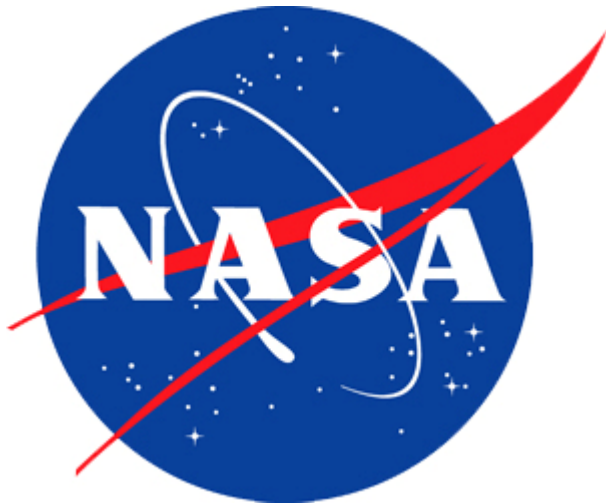


PERSPECTIVES ON HIGHLY ADAPTIVE OR MORPHING AIRCRAFT



Anna-Maria Rivas McGowan

Dan D. Vicroy

Ronald C. Busan

Andrew S. Hahn

NASA Langley Research Center

Hampton, VA

USA



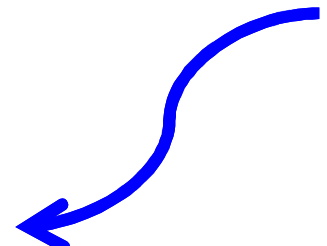
Outline

- What's in a name?
- Morphing History
 - Distant Morphing History
 - Recent Morphing History (Modern Morphing)
- Modern Morphing Myths and Misconceptions
- Closing Remarks



In Air Vehicles: No Clear Agreement on What “Aircraft Morphing” is

- “Aircraft Morphing is...”
 - Large Shape Change
 - Smooth, Seamless Shape Change
 - Unconventional Control Surfaces
 - Reconfigurable Aircraft
 - Reconfigurable Aircraft using Unconventional Control Surfaces
 - Adaptive Wings
 - Real-time, Seamless Wing Shape Control
 - Smart Structures Embedded in Wings for Passive or Active Shape Control
 - Any Kind of Wing Adaptation
 - A Crazy Idea.”
- ***This “Definition Debate” is focused on HOW Morphing is Done***
- ***Likely Without Resolution (too many variables)***
- ***Mission Determines HOW Morphing Should be Done***
- ***More Appropriate to Focus on the Unique (and more Consistent) Capability that Morphing Enables***



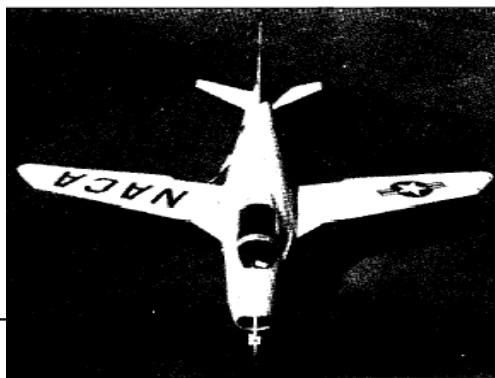
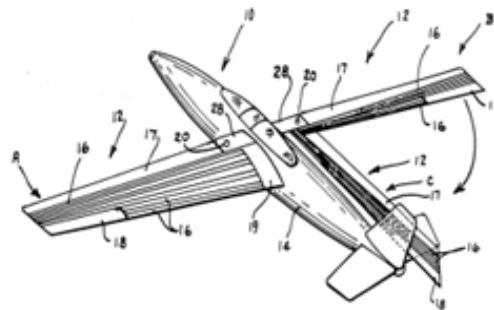
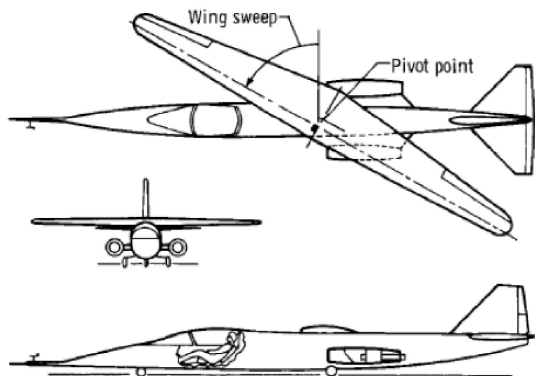
Aircraft Morphing is “Real-Time Adaptation to Enable Multi-Point Optimized Performance in Air Vehicles”



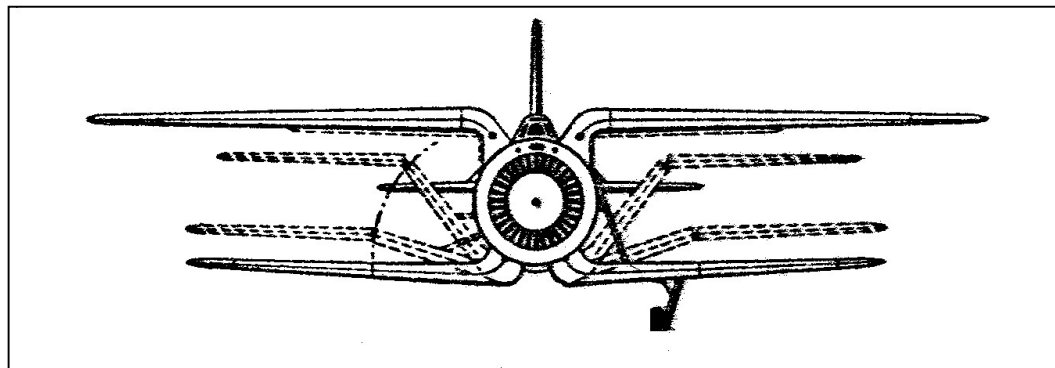
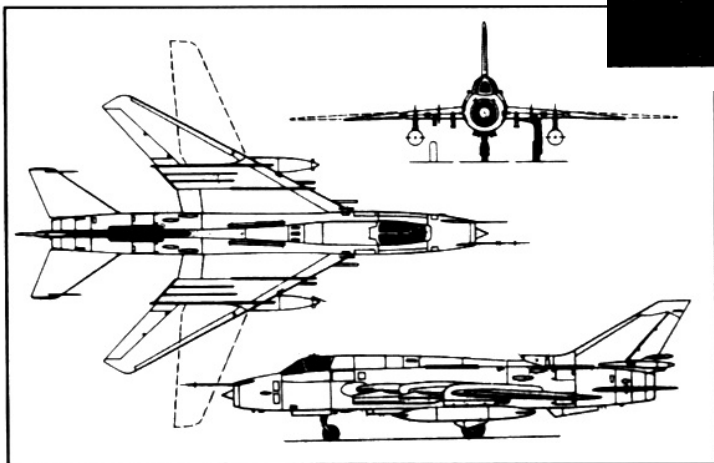
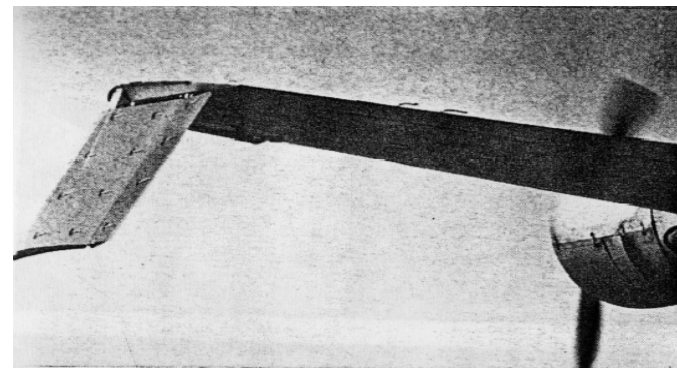
Morphing History: Old and New



