Rapid Trade Studies for Initial Layout with HyperX: Supporting Bottoms Up Weights

HyperX 2025 Conference

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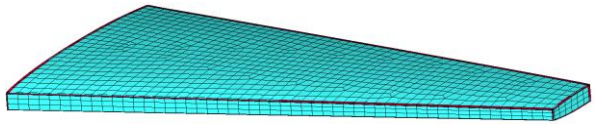
Overview

- Initial Configuration Layouts Typically Involve Input Only from a Few Disciplines
  - Aero Performance, Configuration, Survivability, etc.. have significant input
  - Structures rarely has data to provide objective input in a timely manner
    - Structural Layouts, Finite Element Models, Loads generally lag the rapid design process to provide data fast enough
    - Traditional Methods for structural sizing rely on homegrown tools for sizing (Bruhn Multi-Cell Wing Box)
      - While fast they lack the fidelity of FEM's or flexibility of tailored Design Options
- When Weight is a Consideration, These come from Parametric Values based on Similar Platforms
  - Parametric Values have many knobs for weight determination, but experience and Engineering Judgment are key
  - Benefits of Structural Efficiency between configurations relies on engineering judgment
- HyperX is Allowing Structures to Provide Raw Data to Mass Properties Teams in Near Real Time
  - Using a simplified FEM and Loads to define efficient layouts with sizing provides Estimated Weights when comparing configurations

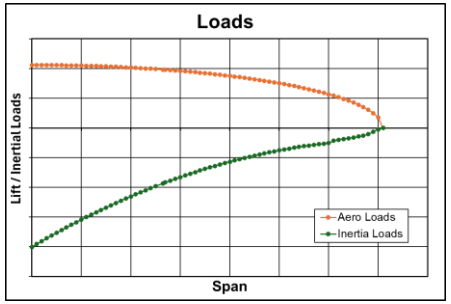
Trade Overview

- Use HyperX to inform and size a structural layout starting with just the big bones layout for a wing
  - Start with just the exterior shell and let HyperX inform the optimal internal structure spacing
  - Sizing loop between Model/FEM & HyperX as necessary to establish optimal configuration
  - Sizing to inform for configuration Down Select

Big Bones

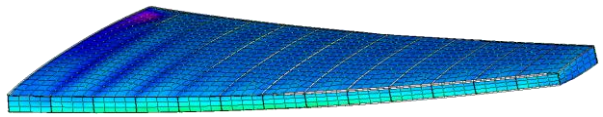


FEM



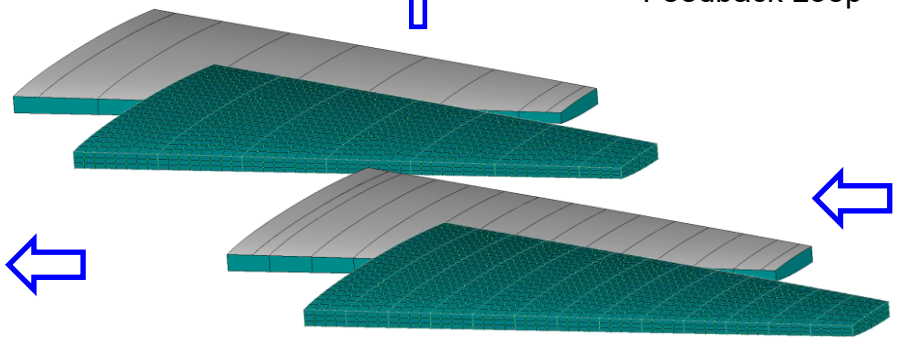
Loads

Feedback Loop

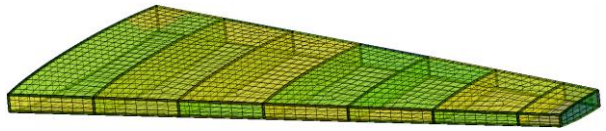


Structure	64" Rib Weight (lbs)
Total	4,388

Basic Layout
(Weight Estimate)



Update Models

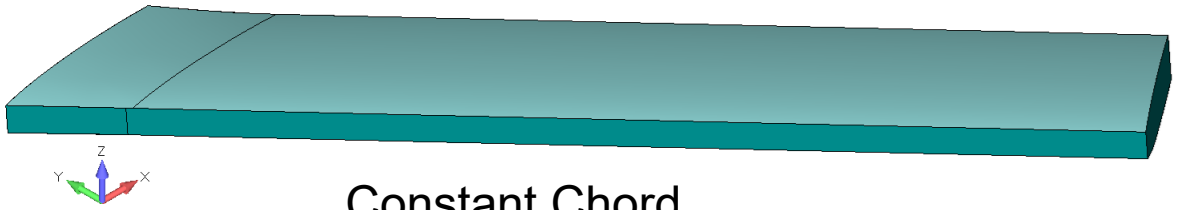


Sizing - HyperX

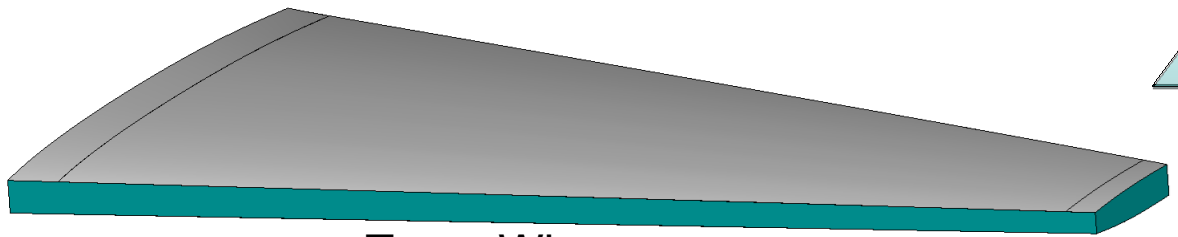
Geometry

Problem: A program is deciding between two wing planforms, Tapered Wing and a Constant Chord. While the constant chord is likely to be less structurally efficient without weight estimate Structures Team suggestions will not carry much weight.

