Is Joined-Wing Configuration Feasible for Transonic Civil Aircraft ?

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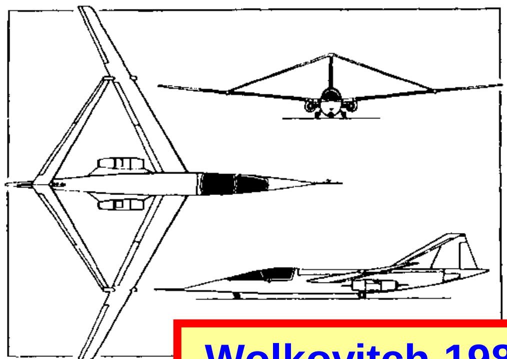
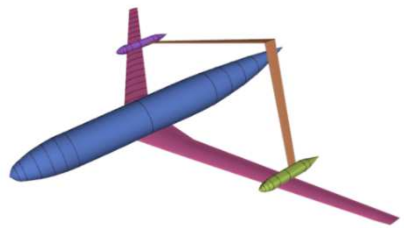


Wolkovitch 1986



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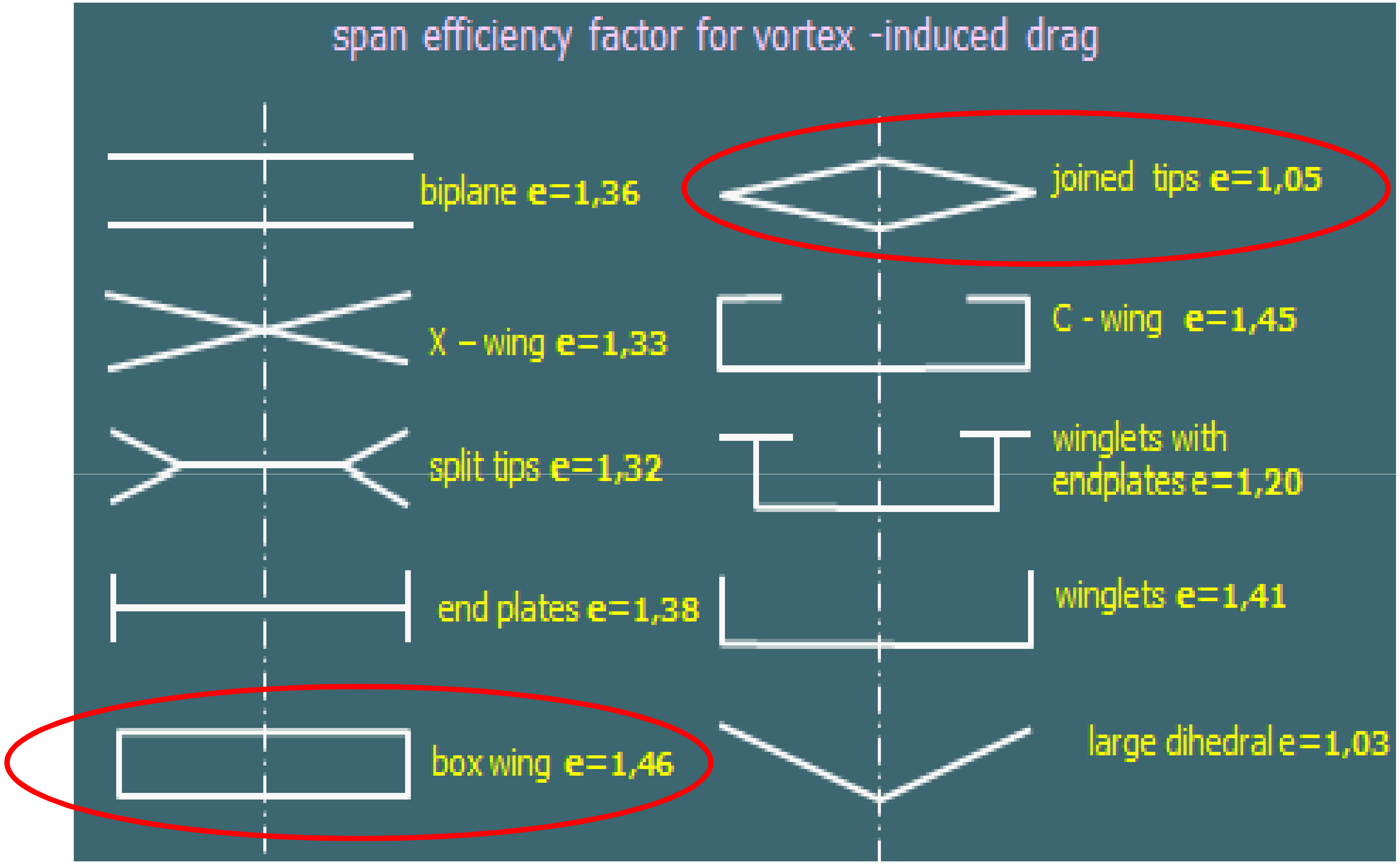
- Introduction & Background
  - NOVEMOR EU Project
    - Conventional configuration – morphing tips etc
    - Join wing configuration feasibility
- Trade offs: non-planar wing concepts
  - what are the advantages/promises of non-planar wing concepts
  - Overview past & present work - JWA
  - aircraft targeted (short range airliner)
- What are the challenges?
- Work in Progress – Regional Jet
  - Transonic wing design - Joined wing
- Conclusions

Wing Shape & Span Efficiency Factor



Munk stagger theorem → Transonic design → sweeping the wing does not affect vortex drag provided lift distribution remains constant when staggering lifting surfaces

Transonic BoxWing – Pros & Cons (Torenbeek)

Is it a competitive design for civil transport ?

Bottom Line – “*some inherent properties makes this proposal **questionable***”:

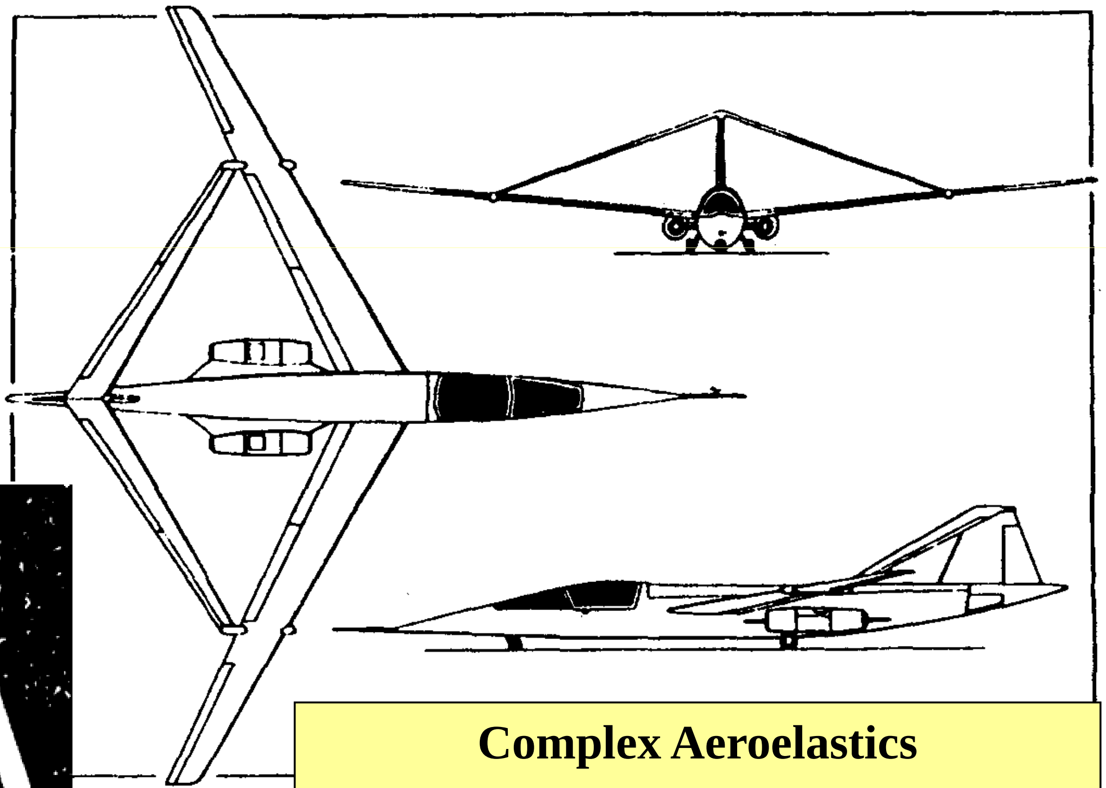
- Aerodynamically and structurally complex
- Costly to develop into efficient lifting system free from *unacceptable aero-elastic behaviour*
- Low induced drag gained at cost of:
  - increased parasitic drag
  - reduced max lift due to low chord Re number
  - presence of non-lifting vertical tip planes
- Due to integrated character, family concept is impossible without major re-design

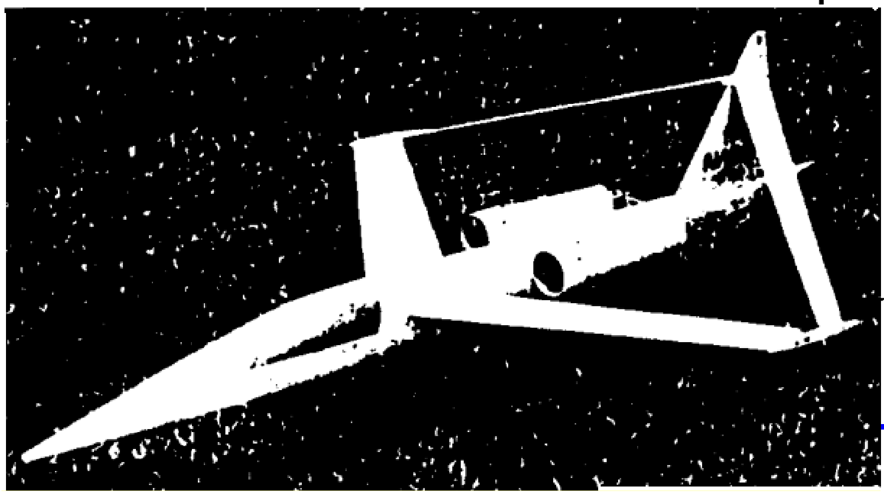
However finds *“**JoinWing** has **inherent advantages** over conventional configurations making it a serious candidate for designing airliners of widely different capacities”*