The Desire for a Morphing Capability is as Old as Flight



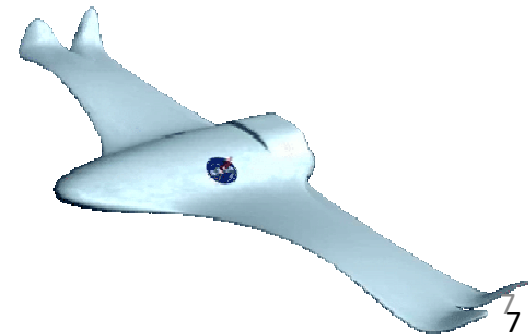
20° SWEEP





Modern Morphing Madness

- In the 1980's and 1990's Smart Materials and Structures hit the World Research Scene
 - Biologically-Inspired and Nano-technology quickly followed
 - The US, Germany and Japan were the initial front runners with several small and large programs
 - Smart materials-based sub-systems began to be used widely in industrial systems
 - The new capabilities offered by smart materials, structures, sensors, bio-tech, nano-tech, MEMS, etc. fostered visions of "Smart Airplanes with Smart Wings" in aeronautics that could fly more like birds
-
- *An over-sold craze?*
 - *The next great leap in aviation?*



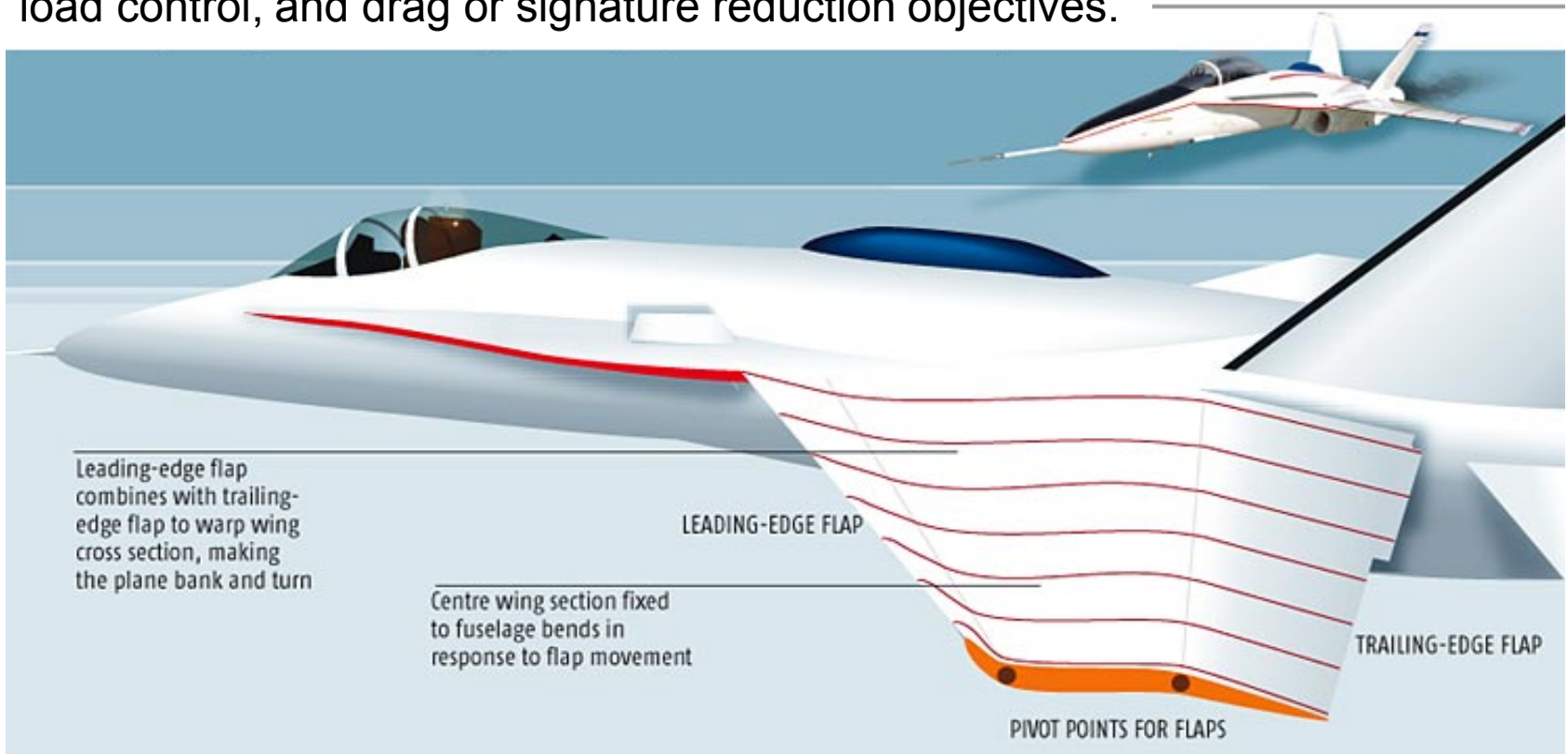


What has 2½ Decades of Modern Morphing Research Taught Us?

- **Morphing is an over-used buzzword**
 - Used liberally in the literature
 - Can help you get funded or get fired
- **Widely varying Morphing research projects that are cannot be quantifiably compared**
- **Benefits of *Real-Time Adaptation to Enable Multi-Point Optimized Performance (Morphing)* are clear**
 - Aircraft: HALE, Fighters, Rotorcraft, UCAVs, Commercial Transports, Propulsion systems
 - Automotive, Maritime, Spacecraft
- **Approaches to enable Morphing go from very promising and to very unsuitable**

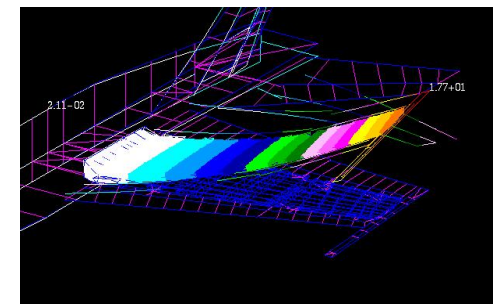
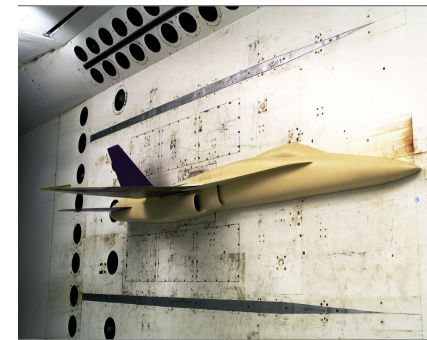
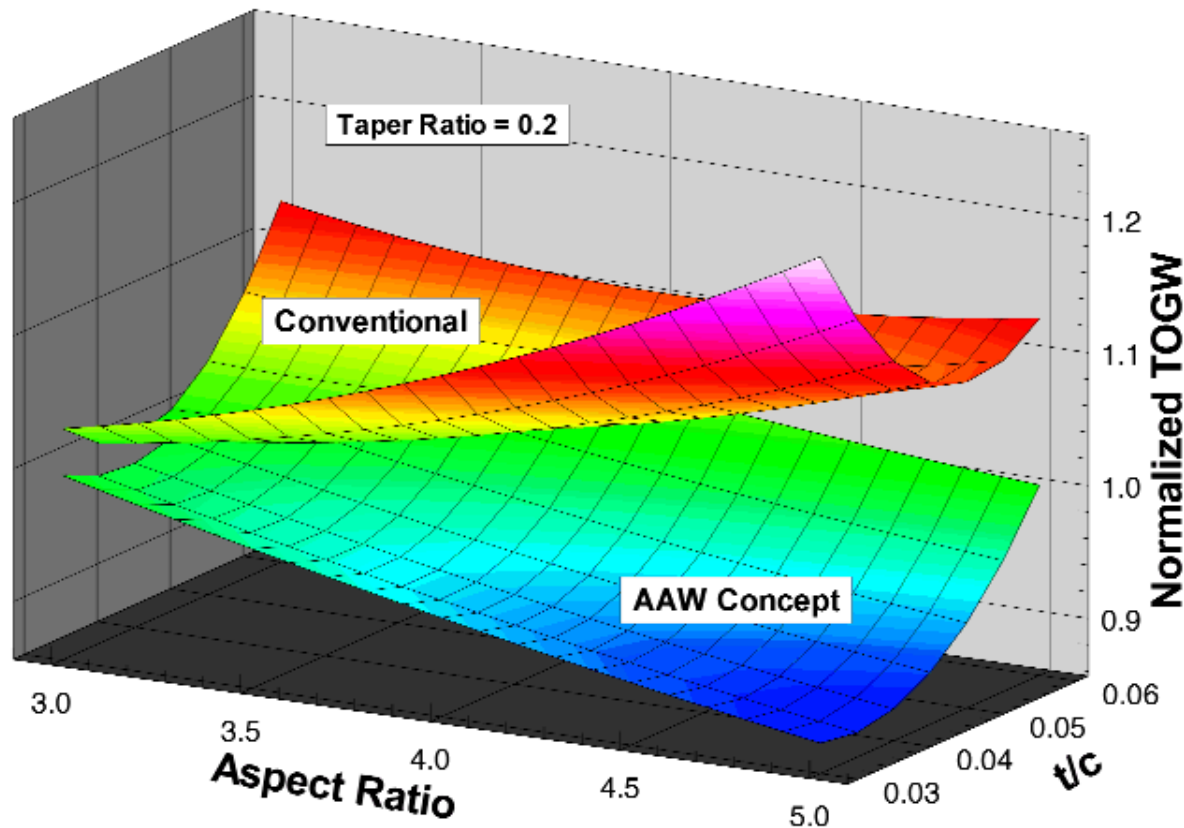
Active Aeroelastic Wing Concept

