LAGRANGE-7

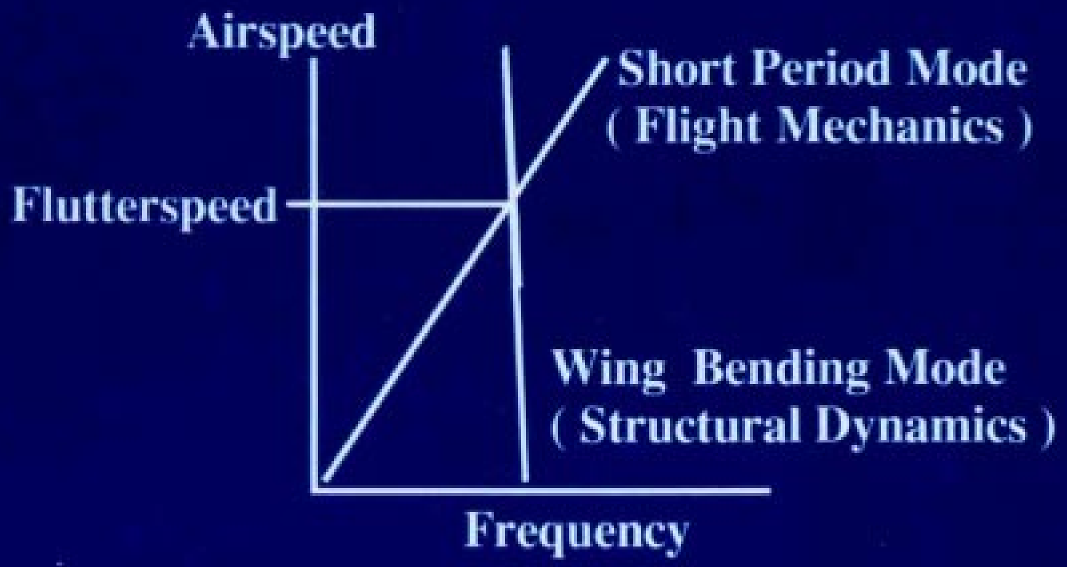
Examples

- Flying Wing Sailplane
- X-31A Wing
- RANGER 2000 Training Aircraft
- EUROFIGHTER Concept Studies
- Stealth Demonstrator
- Light Weight Fighter Wing
- Flutter Wind Tunnel Model
- Topology Optimization for Machined Frame
- Design Element Concept for Stiffened Panel

LAGRANGE-8: Flying wing sailplane SB-13

LAGRANGE-9 (Flying wing example)

Flying Wing Sailplane : Coupling Between Rigid Body and Flexible Aircraft Modes

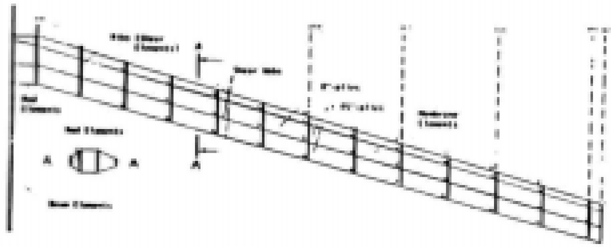


Instability would not be detected by individual disciplines

LAGRANGE-10: SB-13 Redesign optimization

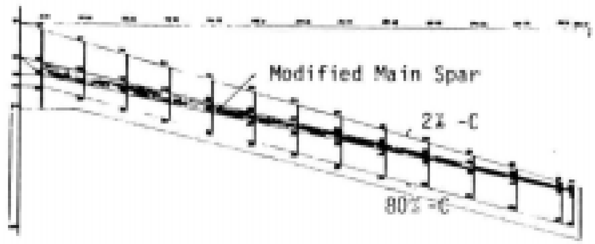
Flying Wing Sailplane

Initial Design

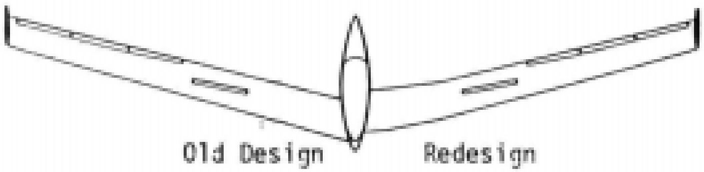


- Constant chord main spar
- Intermediate modulus fiber

Final Design



- Swept main spar
- High modulus fiber



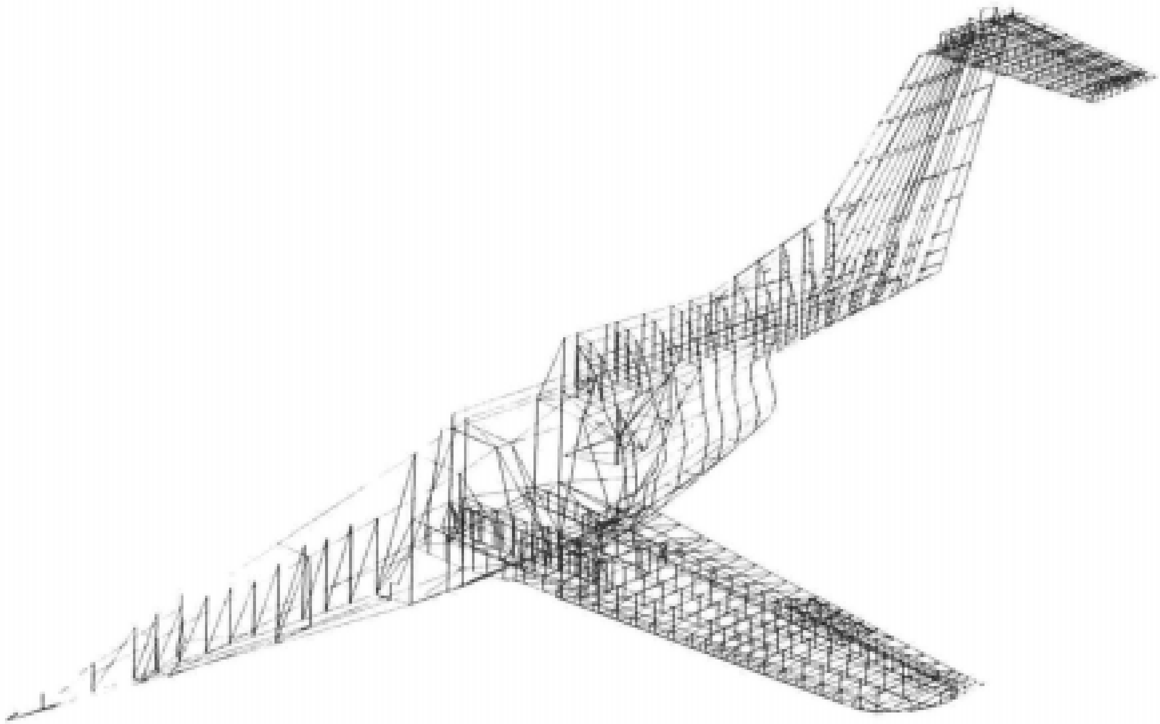
WING GEOMETRY MODIFICATION

- Flutter speed : 65 kts

- Flutter speed : 155 kts
- No weight penalty

LAGRANGE-11:

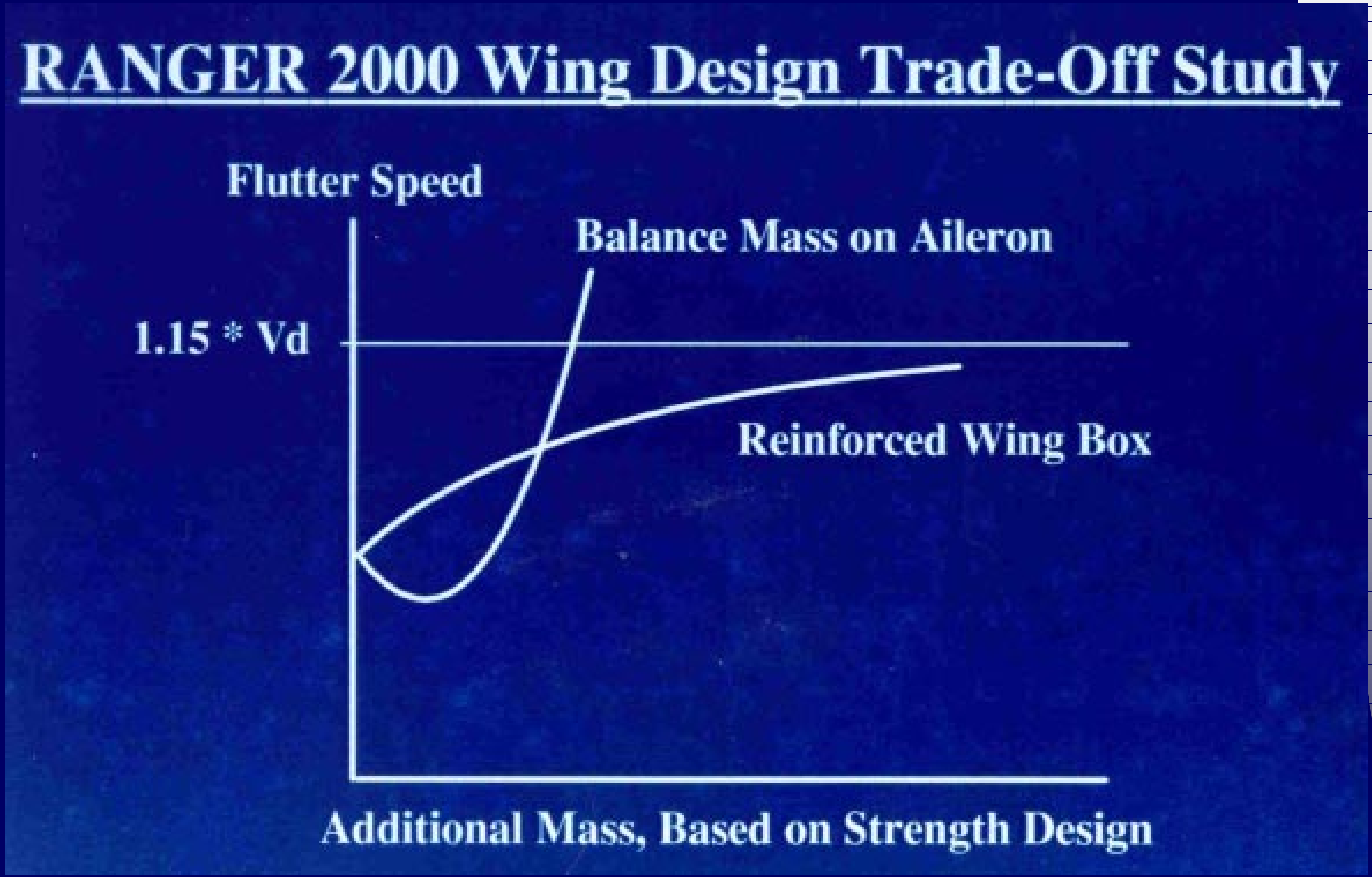
RANGER 2000 Training Aircraft



Finite Element Model for Aeroelastic Design

LAGRANGE-11-2: Ranger 2000 (initial rudder mass balance shown)

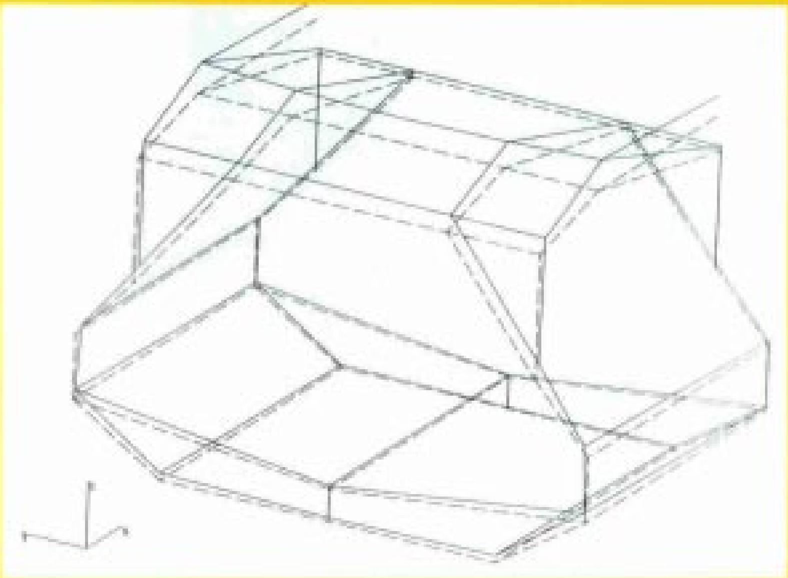
LAGRANGE-12:



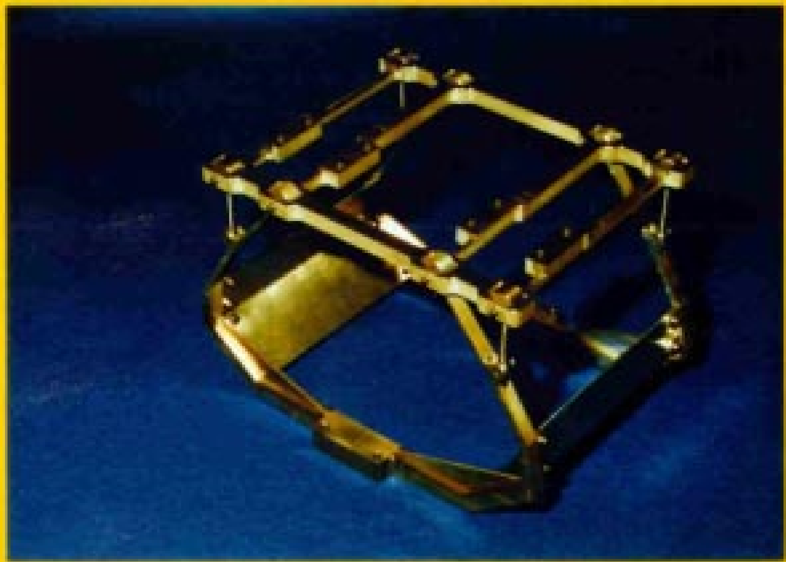
RANGER 2000 Wing Design Trade-Off Study
Flutter Speed
Balance Mass on Aileron
1.15 * Vd
Reinforced Wing Box
Additional Mass, Based on Strength Design

LAGRANGE-13: Model design by updating (optimization)