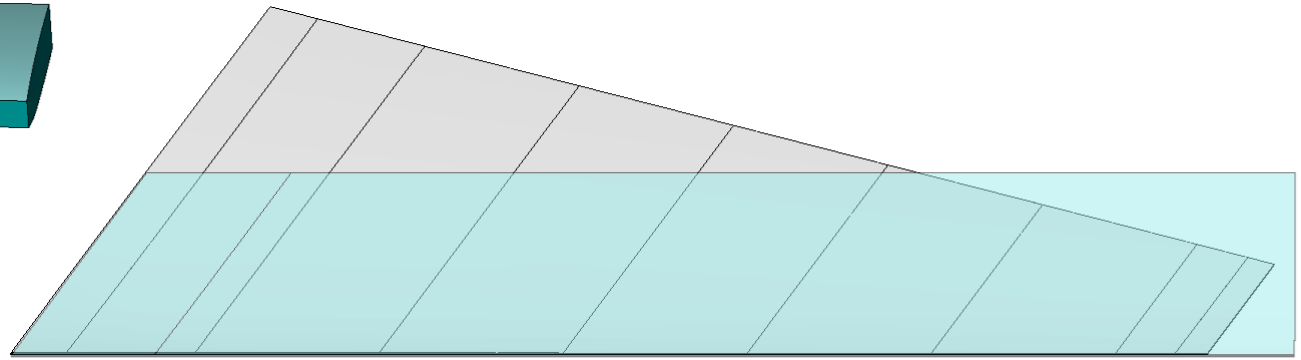
- Using the OML, Basic Structural Lines Representing the Structural Wing Boxes for each Configuration are Drawn
  - Each Planform is sized to meet the Platform Requirements
  - Sizing Structural Box will inform the Structural Efficiency and Planform Weight



Constant Chord



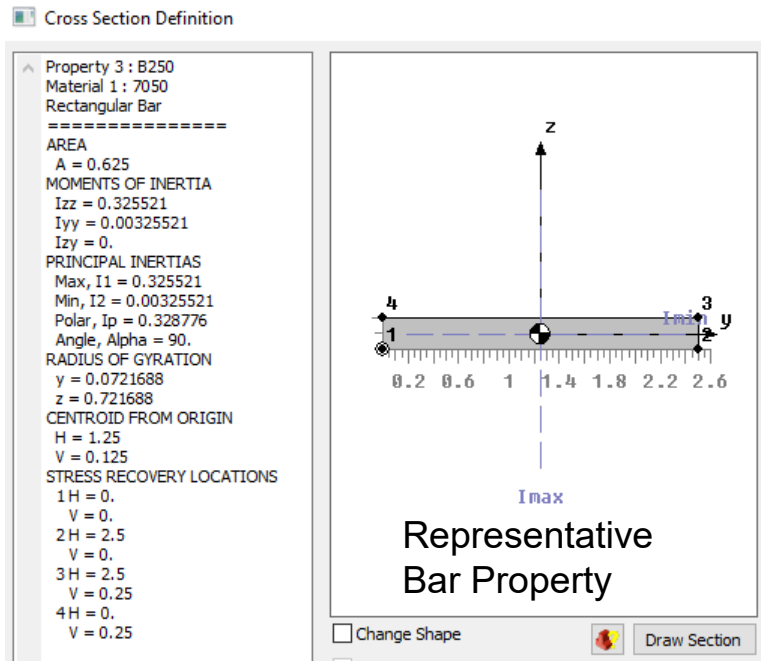
Taper Wing



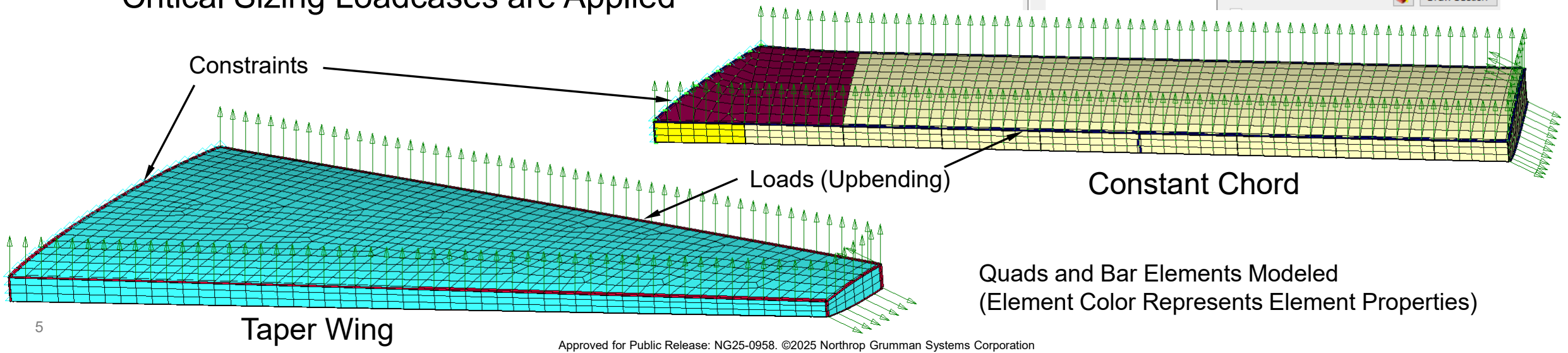
Planform Comparison

Finite Element Model

- A Simplified FEM of Each Planform is Made
  - Paver Mesh used to blast the surfaces with a Mesh
    - Focus is on function of mesh vs. specific Mesh Quality
    - Web and Cap are modeled, no Internal Structure
  - Constraints are Applied at the Wing Root
  - Uniform Properties are applied as initial start
    - Resulting Stress Levels not a focus of the design
      - HyperX will size the structure accordingly based on loads
  - Critical Sizing Loadcases are Applied