Multiple leading and trailing edge control surfaces are optimally used to deform a lighter more flexible wing to achieve maneuver performance, load control, and drag or signature reduction objectives.



AAW MAKES THE ENTIRE WING A CONTROL SURFACE

Active Aeroelastic Wing



- Enables a lighter weight wing design
- Extensive analysis, wind-tunnel and flight data
- From Lab to Flight in... 15 years
- Collaborative Team: Air Force, NASA, Boeing



F-18 Aircraft Modified for AAW Flight Test Program



NASA Dryden Flight Research Center Photo Collection

<http://www.dfrc.nasa.gov/gallery/photo/index.html>

NASA Photo: EC01-0076-1 Date: March 15, 2001 Photo by: Tom Tschida

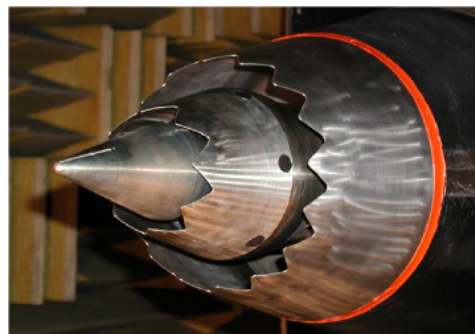
Structural loads testing on the Active Aeroelastic Wing F-18 in the Flight Loads Laboratory at NASA's Dryden flight Research Center, Edwards, California

The Quiet Technology Demonstrator (QTD2) Flies



The 777 experimental airplane sets off for a test flight as dawn is breaking.

- Boeing
- General Electric Aircraft Engines
- Goodrich Corporation
- NASA
- All Nippon Airways



Lab Tests



To combat the sound of jet blast from the rear of the engine, Boeing, General Electric and NASA developed serrated edges called chevrons for the back of the nacelle and the engine exhaust nozzle



Morphing Systems

Tier 2 Developer / Supplier

- Concept development
- Performance prediction
- Engineering design
- Reconfigurable structures
- Seamless skins
- Actuation & controls
- Prototype fabrication
- Test & evaluation
- Optimization
- Manufacturing



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Revolutionary systems design methodology
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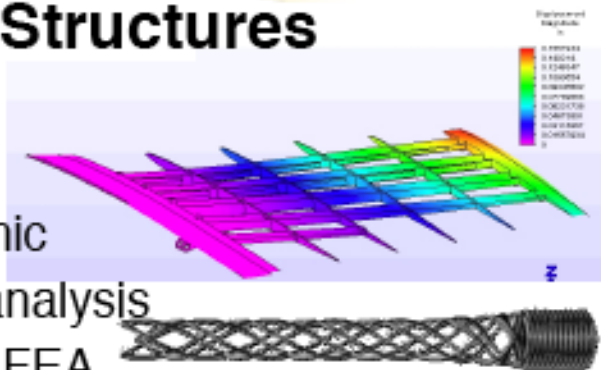
 **GO BEYOND**
10 YEARS OF INNOVATION

Demonstrated Morphing Solutions

Morphing Structures

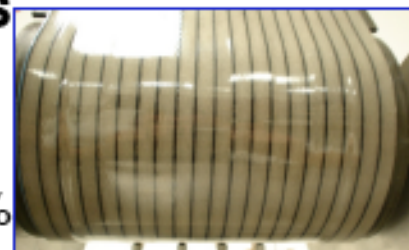
Design tools

- Catia V5
- Aerodynamic design & analysis
- Non-linear FEA
- Rigid & compliant mechanization
- Constitutive materials modeling



Morphing Skins

- Reinforced
- High toughness
- Elongation $\leq 100\%$



SMP

- Hard/Soft switching

Elastomer

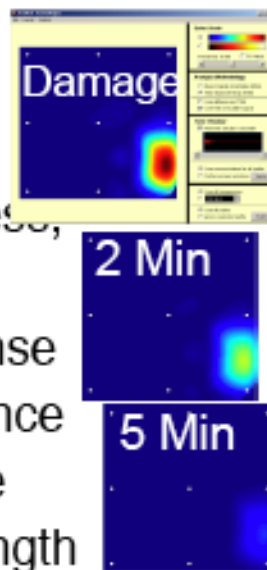
- Always soft



Reflexive Structures

Integrated structural health maintenance systems

- Autonomously detect, assess, prioritize & repair damage
- Repeatable healing response
- In-flight / routine maintenance
- Heals interlaminar damage
- Restores 90% flexure strength



Morphing Materials

- Shape memory polymers (SMP)
- Shape memory composites
- Reinforced elastomers
- High strain & strength reinforcements
- Elastic circuits & heaters
- Graded composites
- Light-activated SMP
- Healing resins



Widely Varying Morphing Research Efforts

Extremely Challenging to Adequately Address All Aspects of an Aircraft Morphing Research Effort

- Aeroelastic Scaling (Static, Dynamic)
- Aerodynamic Scaling (Mach #, Reynold's #)
- Flight Dynamics Scaling (Moments of Inertia, ω_n , Power)
- Structural Scaling (Loads, Density, Distribution)
- Others....

Research efforts with different motivations, constraints and requirements:

- Educate Students
- Develop (a new) Competence in a Professional Research Group
- Explore the advantages of a new technology to solve a problem (not identify the best morphing approach)
- Quick and cheap demonstrations
- Proof of concept demonstrations (usually focused on one aspect)
- Develop more efficient morphing sub-systems (materials, actuators, sensors, control systems, electronics, skins, etc.)