Flutter Wind Tunnel Model for Transport Aircraft



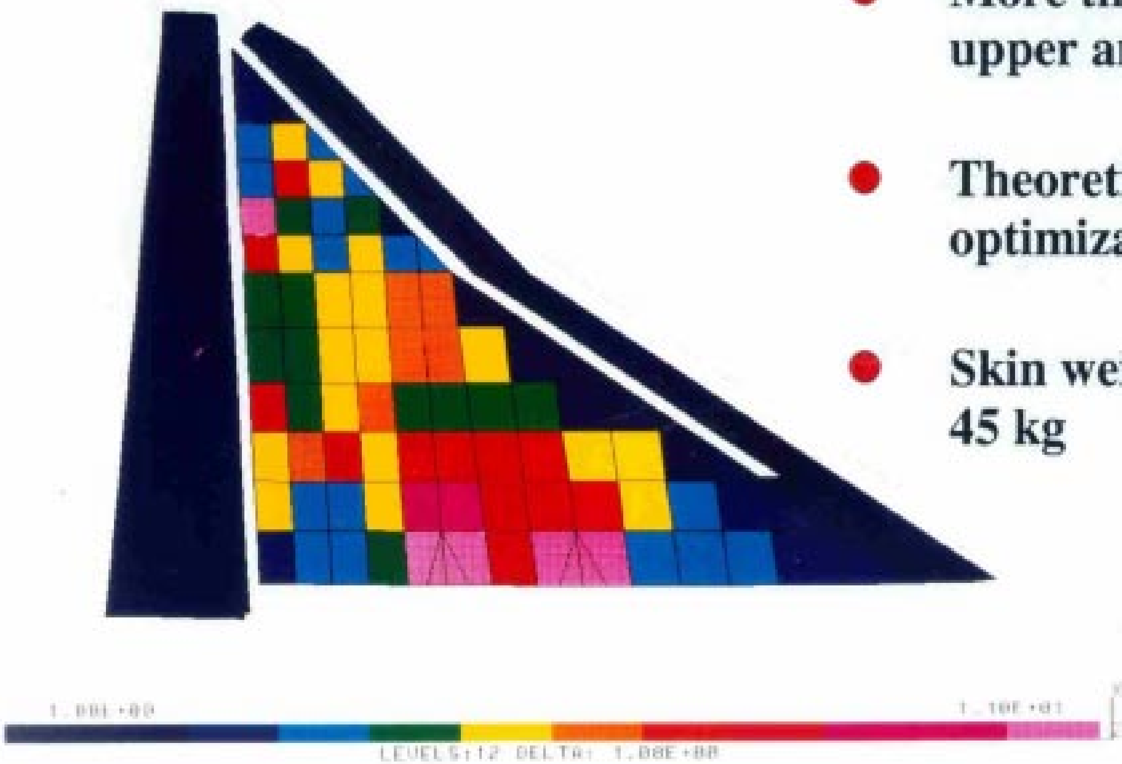
Analysis Model for
Equivalent Stiffness Design
of the Wing/Fuselage Interface



Manufactured Component

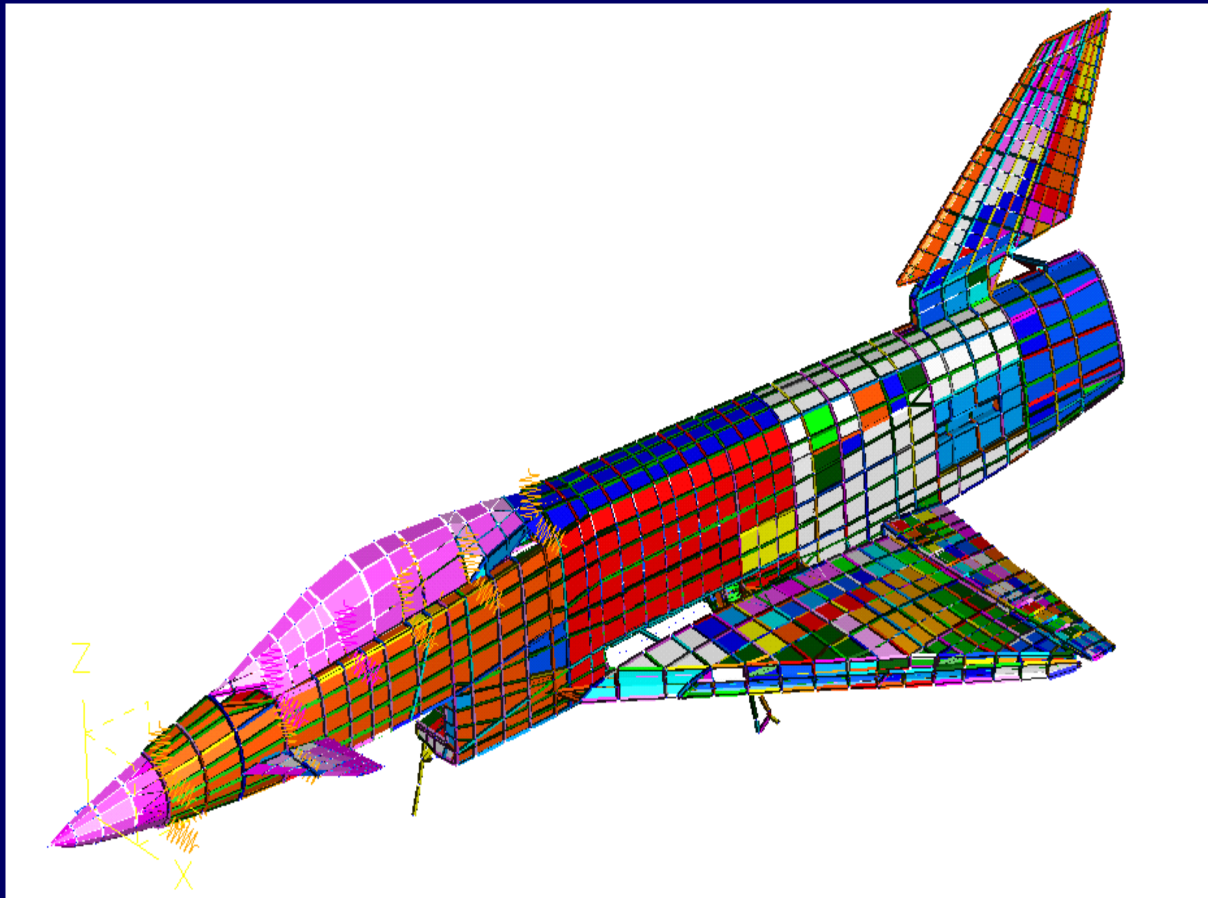
LAGRANGE-14:

X-31 A Wing: Typical Skin Thickness Distribution After Optimization



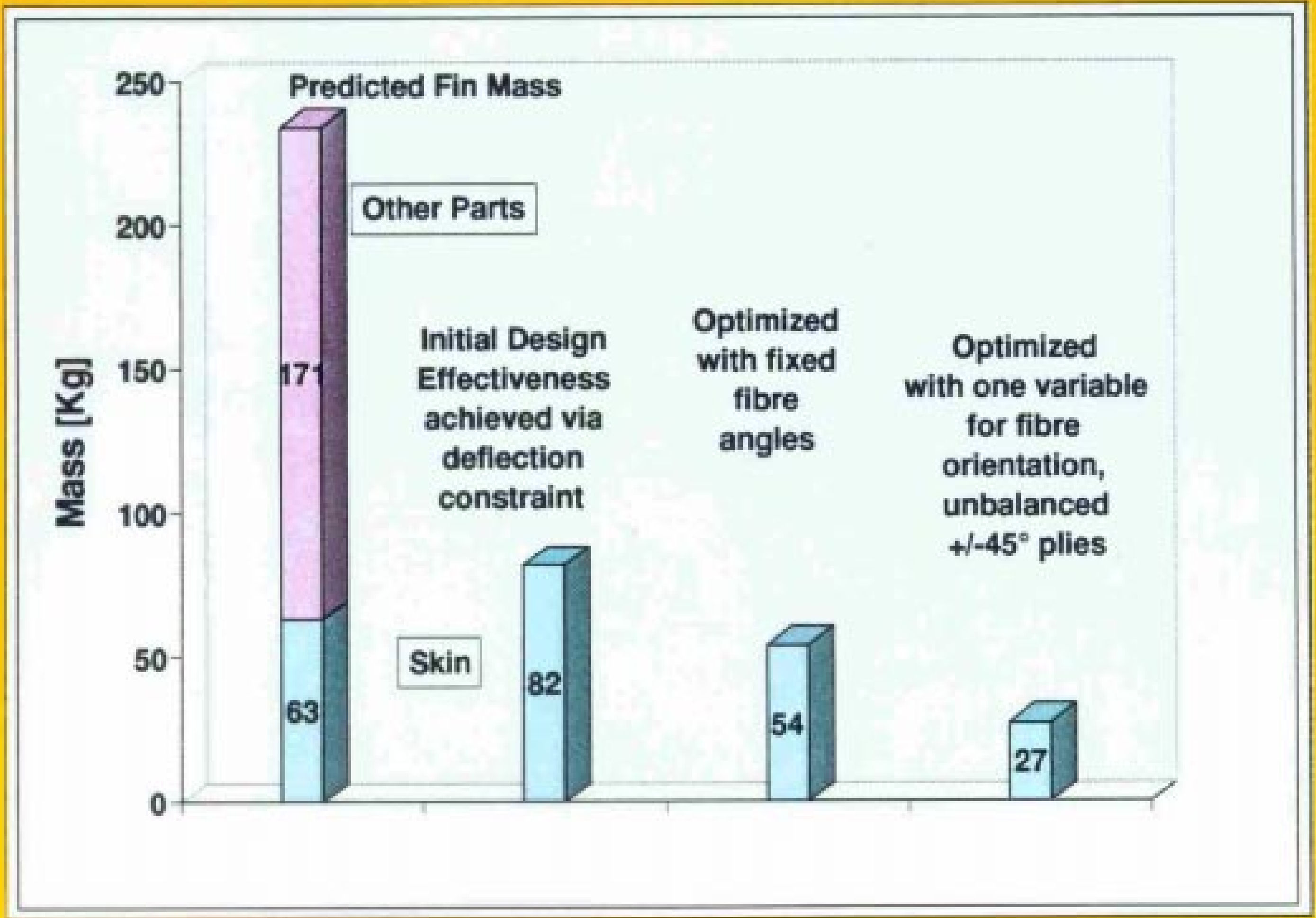
- More than 30 different lay-ups for upper and lower wing skins
- Theoretical skin weight after optimization : 44 kg
- Skin weight after manufacturing : 45 kg

FEM of X-31A with optimized wing structure



LAGRANGE-15:

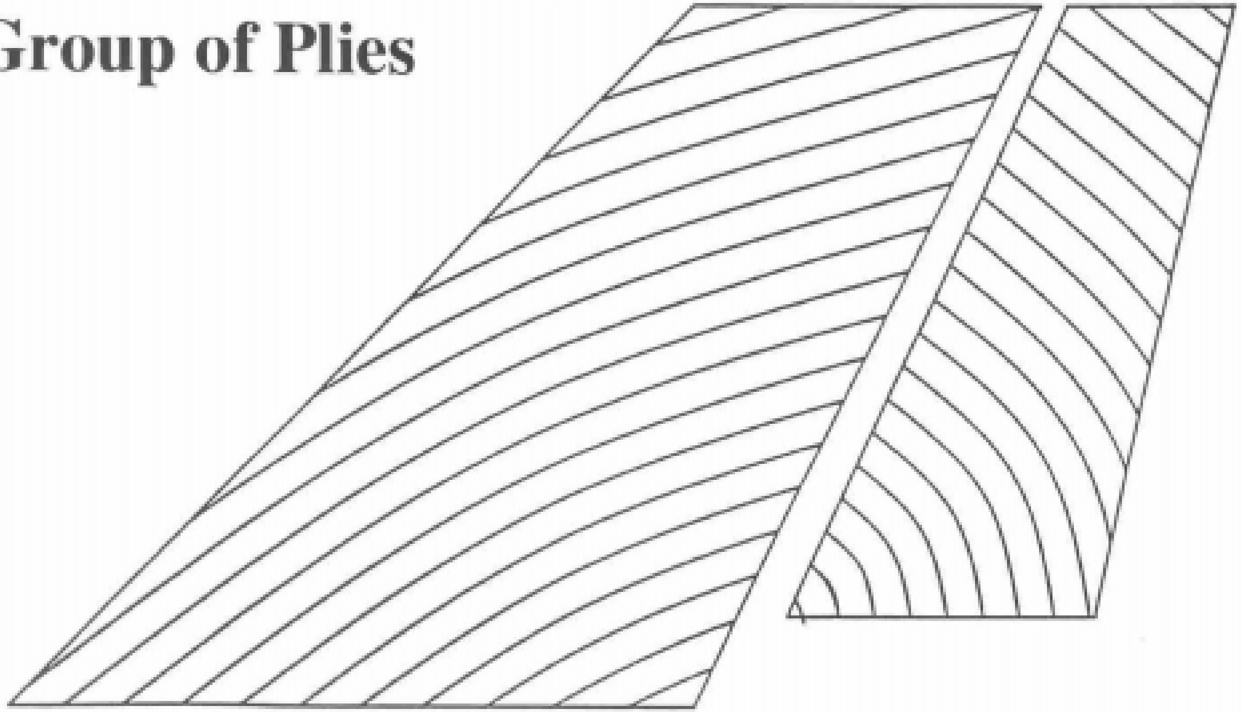
Vertical Tail Design Study



LAGRANGE-16: Tape laying with curved fibers

Vertical Tail Design Study

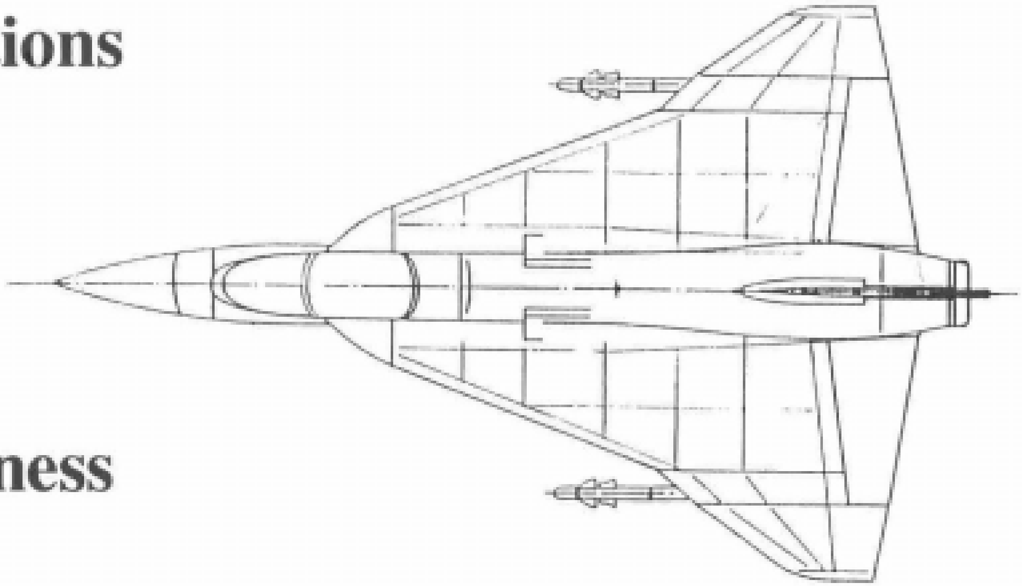
Optimized Fiber Orientation
for one Group of Plies



LAGRANGE-17:

Light Weight Fighter Wing Design

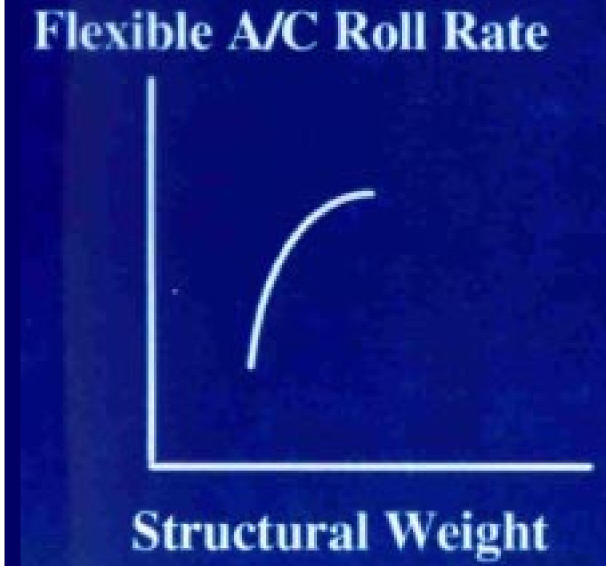
Wing Skin Thickness
and Fiber Orientations
Optimized for
-Strength,
-Flutter, and
-Aileron Rolling
Moment Effectiveness

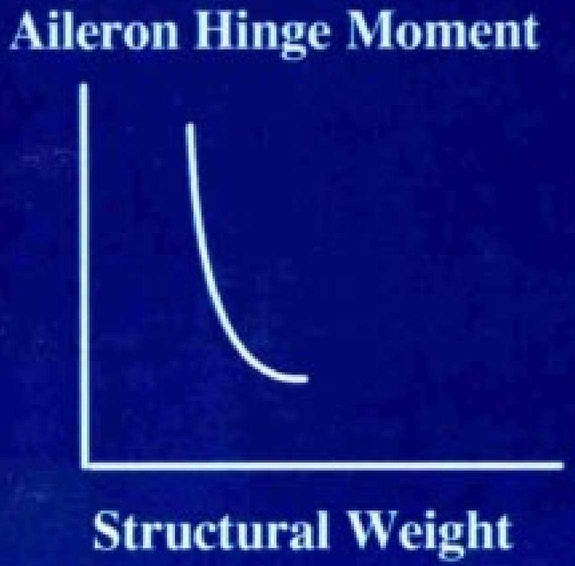


LAGRANGE-18: Rolling moment effectiveness and aileron hinge moment

Light Weight Fighter Wing

Optimization for Impoved Roll Rates



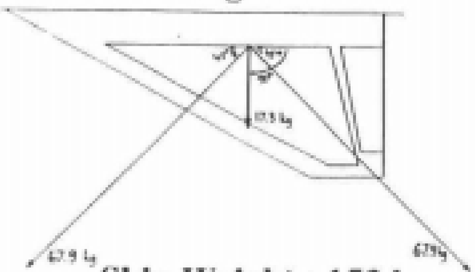


Reduced Hinge Moment as a Fall-Out Results in Additional Weight Savings (Hydraulics)

LAGRANGE-19: Effectiveness of Aeroelastic Tailoring

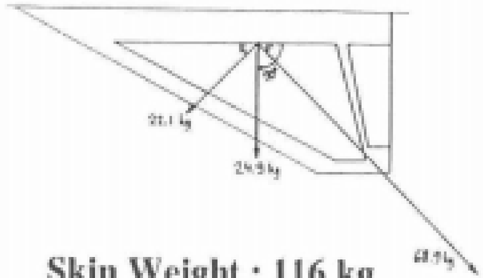
Light Weight Fighter Wing
Optimization Results with Different Design Spaces

Fixed Orientation, Symmetric 45-deg Plies



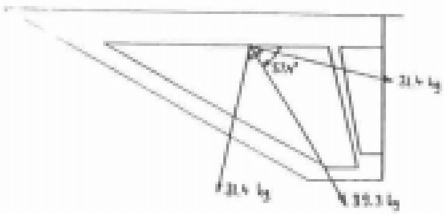
Skin Weight : 153 kg

Fixed Orientation, Unbalanced 45-deg Plies



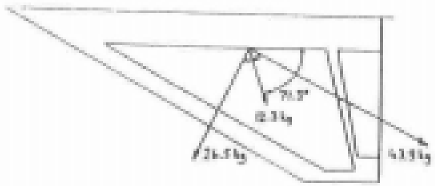
Skin Weight : 116 kg

All Plies are Free Rotate Together, Symmetric 45-deg Plies



Skin Weight : 102 kg

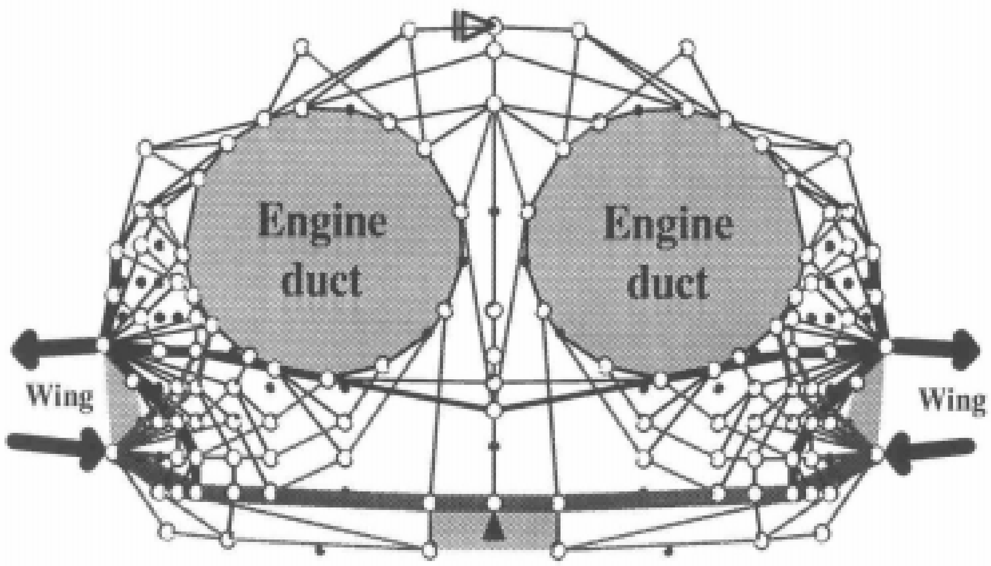
All Plies are Free to Rotate Together, Unbalanced 45-deg Plies



Skin Weight : 83 kg

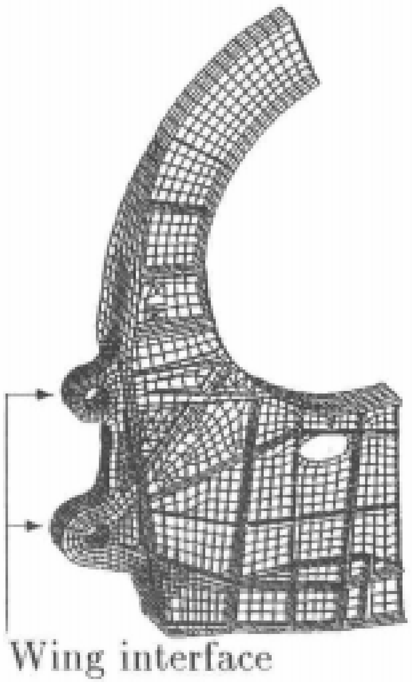
LAGRANGE-20:

Topology Optimization for Fuselage Frame

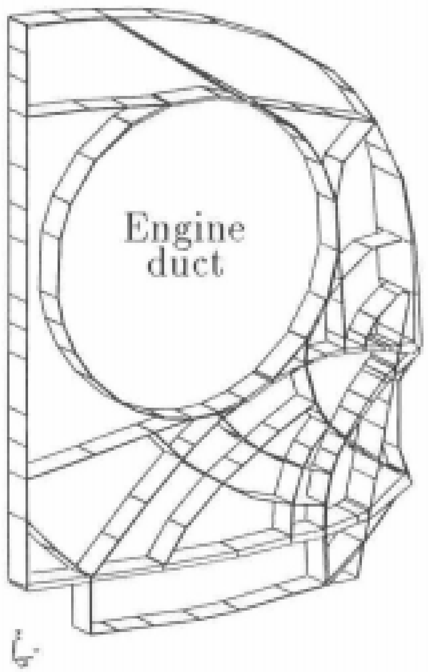


LAGRANGE-21:

Topology Optimization for Fuselage Frame



Conventional Design



Result of Optimization

LAGRANGE: other examples

- Hermes spaceplane (flutter, dynamic response of equipment)
- FTT Stealth Demonstrator
- Active Aeroelastic Wing optimization studies
- MDO project (A-340)
- UNSI project (CFD codes)
- C-160 Transall (flutter analysis model from GRT data)
- Missile fin (mass balance for flutter)
- Mako Trainer
- Active All-Movable Vertical Tail

Aircraft design process in the past

- Configuration
- Aerodynamic design, wind tunnel tests
- Structural concept and design
- Static sizing (for fixed loads)
- Aeroelastic analysis and tests
- Flight envelope limitations, reduced performance
- Repair, redesign

Optimization tasks in the design process

Preliminary design:

- external geometry
- control surfaces position and shape
- Control concepts
- Flutter and static aeroelastic sensitivities
- Structural design drivers, materials, design and manufacturing concepts.

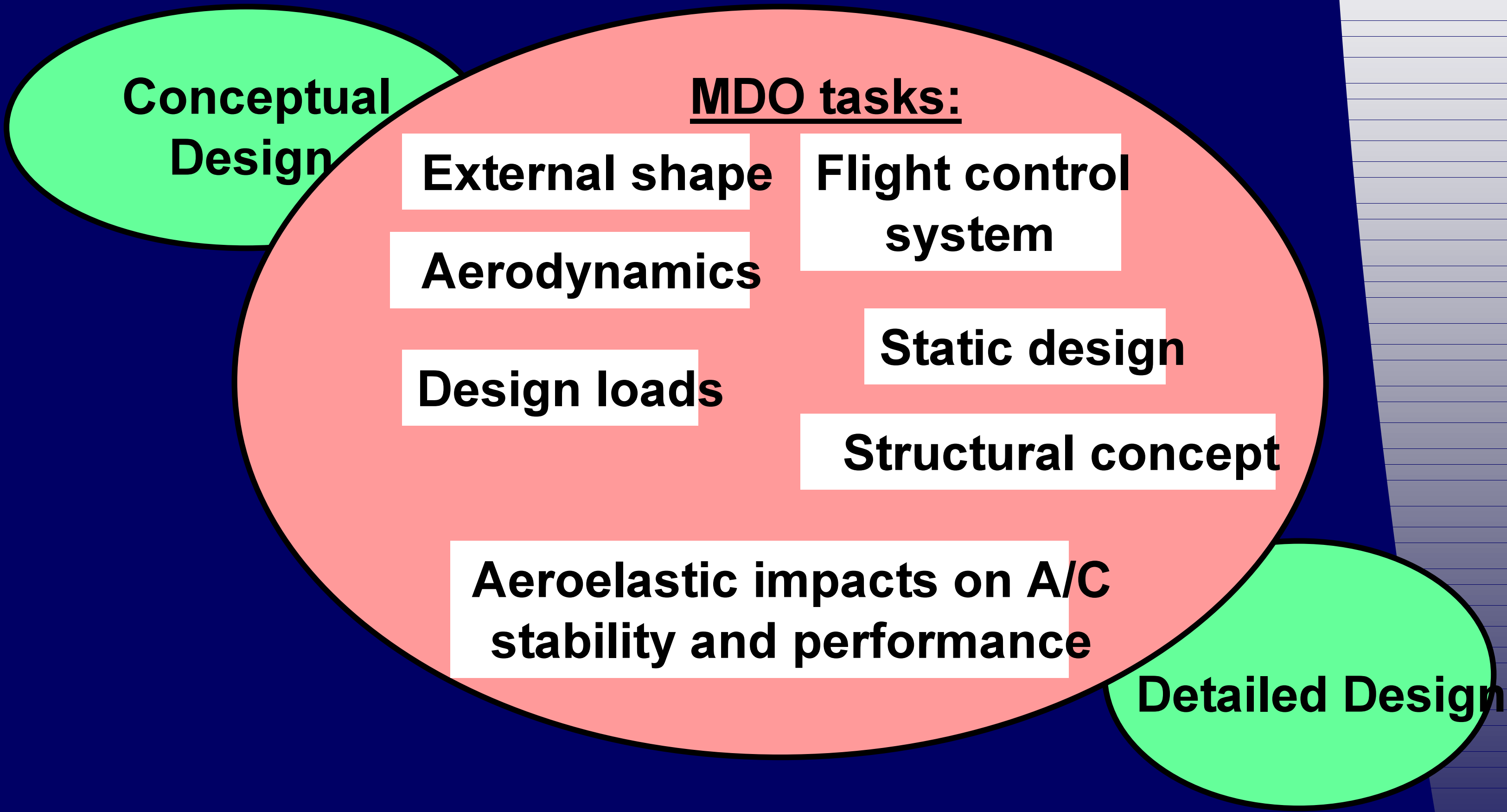
Predesign:

- Confirm predictions (mass, stability, performance)
- Refined models and methods

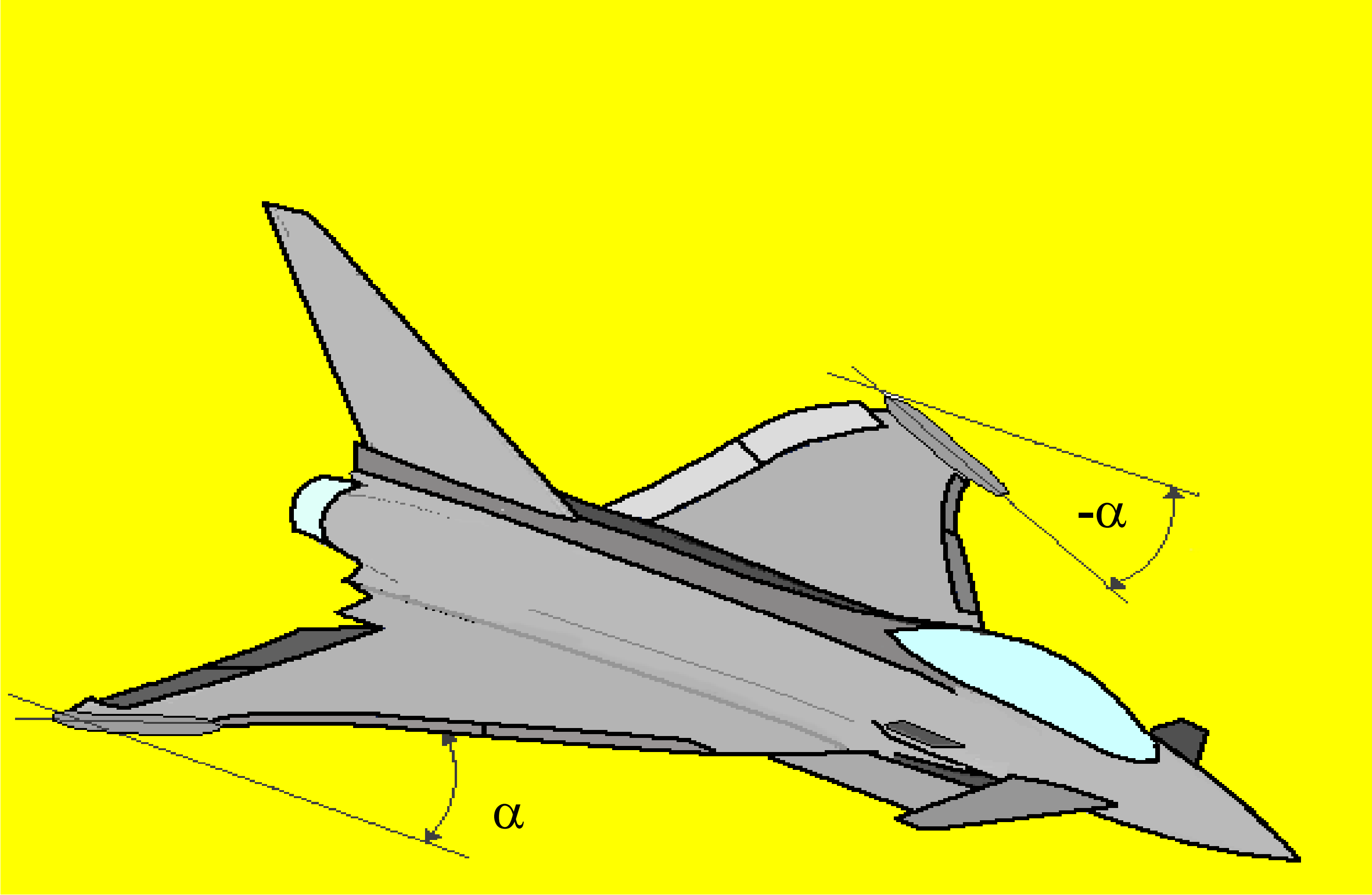
Design:

- Individual parts optimization

MDO in the Aircraft Design Environment



MDO Application for Active Flexible Aircraft Design



Intentions

Current practice:

Use structural optimization to minimize negative aeroelastic effects.