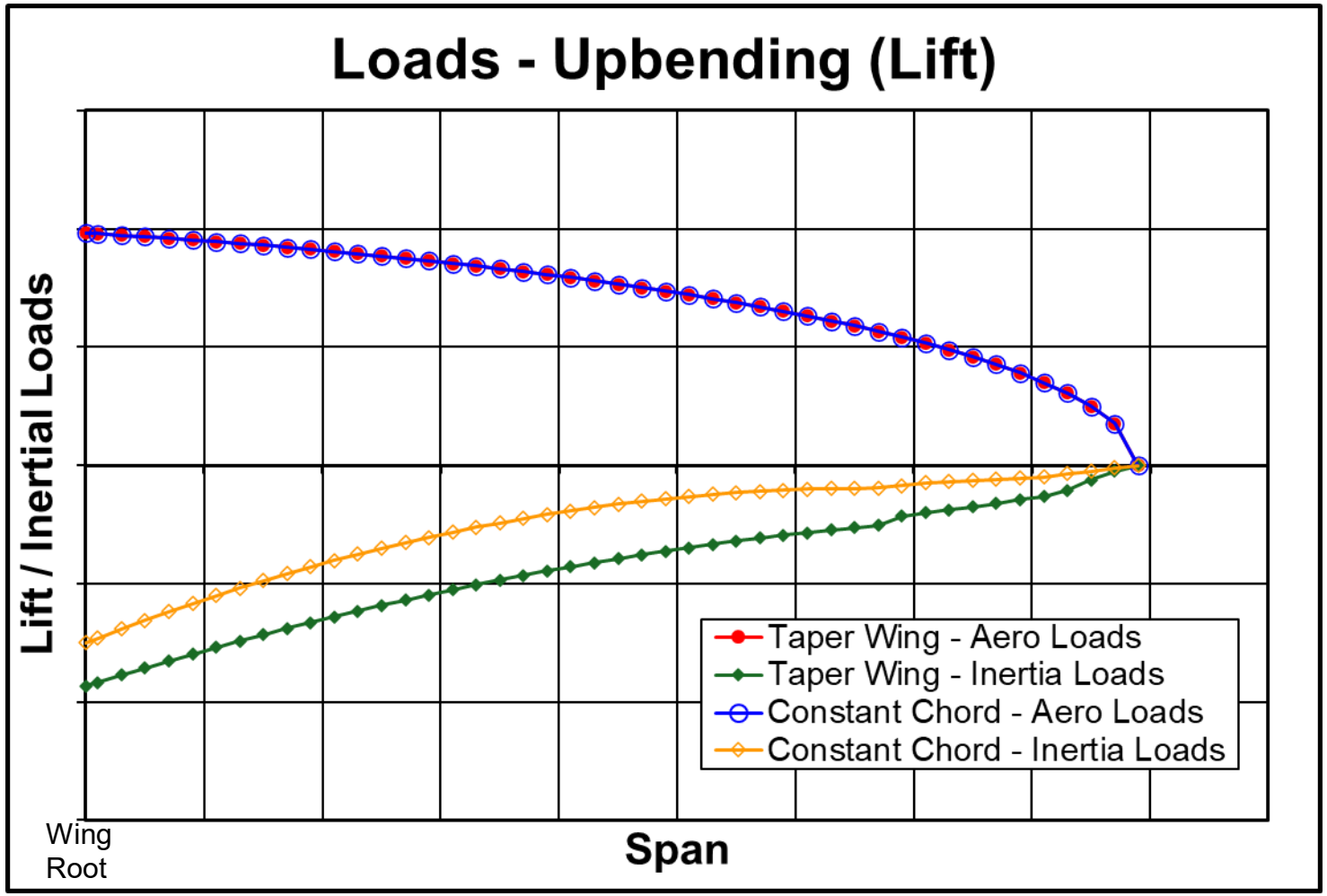
Representative Bar Property



Quads and Bar Elements Modeled
(Element Color Represents Element Properties)

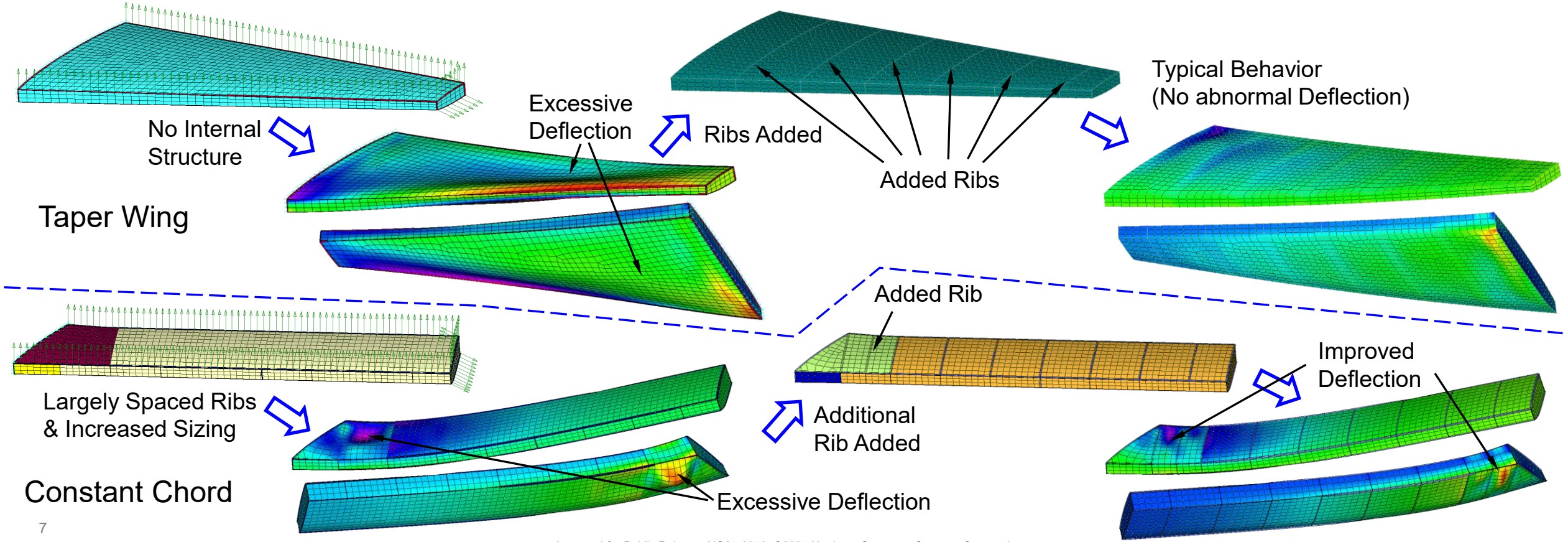
Loads (Lift and Inertia)

- Loads are Based on a Simple Elliptical Distribution for a Wing
  - Considered 2 Primary Load Cases
    - Wing Up Bending (Positive Lift)
    - Wing Down Bending (Negative Lift)
      - Ratio of the Lift Load
- Estimated Inertia Loads Subtracted from Lift Loads
- Loads Applied to FEM as Resultant Load Case



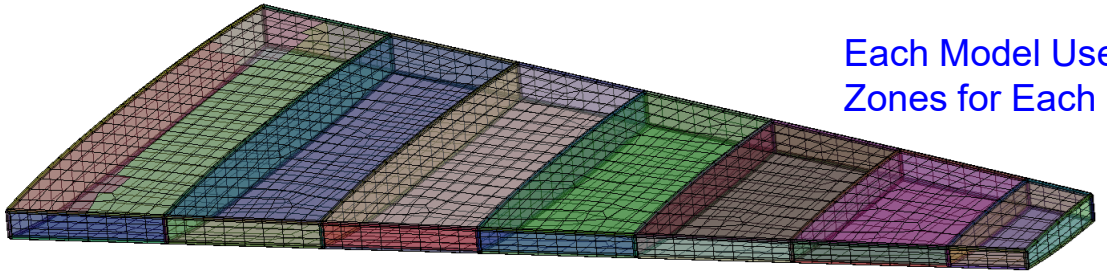
Reality Check

- A Simple FEM Mesh and Loads Proved to be an Oversimplification
  - Deformations of the structure showed unexpected behavior for the expected loading
    - Assessments of the causes indicated at least some internal structure is necessary for proper behavior
    - HyperX is meant to size structure that behaves properly, not account for poor quality data



Structural Sizing in HyperX

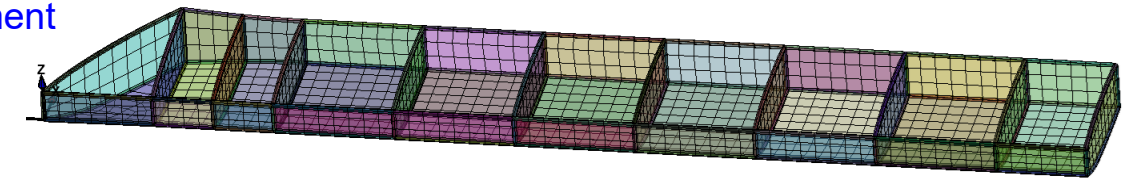
- Initial Design Assumptions was to Follow a Metallic Skin and Stringer Design
- Sizing Studies were performed using a couple of Methods
  - Orthogrid was used to determine Stringer and Rib Spacing for Skins based on loading
    - 0° is the spanwise direction and Spars and Ribs sized only as Orthogrids
    - While feasible, Grid like machining quickly determined to not be one of the manufacturing options
  - Open Section Zee Fastened Stringers were used as the Primary Method for Skins
    - Buckling Span – X is used to account for the rib spacing
    - Buckling Span is varied to assume impacts of rib spacing
    - Stiffener Heights are varied to assess impacts on sizing
- Sizing started with Tapered Wing and Informed Sizing on Constant Chord