Several Misconceptions and Myths about Morphing Have Persisted



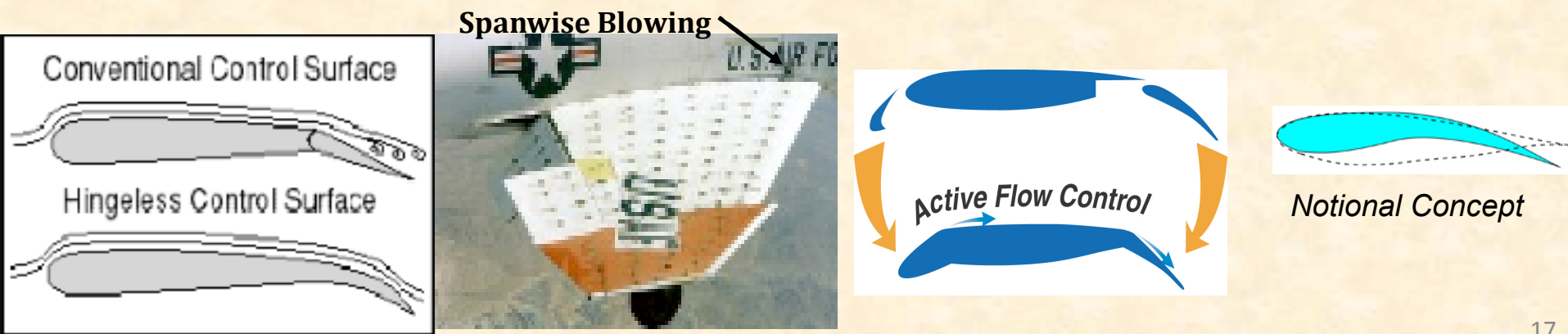
Modern Morphing Myths and Misconceptions



Modern Morphing Myths & Misconceptions

MORPHING PAY-OFFS AND PENALTIES CAN BE GENERALIZED TO A SINGLE ANSWER

- “Morphing” is often considered “one” technology in design trade studies
- ***“We also considered morphing in our trade study...”*** (For example morphing for camber change)
- Morphing is not ONE technology or approach
- It is misleading (or inaccurate) to consider it as such in design studies
- Each individual approach to morphing has its own quantifiable Pay-offs and Penalties





Example Wing Morphing Approaches

Wing Adaptation

Airfoil Shape/ Camber/ Leading Edge Shape/ Bumps (Small and Large)

Aspect Ratio/ Wetted Area

Sweep

Twist

Dihedral

Leading Edge Droop

Seamless Control Surfaces

Numerous Micro Surfaces

Key Benefits

Varying Stall Speed, Low Speed Handling, Control Effectiveness

Trade Induced Drag vs. Parasite Drag, Slower Speed Landing, Higher Speed Cruise, Vary L/D

Lowers Drag at High Speeds

Vary Spanwise Lift, Minimize Induced Drag, Vary Wing Bending

Vary Stability vs Maneuverability

Low Noise at Low Speed

Survivability, Drag Efficiency

Vary Spanwise Lift, Control effectiveness

Integrated Technologies:

- Micro Flow Control (Separation control, circulation control, etc.)
- Active Aeroelastic Wing (Entire wing is a control surface for maneuvering)
- Simplified High Lift System (Aggressive high lift with simplified control surfaces and flow control)



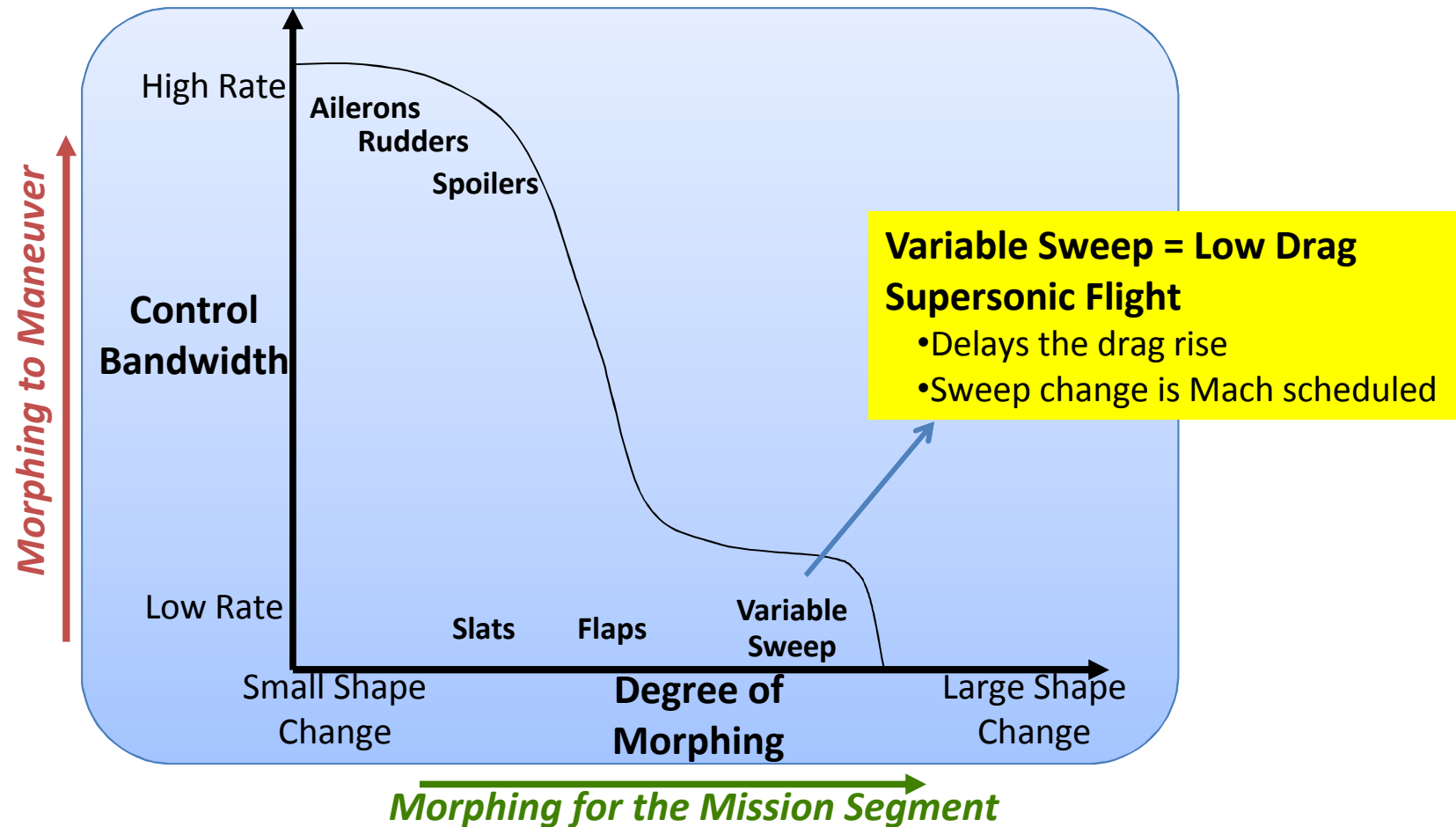
Modern Morphing Myths & Misconceptions

MORPHING MUST BE SEAMLESS OR LARGE SHAPE CHANGE

- Excellent goals
- But unnecessary design constraints
- May lead to a non-optimal approach from the vehicle perspective
- The ultimate goal of morphing in an aircraft is to **TRANSFORM THE *AIRFLOW***. Not the structure
- Remember: it's about flight performance not structure.
- From the Airplane's Perspective:
Structural Shape Change = Aerodynamic Shape Change
- ***Many*** ways to transform the airflow
 - May not need seamless or large shape change
 - Small, distributed transformation may be more effective or efficient