New approach:

Use MDO concepts to allow positive aeroelastic effects

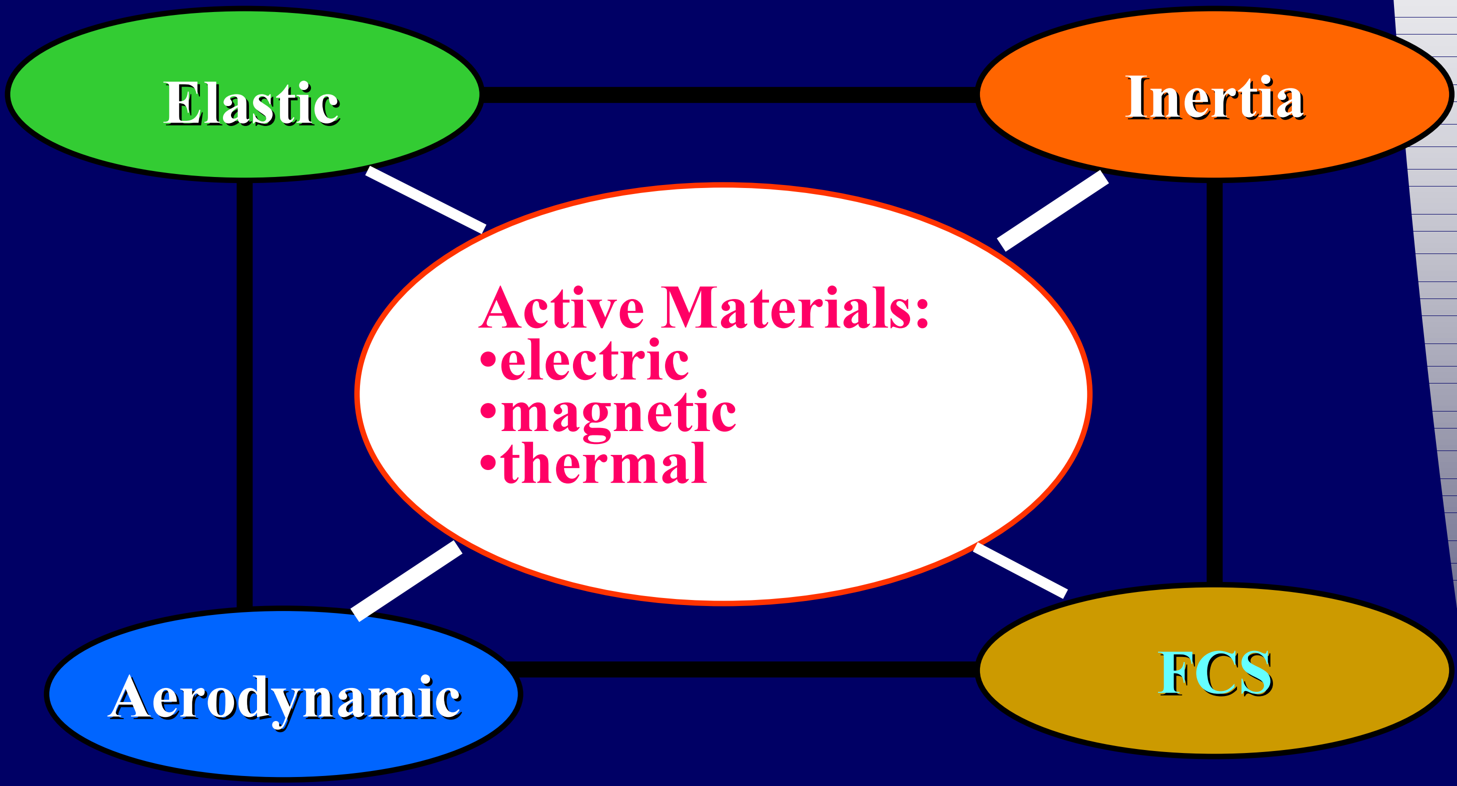
for better designs with respect to:

- weight and cost of the structure
- reduced demands on the actuation system
- improved aerodynamic performance
- increased maneuverability
- reduced loads

Active Flexible Aircraft Concepts

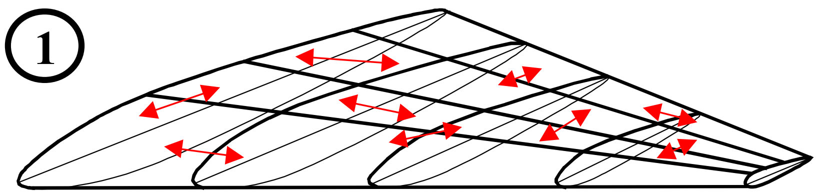
- Multiple control surfaces, acting as tabs
- Unconventional, new control surfaces
- Hingeless control surfaces
- Direct deformation of the main structure by active structures and materials elements

Active Materials in the Modified Aeroelastic "Triangle"



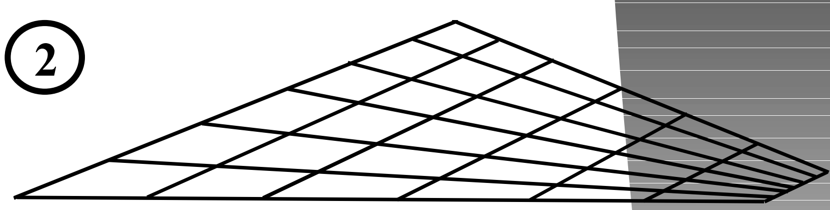
Required Steps to Design for Active Structures Concepts

1



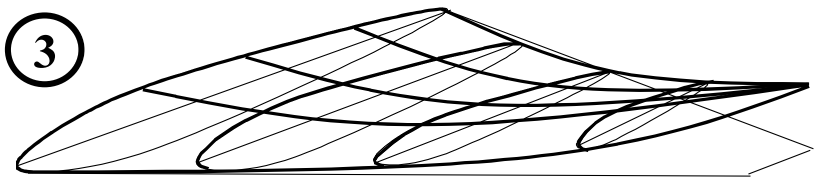
Apply internal forces to generate deformations in structural model

2



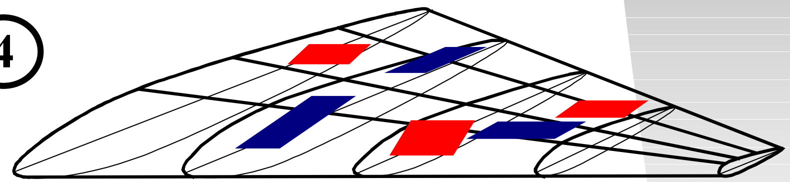
Calculate aerodynamic angle of attack distribution from initial deformations

3



Calculate aeroelastic equilibrium from initial deformations

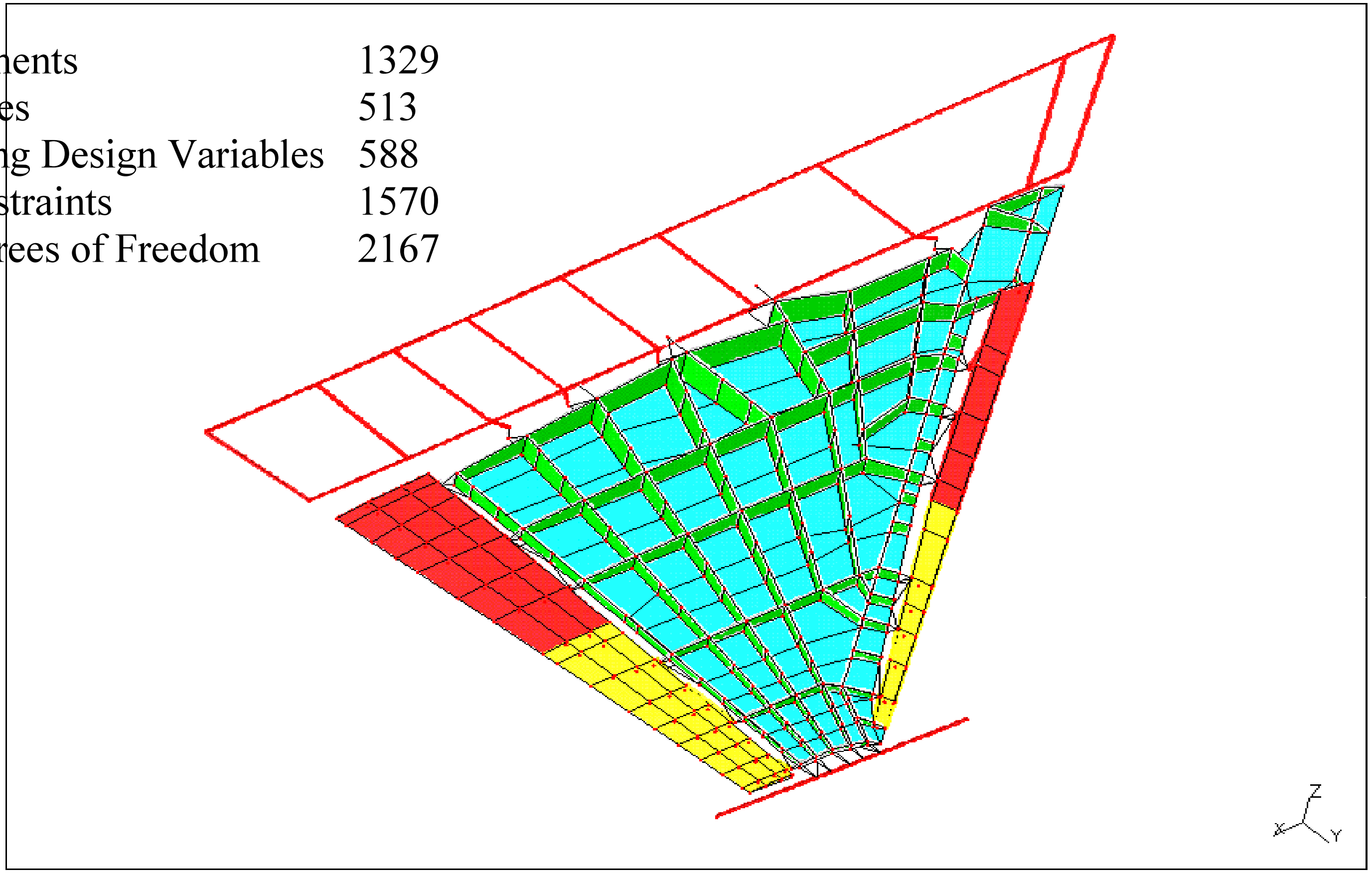
4



Optimize location and direction of active components

Finite Element Model of Wing

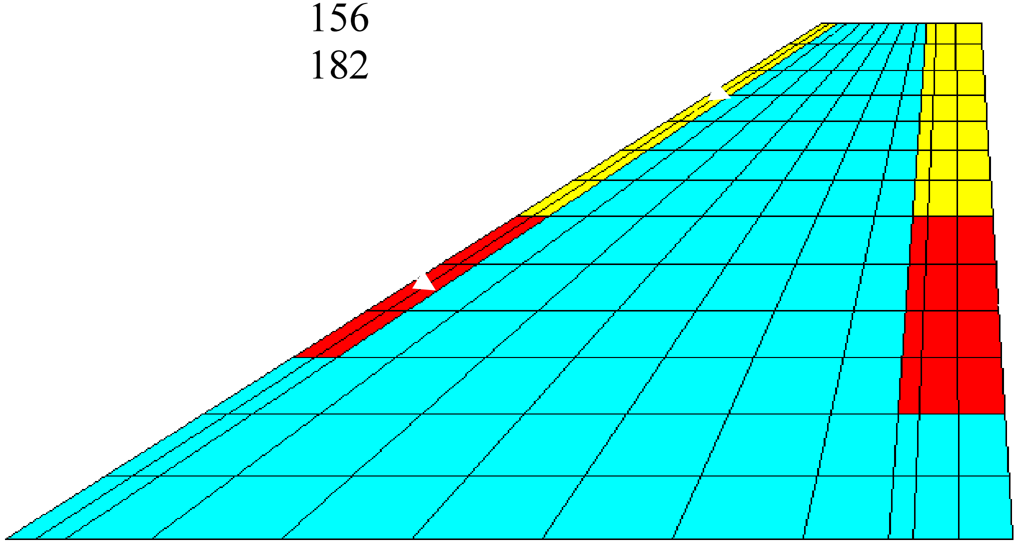
Elements	1329
Nodes	513
Sizing Design Variables	588
Constraints	1570
Degrees of Freedom	2167



