Active Aeroelastic Aircraft Concepts

by
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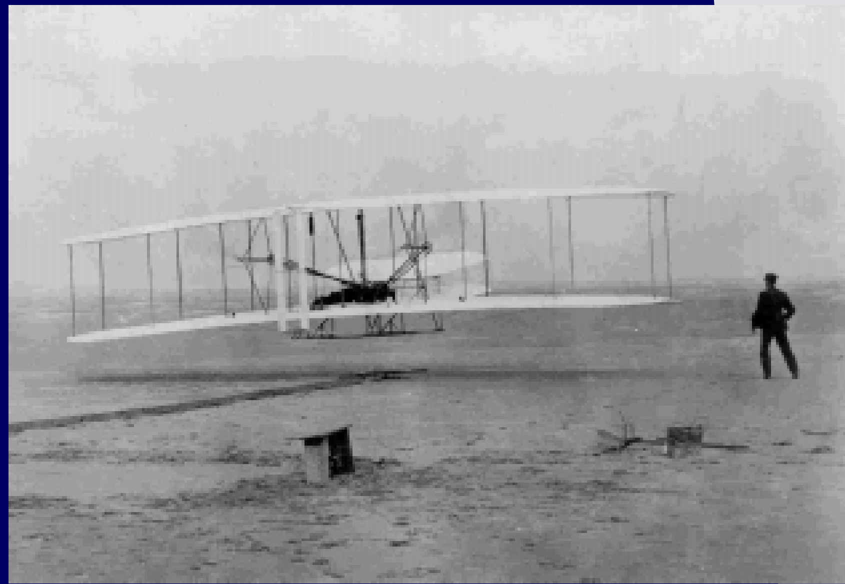


RTA-AVT-86 Technical Course
METU, Ankara, 25-29 March 2002

Active Flexible Wings - a Vision

Das Flugzeug, das wie ein Adler flattert

Fliegen wie ein Adler oder eine Libelle – ein alter Menschheitstraum. Jetzt arbeitet die amerikanische Raumfahrtbehörde NASA an einem neuen Model, das sich wie ein Vogel oder ein Insekt am Himmel bewegt und nur mehr wenig Kerosin verbraucht.

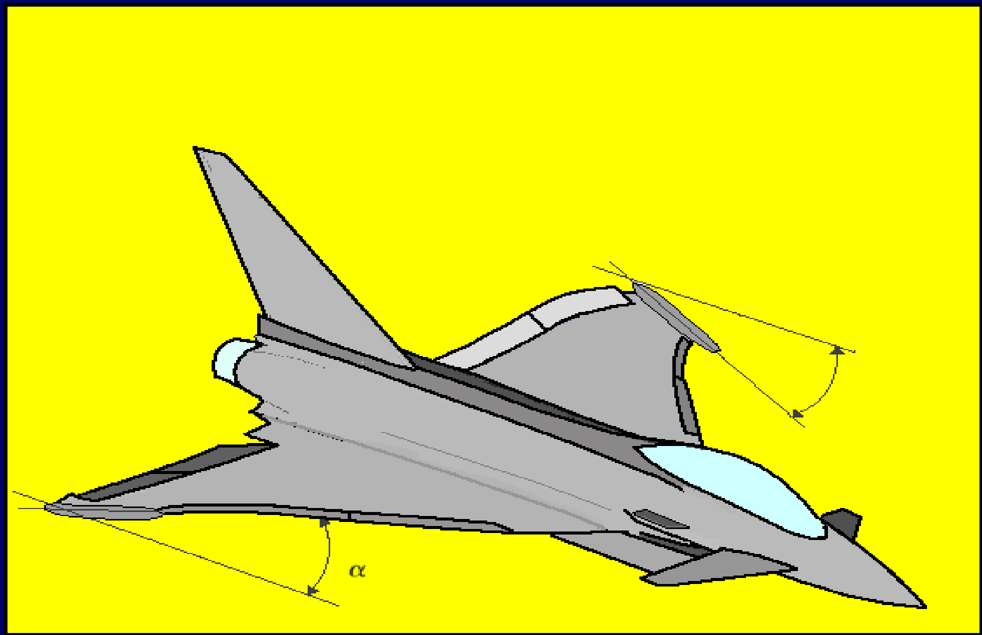
Projekt-Mitarbeiterin Anna McGowan: „Vögel schweben auf der Stelle, fliegen rückwärts und seitwärts. Insekten können sogar verkehrt herum oder Loopings fliegen. Das neue Flugzeug soll seine Schwingen auf Kommando ausbreiten und wie ein lebender Organismus verändern." Als Material soll ein spezieller Kunststoff dienen, der durch seine Eigenspannung die Flügel selbstständig beugt und streckt." Der Prototyp soll im Jahr 2021 starten.