WOLKOVITCH (1986)
Joined Wing Aircraft JWA

Advantages Claimed

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



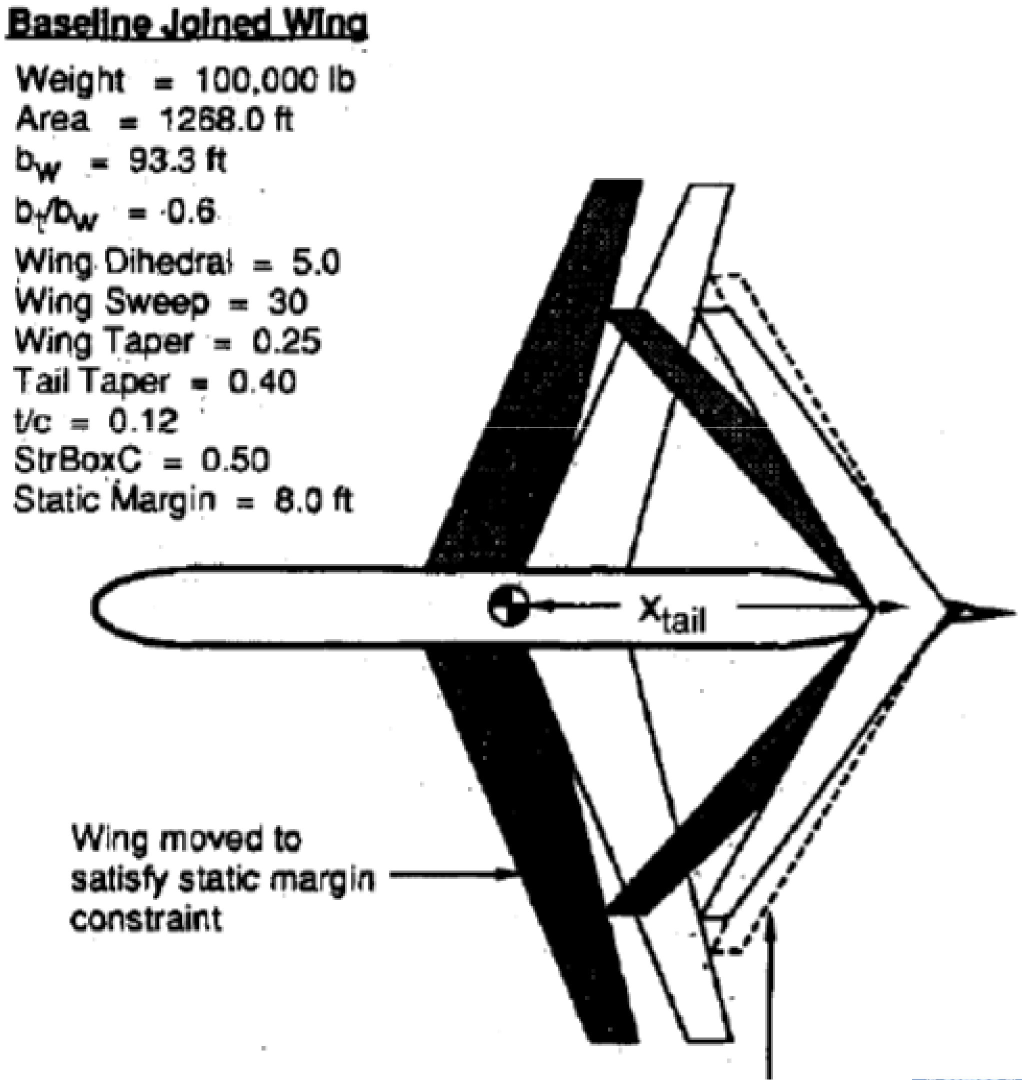


Complex Aeroelastics

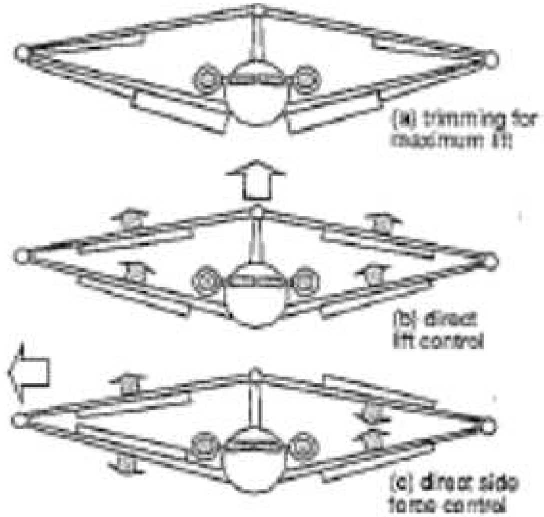
Highly Integrated Structures & Aerodynamics

Kroo/Gallman Joined-Wing baseline (1991-96)

- AR ≈ 6.86 – (Very low !!)
- wing weight depends strongly on applied loads
- JW structures carries loads differently from conventional A/C
- JW results compared to DC-9-30
- Fully-stressed design to avoid buckling instability increases DOC by 4%
    - maybe less for other structure design
- Any design change to reduce tail sweep improves performance
- Low max lift in TO → takeoff field length



Torenbeek Book (p177-82) → JWA Advantages Claimed (1)



Advantages claimed….

- Lightness
- Stiffness
- Low vortex drag
- Low wave drag – good transonic area distribution
- Direct lift & side-force control capability
- High trimmed max lift
- Quieter in climb-out & landing approach than conventional A/C

Structural Principles & Weight

- Low structural weight – Note: effective bending axis tilted
  - Thinner wings possible (RBM less !!)
- Less flutter tendency
- Fuselage supported at 2 points...... Wide body (2 aisle feasible)
- Under positive load factors, rear wing in compression → *overall column buckling is critical design issue*

Torenbeek → JWA Advantages Claimed (2)

Aerodynamic Aspects

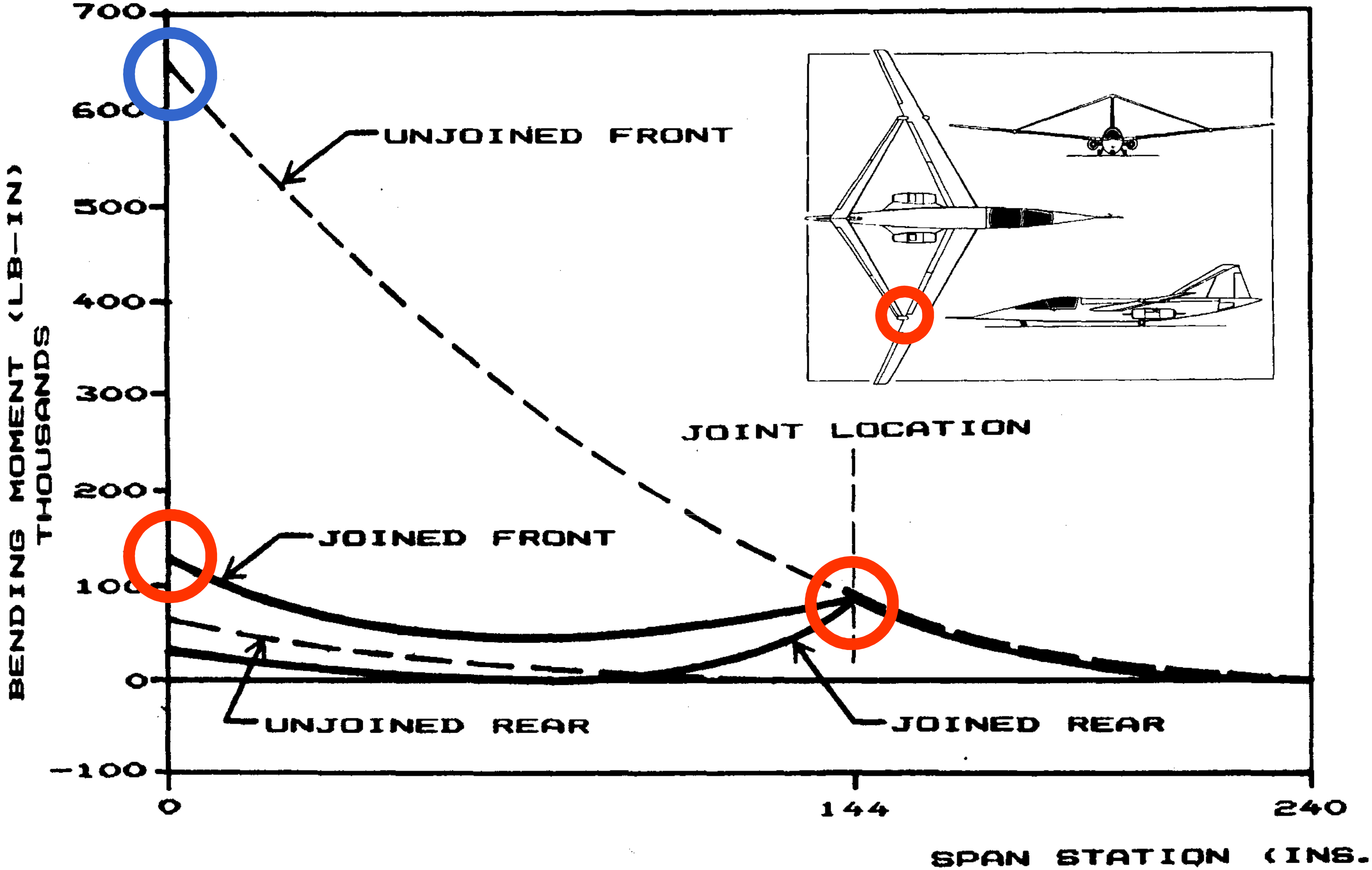
- Low CDi (higher effective AR possible) see CEAS 2009 paper
- **CDi varies as 1/span^2**
- Low Trim Drag
- Low wave drag - better volume distribution