Aerodynamic Model of Wing

EADS

Total Planform Area	50 m^2
Total Span	10.5 m
AR	2.205
Panels	156
Nodes	182



Design Conditions and Constraints

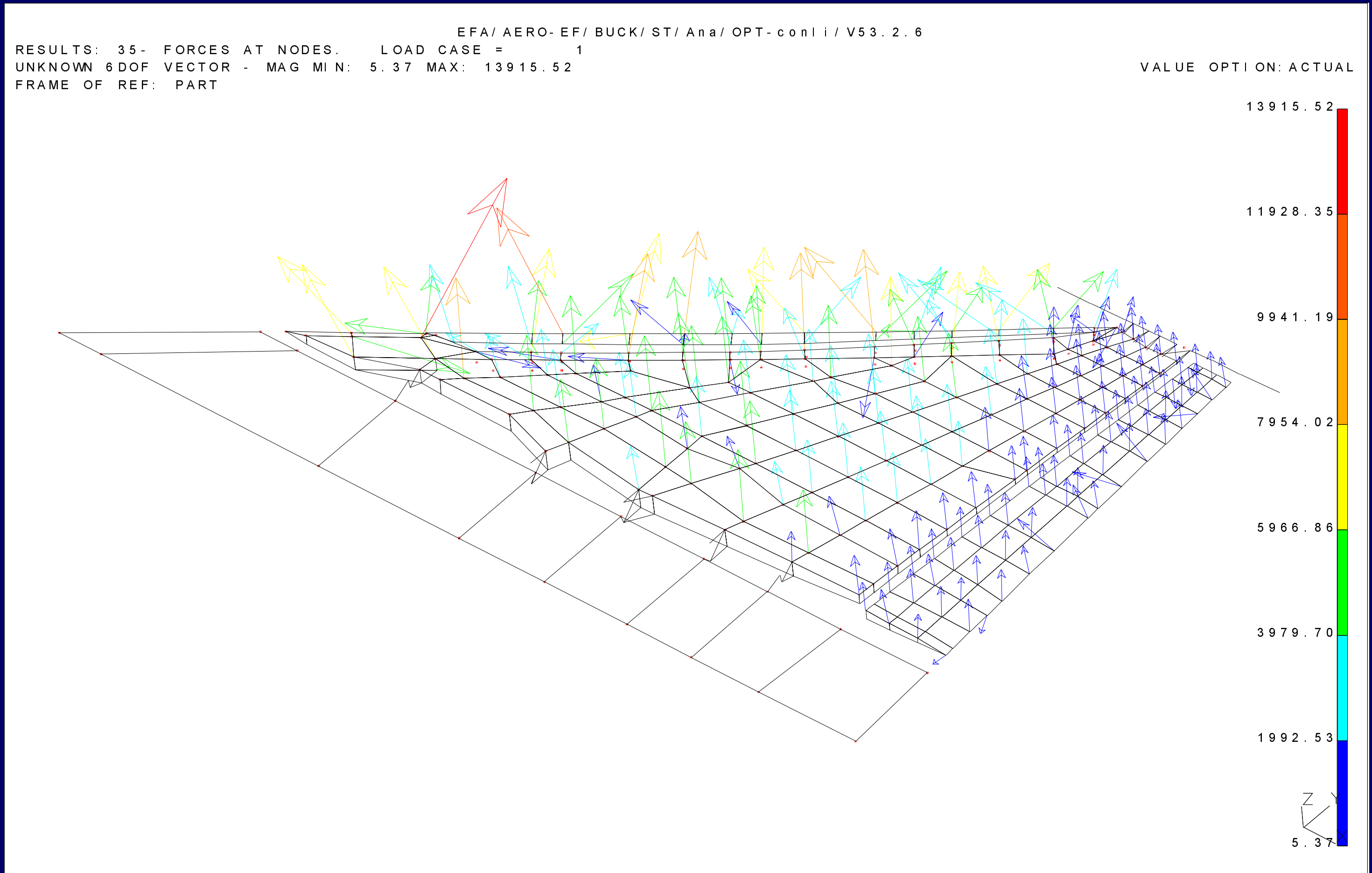
•**Static:** strength and buckling stability
for two load cases (+9g, -4g)

•**Flutter:** V_F › 1000 kts

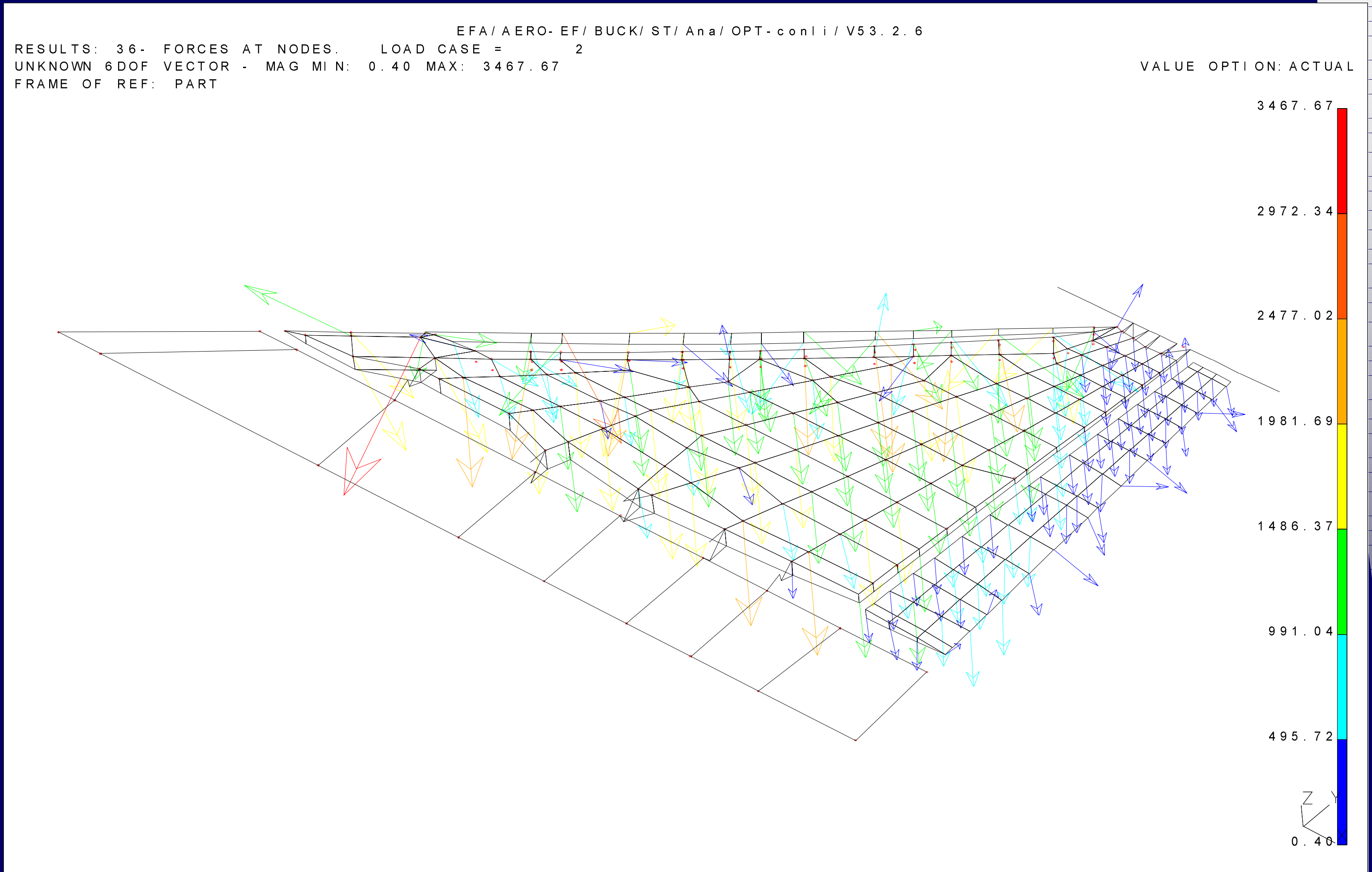
•**Static Aeroelasticity:**

- minimum roll rate: 120°/s @ Ma 1.2, S/L
- max. hinge moment: 15 kNm
- max. control surface deflection: 15°

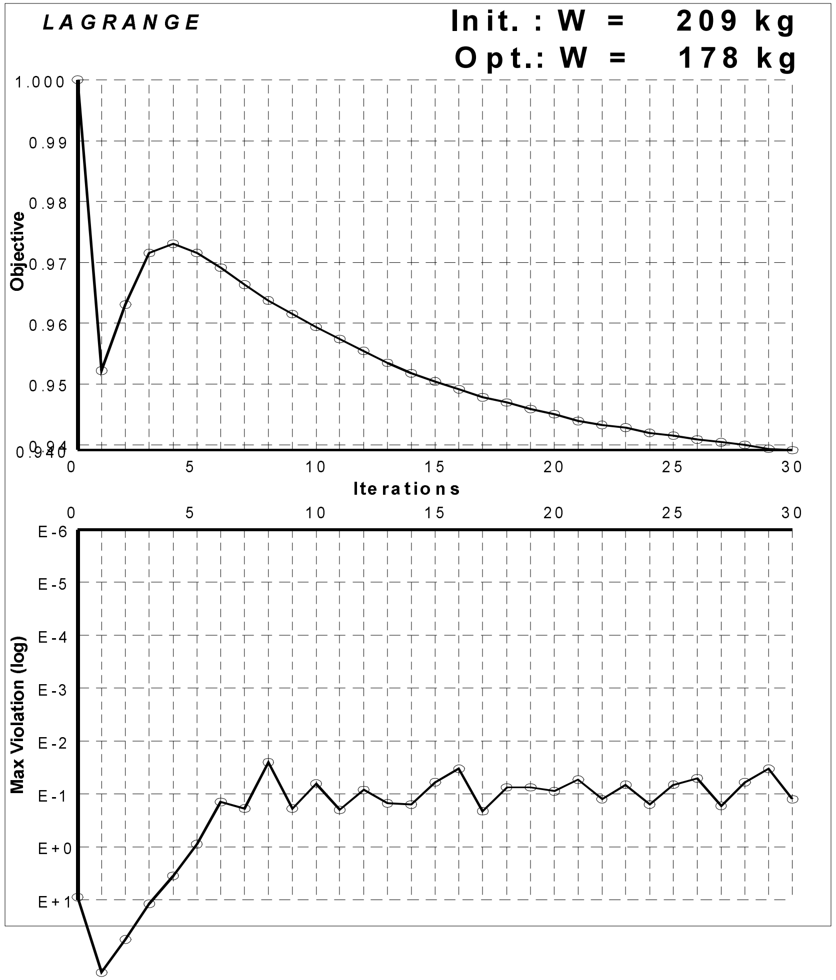
Forces for Static Load Case 1: 9g at Ma 0.9, Sea Level



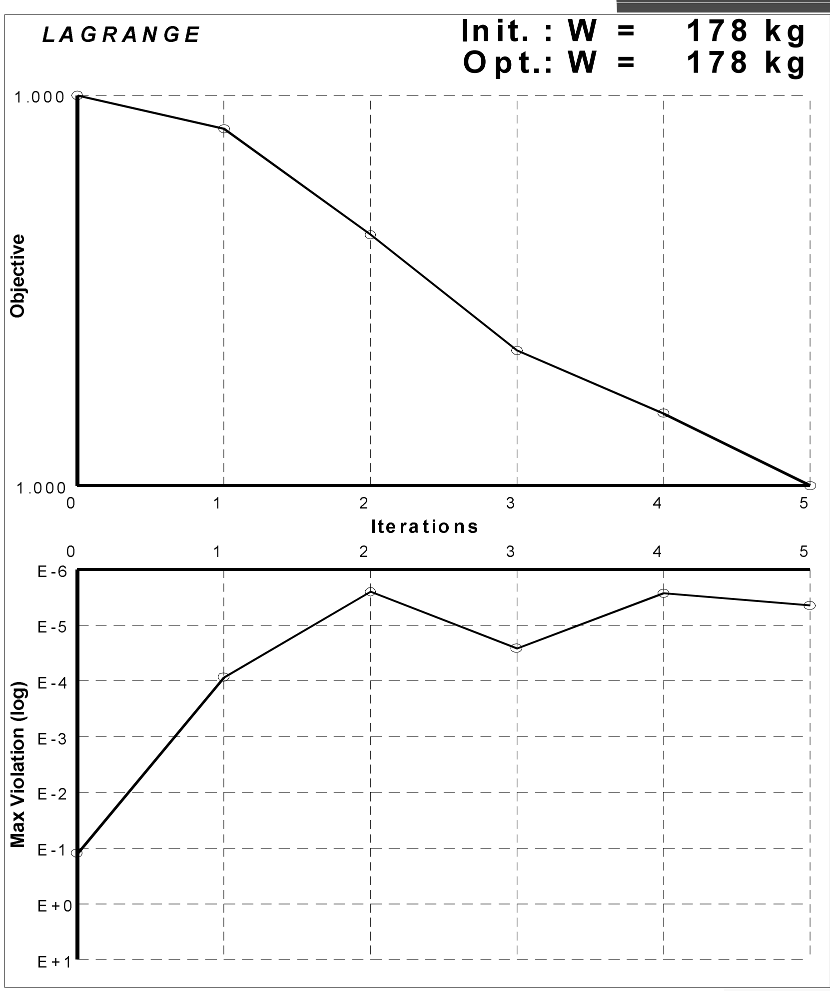
Static Load Case 2:
-3g at Ma 1.2, Sea Level



