

# Aerodynamic Issues of Unmanned Air Vehicles Workshop

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**U.S. AIR FORCE**

## Aero-Structural Coupling and Sensitivity of a Joined- Wing SensorCraft

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*Air Force Institute of Technology*

# Report Documentation Page

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# Overview



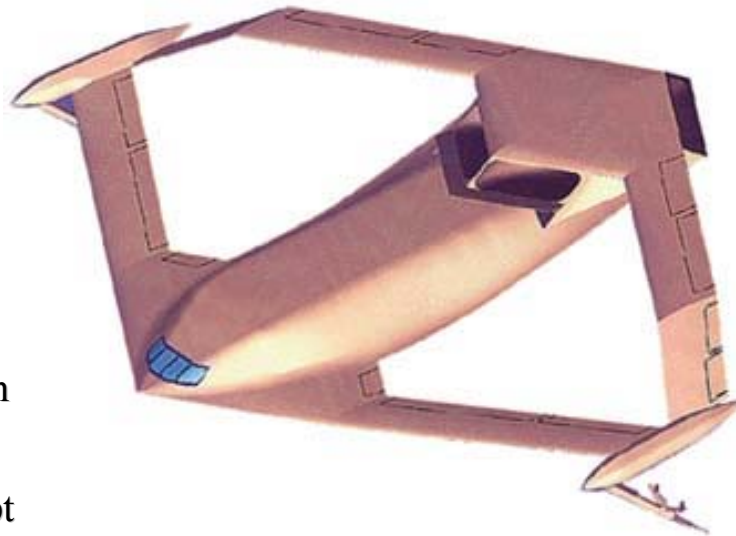
- **Background on Joined-Wing SensorCraft**
  - History of the Joined-Wing
  - SensorCraft Background
  - Configuration Issues
- **Modeling**
  - Parametric Modeling & Design Method
  - Aerodynamic Panel Model
    - PanAir
    - FlightLoads
  - Structural Finite Element Model
- **Related Studies**
- **Conclusion**



# History of Joined Wings



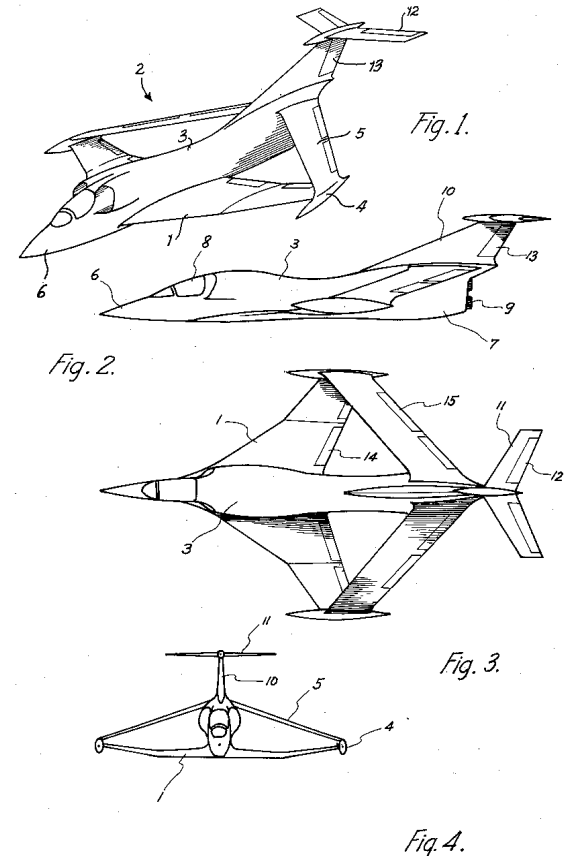
- Advantages Claimed
  - Reduce induced drag
  - Improve Stability
  - Strengthen Wing
  - Prevent Flutter



Lockheed Martin  
 “New Strategic  
 Aircraft” Concept

Staggered Wing,  
 Ratony, 1977

U.S. Patent Oct. 11, 1977 Sheet 1 of 4 4,053,125





# Joined / Box Wing Studies



- **Wolkovitch (1986)**
  - Highly Integrated Structures & Aerodynamics Concept
- **Gallman & Kroo (1996)**
  - Buckling Critical
- **Livne (2001)**
  - Survey
  - Complex Aeroelastic Behavior

NASA : Box Wing Airliner (325 Passenger)



Lockheed Martin  
Concept to  
Replace  
C-141 & KC-135



# SensorCraft Background



- **Air Force Requirement**
  - A UAV for continuous, long term intelligence, surveillance, and reconnaissance (ISR) missions
  - Joined wing magnifies sensor footprint by providing 360 degree coverage of the area of interest



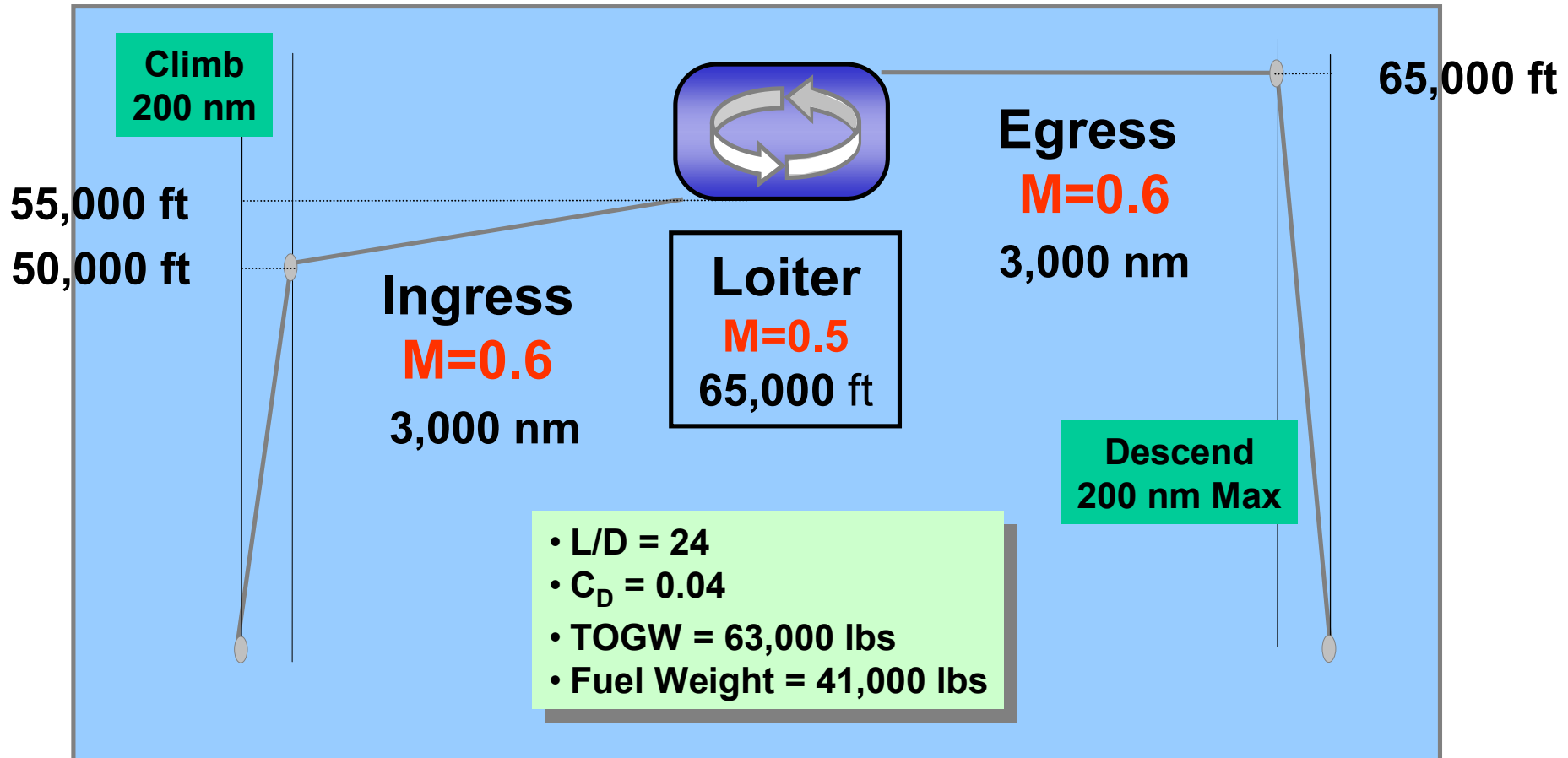
**Notional UAV Joined Wing SensorCraft Concept (Boeing)**