Fast & Slow, Large & Small Morphing



Often Use Large Shape Change to Accommodate Different Mission Segments

Take Off to Cruise

High Speed Flight to Low Speed Flight

Low bandwidth, appropriate for the slow change in mission segments



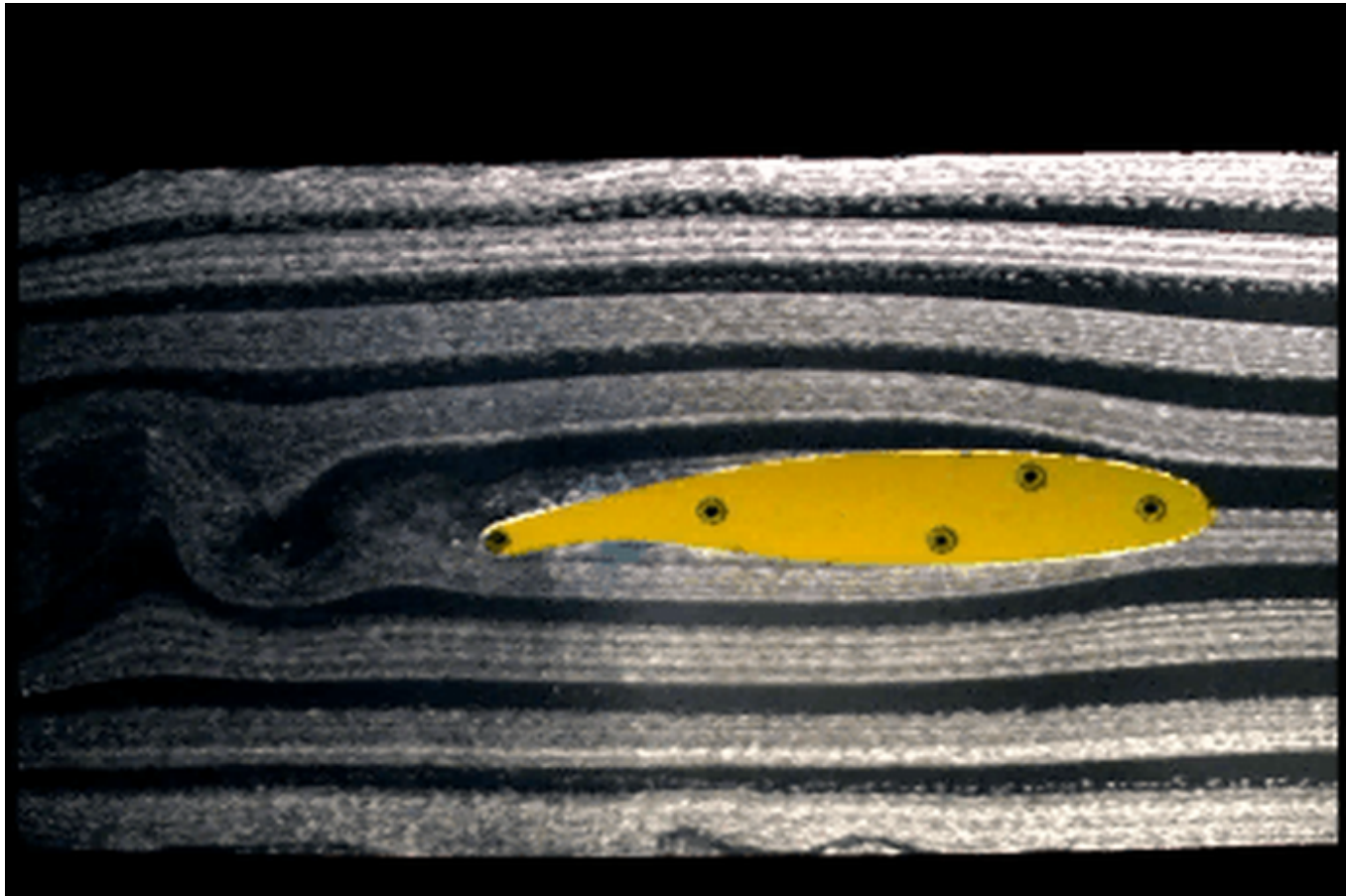
Morphing WithOUT Shape Change??



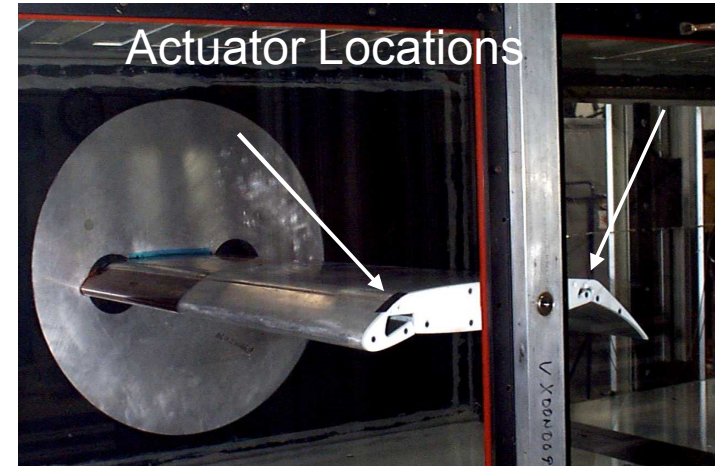
Nothing Changes Shape - Is it still Morphing?

From the Airplane's Perspective:

Structural Shape Change = Aerodynamic Shape Change

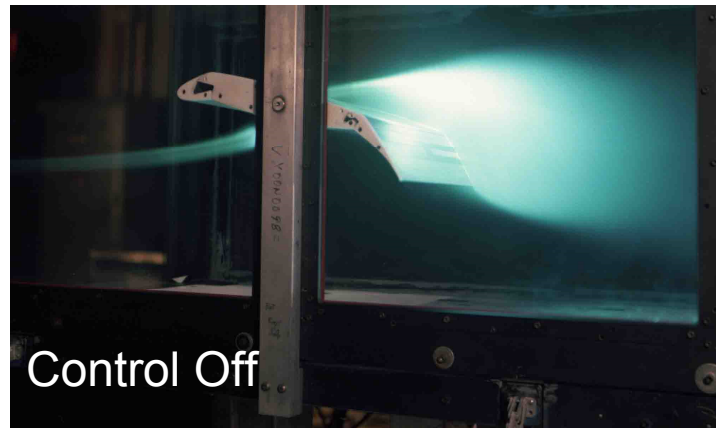


Blending Adaptive Structures with Adaptive Flow Control

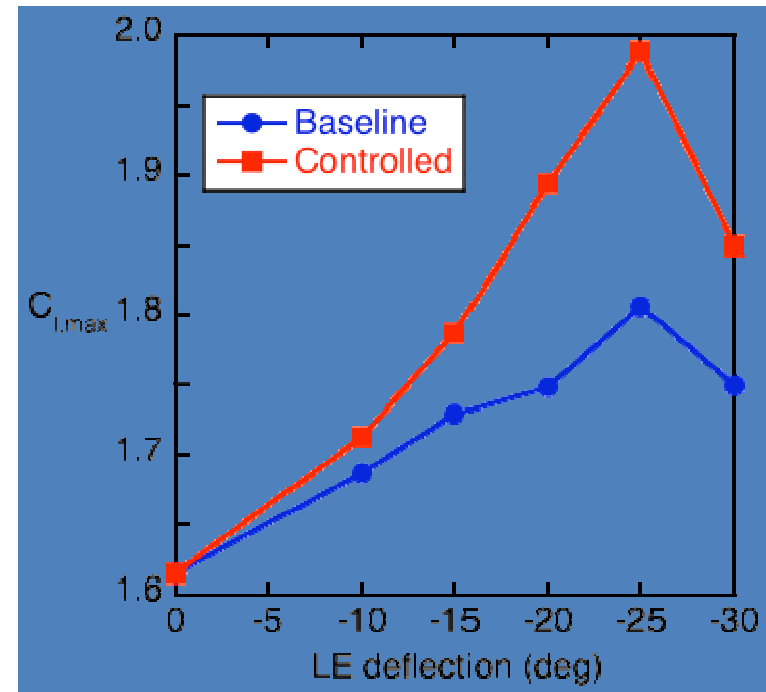


- Simplified High Lift with zero-net-mass blowing
 - Applied to existing commercial airliner yields projected 3.3% reduction in drag and weight, 1.5% reduced cost
 - Implemented at vehicle design stage yields projected **15% reduction in weight, 49% reduction in power, 20% reduced cost** (Industry Estimates)

Separation Control to Enable Simplified High Lift Systems



Separation on the Leading Edge is Controlled Using Oscillatory Blowing



Simplified High Lift System





The Function of the Morphing Mechanism is to Enable the Aircraft's Mission

Morphing Mechanisms May Include A Combination Of:

Large Shape Change

Small Shape Change

Aerodynamic Shape Change

Passive or Active Aeroelastic Control

Multiple Small Control Surfaces

Etc.