Optimization Histories for Objective function and constraints

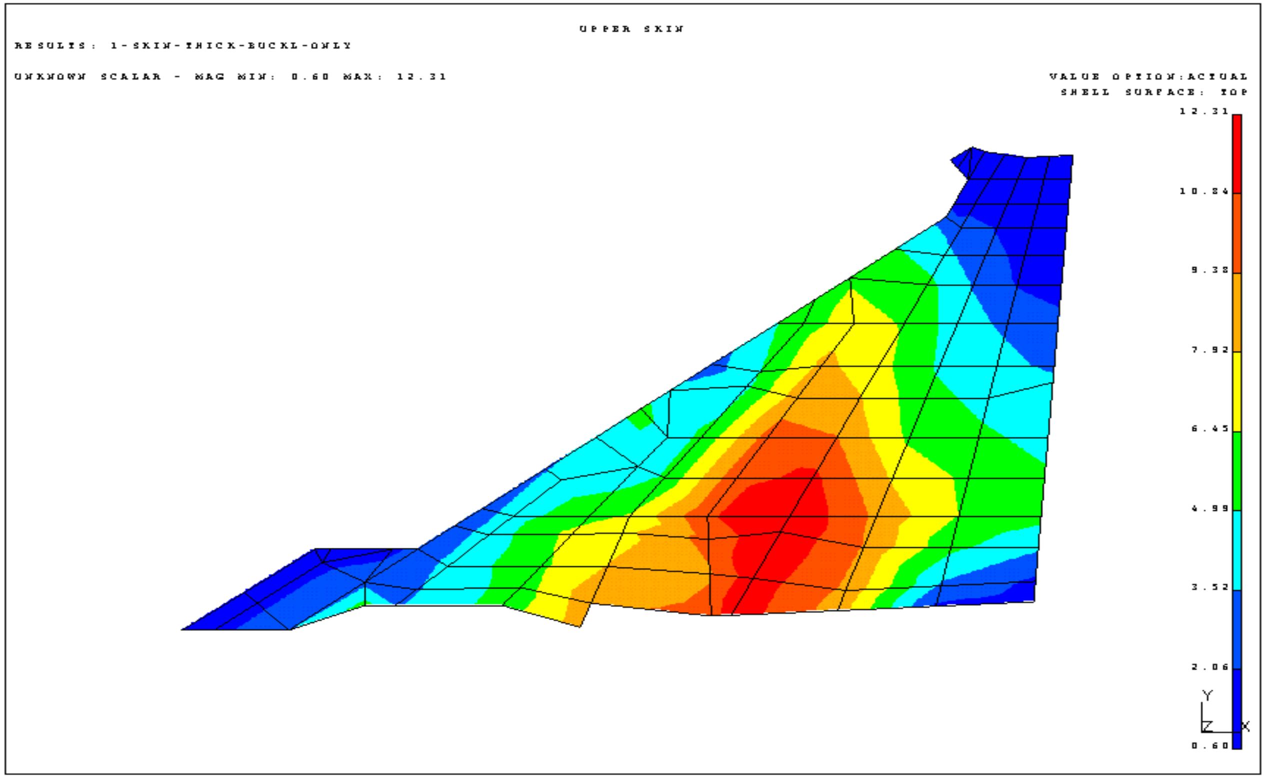


CONLIN

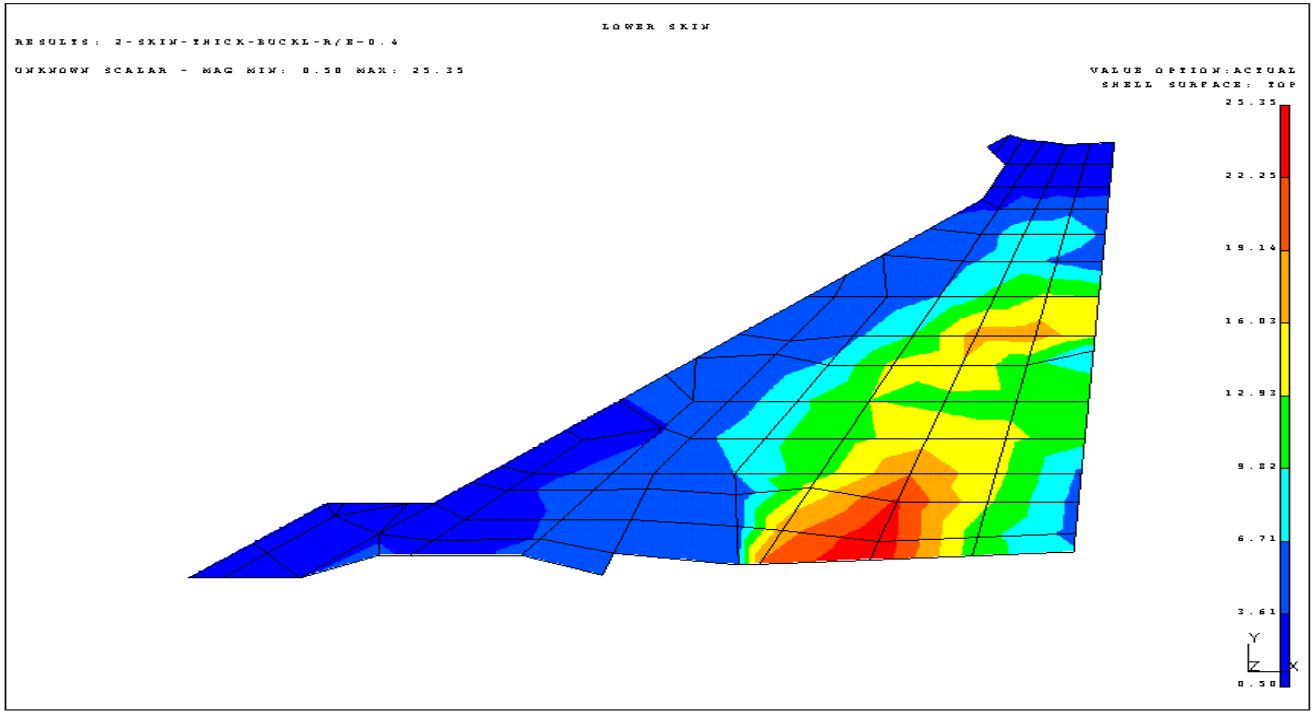


RQP1

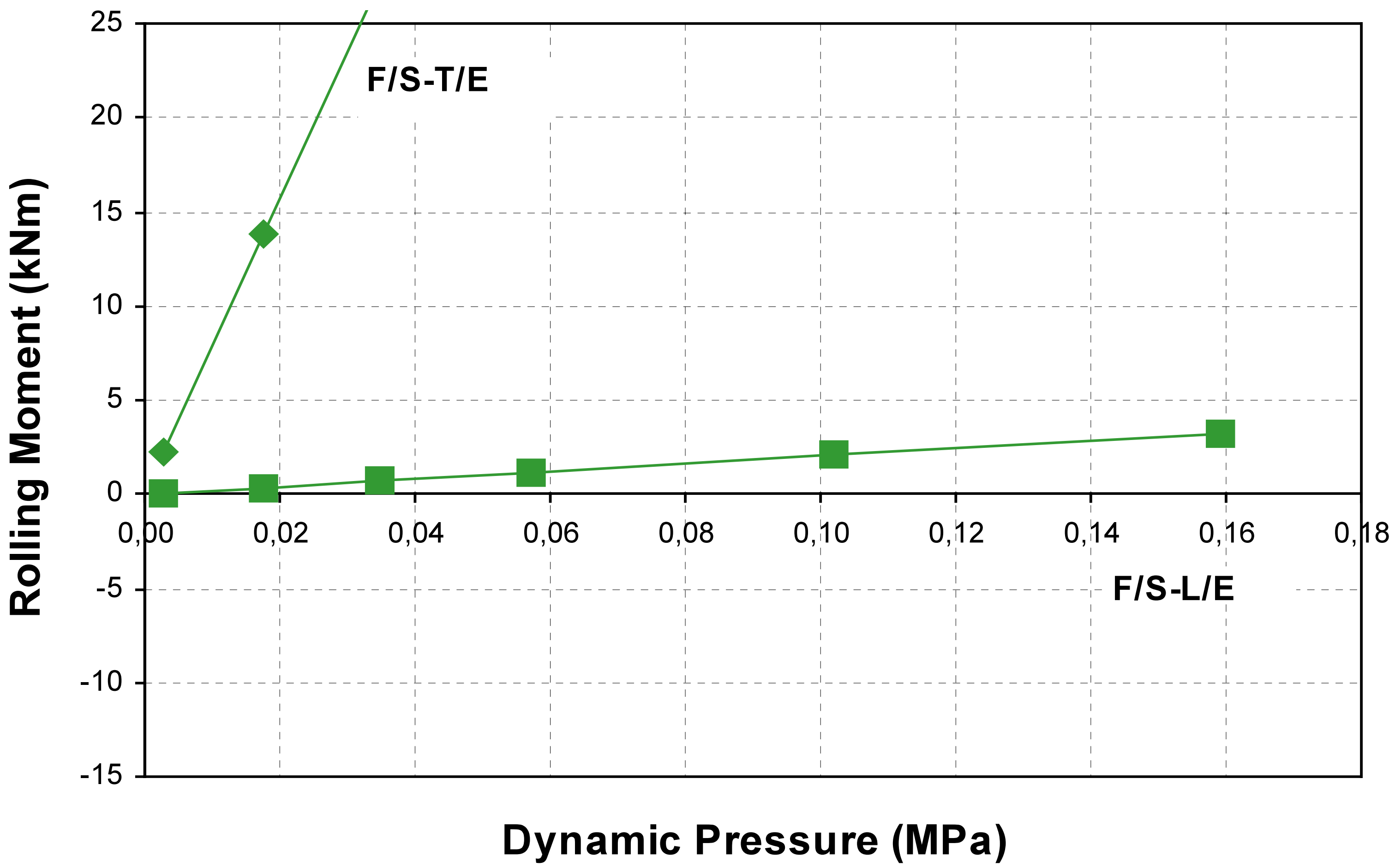
Upper Skin Thickness Distribution with additional rolling moment effectiveness constraint



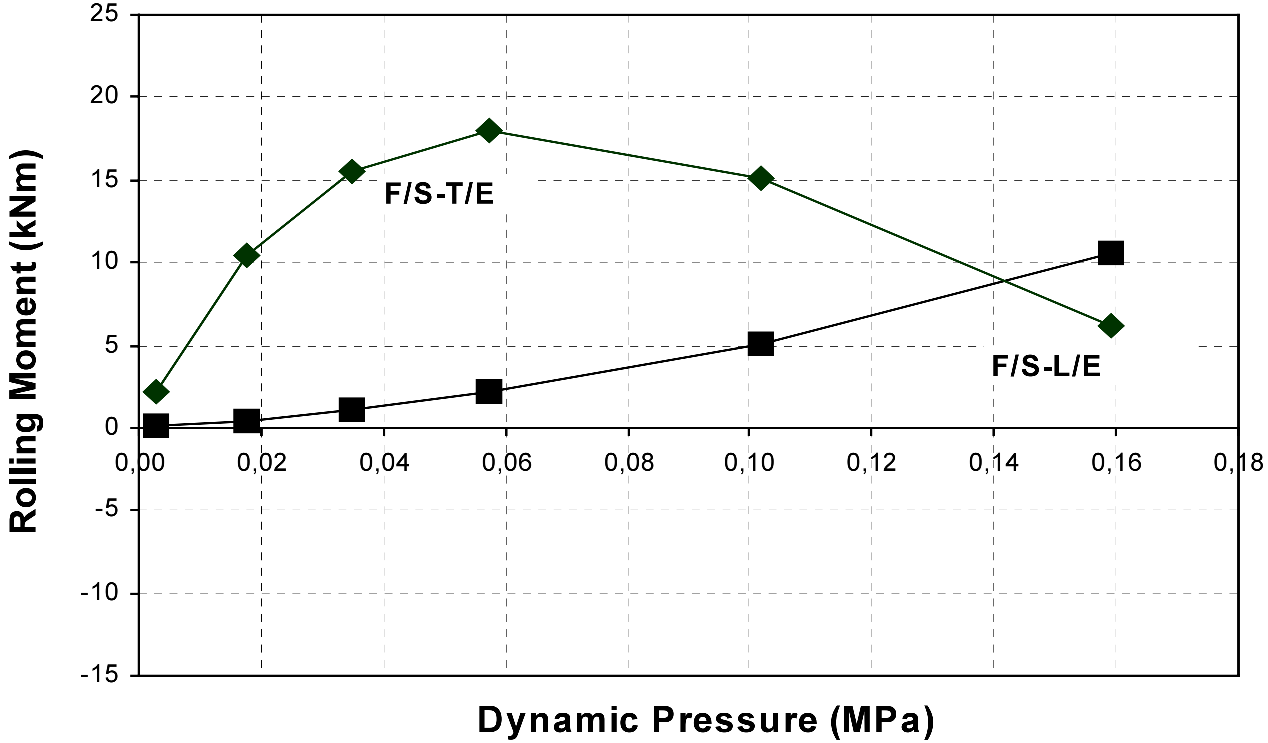
Skin Thickness for Lower Skin



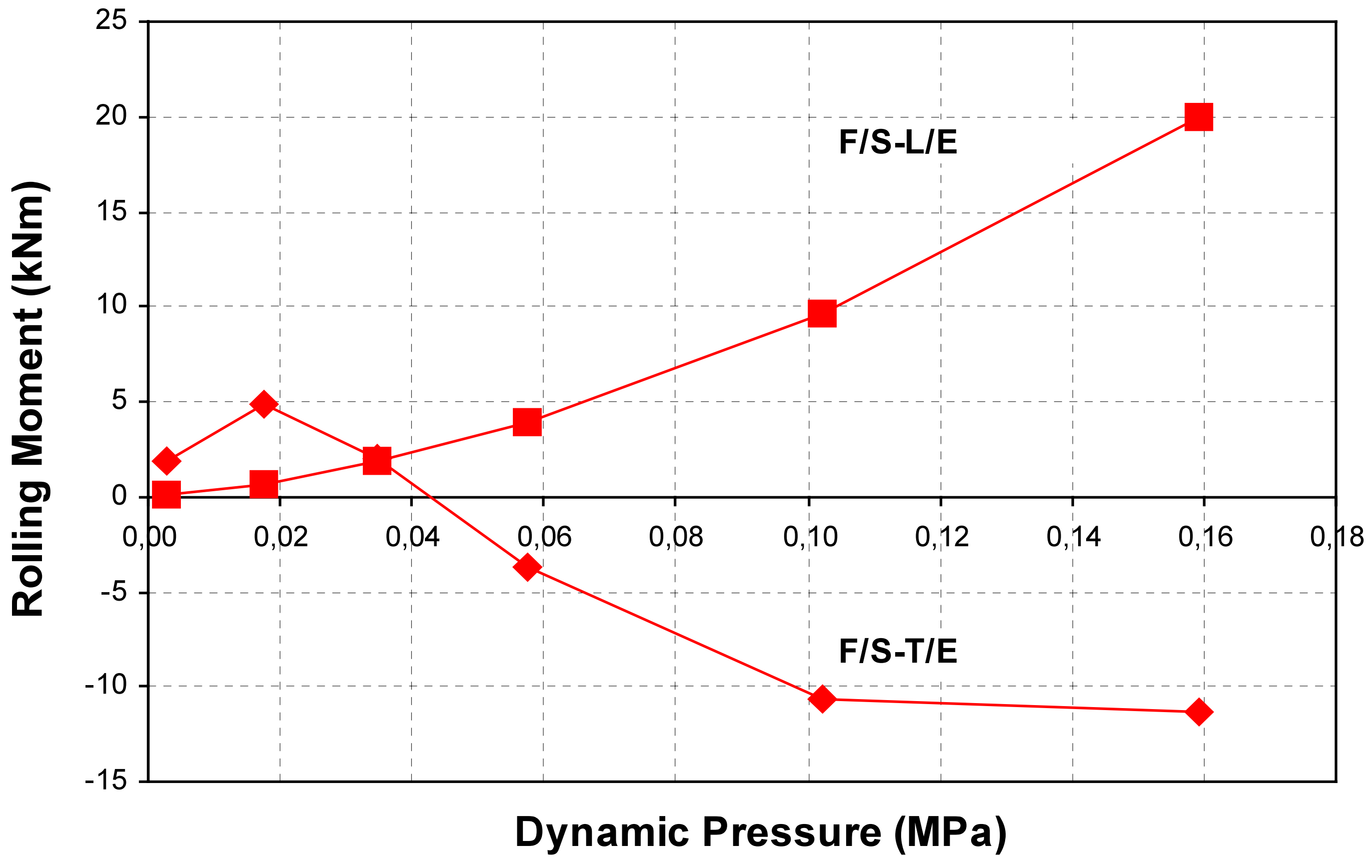
Rigid Rolling Moment for 1° Deflections (Original Design)