Design integration

- Integrated structure requires deeper analyses
  - *Integrated* Aero + Structures + unsteady analysis
- Locate undercarriage in Fuselage - less weight but blip/fillet required on fuselage

Stability & Control

- *" a well-designed JWA configuration is likely to have S & C characteristics as good as, or better than, a conventional one"* .... Torenbeek

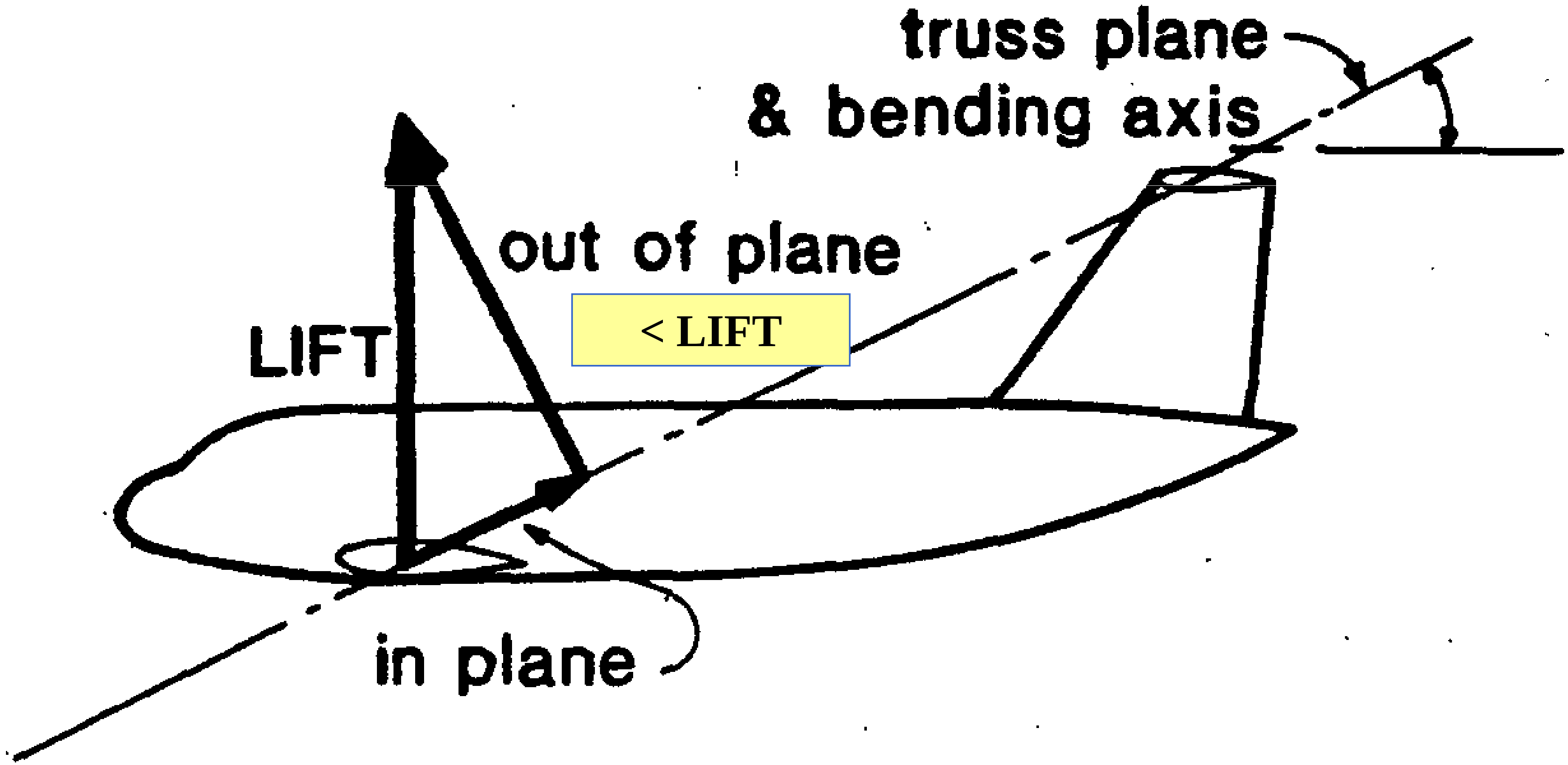


BENDING MOMENT RELIEF - JW (0.6 y/s)

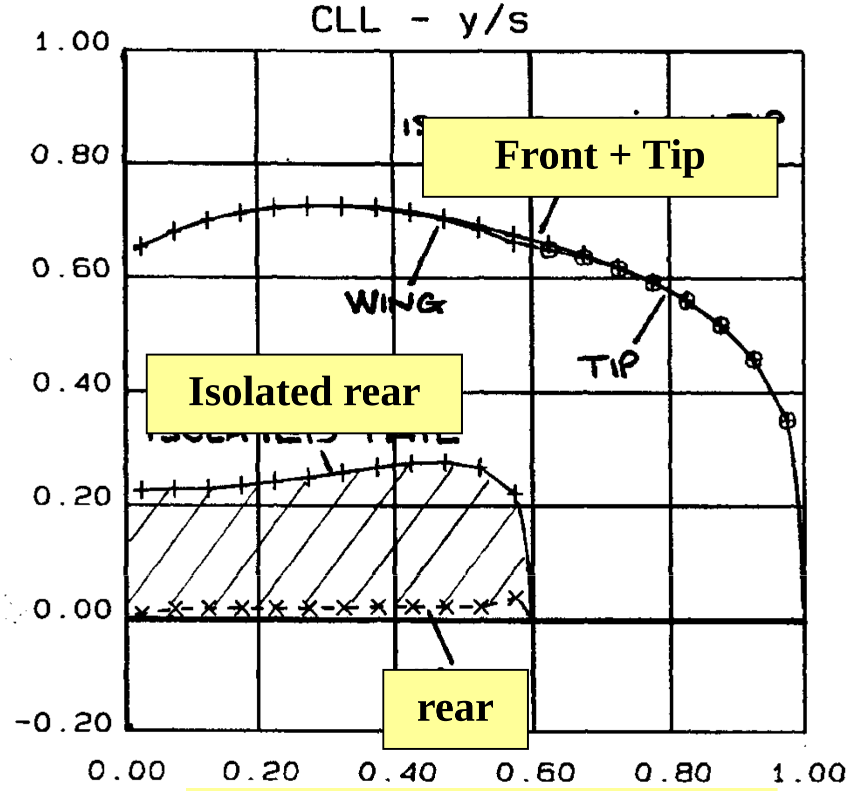
Tilted Bending Axis & Components of lift

Less Bending Moment !!

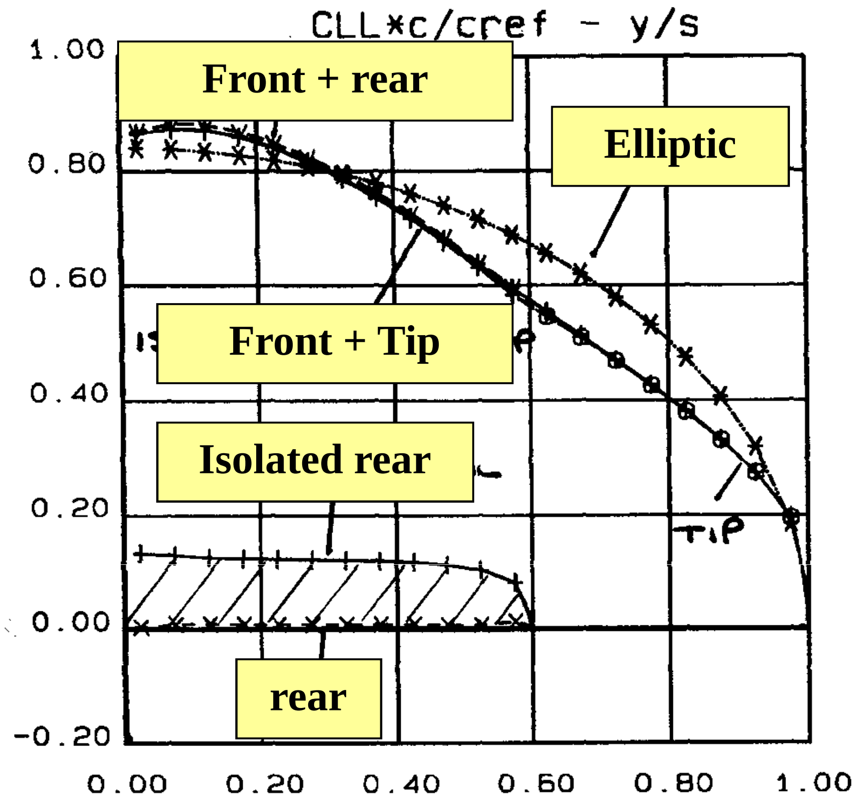
- **Out-of-plane** components bend wing structures about bending axis tilted to longitudinal axis
- **In-plane** components well resisted by truss structure formed by joined wings



