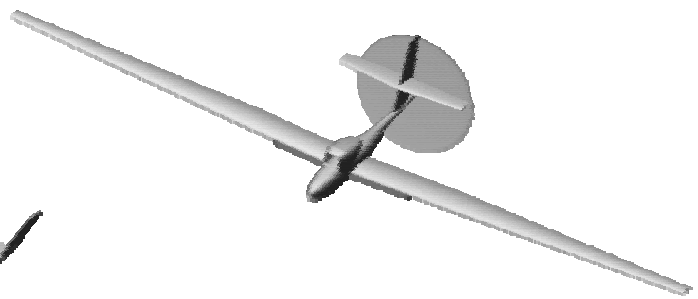
Histogram

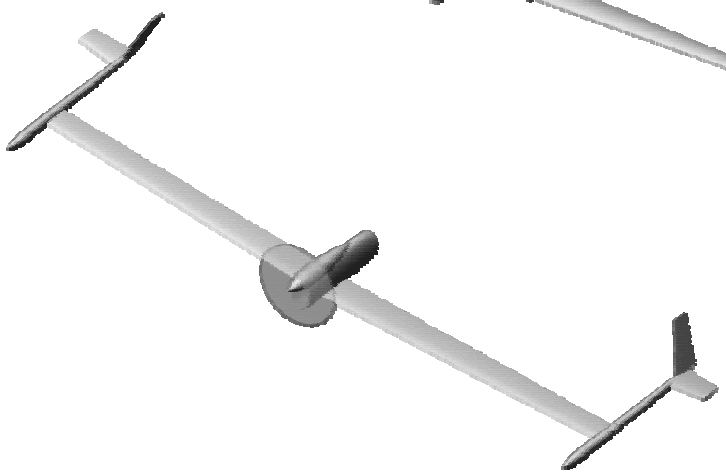


Case Study:
ERAST Proof-of-Concept

Design Proposals





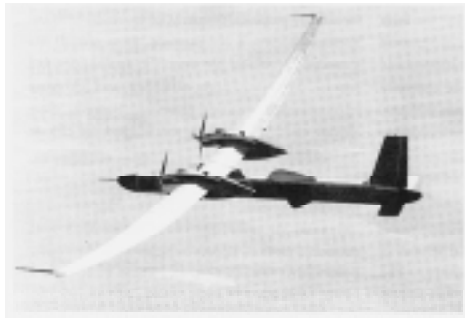


<u>Design Mission:</u>
Subsonic
85k ft cruise altitude
50 fpm R/C at altitude
4 hr endurance at altitude
100 lb payload
Engine: 80 hp at altitude