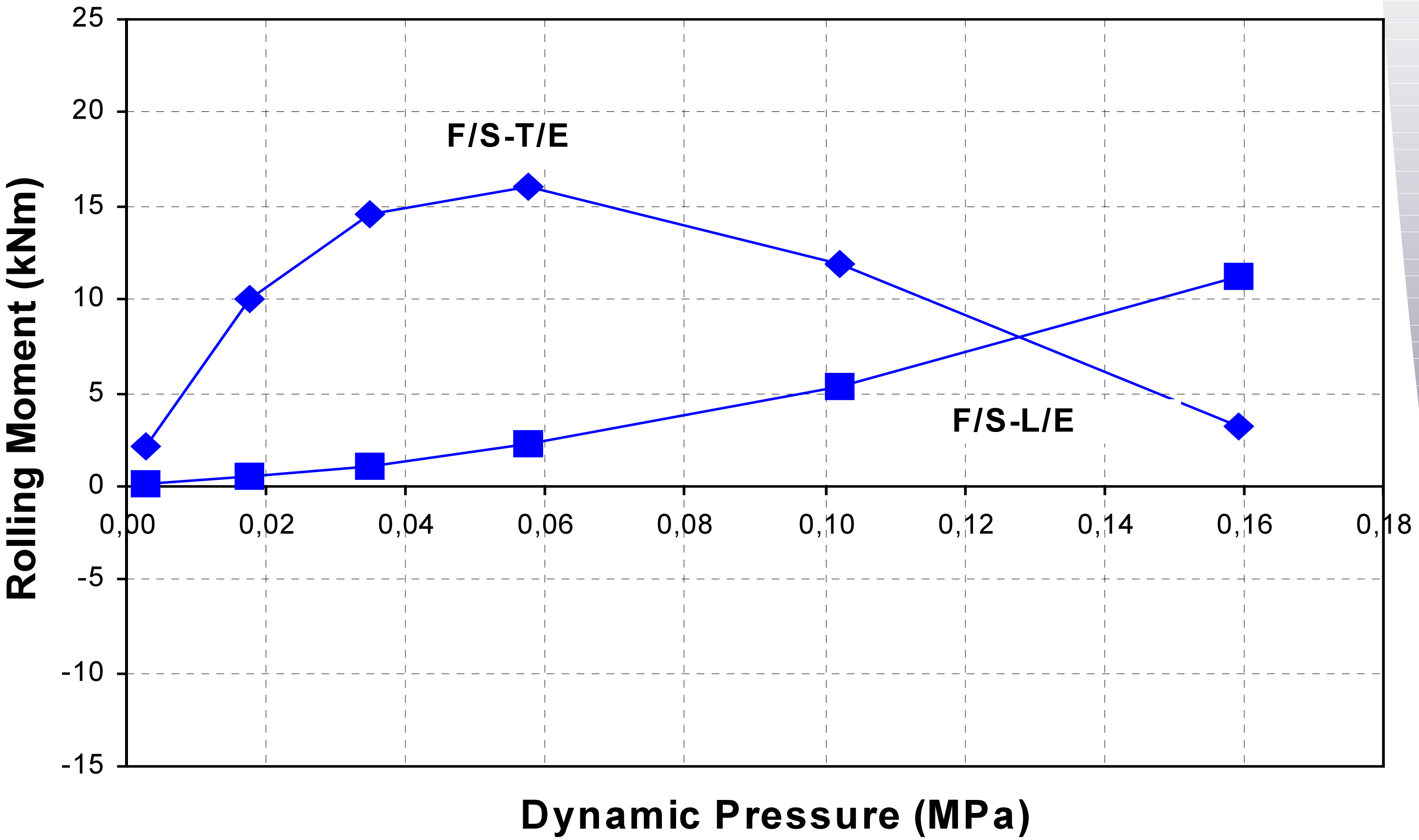
Total Rolling Moment for 1° Deflections (Original Design)



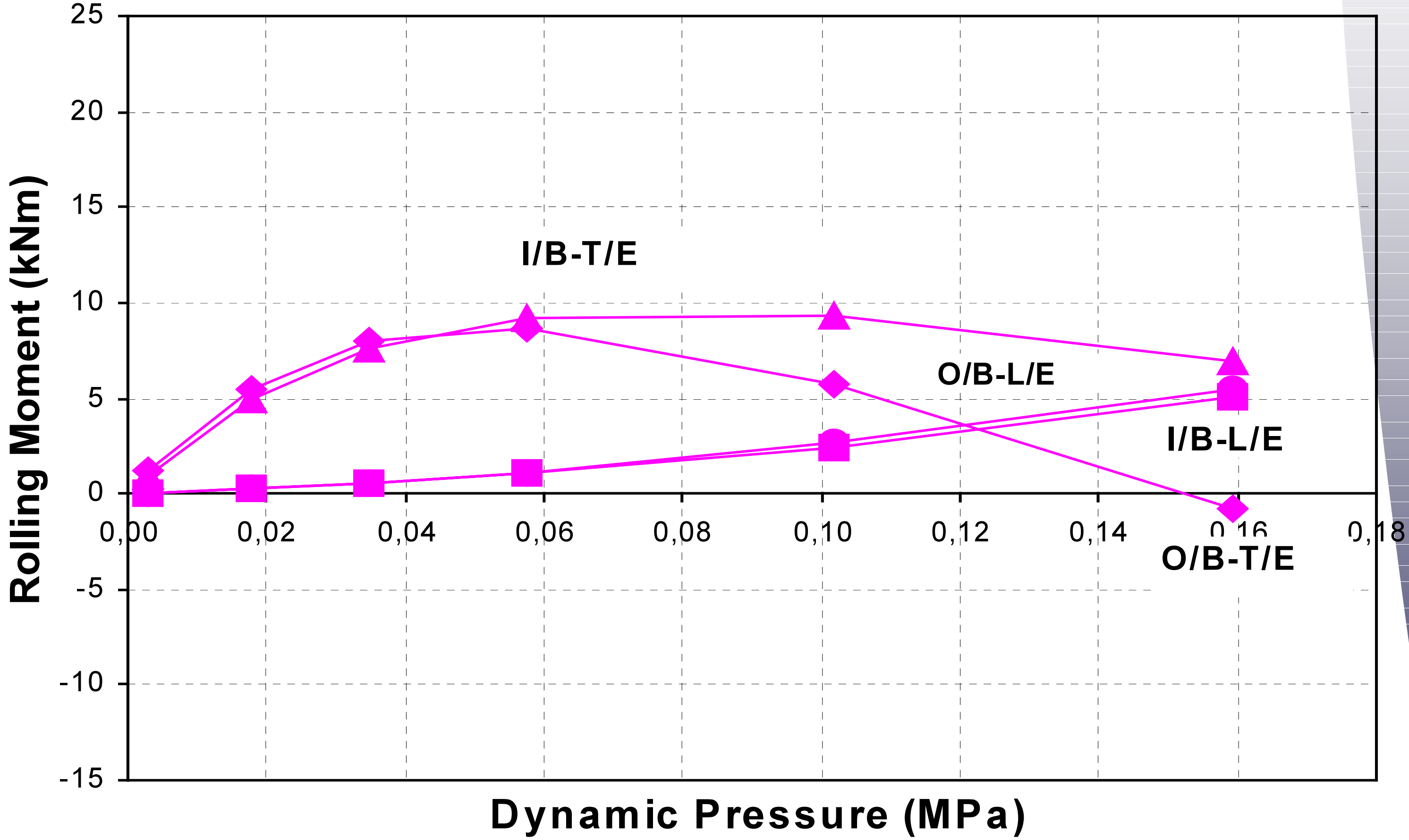
Total Rolling Moment for 1° Deflections (Static strength only)



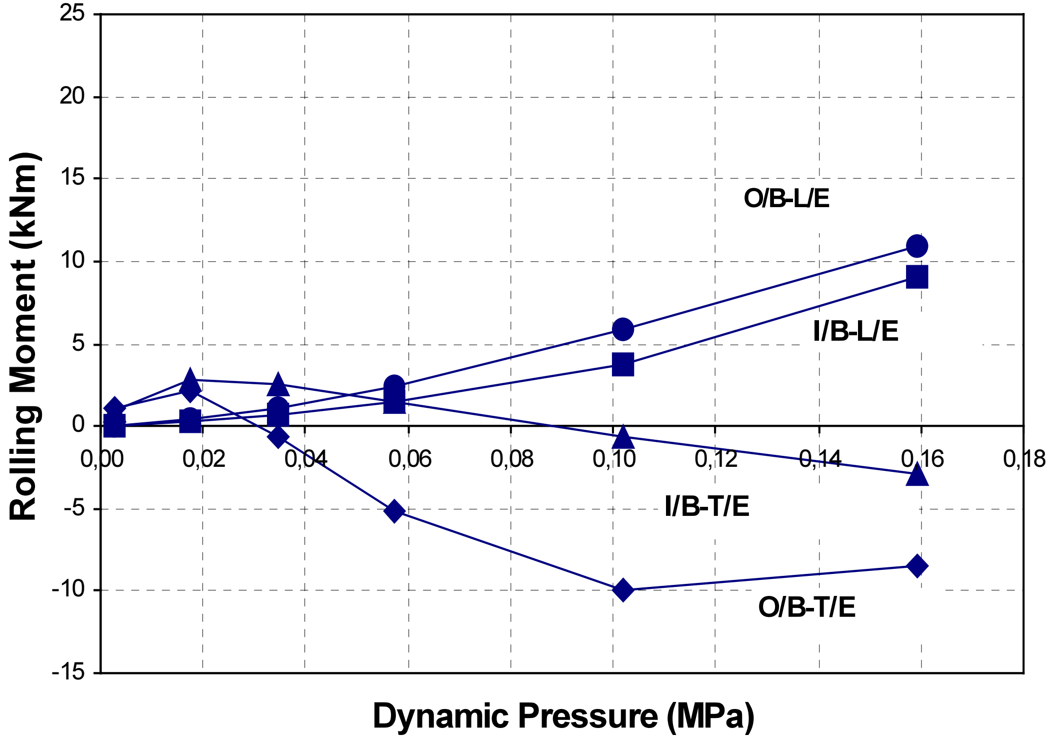
Total Rolling Moment for 1° Deflections, (including buckling) Optimization)



Total Rolling Moment for 1° Deflections (Original Design)

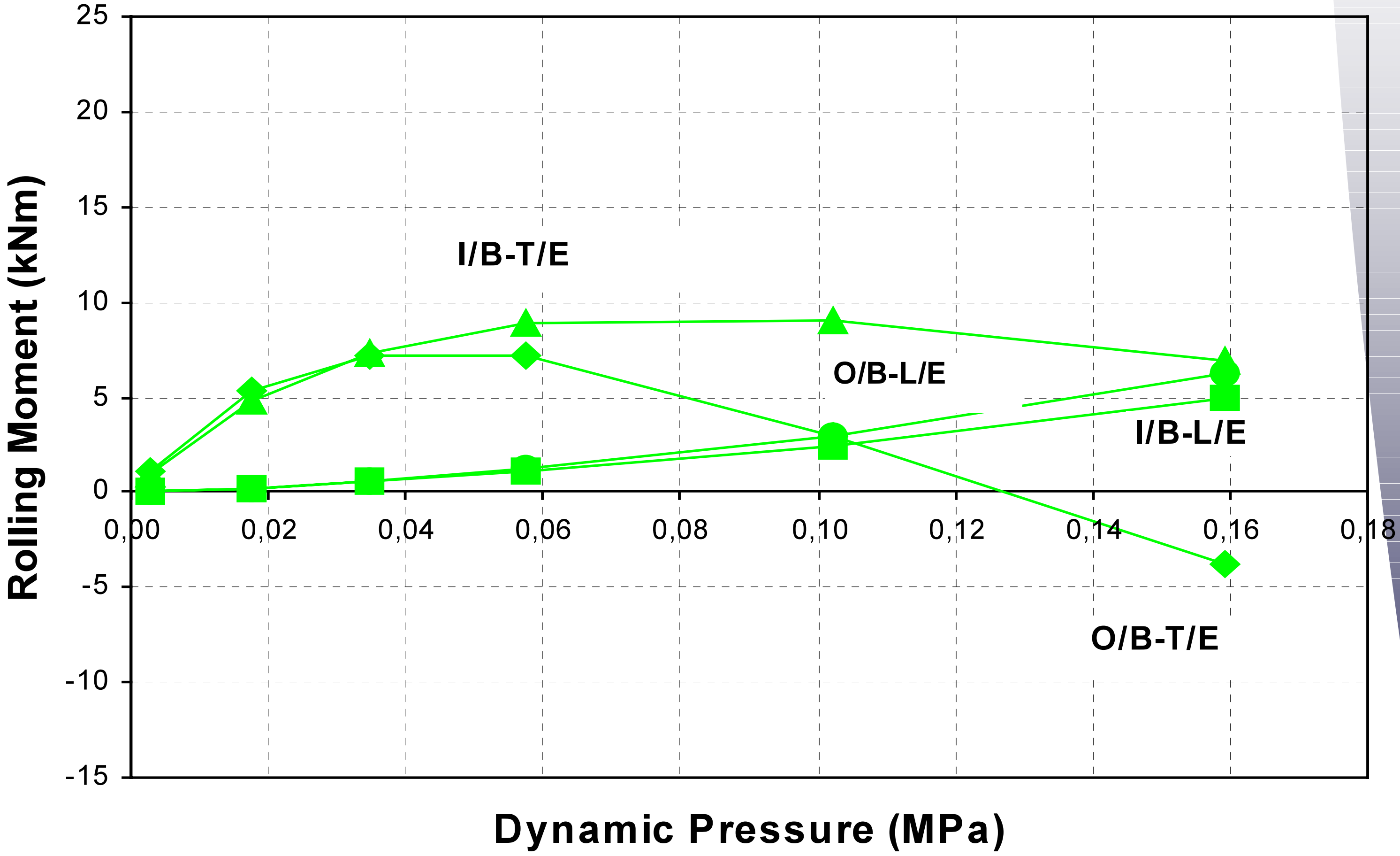


Total Rolling Moment for 1° Deflections (Static Optimization)

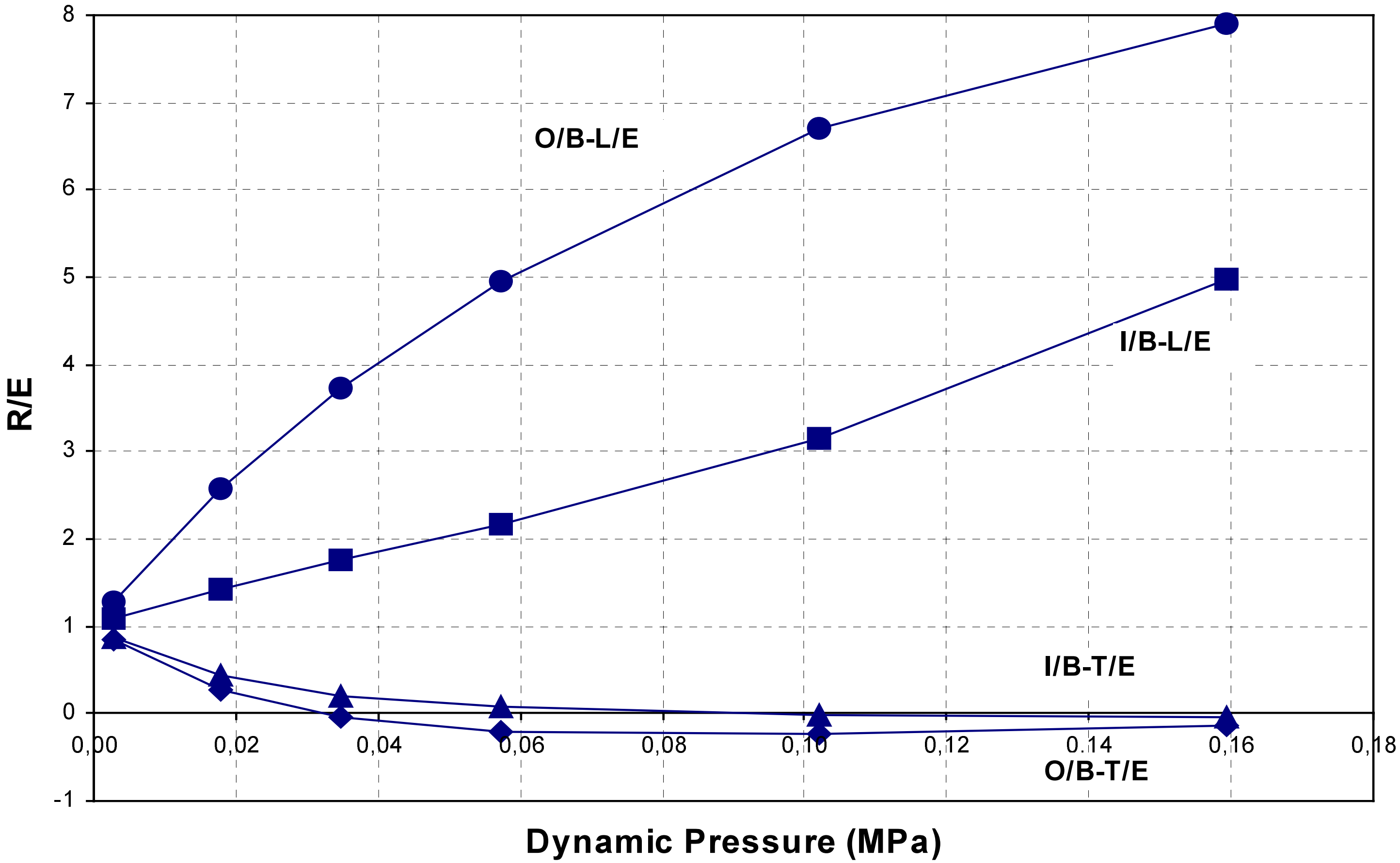


	Hinge Moments (kNm)	Deflection Angle (Degrees)
I/B-L/E	2.89	8.69
O/B-L/E	1.58	
I/B-T/E	-22.79	
O/B-T/E	11.61	