JW1 - SPANWISE LOADINGS WITH & WITHOUT MUTUAL INTERFERENCE.
Mach 0.35, AoA = -2 deg, CL = 0.66

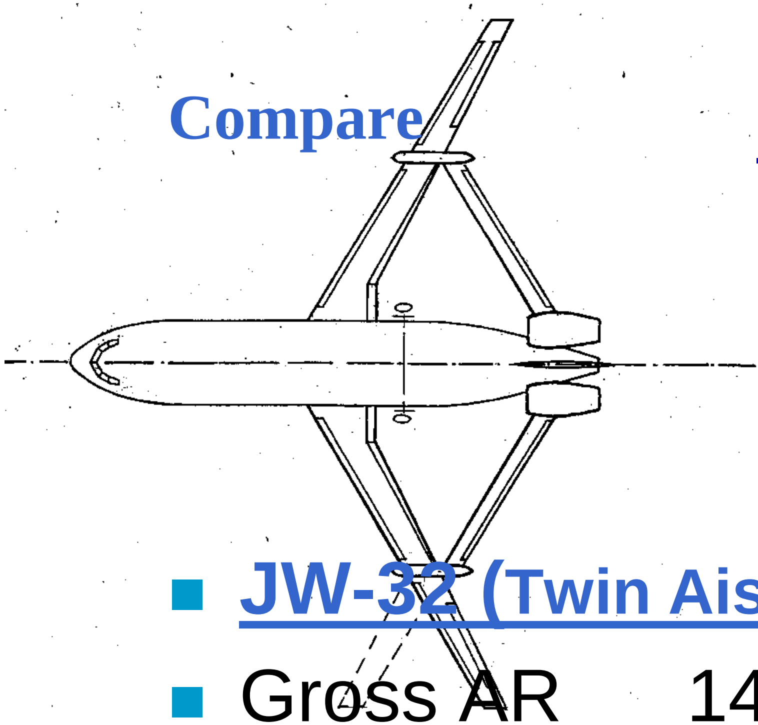


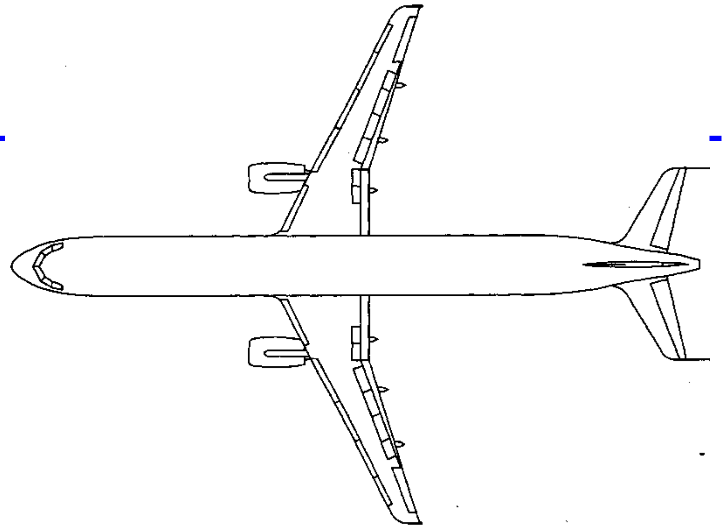
CLL – y/s



CLL*c/cref – y/s

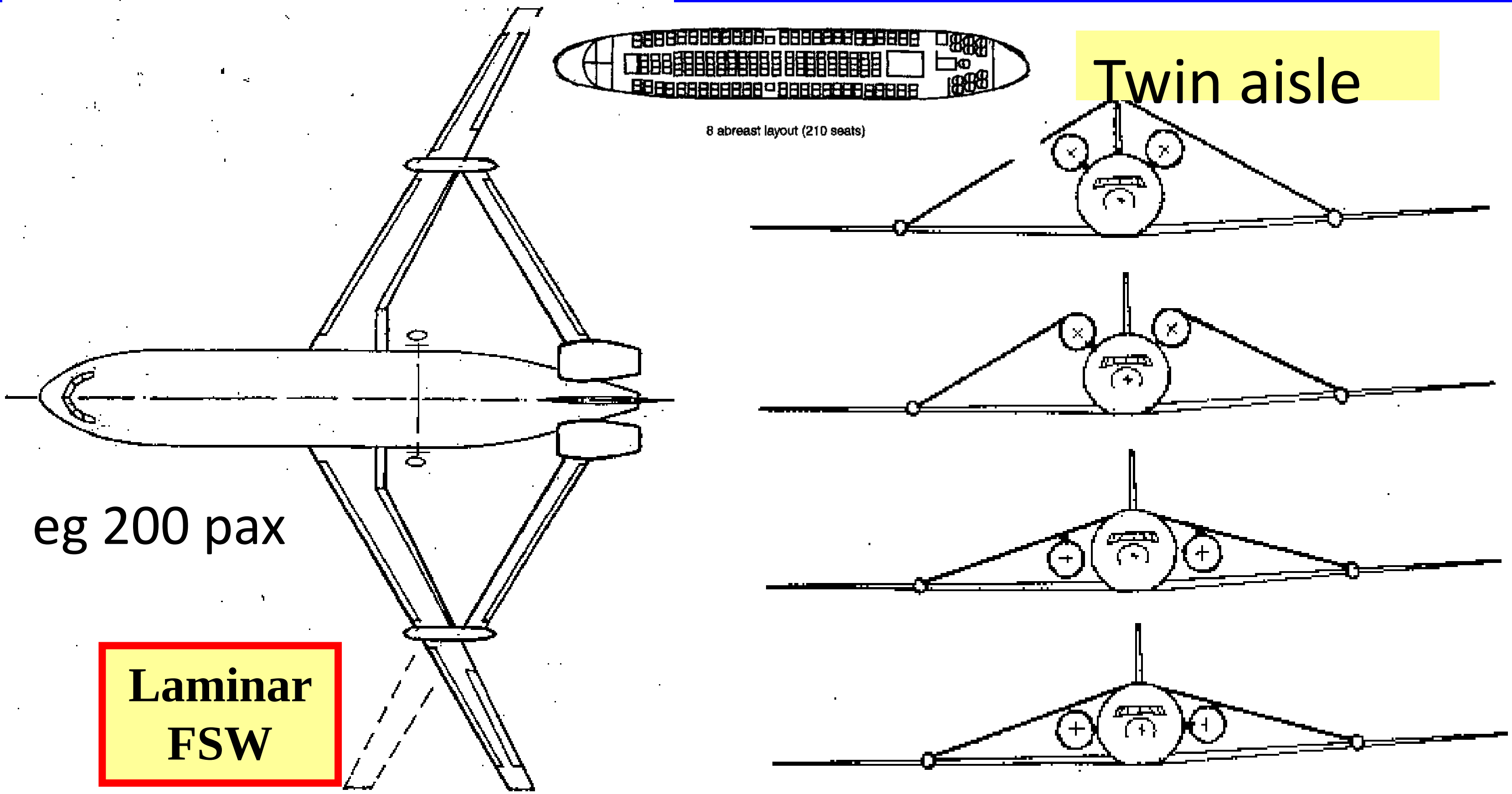
Compare





JW-32 (Twin Aisle)		A321-100 (Single Aisle)	
Gross AR	14	about 10	
b/Swet$^{1/2}$	1.53+	1.15	
L/D	21	18	
Wings Fuel	600	837	ft^3
sfc	0.55	0.57	
X	18370	13750	nm
C_{Lmax}	2.3	2.9	

Joined-Wing Concept for Efficient Civil Transport

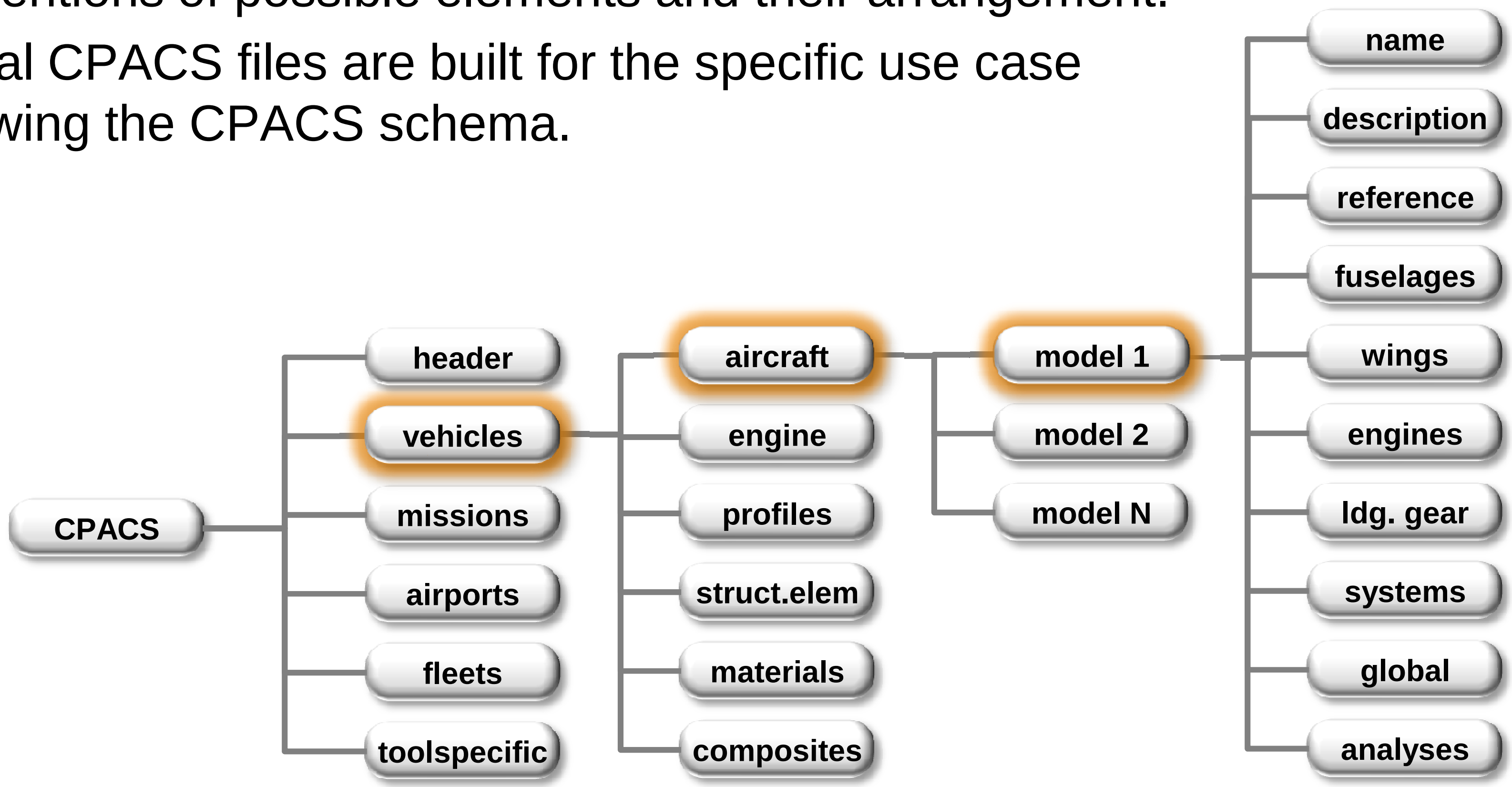


- Nangia CEAS 2009 Paper: **JW32**
  Aerodynamic – Efficient Configurations& Structural Design Challenges Arising – Joined Wings & Oblique Wings