...Whatever it takes to enable the Mission



Modern Morphing Myths & Misconceptions

MORPHING TECHNOLOGY MUST WEIGH LESS OR BE LESS COMPLEX THAN CONVENTIONAL SYSTEMS

- Excellent goals
- But unnecessary (or inappropriate) design constraints
- The morphing sub-system may be heavier or more complex
- The overall system must be more efficient
- Modern Example: Retractable Landing Gear
 - Heavier, More Complex, Harder to Maintain
 - But ***required*** to enable an efficient airplane to fly at high subsonic or greater speeds



Increased Dimensionality For All Disciplines

For Example, In Flight Dynamics and Control:

Flight dynamics and control challenges associated with morphing:

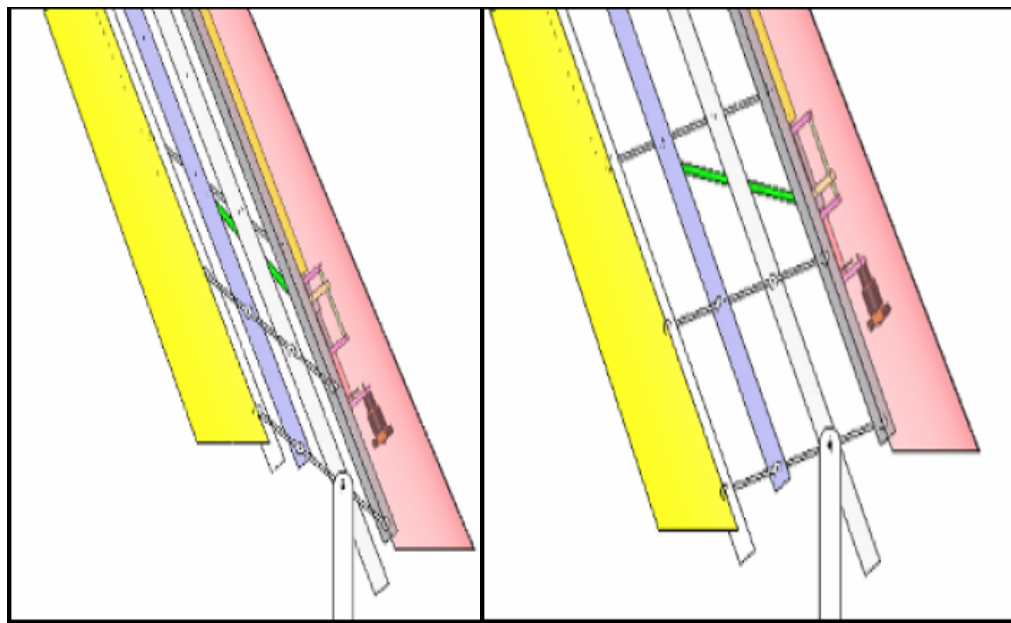
- **Widely varying mass properties (Moments Of Inertia & CG)**
- **Widely varying aerodynamics (AC, trim changes, stability margin)**
- **Widely varying aircraft dynamics (directional stability, short period mode, effective dihedral, etc.)**
- **Said from a Pilot's perspective: Essentially flying very different “airplanes” during the same flight**



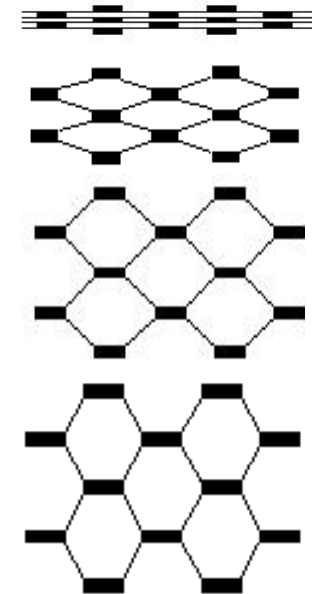
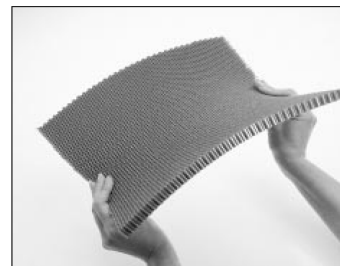
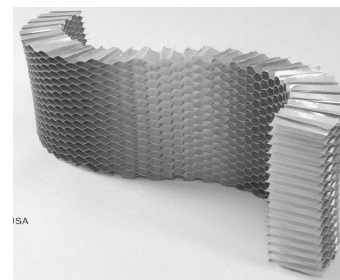
Structural Design Paradigm Shift Required

- For 100 years the trend has been to create stronger & more rigid structures as aircraft aero & g-loading requirements have increased
- To make morphing a more viable option, structures should allow morphing without fighting against structural stiffness

- Aircraft structural design to facilitate morphing may include:
 - System-level mechanization
 - Micro-level design of structures with flexibility in particular directions
 - Using smart materials for key components
 - In-flight aeroelastic tailoring of contours using active controls



System-Level Mechanization for a Wing Structure – Parallelograms Stiff for Normal Loads While Allowing In-Plane Shape Change