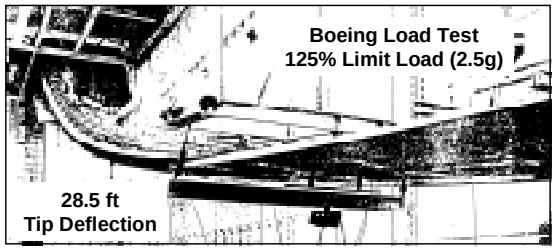
Case Study:
ERAST Proof-of-Concept

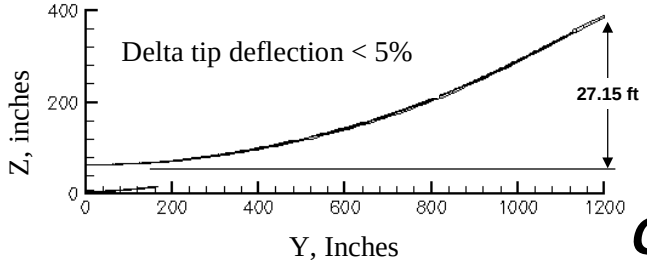
ELAPS Calibration Model

Boeing Condor UAV

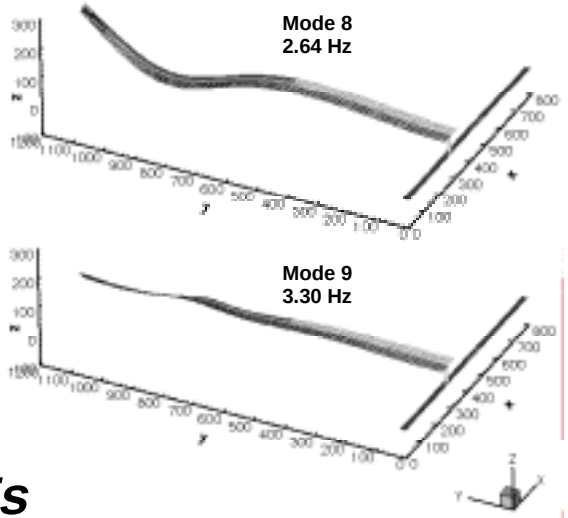


Static Deflection Comparison





Flutter Mode Comparisons



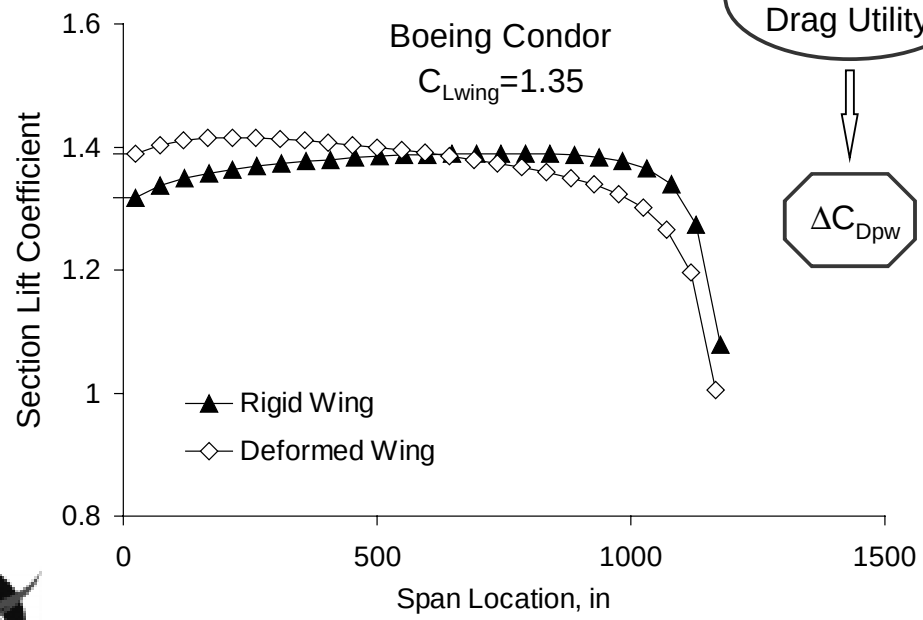
Group Weight Statement

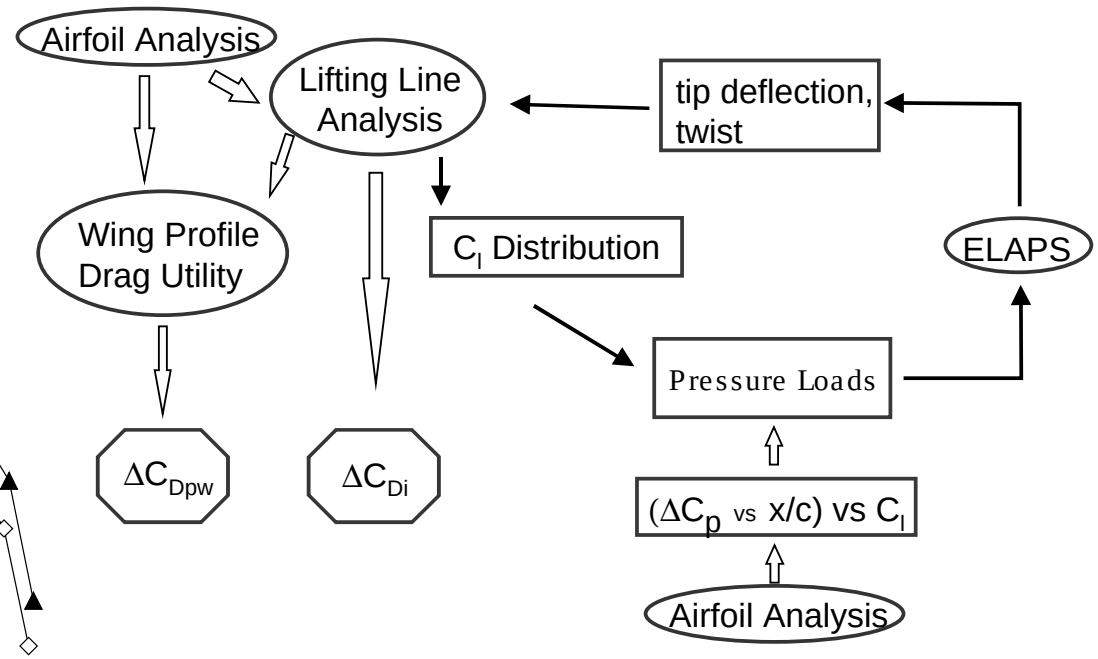
Component NOMF PDFs

$NOMF_i = f(x)$

Case Study: ERAST Proof-of-Concept

Aeroelasticity Analysis





Case Study:
ERAST Proof-of-Concept

Mass Property Analysis

ELAPS Model

Structural Sizing