# Notional Mission Profile

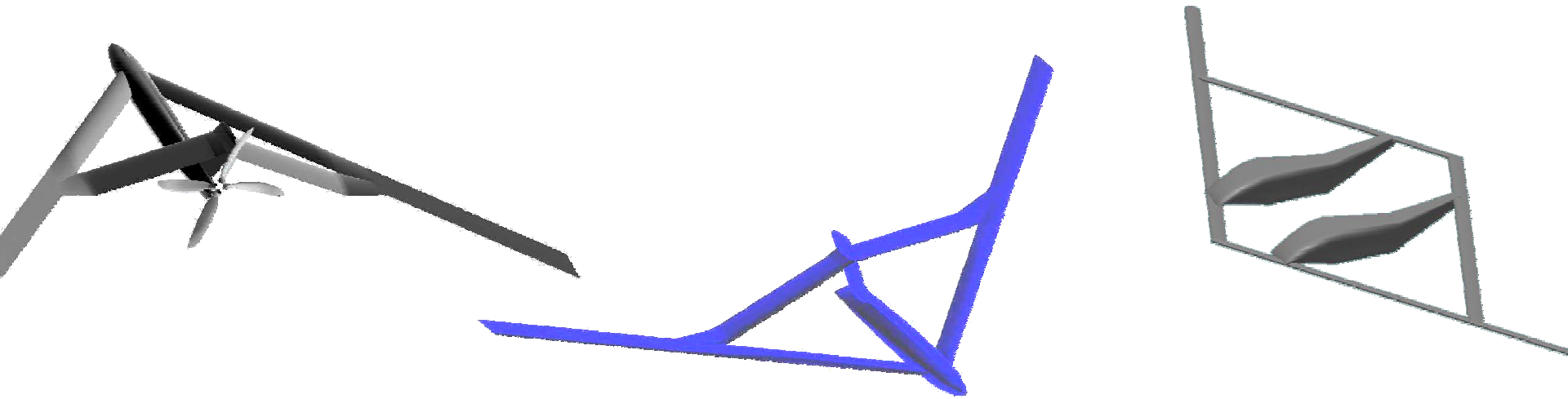


Breguet Range Equation: 
$$R = \left(\frac{V}{C}\right)\left(\frac{L}{D}\right)\ln\left(\frac{W_{i-1}}{W_i}\right)$$





# SensorCraft Concept



- **Developed by a team of AFRL in-house engineers**
- **Designed with the concept of designing an aircraft around the desired sensor package, rather than trying to pack sensors into an already existing platform**
- **Provides the required 360 deg coverage in a joined-wing configuration**
- **Further analysis is now being performed by students at the Air Force Institute of Technology**





# SensorCraft Complexity



- **SensorCraft Issues**
  - Many current tools are unable to process unusual configurations
  - Need to examine several points in the mission profile
  - Complex aerodynamics at the joints
  - Conformal, load bearing antenna integration
  - Non-linear structural analysis
    - **Wing buckling and bending**
  - Interaction of structural and aero loads
- **Solution requires simultaneous, interactive examination of:**
  - Sensors, including the structural characteristics
  - Structural analysis
  - Flexible aerodynamic loads



# Overview – Modeling



- **Background on Joined-Wing SensorCraft**
  - History of the Joined-Wing
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  - Configuration Issues
- **Modeling**
  - Parametric Modeling & Design Method
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# Design Tools



## AML Design Environment:

- Object-oriented With Native Geometric Modeling
- Dependency-tracking & Demand Driven Process
- Run-time Object Creation

## PanAir Aerodynamic Solver:

- Linear panel geometry for complex configurations
- High order continuous singularity distribution
- Wake shaping capability