Zones for Sizing – Taper Wing

Each Model Used 1 or More
Zones for Each Bay Segment

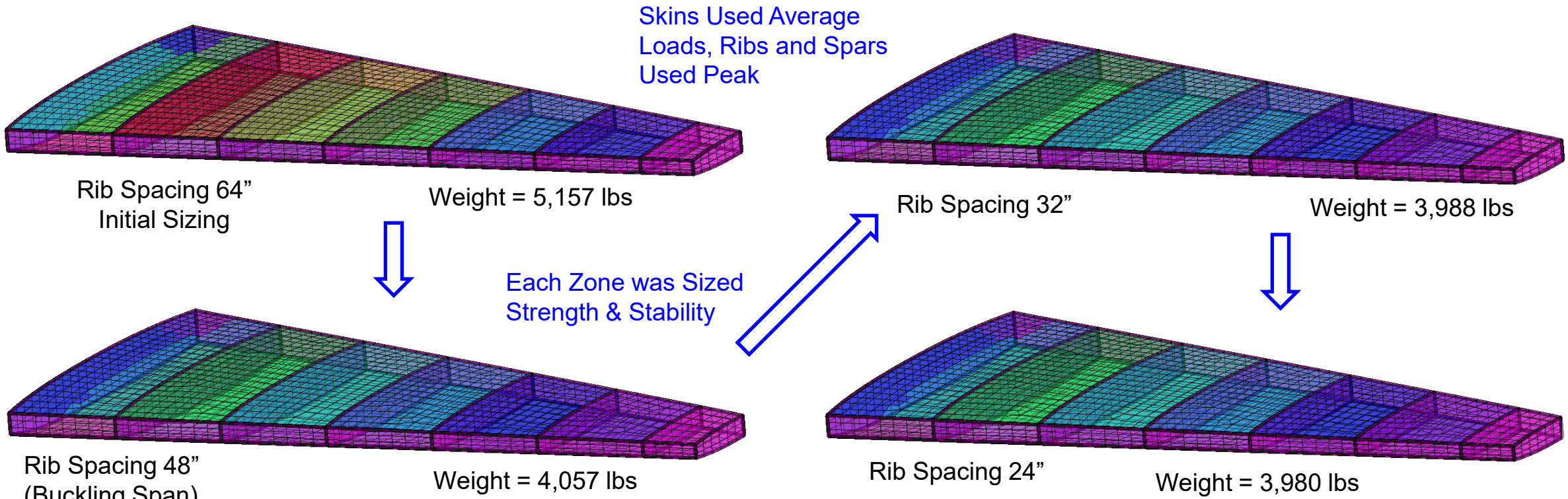
Distinct Zones Shown



Zones for Sizing – Constant Chord

Taper Wing Structural Sizing

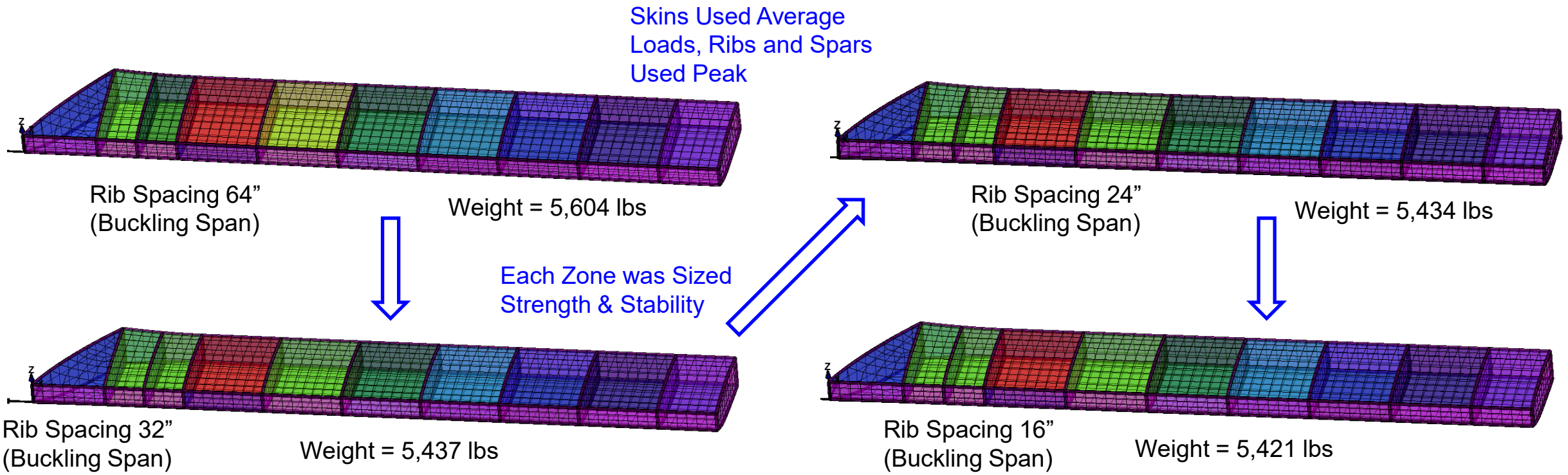
- Skin Sizing Iterated on Zee Fastened Stiffener for Assumed Construction
  - Initially let Zee Stiffener height float up to 2.25”
  - Later ran sizing with 3.5” high stiffener
  - Sizing based on all Aluminum 7050 construction



Zee Stiffener Height ≤ 2.5” – Taper Wing

Constant Chord Wing Structural Sizing

- Orthogrid Sizing Iterated to Determine Stiffener Sizing for All Structure
  - Spars and Ribs construction assume Orthogrid construction
- Skin Sizing Iterated on Zee Fastened Stiffener for Assumed Construction
  - Sizing based on all Aluminum 7050 construction with 3.5” Stiffeners

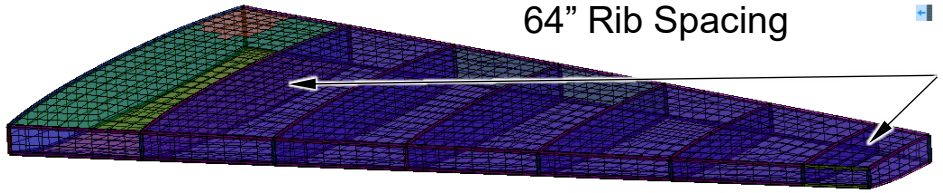


Zee Stiffened Sizing of Skins – Constant Chord

Sizing Criterion

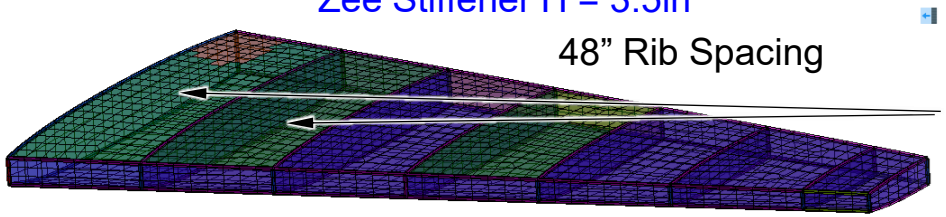
- Sizing Criteria for the Taper Wing Shows it is sized by Stability, Constant Chord Primarily by Strength