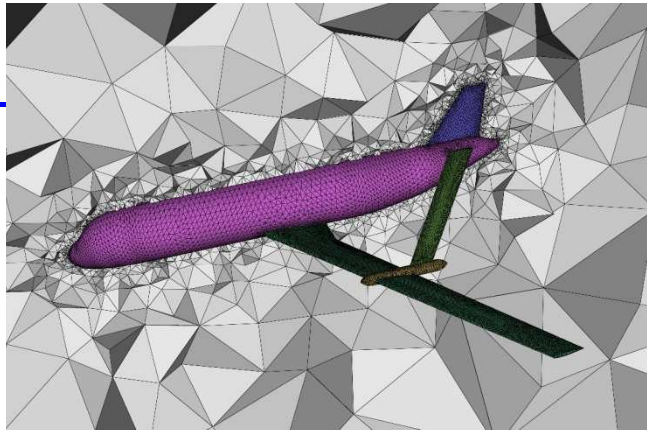
CPACS Data Model

Common Parametric Aircraft Configuration Scheme

- Extensible Markup Language **XML**: Open W3C **standard**.
- Text format using <tags> to build hierarchic structure.
- CPACS is a **XML schema definition** containing conventions of possible elements and their arrangement.
- Actual CPACS files are built for the specific use case following the CPACS schema.



Auto Grid Gen - Delaunay Meshes



"There exists one triangulation/tetrahedrization of (the convex hull of) a set of points such that the circum-circle/-sphere of any simplex contains no other points than its corners."

Chew: Surface mesh: 2D, use circumsphere.
- Careful on thin objects – wings, esp. near sharp TE
- High arithmetical precision required in geometric calculation

1. Initialization:
   Surface: quad mesh in parameter space,
   Volume: bounding surface points
2. Improvement:
   Iterate:
   add points, ***rearrange locally*** ("edge flips" in 2D)
   until all criteria satisfied

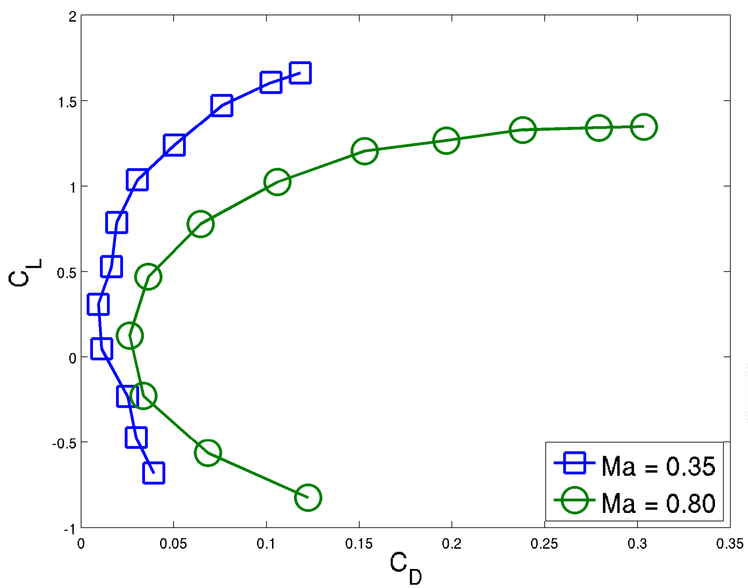
L.P. Chew, *Guaranteed-Quality Mesh Generation for Curved Surfaces,* Proc. 9th Annual Symp. Comp. Geometry, San Diego, 1993

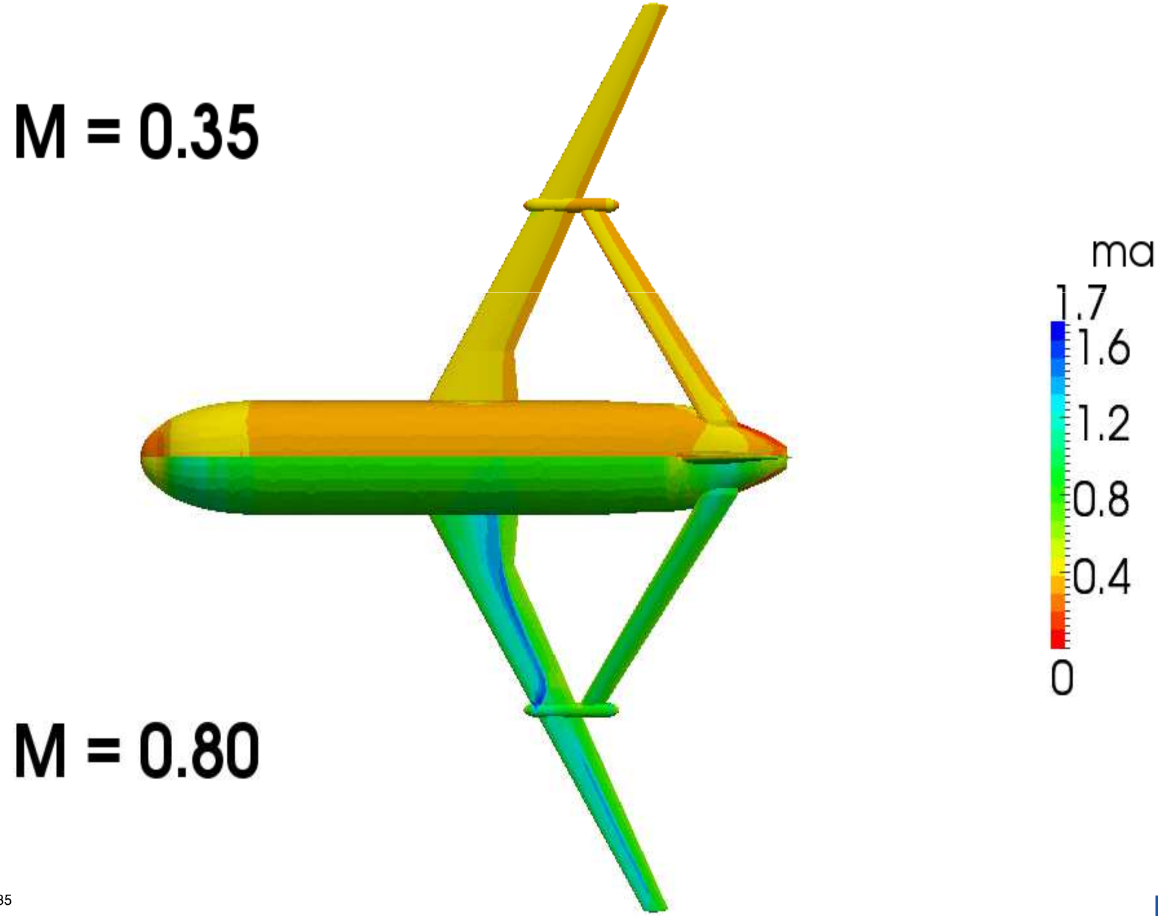
Initial Aero Characteristic: Euler Simulation

Two test conditions:

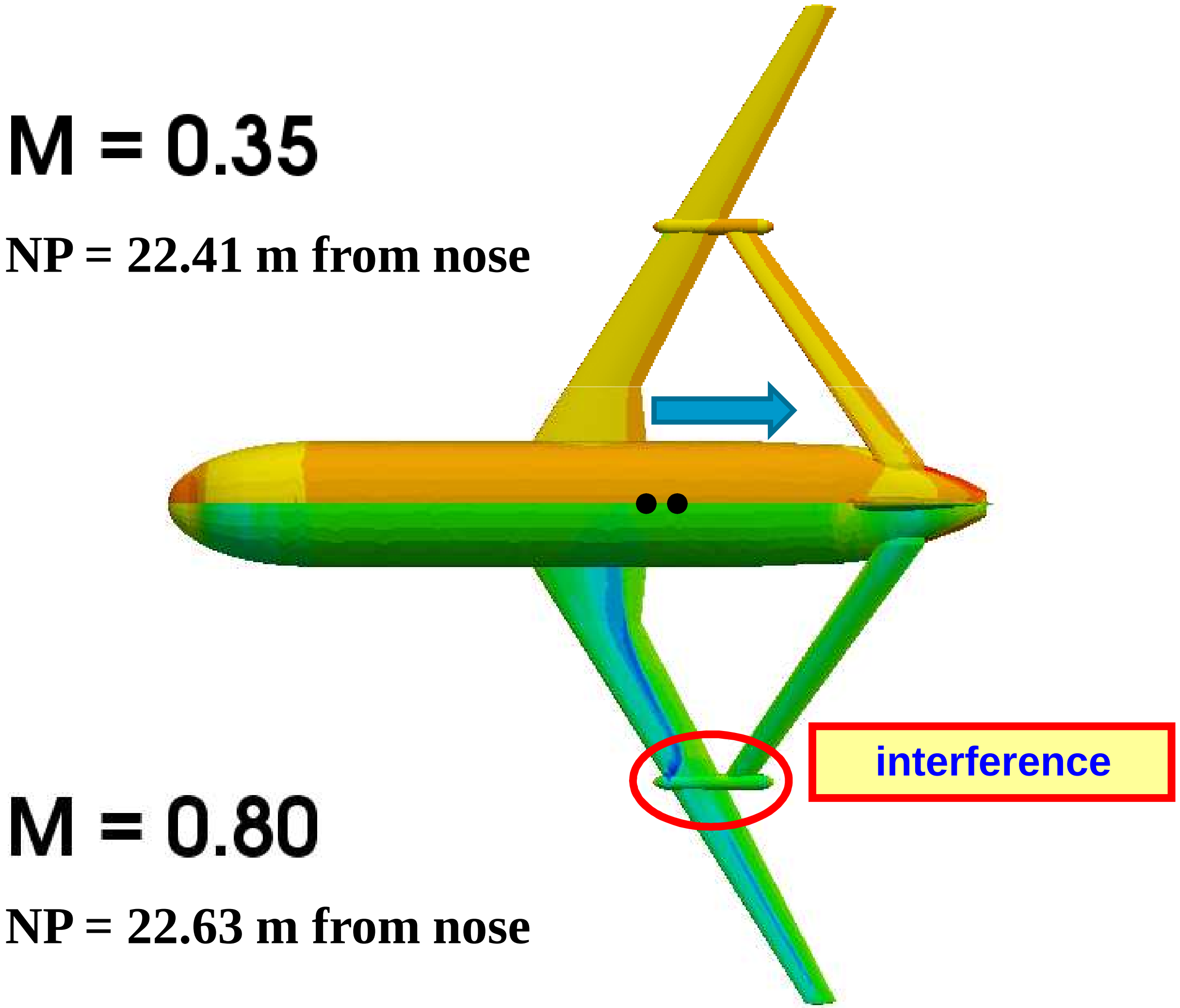
- M 0.35
- M 0.80
-Strong shock occurs at M 0.8 – high drag