## MSC.FlightLoads Solver:

- Combined structural-aerodynamic model

## ASTROS:

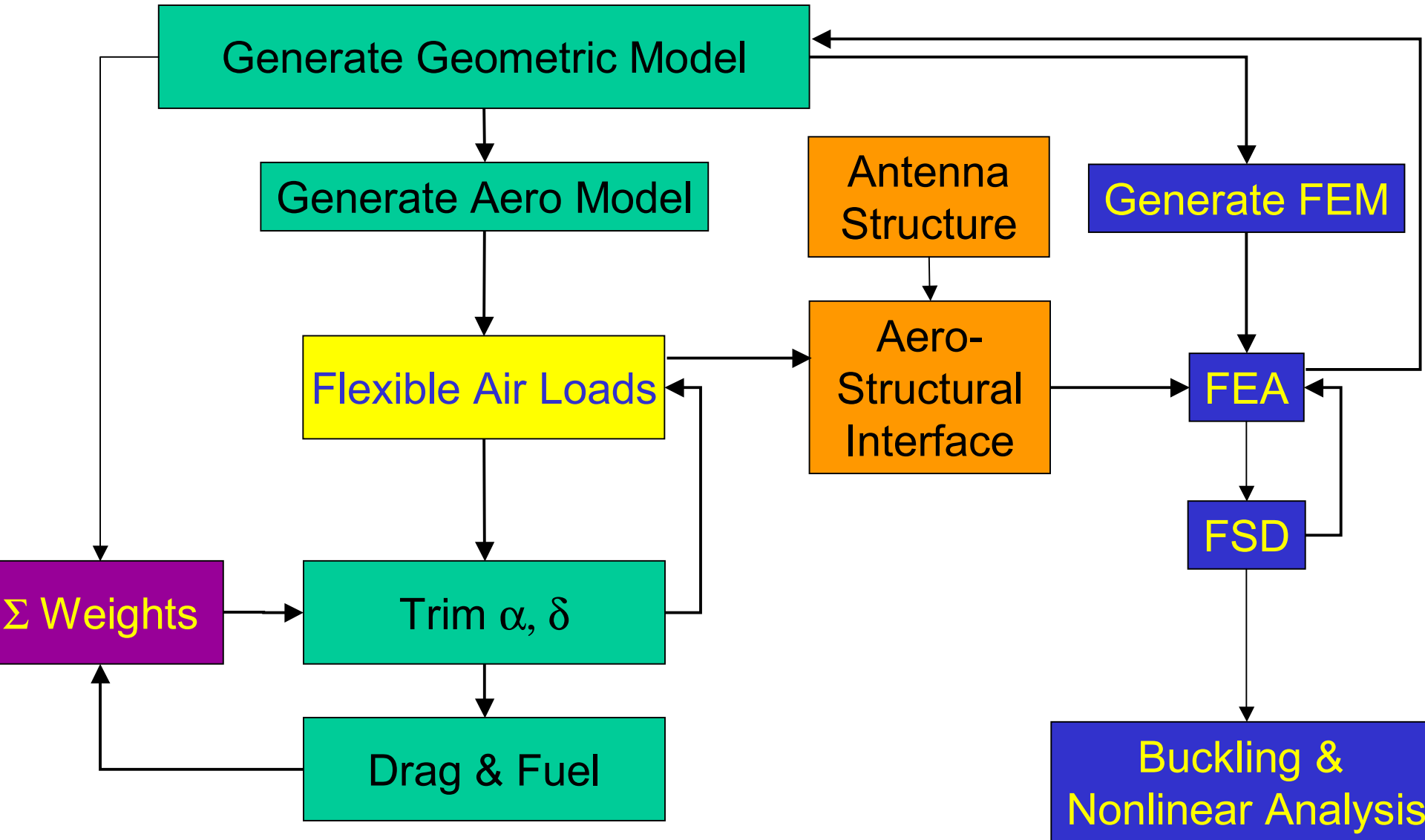
- Structural Optimization
- Linear Fully-Stressed Design (FSD)

## MSC.Nastran:

- Non-Linear Analysis
- Gradient-Based Buckling Design



# Joined-Wing Design Flowchart





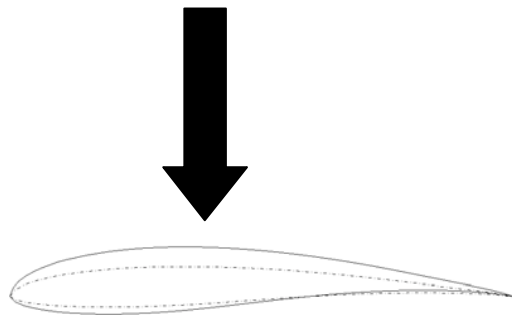
# Object-Oriented Wing Building

~ AML Design Environment ~

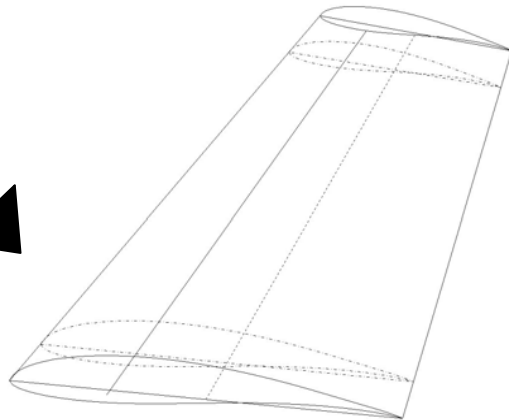


Start with  
Basic Building Blocks:

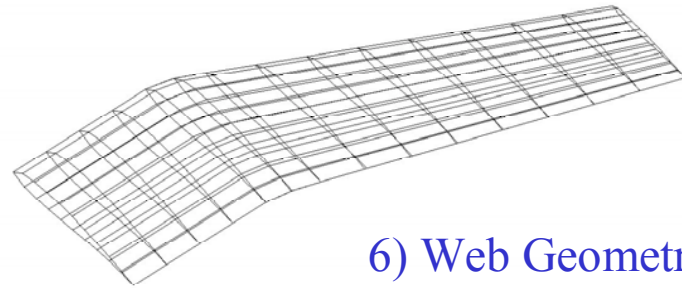
- 1) curve
- 2) contour
- 3) surface



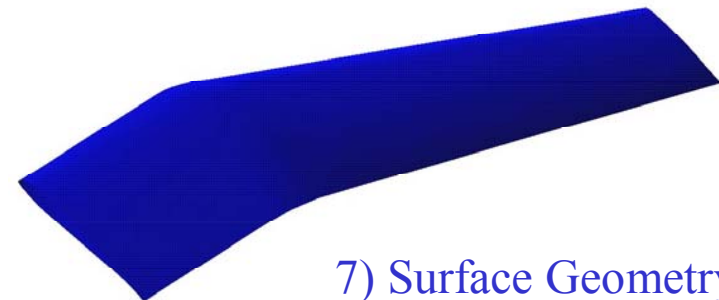
4) Airfoil



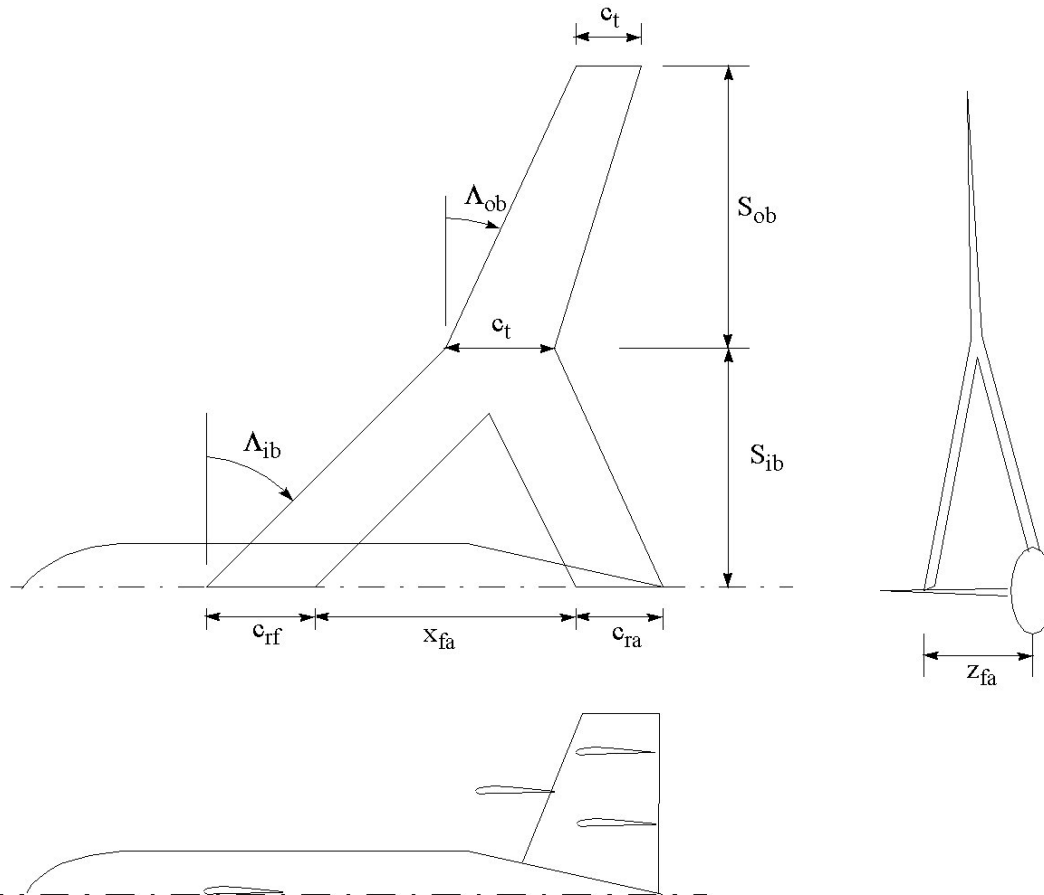
5) Wing Panel



6) Web Geometry



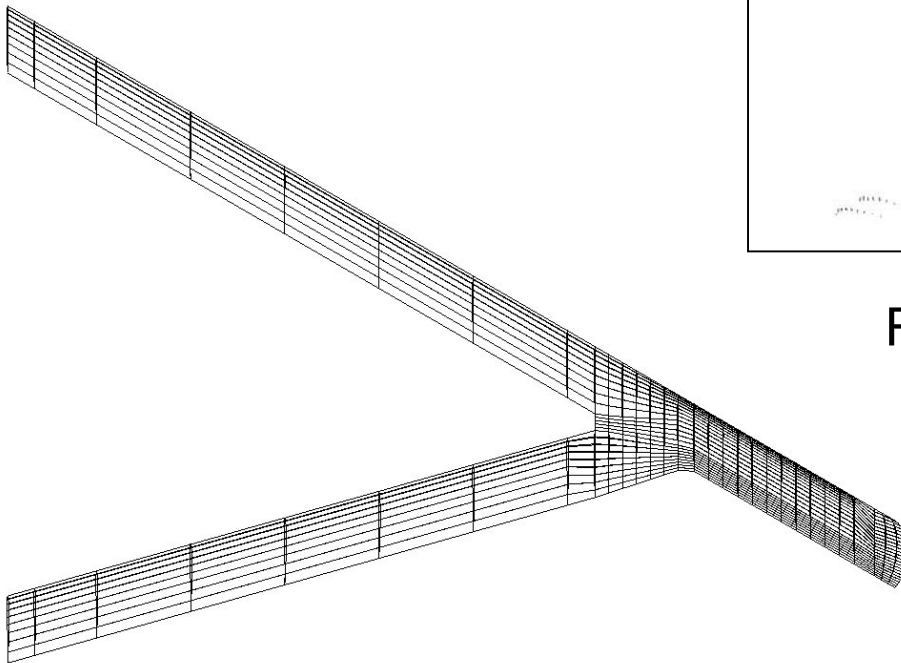
7) Surface Geometry



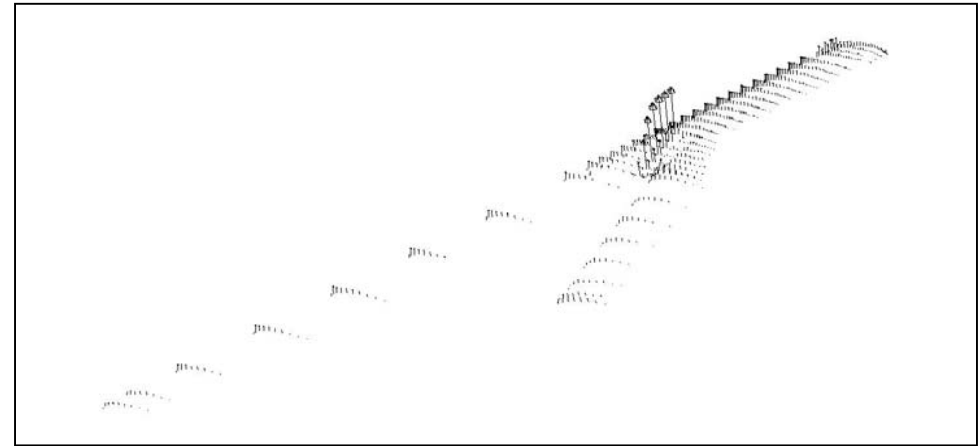
Inboard Span ( $S_{ib}$ )	26.0 m
Outboard Span ( $S_{ob}$ )	6.3 m
Chord ( $c_{rf}$ , $c_{ra}$ , $c_m$ , $c_t$ )	2.5 m
Wing Separation ( $x_{fa}$ )	22.0 m
Wing Offset ( $z_{fa}$ )	7.0 m
Sweep ( $\Lambda_{ib}$ , $\Lambda_{ob}$ )	30 deg
Airfoil	FX-60-126-1
Planform Area	145.0 m <sup>2</sup>
Wing Volume	52.2 m <sup>3</sup>