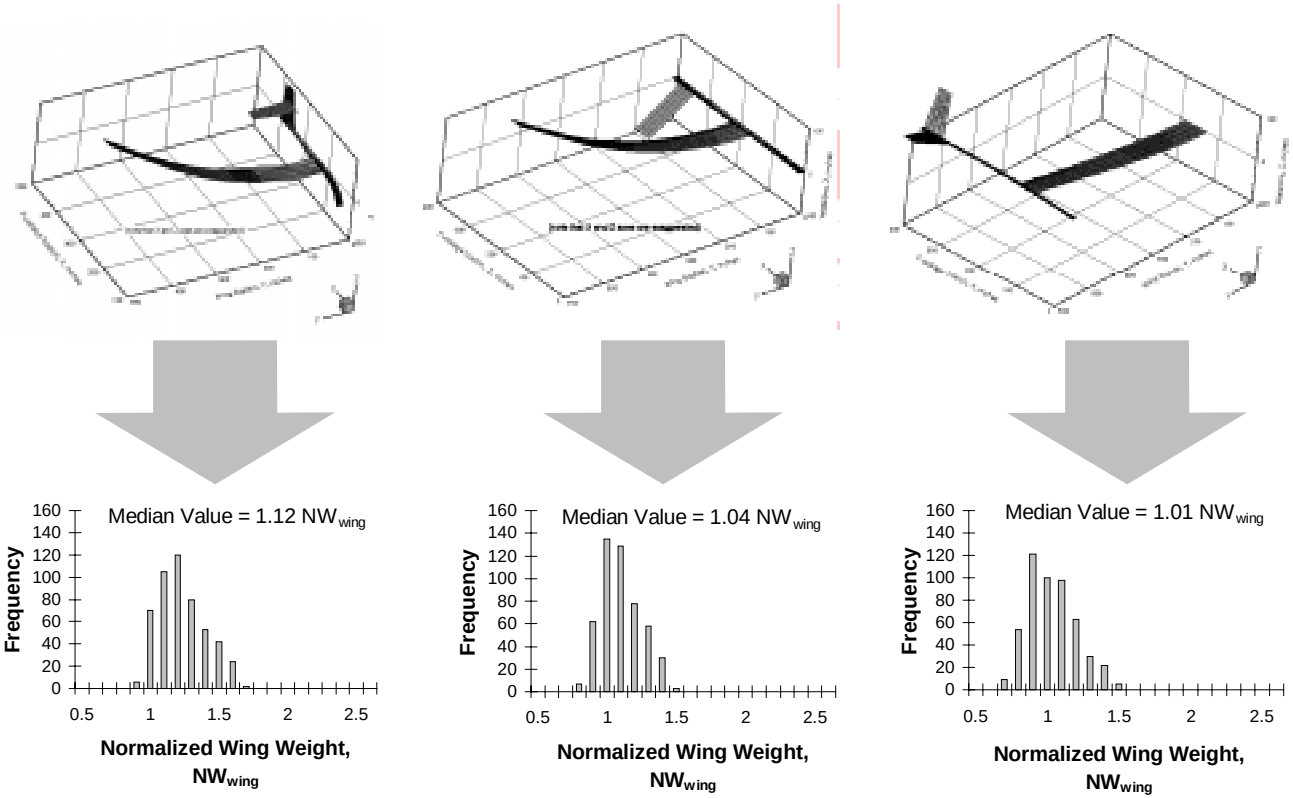
Ideal Mass

$NOMF_i = f(x)$

As-built Mass

Monte Carlo

Histogram or PDF



Summary & Conclusions

- ELAPS is a structural analysis tool uniquely suited to multidisciplinary conceptual design
  - Enables high-fidelity structural behavior knowledge early in the design process (including aeroelasticity)
  - Speed of modeling and analysis significantly reduces design and analysis cycle time
- The ELAPS-based stochastic mass property analysis process facilitates weight risk assessment, especially in cases of advanced technology or unusual vehicle configuration