CL = 0.3, Euler solution



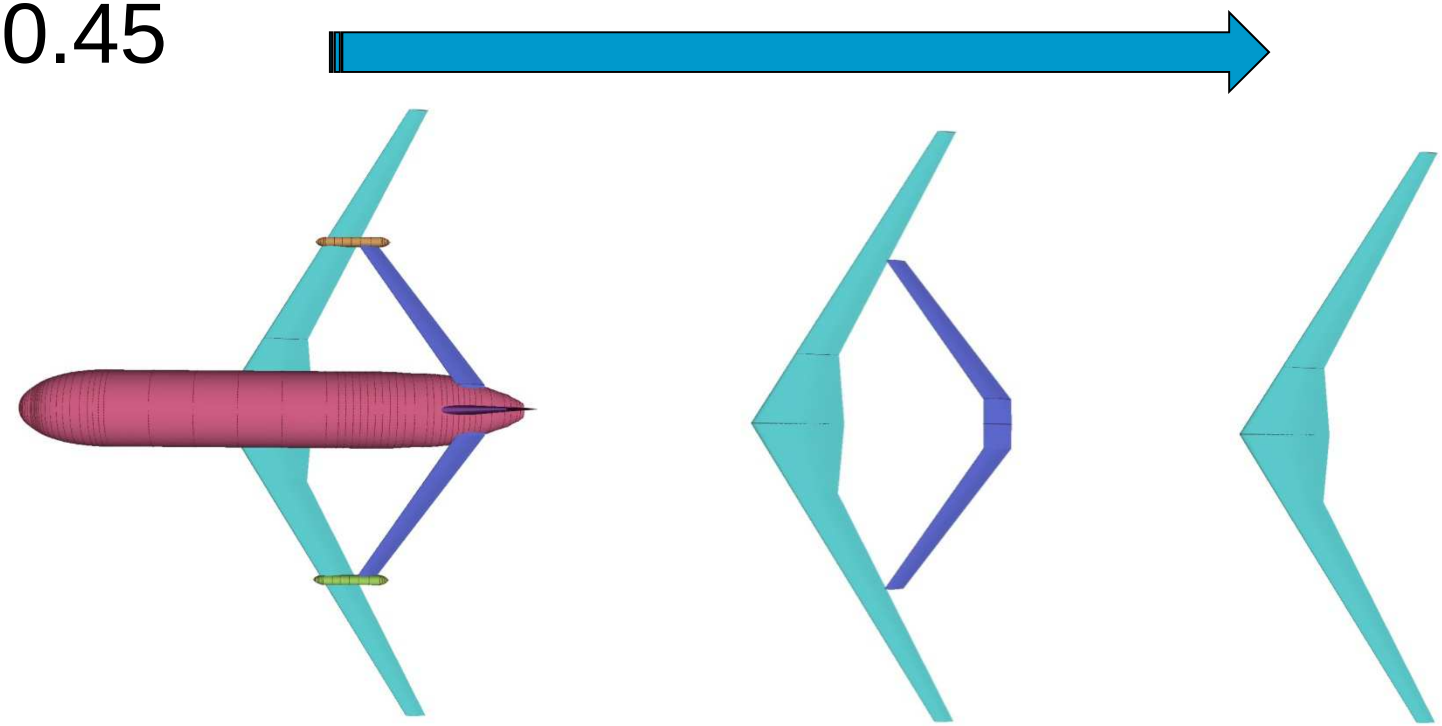


Shift of neutral point & Undercarriage Location Assessment

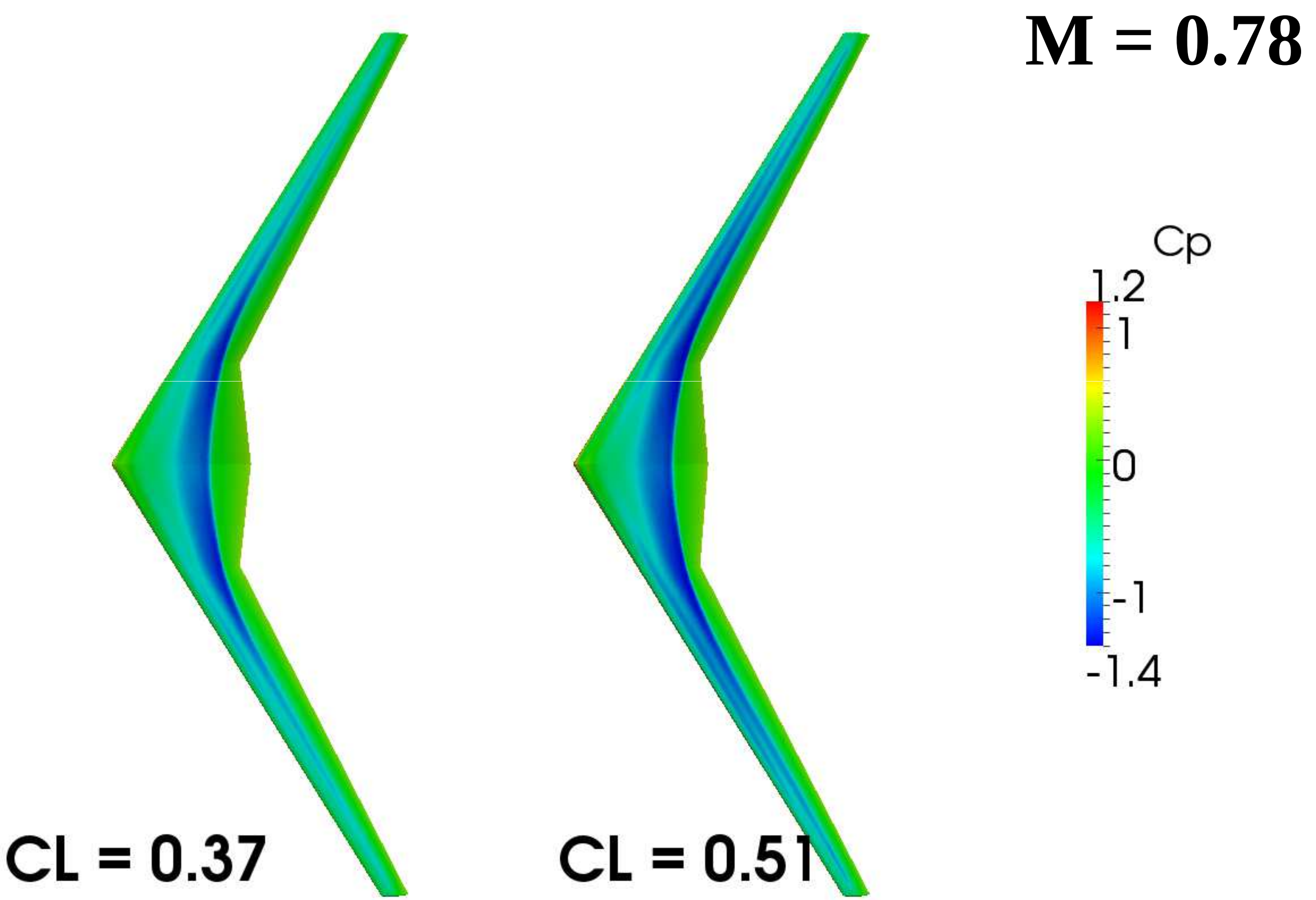


Simplification towards Main Wing Design

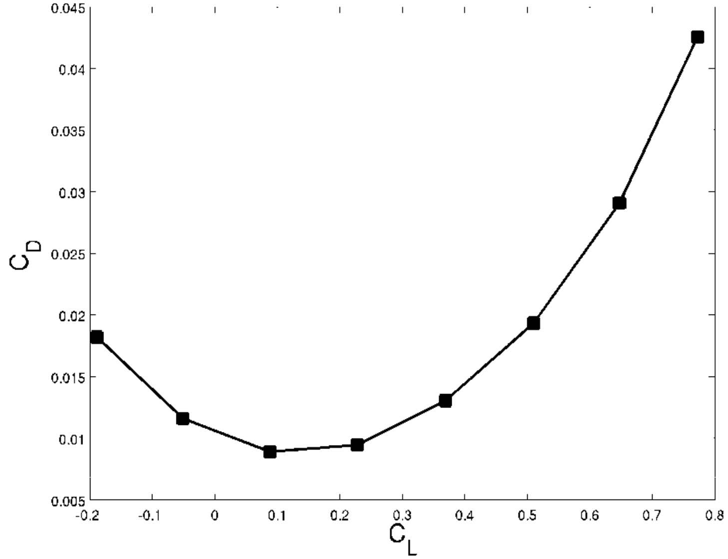
- First the Main Wing then the second wing
- Main Wing at Mach = 0.78, maintain CL ~ 0.45