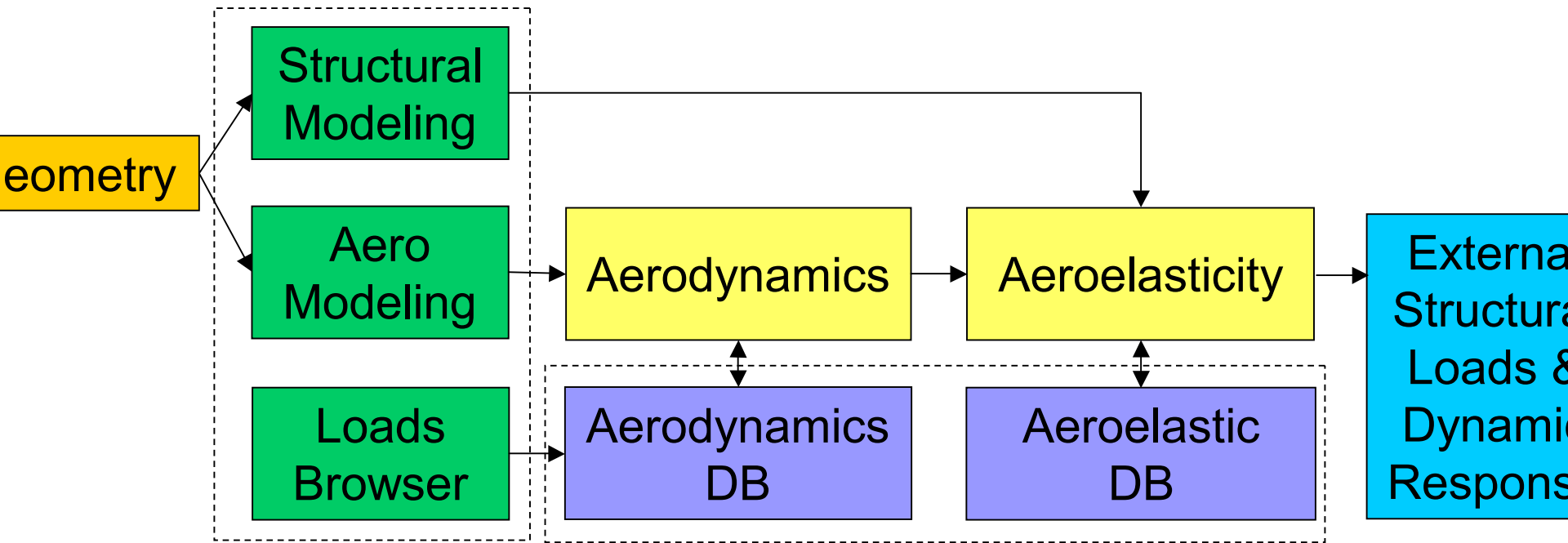
# Joined-Wing Aero Model ~ PanAir Aerodynamic Solver ~



**PanAir Panel Model**



Rigid Trimmed PanAir Pressure  
Vectors on the Top Skin



- Begin with geometry from user-preferred sources (i.e. IGES, CAD, etc)
- Define the aerodynamic and structural models
- Perform aerodynamic calculations
- Analyze the combined structural-aerodynamic model to provide both component and total vehicle aeroelastic responses
- View the results and produce external loads that can be passed to the stress group for detailed design and verification



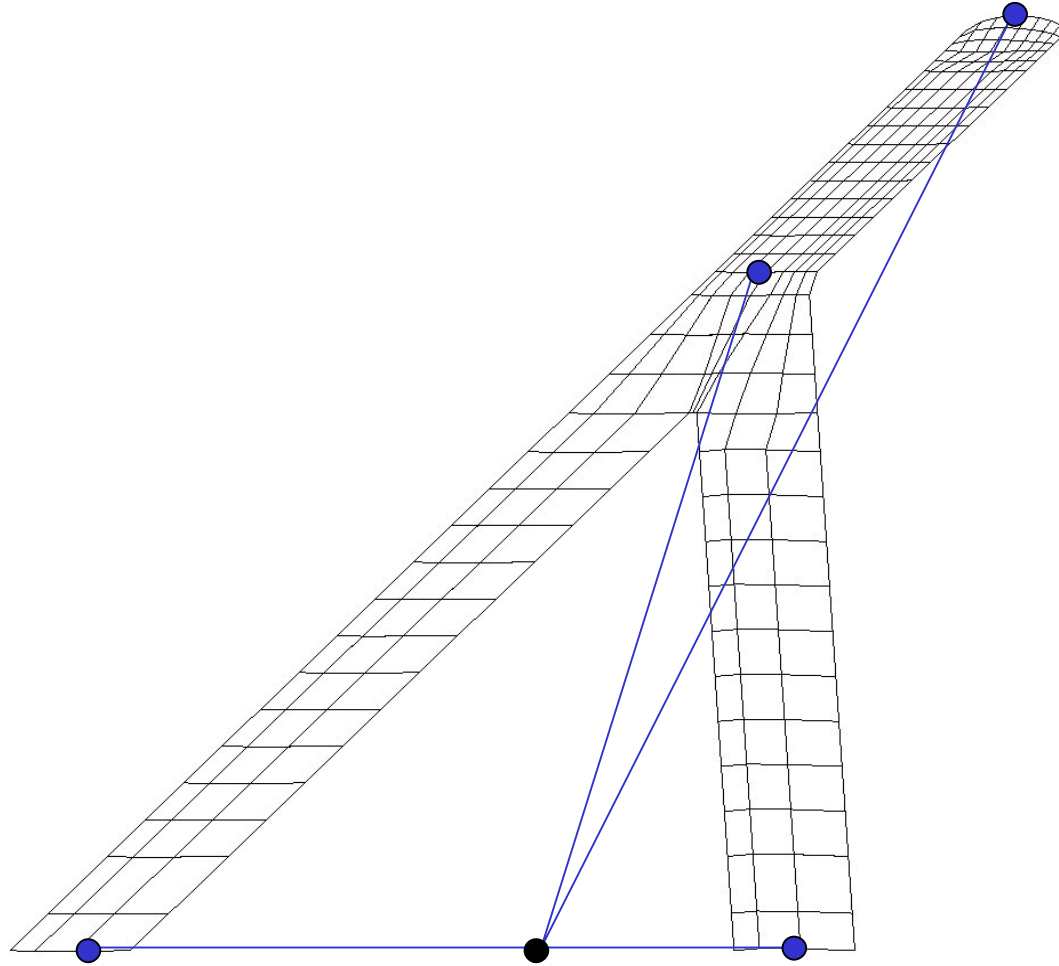


- **Input a simple structural geometry**
  - Include degrees of freedom
- **Build a flat-plate aero model, including control surfaces**
- **Spline the aero model to the structure**
  - Identify aero and structural monitoring points
- **Examine the model at various points in the mission profile**
  - Takeoff, ingress, mid-loiter, 2-g turn, egress, and landing
- **Export to NASTRAN for structural analysis**
- **Use NASTRAN results to complete the aerodynamic analysis**