Honeycomb as a Micro-Level Structural Element With Differential Flexibility



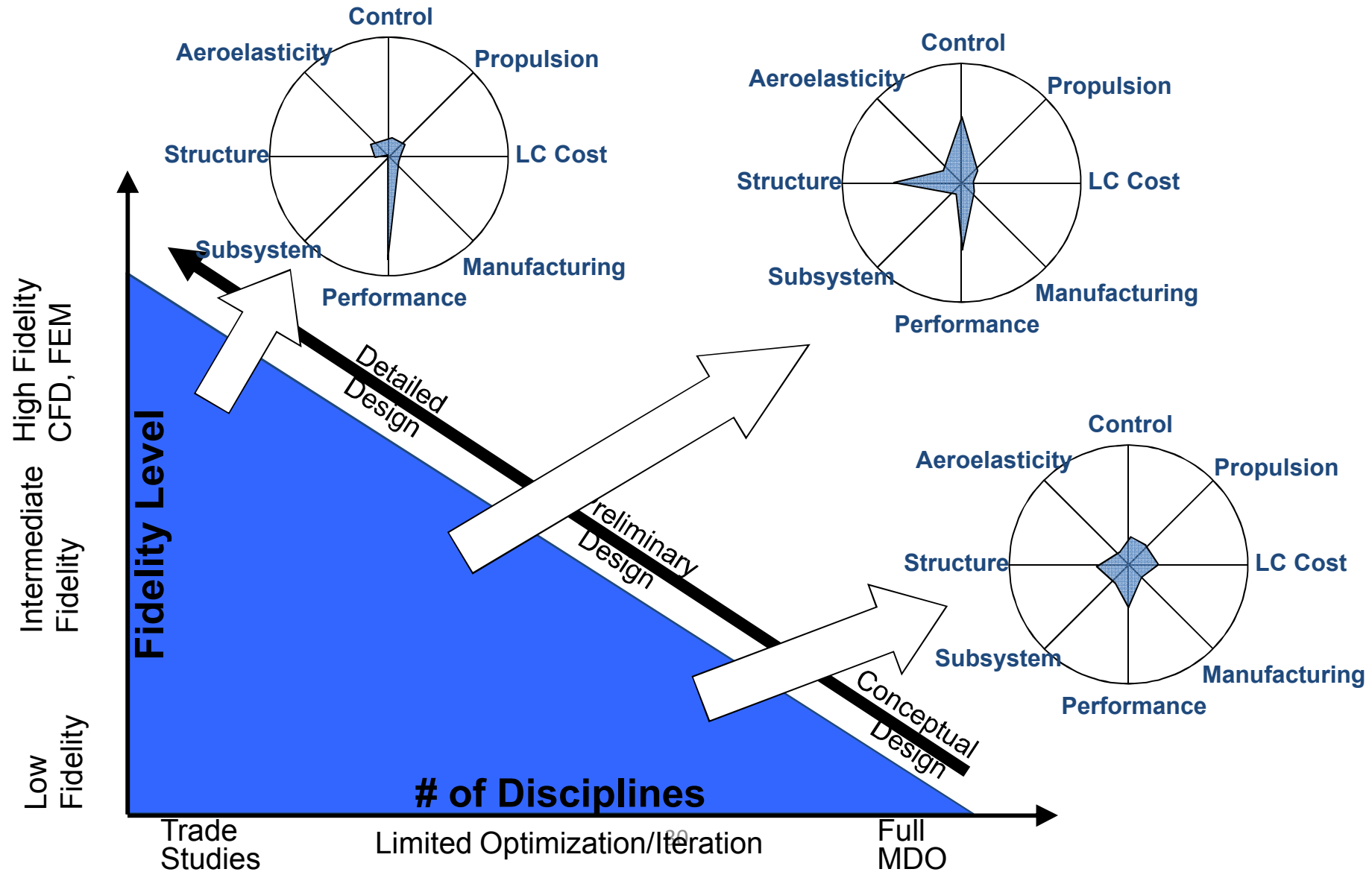
Modern Morphing Myths & Misconceptions

OPTIMIZING THE MORPHING TECHNOLOGY = OPTIMIZED VEHICLE PERFORMANCE

- Also an excellent goal
- But still may be an insufficient (or an inappropriate) design approach
- For example: optimizing control using SMAs, Piezos, etc., instead of optimizing gross weight
- Very common in the literature (for understandable reasons: Technology Push)
- System design is nearly always a compromise of integrated sub-systems
- Morphing is a multi-discipline, multi-level challenge focused on the **SYSTEM** performance
 - **Multi-discipline:** structures, aerodynamics, thermodynamics, etc.
 - **Multi-level:** materials, actuators/mechanisms, structures, leading edges, wings, vehicle
- Can assemble a team of experts that integrate optimized sub-components to create a very non-optimal system

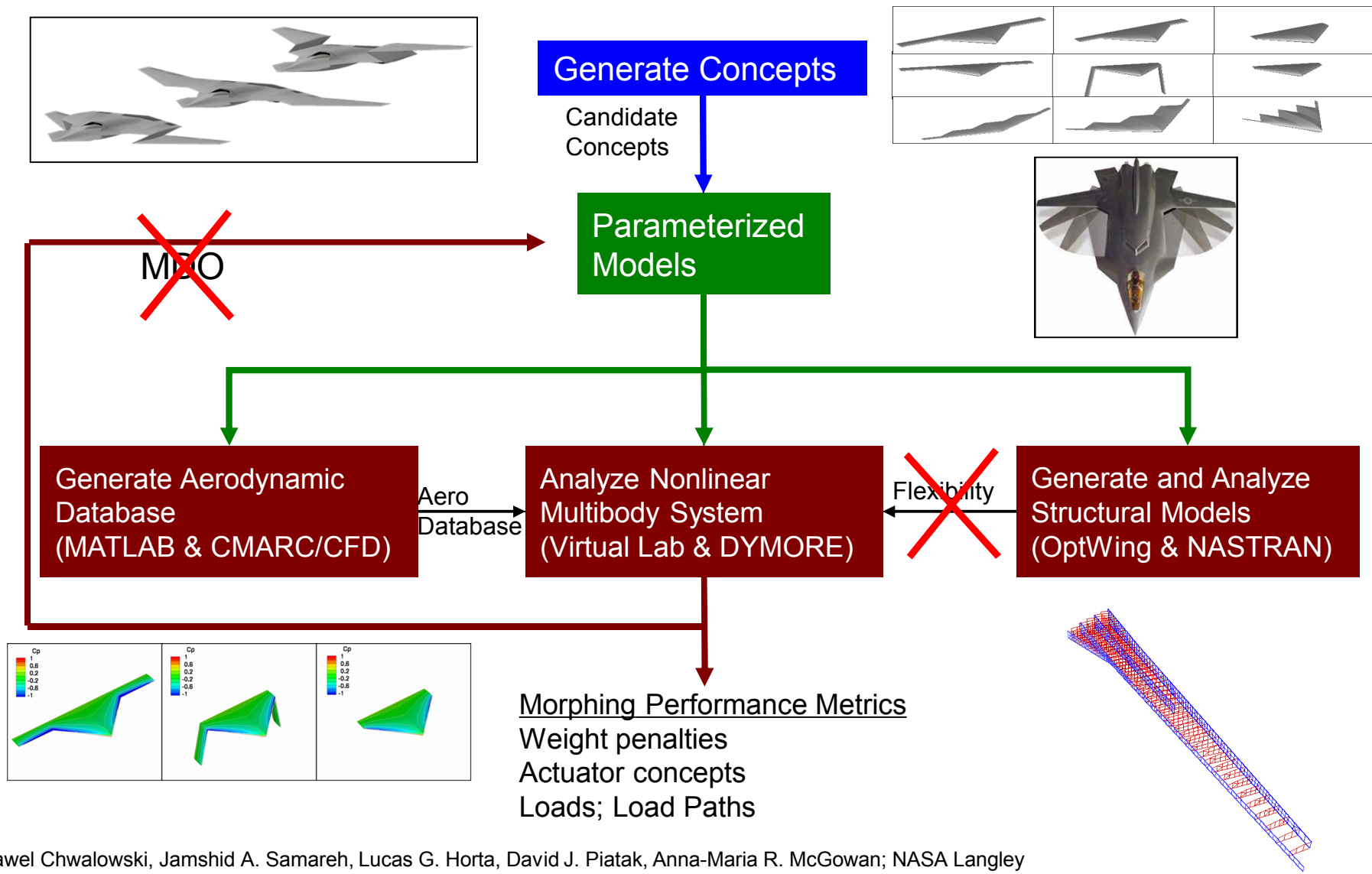


MDO Practices



Integrated Aerodynamic/Structural/Dynamic Analyses of Aircraft with Large Shape Changes

Goal: To develop a consistent multidisciplinary analysis tool that would enable the efficient and the accurate assessment of multiple morphing concepts with second-order fidelity





Some Considerations

Extremely Challenging to Adequately Address All Aspects of an Aircraft Morphing Research Effort

- Aeroelastic Scaling (Static, Dynamic)
- Aerodynamic Scaling (Mach #, Reynold's #)
- Flight Dynamics Scaling (Moments of Inertia, ω_n , Power)
- Structural Scaling (Loads, Density, Distribution)
- Others....