64” Rib Spacing

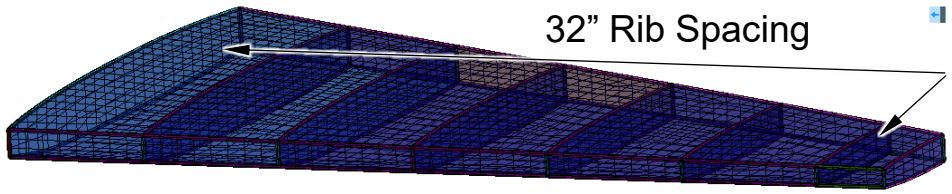


Zee Stiffener H = 3.5in

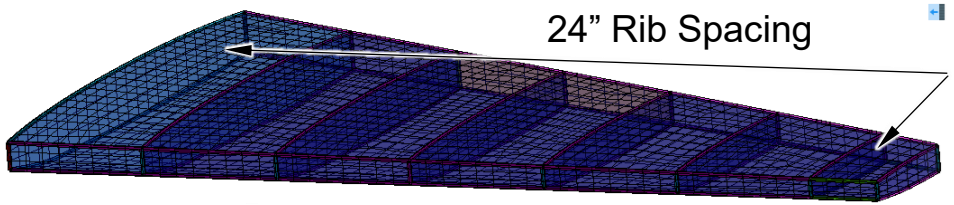
48” Rib Spacing



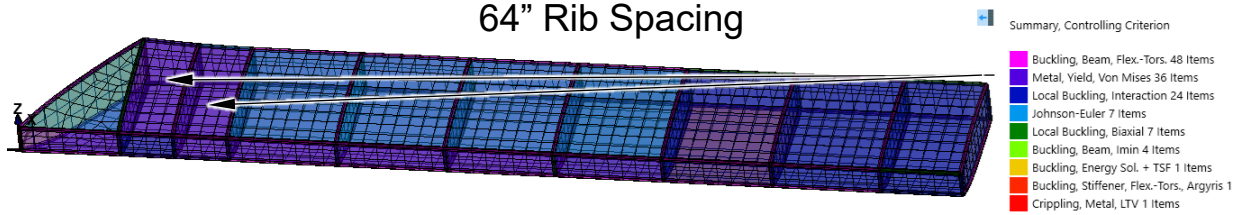
32” Rib Spacing



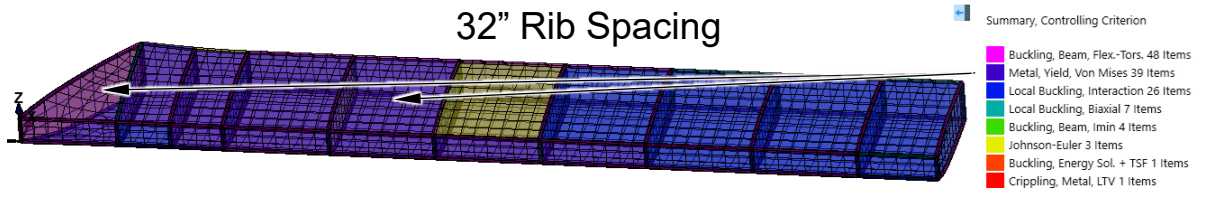
24” Rib Spacing



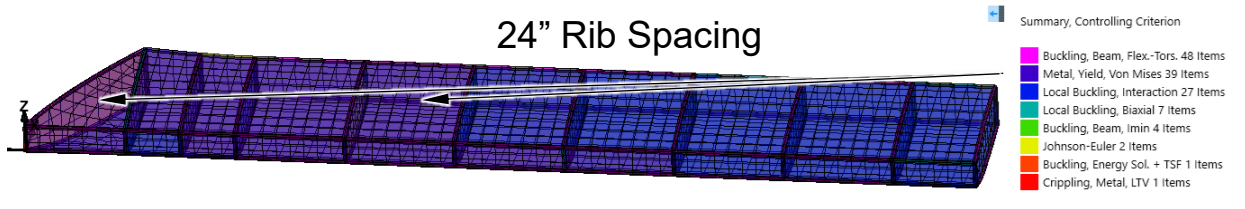
64” Rib Spacing



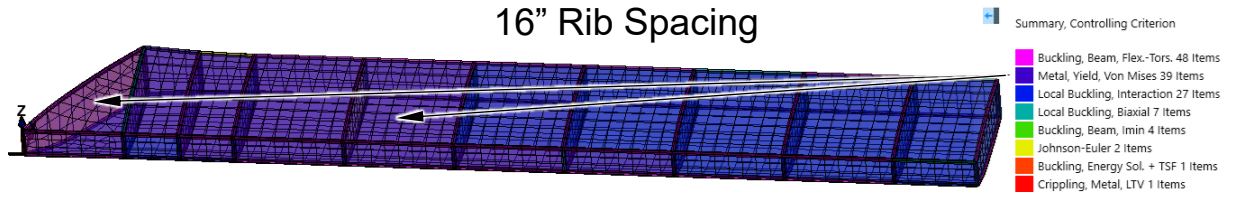
32” Rib Spacing



24” Rib Spacing



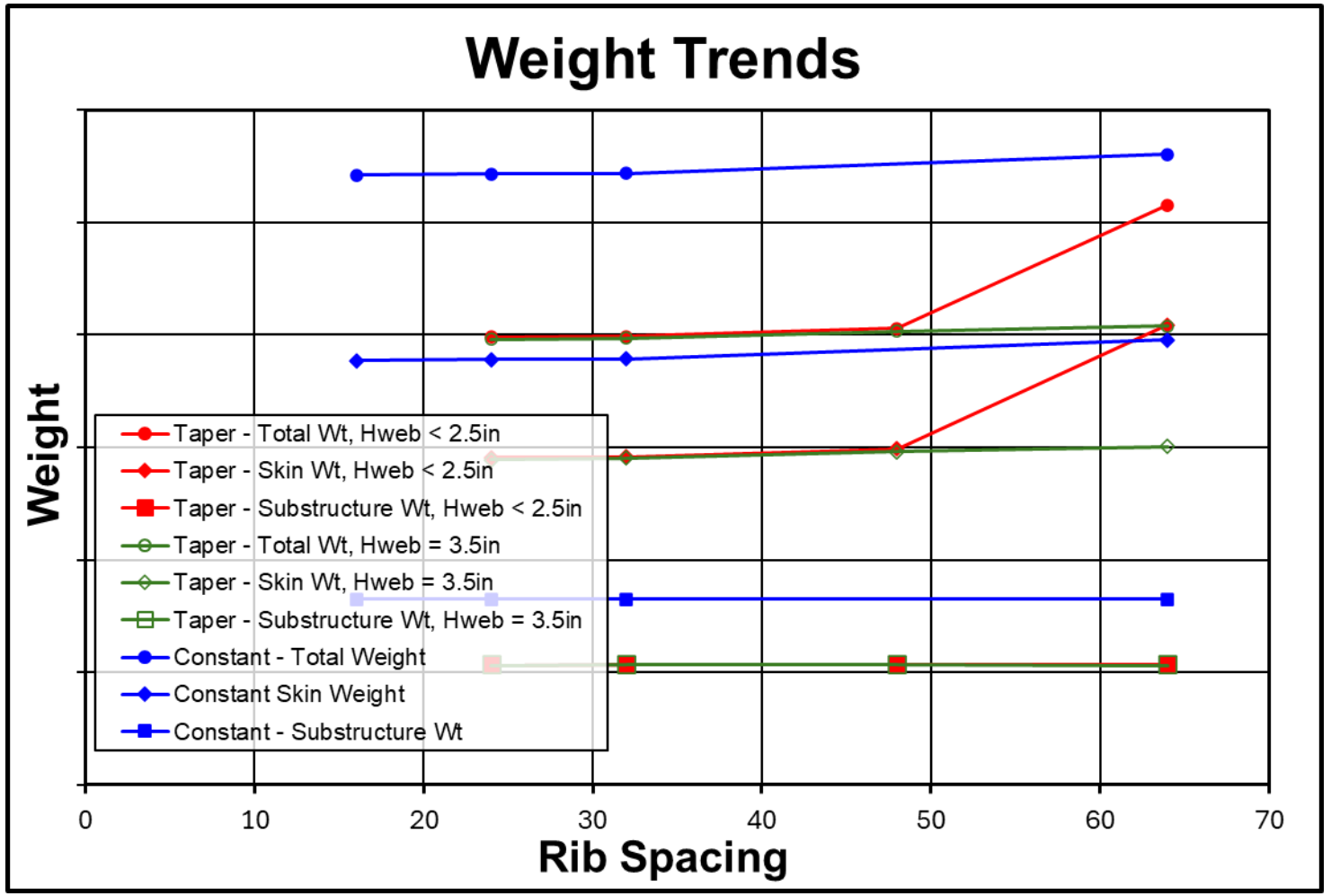
16” Rib Spacing