# Aero-Structural Model

~ FlightLoads ~

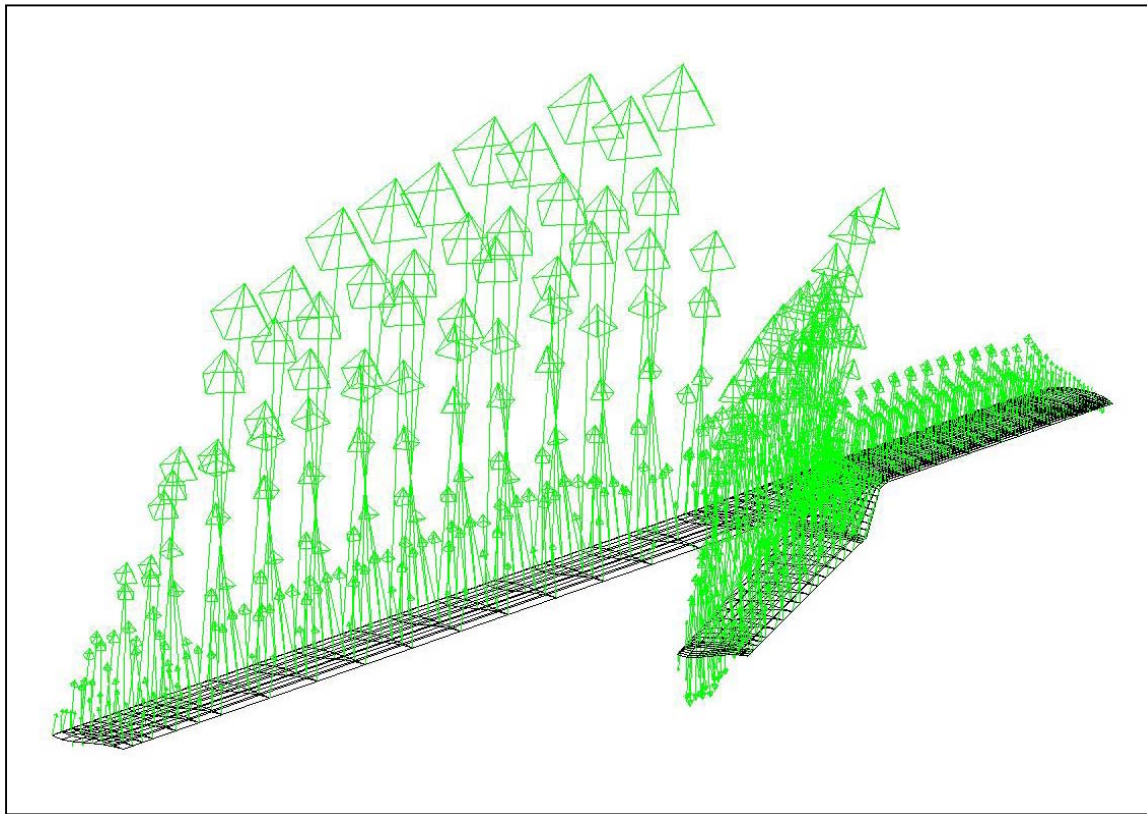




# Joined-Wing FEM



## Rigid Trimmed Forces at the Structural Grid Points





# Overview – Related Studies



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# Related Research

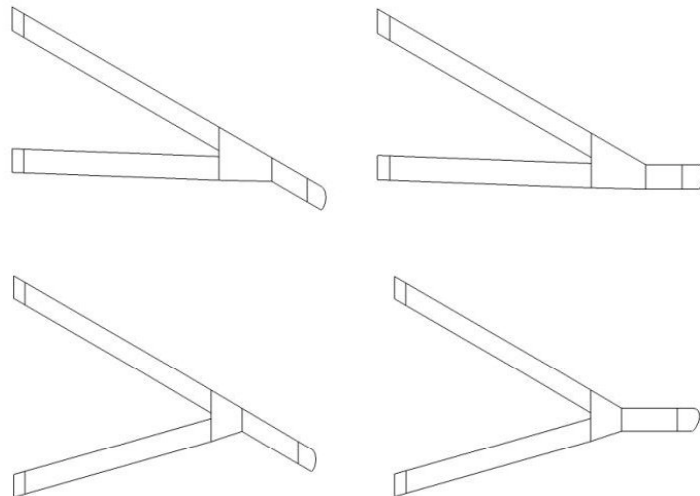


- **Previous Work**

- Joined-Wing Structural Weight Modeling Study (Blair/Canfield)

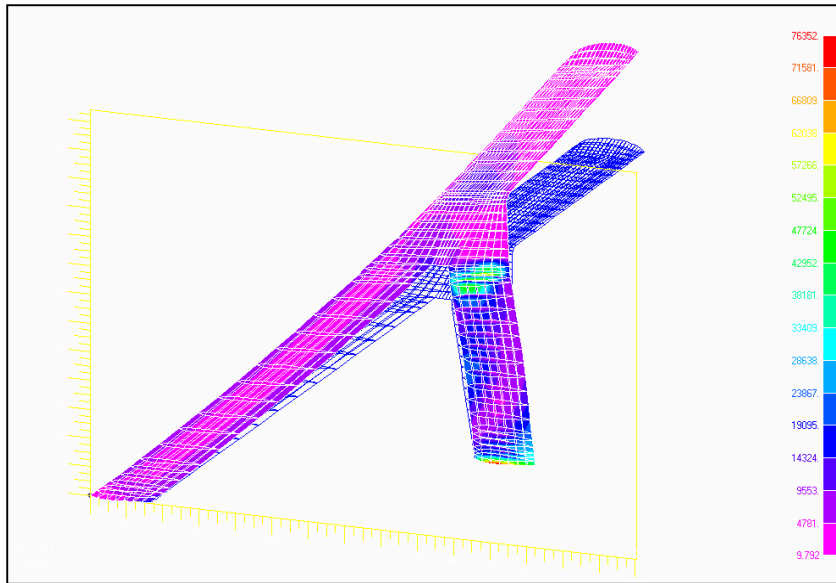
- **Concurrent Work**

- Stochastic Finite Element Analysis (Pettit/Ghanem)
- Reliability Based Structural Design (Roberts)
- Structurally Integrated Conformal Antennas (Smallwood)