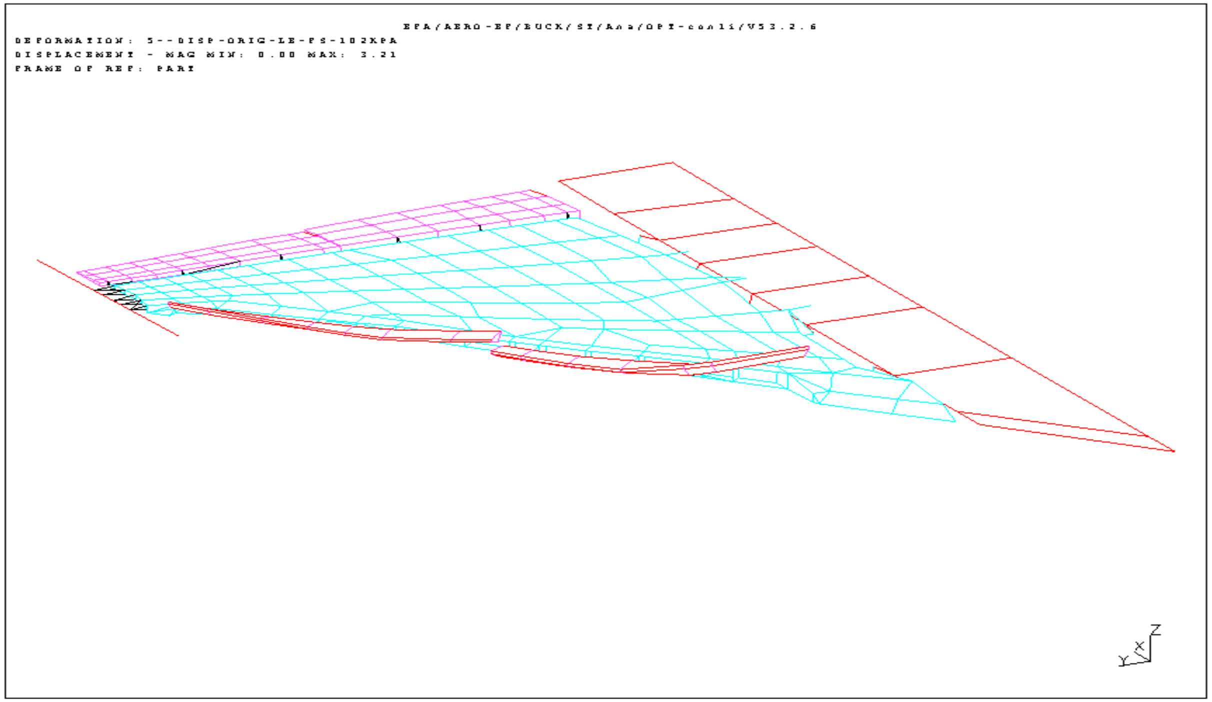
Total Rolling Moment for 1° Deflections (buckling included)



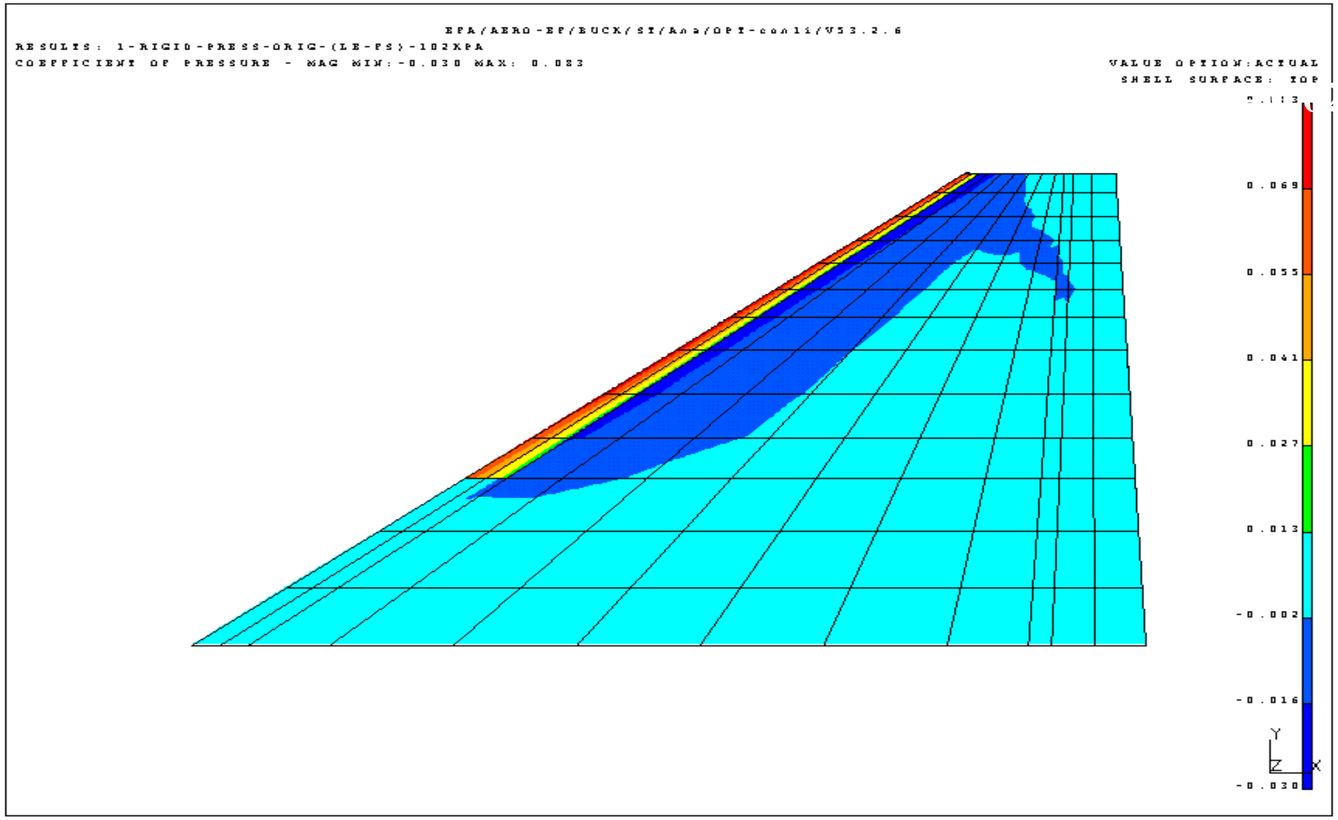
Rolling Moment Effectiveness vs. Dynamic Pressure for 1° Deflections (Statically Optimized)



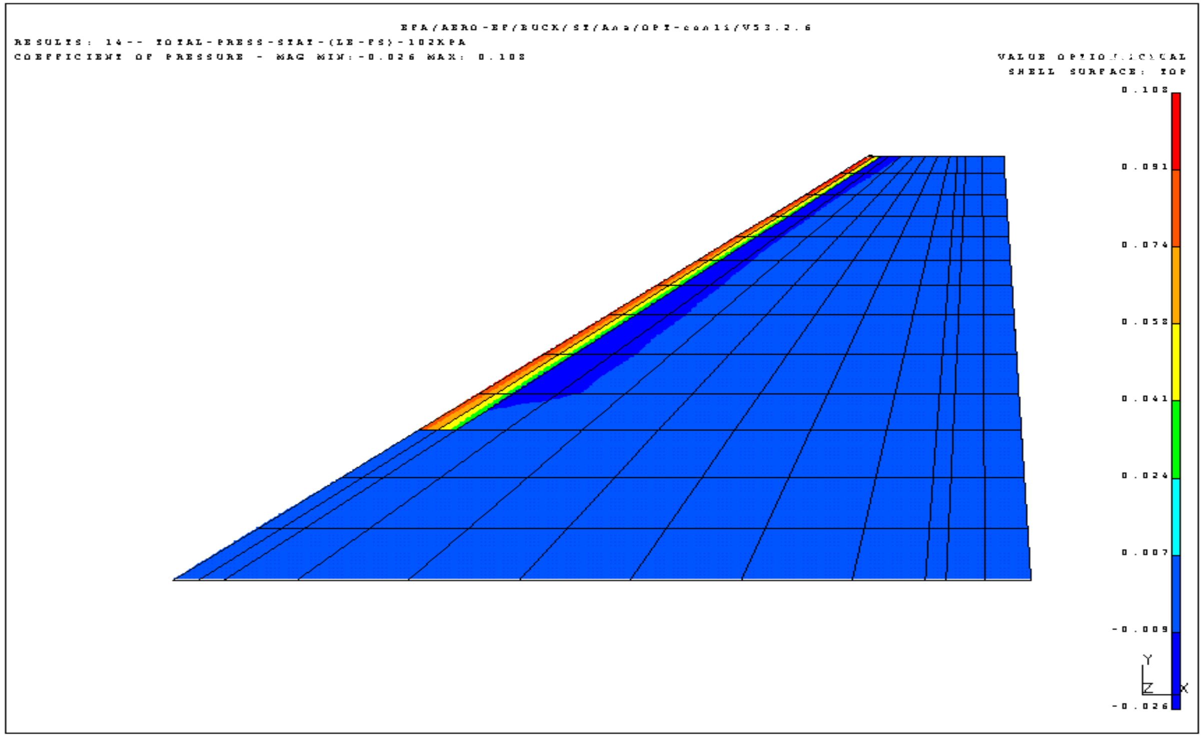
Leading Edge Control Surface Deflections for Original Design (L/E-F/S at (1° defl, M1.2, 102kPa))



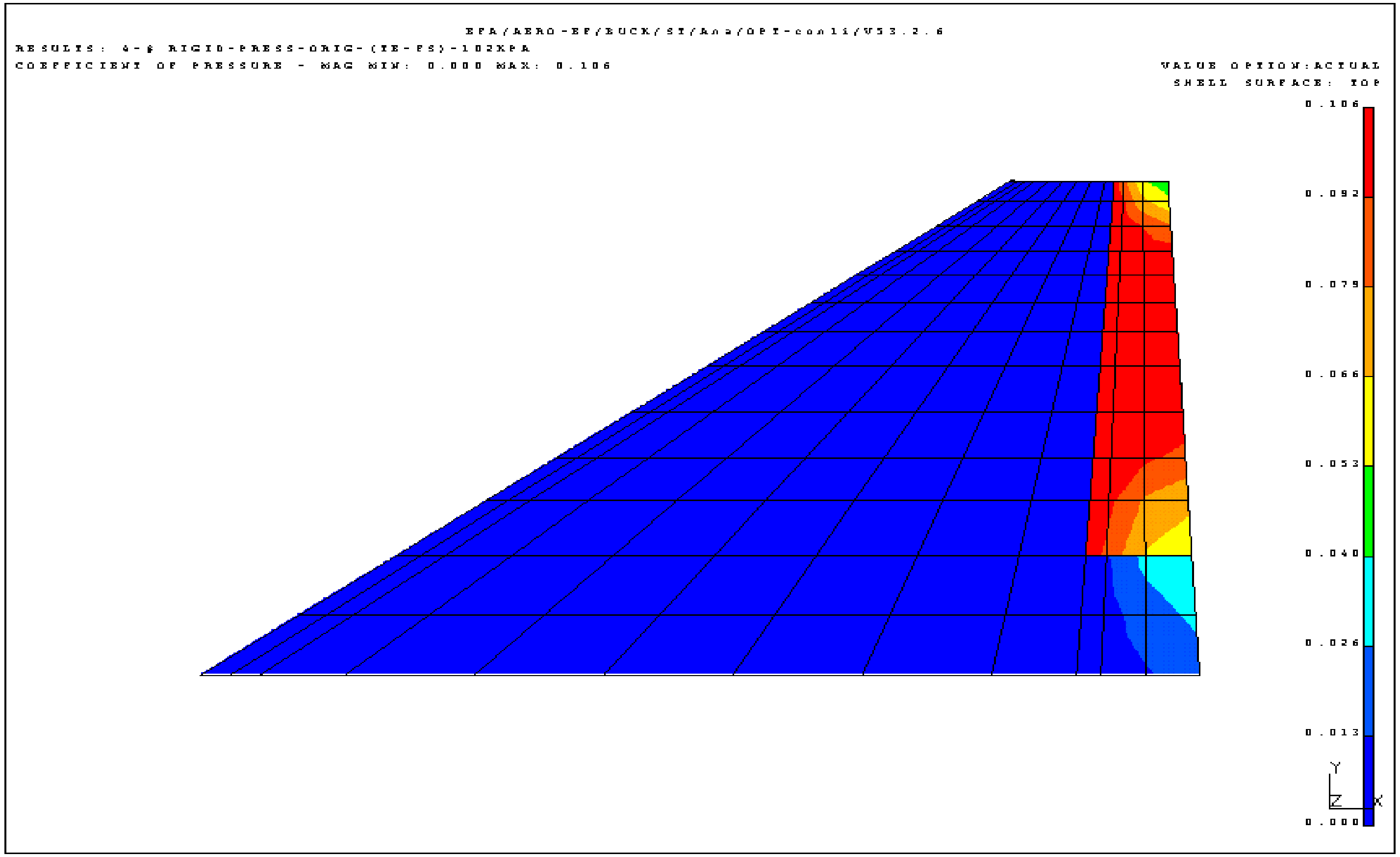
Rigid Pressure Distribution for L/E-F/S (1° defl, M1.2, 102kPa)



Total (flexible) pressure distribution for L/E-F/S, statically optimized (1° defl, M1.2, 102kPa)



Rigid Pressure Distribution for T/E-F/S (1° defl, M1.2, 102kPa)



Total Pressure Distribution for T/E-F/S, statically optimized (1° defl, M1.2, 102kPa)