Rib Spacing Based on Buckling Span Adjustments

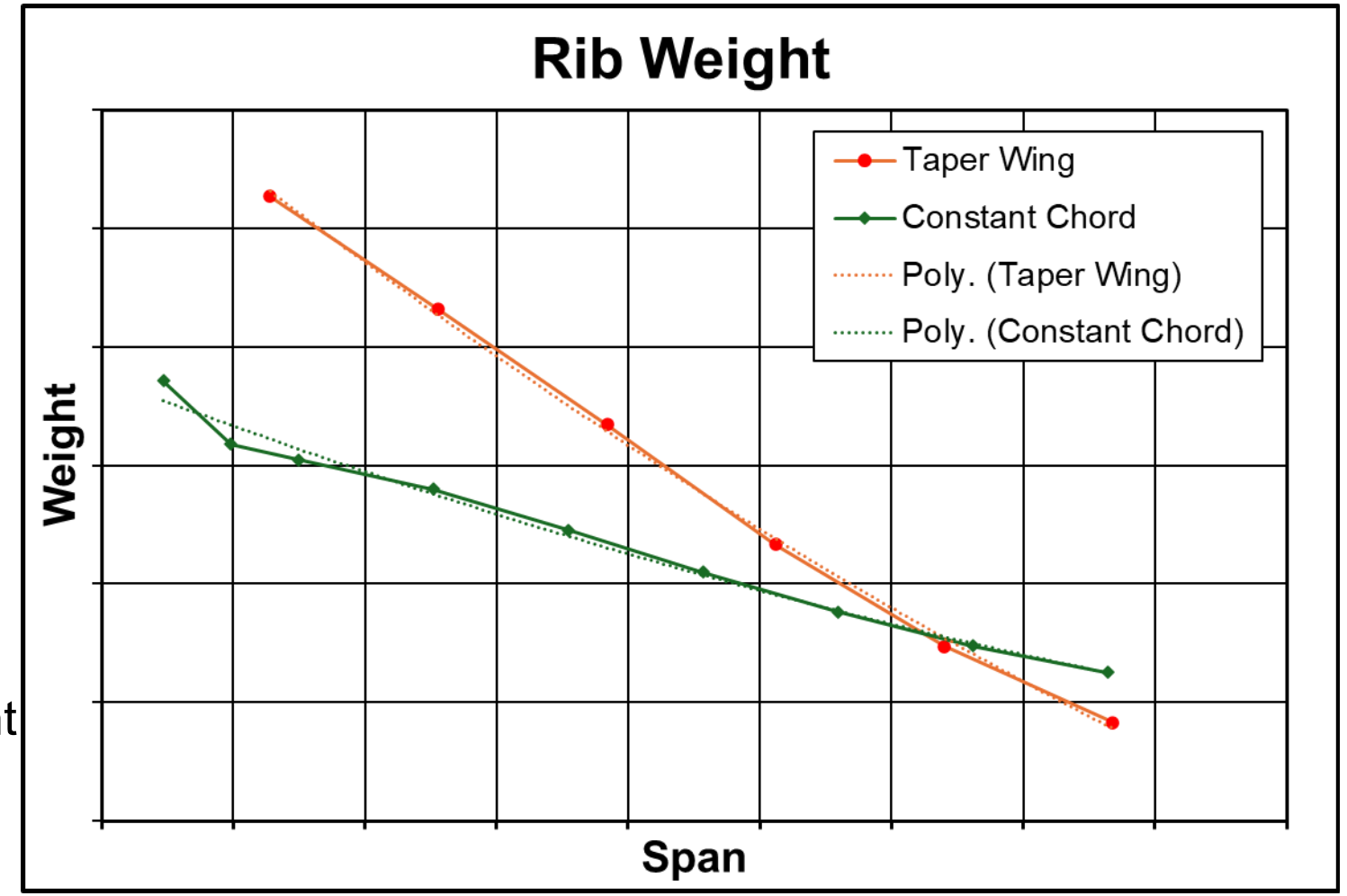
Weight Trends – Zee Stiffened Skins

- Weight Trends for the Zee Stiffened Skins are Plotted
  - Taper Wing looked at Zee Stiffeners that where Hweb ≤ 2.25” and Hweb = 3.5”
  - Constant Chord optimized on Hweb ≤ 3.5”
  - Substructure (Spars & Ribs) sizing was not changed as loading did not change
- Taper Wing Showed that the Skins were sized by Stability and the Constant Chord was Sized by Strength