Morphing: Real-Time Adaptation to Enable Multi-point Optimized Performance

- More descriptions (with the designer or user in mind)
 - Scaling, assumptions, scope of research
- Multi-point Optimized Performance
 - Avoid over-constraining the solution
 - Identify why the approach was chosen (and potential alternative solutions)
- Integration of systems and sub-systems
 - Boundary conditions and operation requirements
 - Multi-discipline challenges and requirements

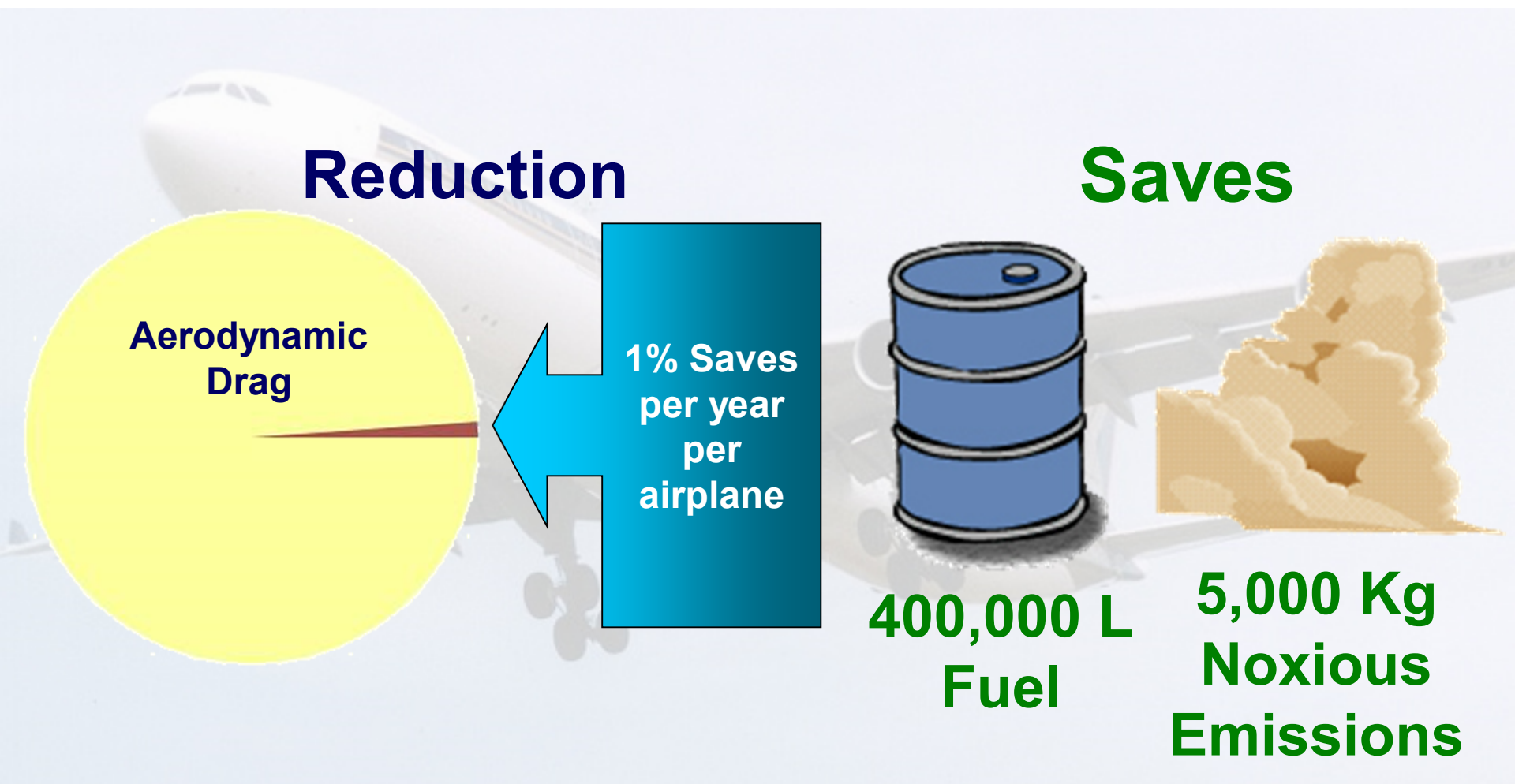


Closing Remarks

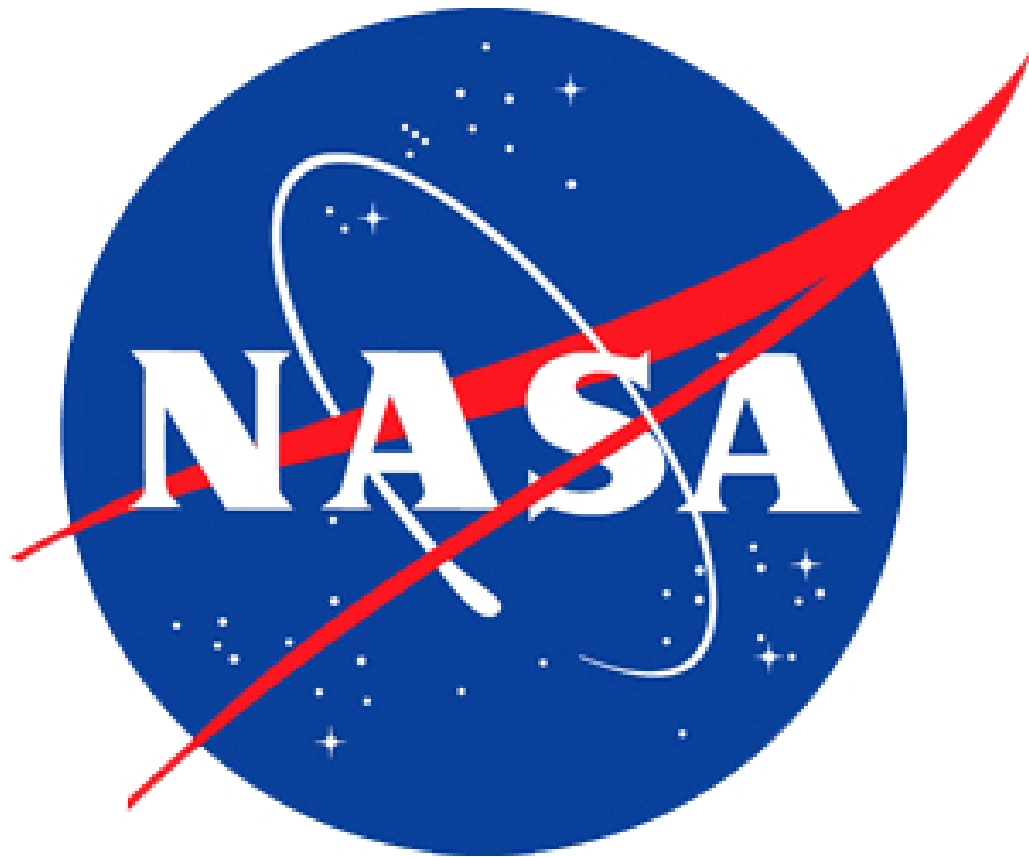
- Aircraft Morphing is not a new aspiration
- New technologies may enable more of the vision for Aircraft Morphing to be realized
 - Smart materials, innovative structures, micro-sensors, flow control, nano-technology, etc.
- Morphing is an abused “buzzword” that is used liberally in the literature giving rise to some misconceptions and myths
 - Caution must be used in comparing results from the literature
- Morphing research is often over-constrained
 - Must be seamless, Must be structural change, Must use a particular material, Must be large change,
- Mission requirements should drive the morphing approach
 - Not a definition of morphing
 - Or the sex appeal of the technology
 - Or the capability of the research group (if possible)
- Morphing Capability isn’t a passing fad (Different Approaches to Morphing May Be)
 - Morphing Capability is an enduring and relentless goal to expand the capabilities of air vehicles
 - Performance demands are not shrinking; they are expanding
- What’s next?
 - The **Greening of the Airplane**: Addressing environmental goals without compromising flight performance



Drag Reduction & Environmental Impact



Based on an A340 Aircraft - Wolfgang Schneider, EADS Airbus



Questions?