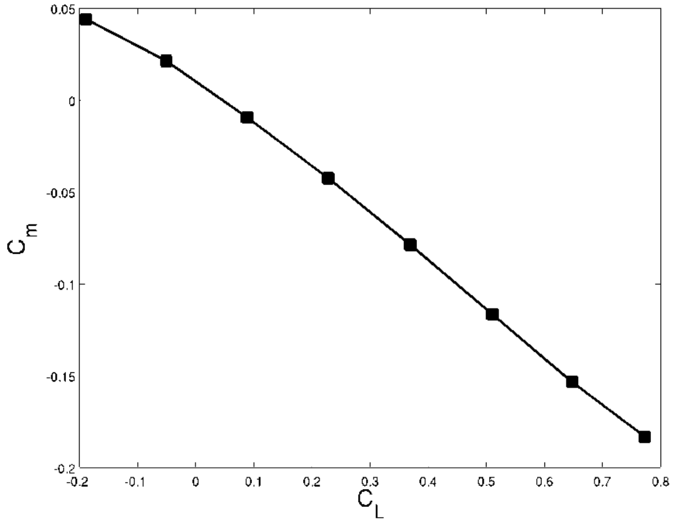


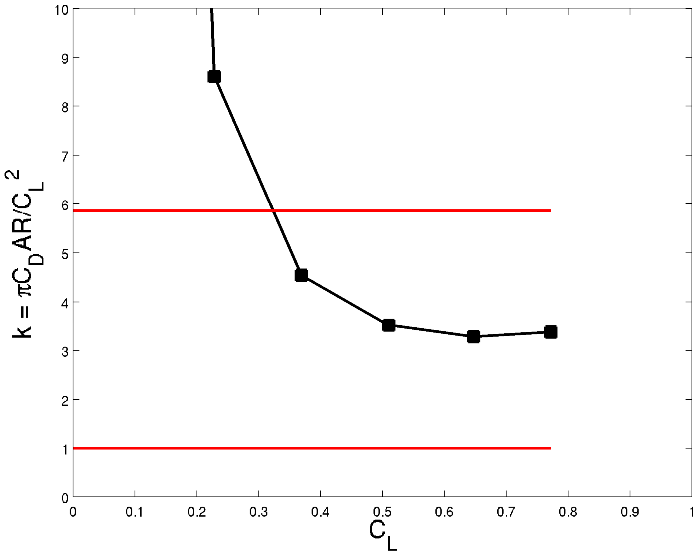
JW32 baseline with designed airfoils DS0



JW32 baseline with designed airfoils DS0



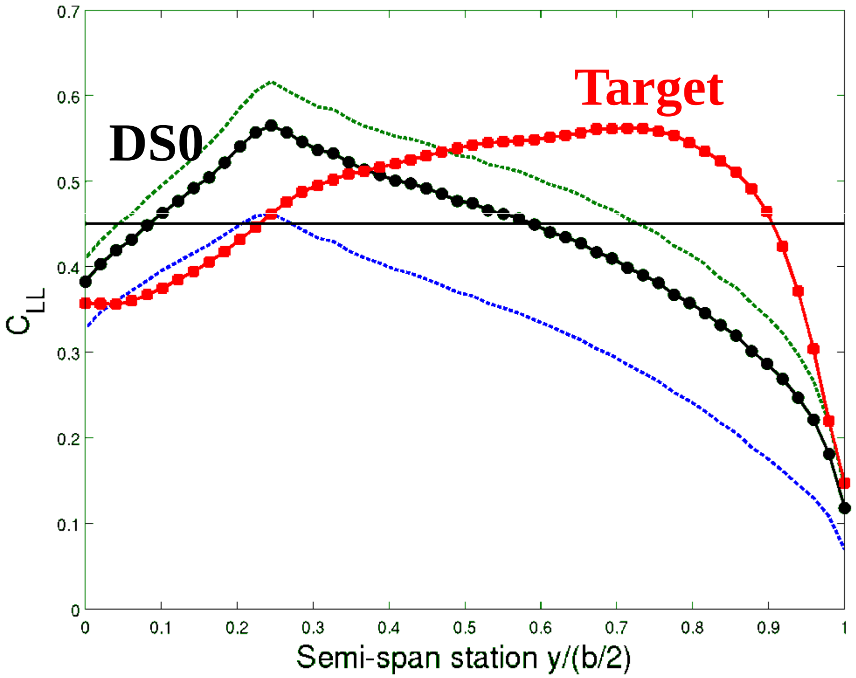


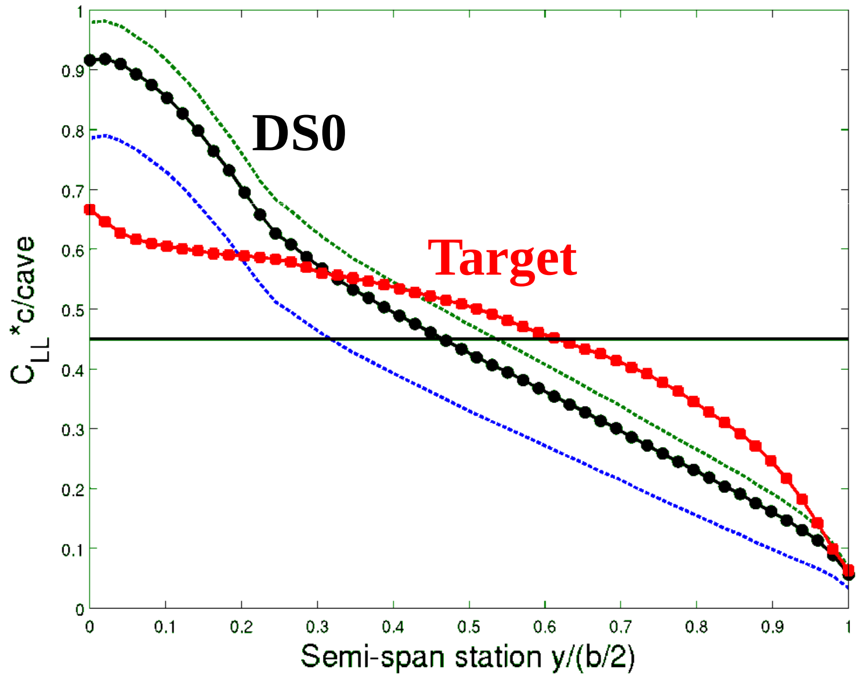


Room for optimization!