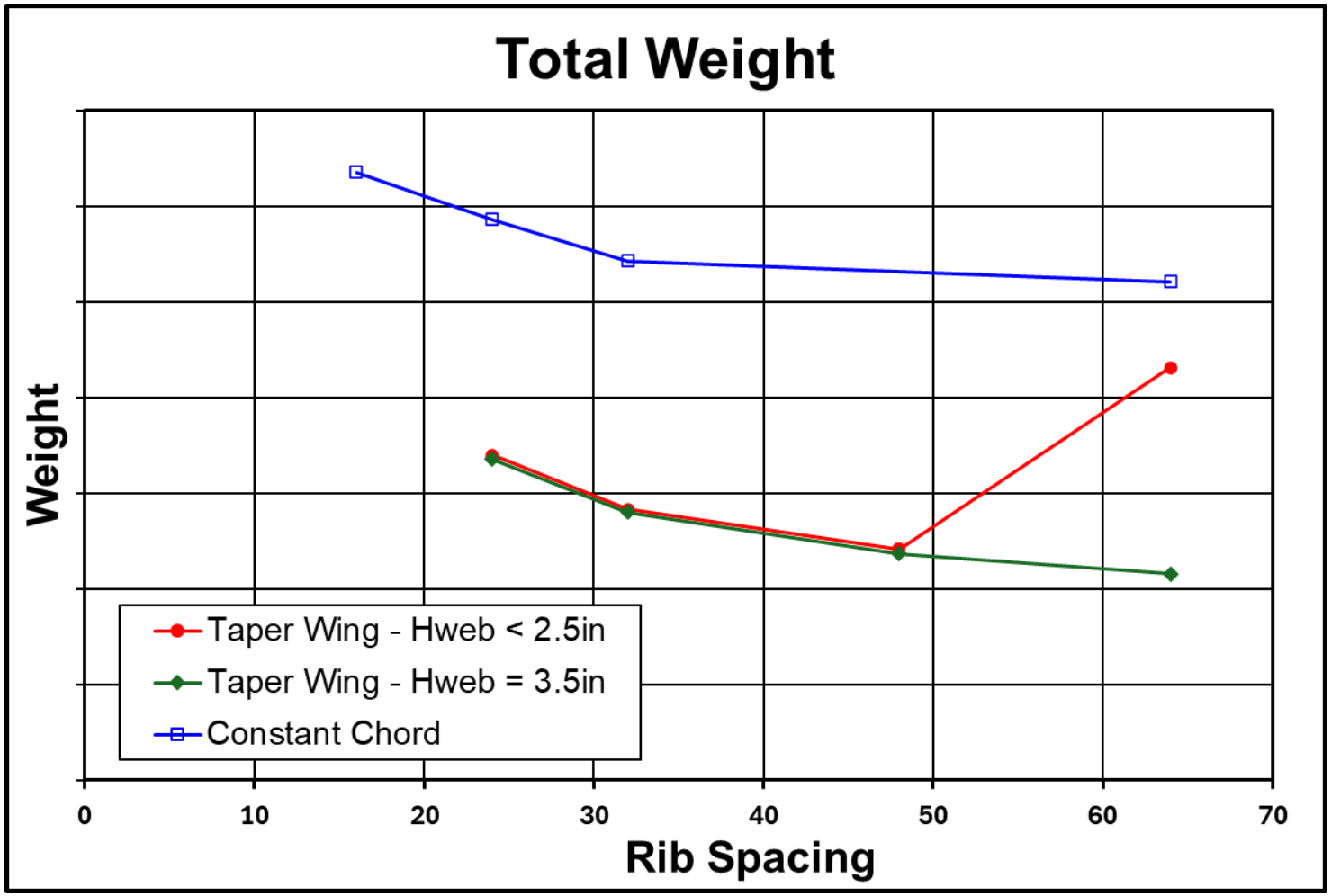
Rib Weight Trends

- Rib Weight was Generated for each of the Sized Interior Ribs
  - Trend Line was used to estimate rib weight as a function of span
- Total Weight of the Wing is the Skin & Spar plus the Ribs
  - Quantity of ribs depends on rib spacing
  - Trendline used to estimate rib weight as a function of span
    - Weight reduction in rib sizing not accounted for in Estimated Weight



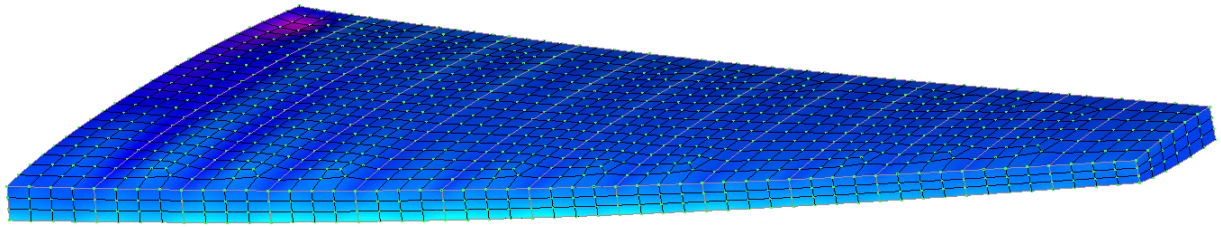
Wing Optimization

- Wing Sizing Needs to Account for Rib Spacing
  - Wing Sizing plus additional ribs based on rib spacing
  - Does not account for rib weight reduction for increased quantity
- Assumptions Show that 64” Rib Spacing with 3.5” Tall Zee Stiffener is Most Efficient
- Note that HyperXpert is not Run for this Phase
- Constant Chord being Strength Driven Results in Overall Heavier Configuration

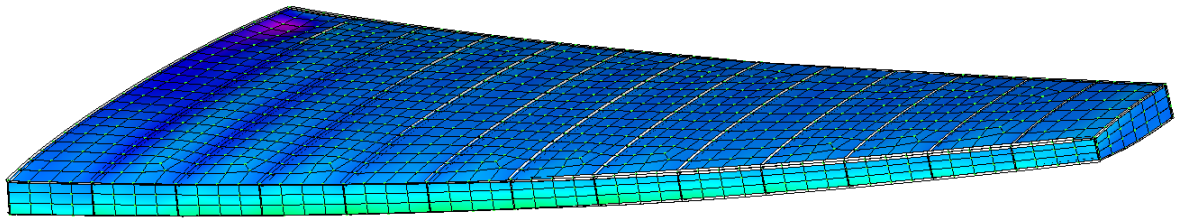


Updated Sizing – Taper Wing

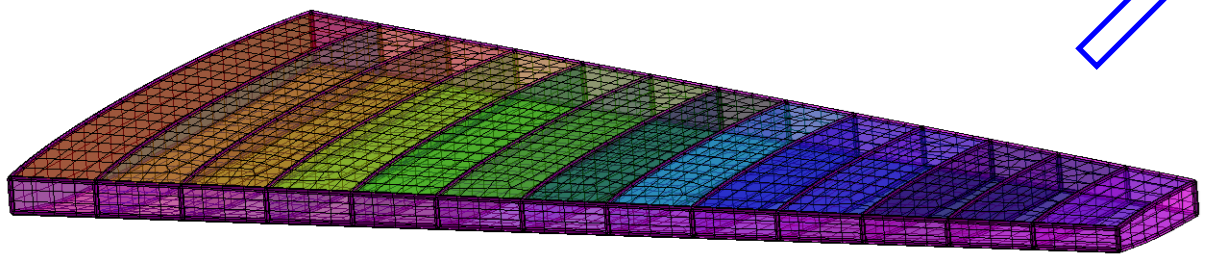
- Using the Estimated Sizing the FEM is Updated using the 32” Rib Spacing
  - Used to see how sizing a simplified FEM compares to one with all the structured modeled
  - One more sizing loop using Updated Properties from HyperX sizing is performed