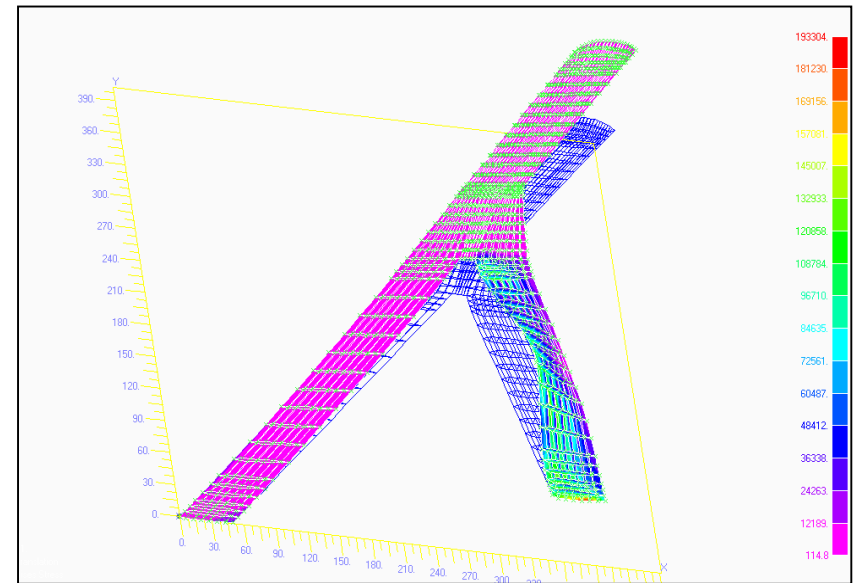




- FEM Resized (Fully-Stressed): Linear FEA
- Aeroelastic Load was Applied in Geometrically Nonlinear FEA

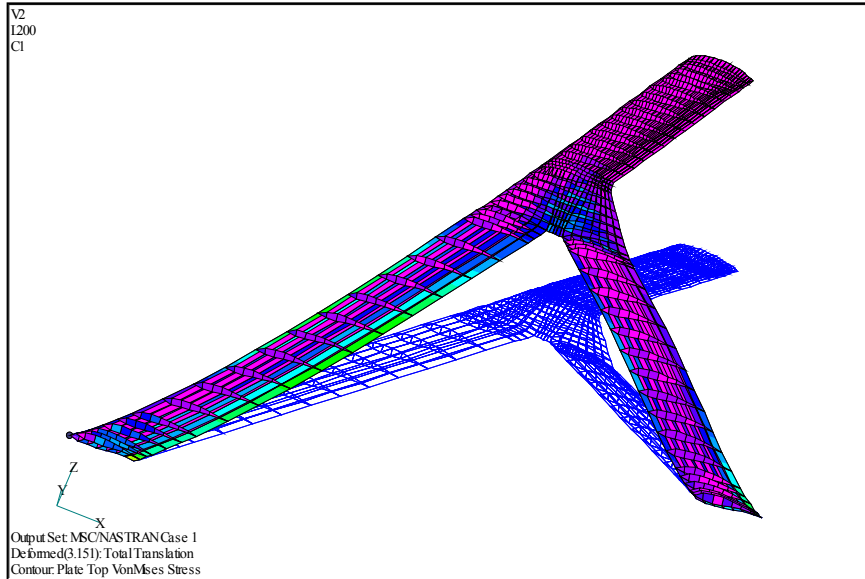


**Linear Results**



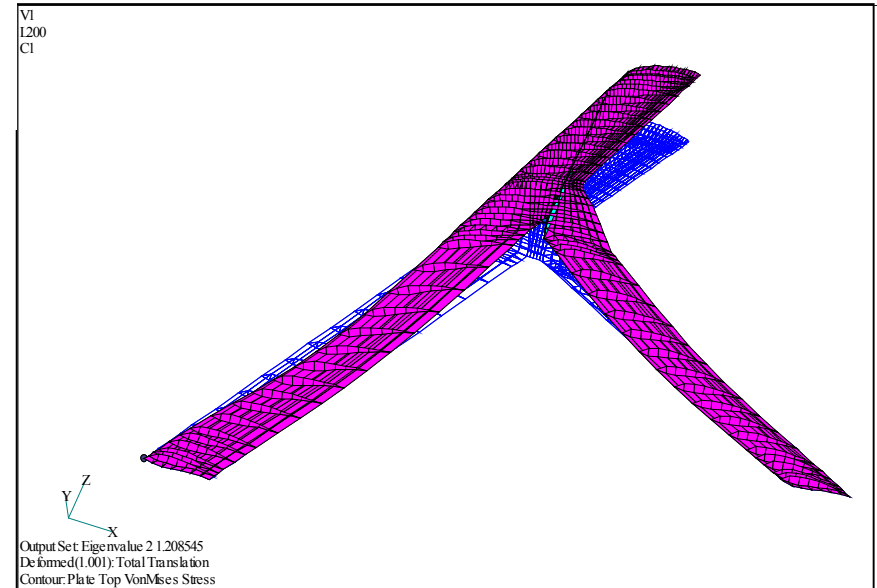
**Non-Linear Results**

Conclusion: Non-linear Analysis Critical in Designing Joined-Wing



Linear FSD  
Static Deformation

Buckling Deformation  
of Linear FSD





# Conclusions



- **The joined-wing SensorCraft presents designers with unique technical issues**
- **Accomplishments**
  - Design Environment for Nonlinear Flexible Trim
  - Interactive Aero-Structural Model
- **Next Steps**
  - Un-Sweep Outboard or Aft Wing
  - Design for Buckling and Non-Linear FSD
  - Tailor Aft Wing Buckling to Alleviate Flexible Load
  - Verify aerodynamic results with CFD