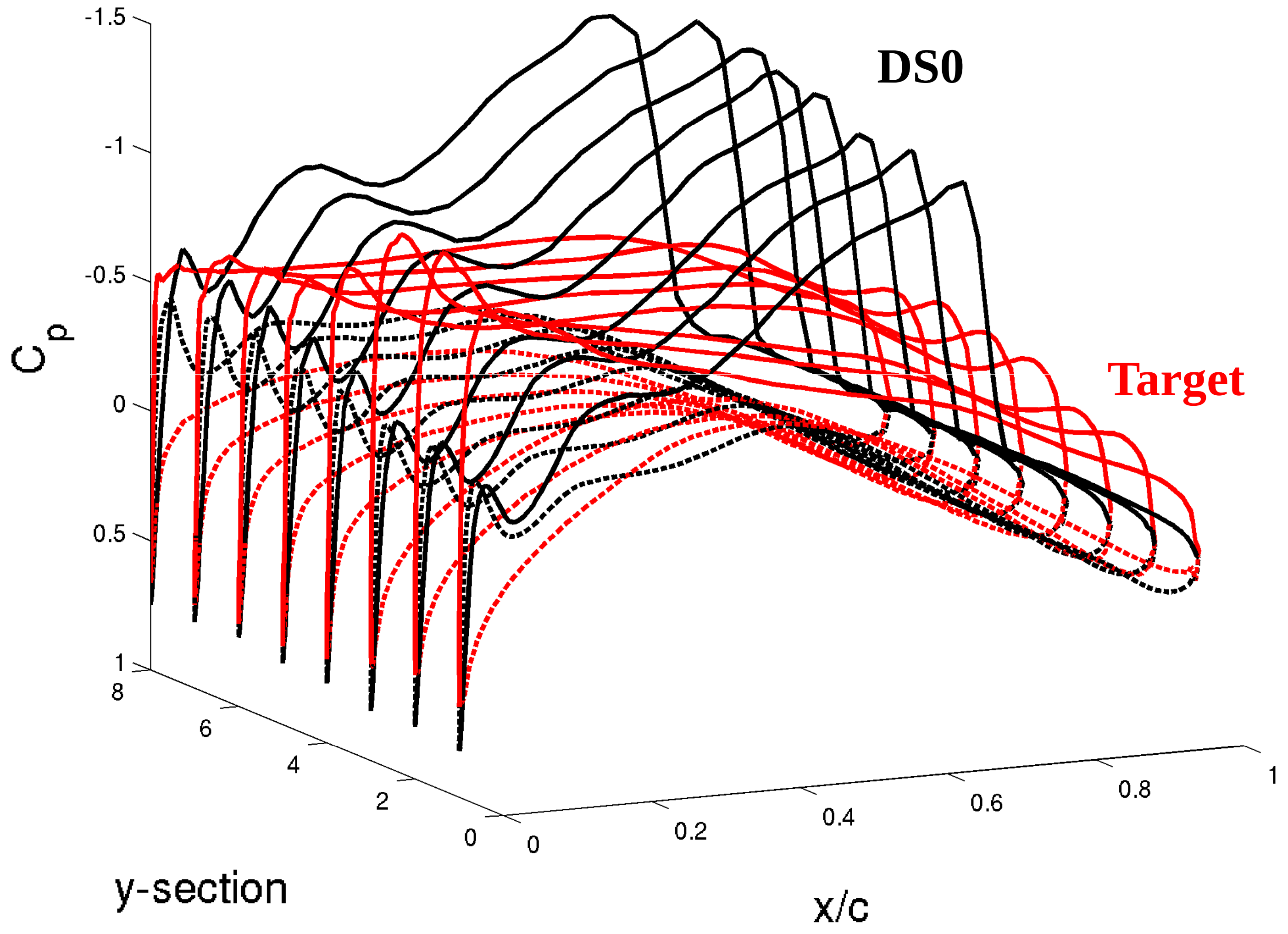
Choose a designed target, 1

- Designed point at Mach 0.78, CL ~ 0.45

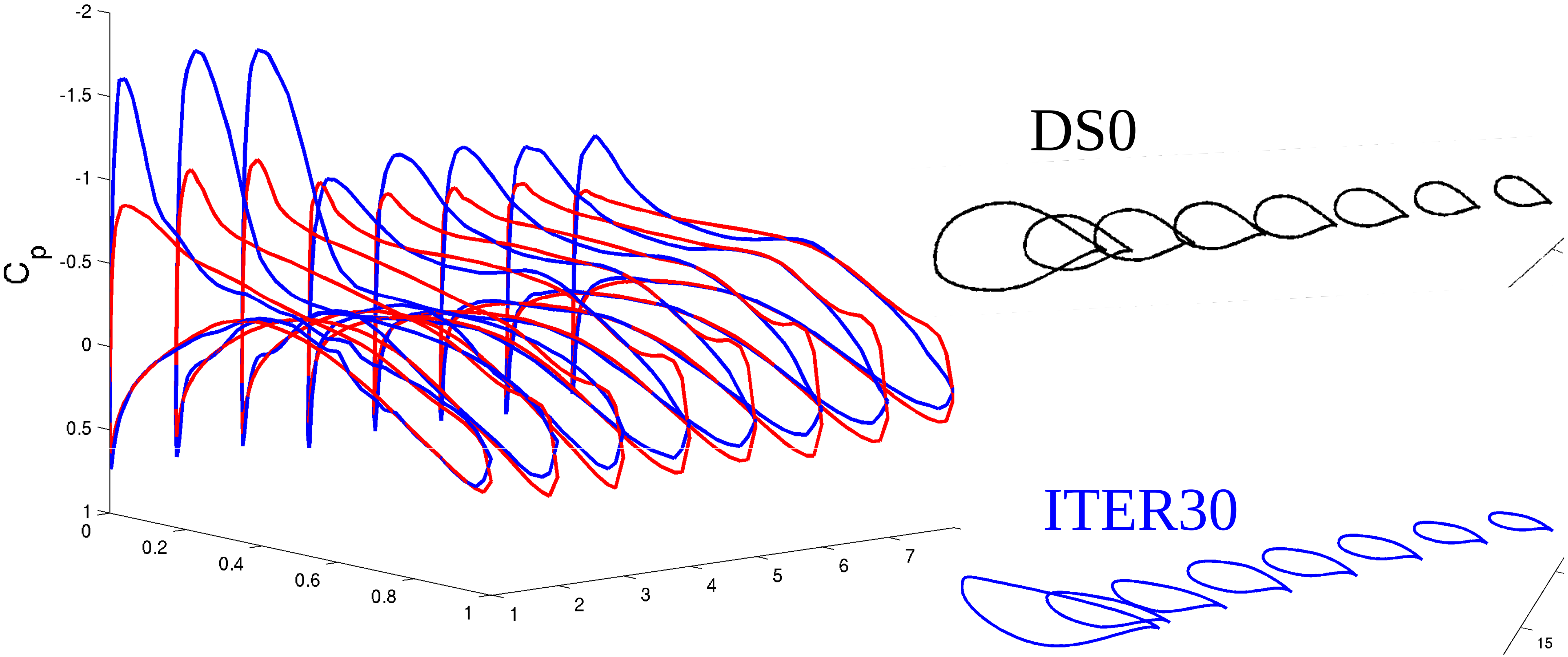




Choose a designed target, 2

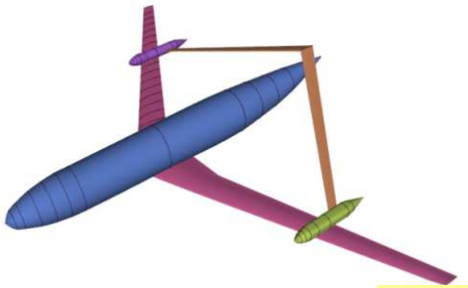


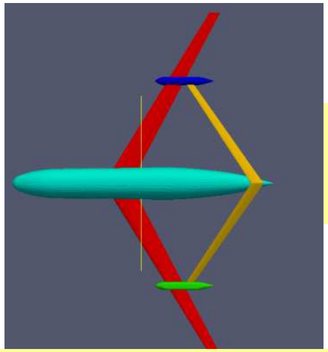
Work on progess – ITER 30: Shock Reduction!



	CL	CD
DS0	0.46367	0.01698
ITER-30	0.47682	0.01321
TARGET	0.46254	0.00947

Recent Work – Inverse Wing Design
Wings in presence of each other Needed

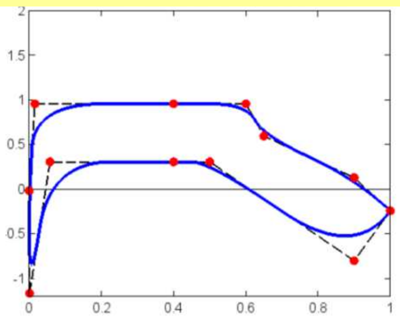


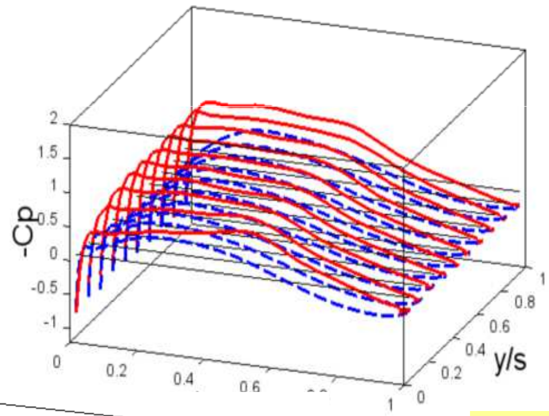


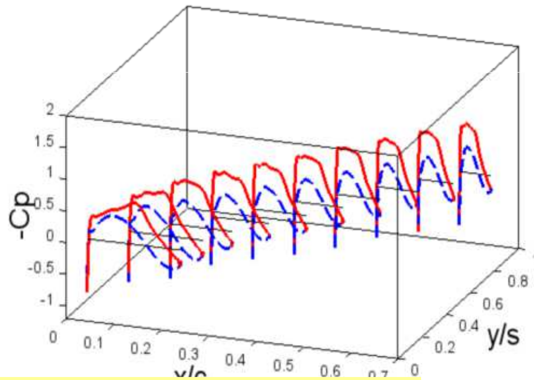
reduced WB interference

JW Single-aisle Civil Concept

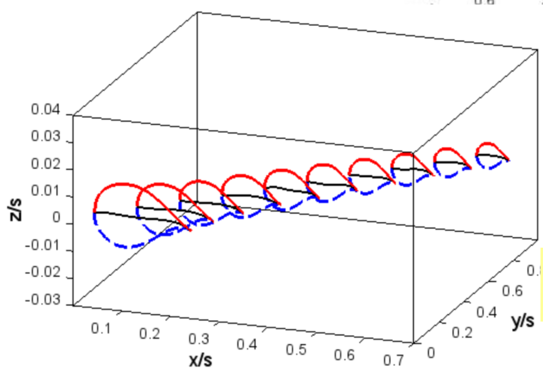
Typical Target 2-D Cp loading







3-D loadings achieved on Main Wing



3-D Wing Shape Achieved

Joined Wing, Challenges, CONSIDER

- **Efficient low-weight design – needs material props, structure / applied loads.**
- **Generic layout: continuous box: forward low wing to tip: optimum**

- **Rear wing joined to the forward wing on a fuel tank and fairing, reducing adverse aerodynamic interference. Load diffusion at join needs analysis.**

- **For positive "G", End loads & Buckling Modes on Rear Wing.**
- **The inner rear wing needs further evaluation. Attachment to rear mounted nacelles reduces the length of the rear wing; Attractive.**
- **Large negative sweep of the rear wing allows a high t/c for a given amount of compressibility drag: Benefit wing stiffness.**

- **Wing mounted moveable surfaces to be finalised - narrow and slender. The torsion loads fed into the wing box by the control surfaces needs evaluation.**

- **Ailerons Possibly substituted by roll spoilers !**

Joined Wing, Challenges (2), CONSIDER

- **Passive load alleviation desired - Washout through Aero-elastic tailoring**
- **Develop New structural tools / methods - scaled expts.**
- **Wing Structure Weight Analysis**
  - **Wing Junctions: Forward-Swept Rear Root**
  - **Fuselage / Propulsion integration, additional forces, Moments & Aero-elastics**
  - **Off-Design Performance, Lateral & Directional Aero-elastics**
  - **Experimental Work (Many Aspects)**

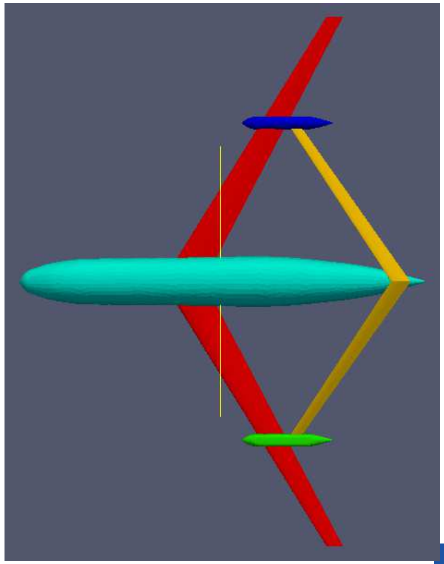
Concluding Remarks

Torenbeek concludes:

-*"Joined wing has several inherent advantages over conventional config → serious candidate for designing"*:

- Small-passenger planes
- Airliners – large & small

-*JWA is highly integrated concept with more complex lifting and flight control systems than usual → probably more costly to manufacture and maintain*



-Less solid knowledge base

- need to start

-Need now to built that knowledge base

- Configuration development
- Structural verification
- propulsion integration