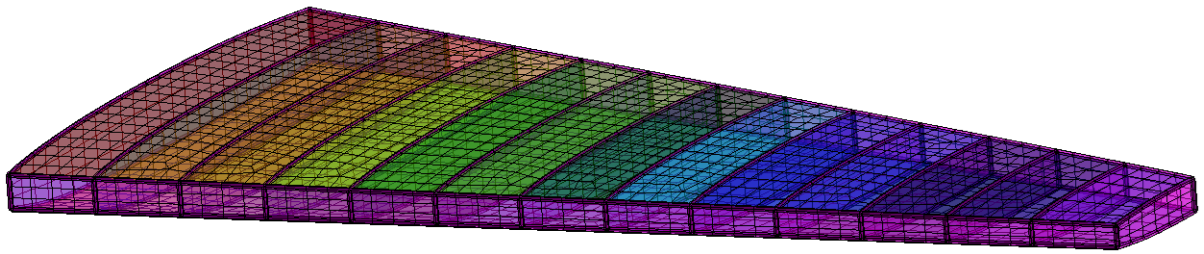
Added Ribs



Update Properties from HyperX
(Plate & Flange Thickness/Width)



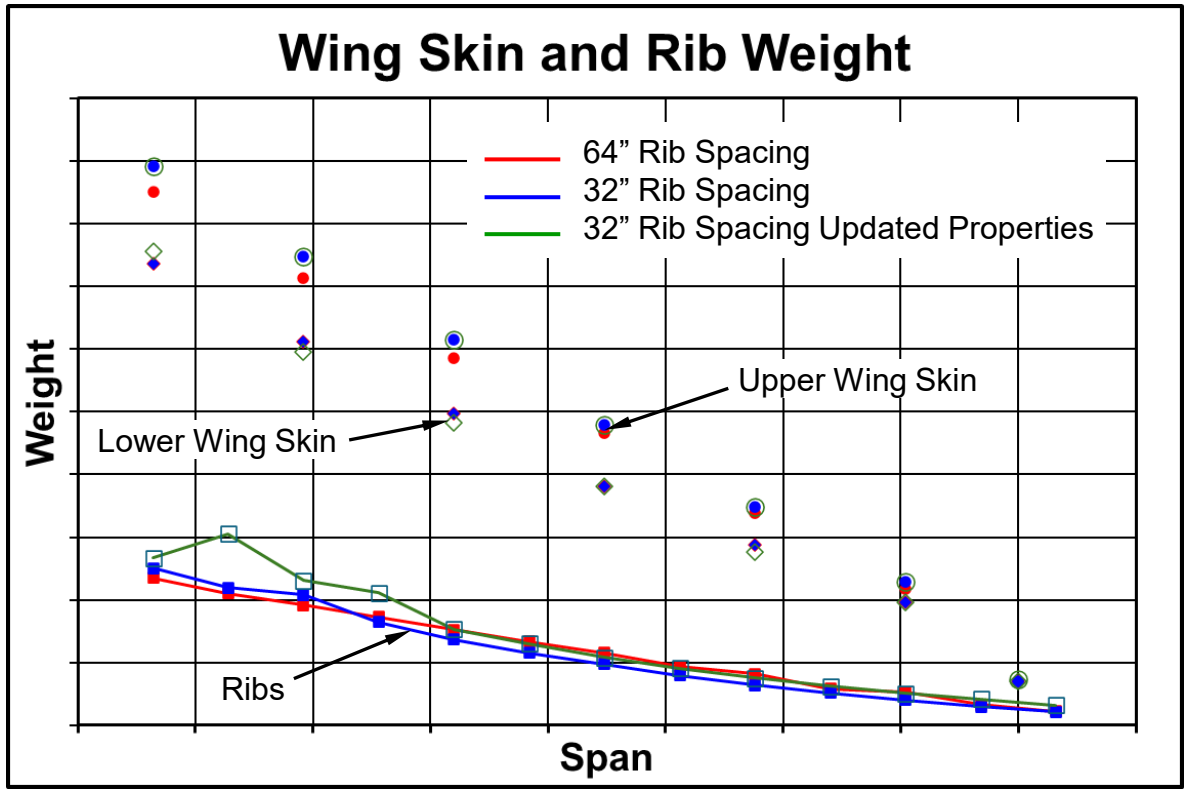
Weight = 4,428 lbs for 2.25” & 3.5” Stiffener



Weight = 4,429 lbs 3.5” Stiffener

Summary – Taper Wing

- Using a Coarse Structural Layout HyperX Can Give Representative Weight Values
  - Rough sizing was within 1% of Detailed sizing with one iteration of property updates
  - Highly redundant structure may need more sizing updates



Structure	64" Rib	32" Rib		32"Rib Upated Prop	
	Weight (lbs)	Weight (lbs)	Diff (lbs)	Weight (lbs)	Diff (lbs)
Upper Wing	1620	1690	70.0	1692	72.0
Lower Wing	1283	1390	107.0	1379	96.0
Front Spar	238.5	195.1	-43.4	179.4	-59.1
Rear Spar	317.2	266.7	-50.5	286.8	-30.4
Kick Rib	151.8	146.3	-5.5	133.4	-18.4
Ribs	777.1	740.2	-36.9	758.2	-18.9
Total	**4388**	**4428**	**40.7**	**4429**	**41.2**

Comparison based on 3.5” Stiffener
64” Rib – Rib Weight based on Measured Ribs plus Projected Weight of Additional Ribs for 32” Spacing

Conclusion

- HyperX gives Accurate Weight Estimates with a Simple Layout
- HyperX can be used to Settle the Age-Old Question of “What Spacing is Optimal”
  - Data can be quickly obtained to drive critical decisions on sizing
  - Allows structures to provide data on impacts for configuration
- Using a Data Oriented Approach Corrects for Inaccuracies that Mass Properties Parametric Models may Not Predict
  - Mass Properties would not account for the difference in sizing criterion
    - Taper Wing sized by stability, Constant Chord primarily sized by strength criterion
  - Provides knowledge to analyst on critical sizing criterion and expands load path understanding
- Structural Trades can Performed much Earlier in the Design Process to Help Influence Weight Sensitive Designs
  - Help mature Mass Properties estimates by using Estimated Weights instead of Parametric Weights

Questions?