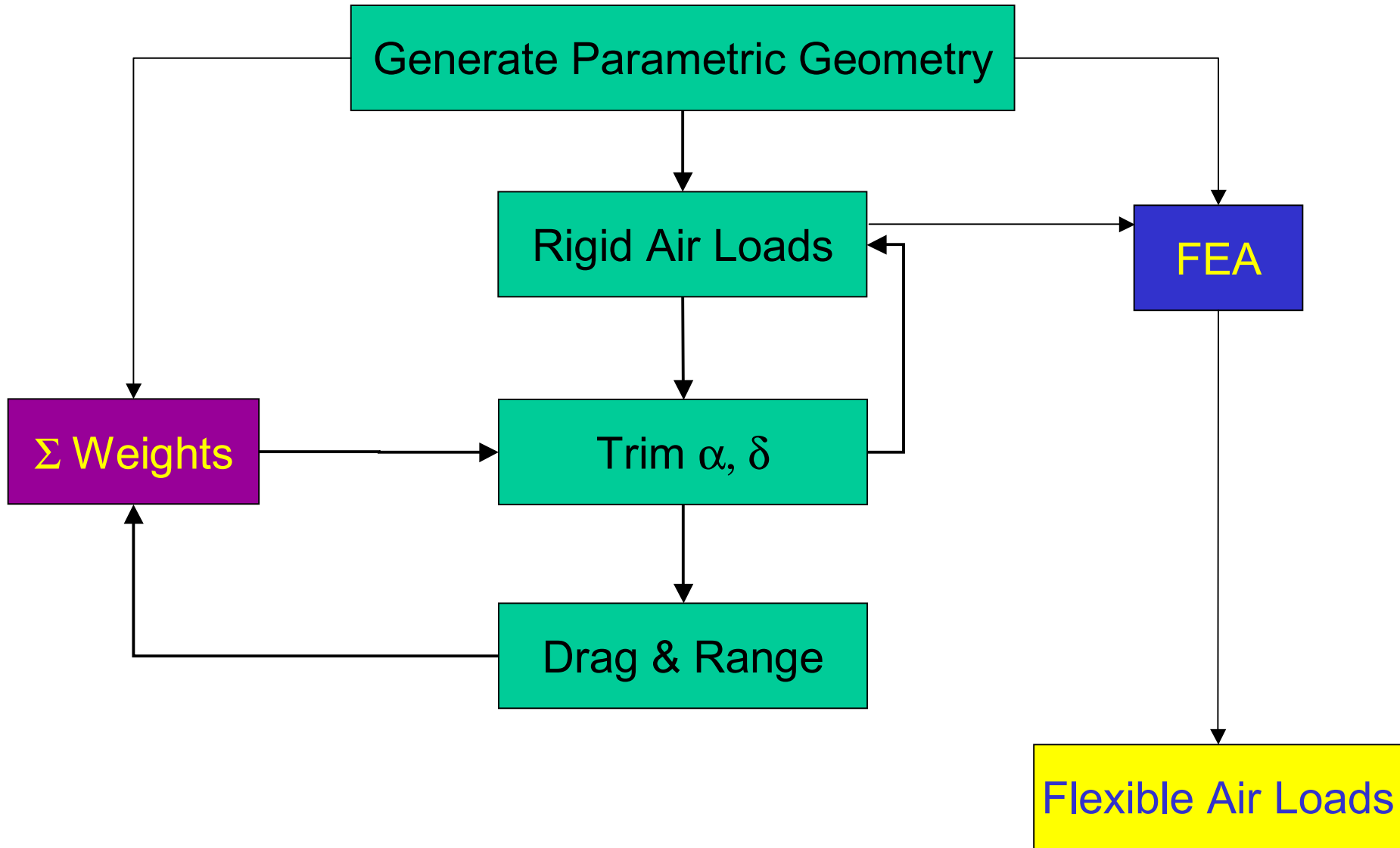




# Backup Slides

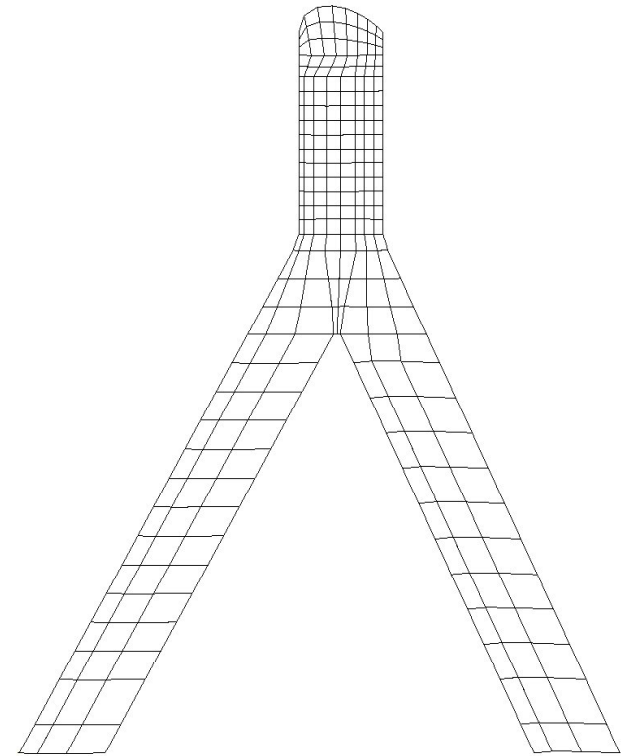
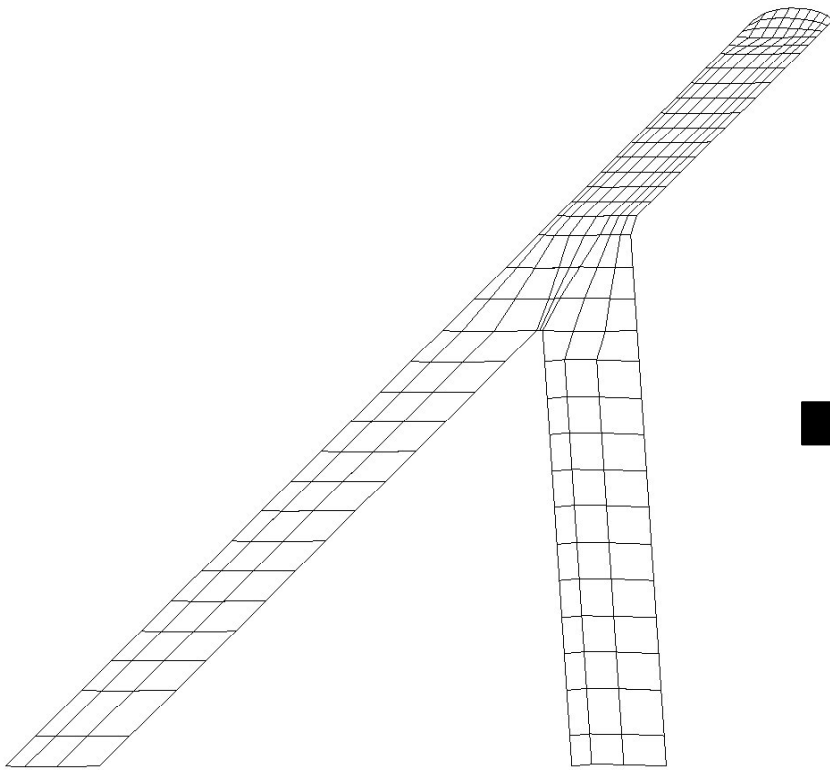


# Joined-Wing Analysis Flowchart





# Un-Sweep Outboard Wing



Negative Aft Wing Lift

Positive Lift