Active Structures Concepts

- Historic review
- (Flexible) flying structures in nature
- The role of flexibility
- Aeroelastic sensitivities
- Applications
- Concept categories
- Smart materials
- Adaptive actuators
- New active structures concepts
- Examples
- Conclusions

Active Structures Concepts
- Definitions -

•Aircraft Structures which are actively deformed (by different typed of actuation devices)

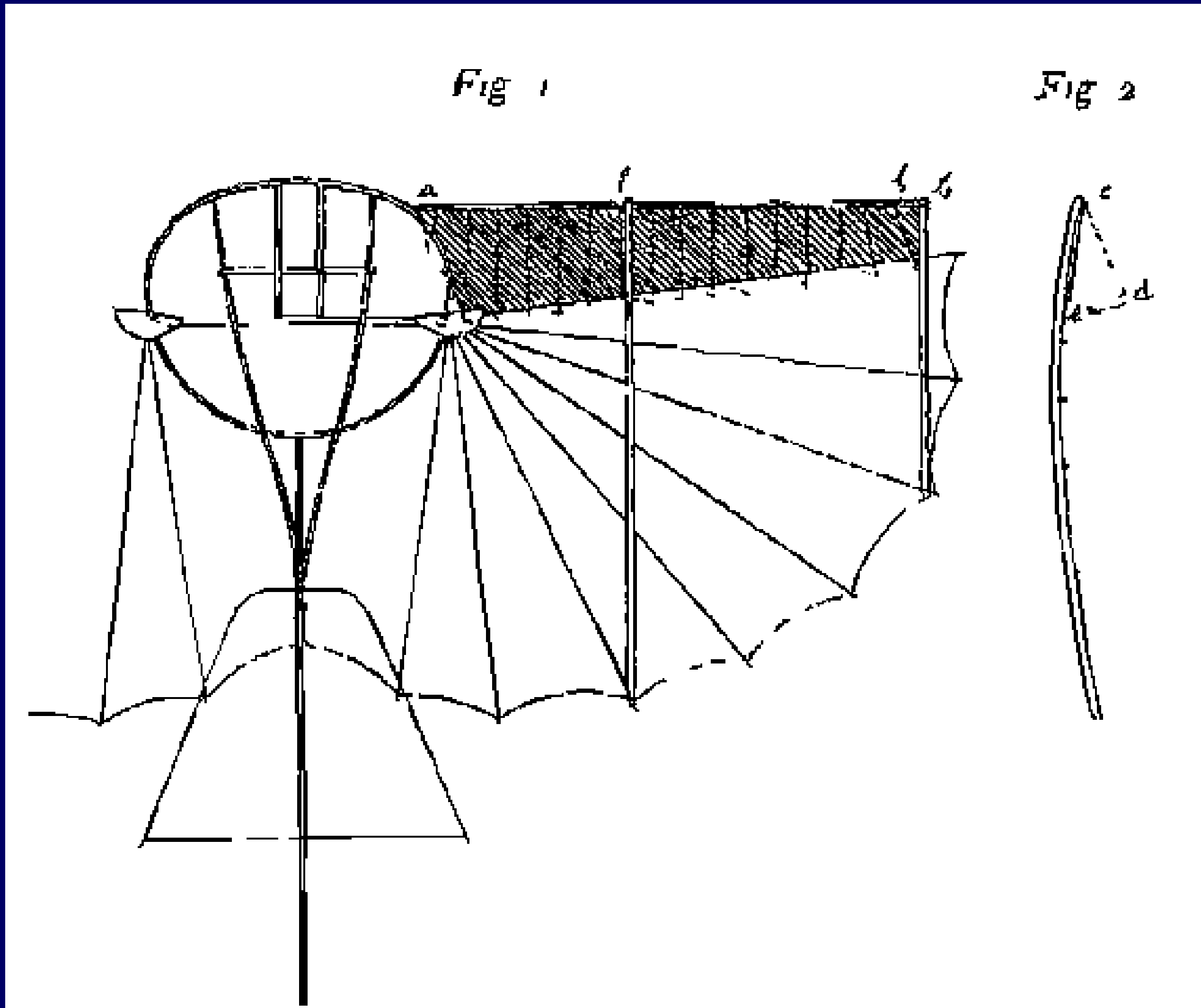


•Here limited to static deformations.

Active aircraft structures - The early years -

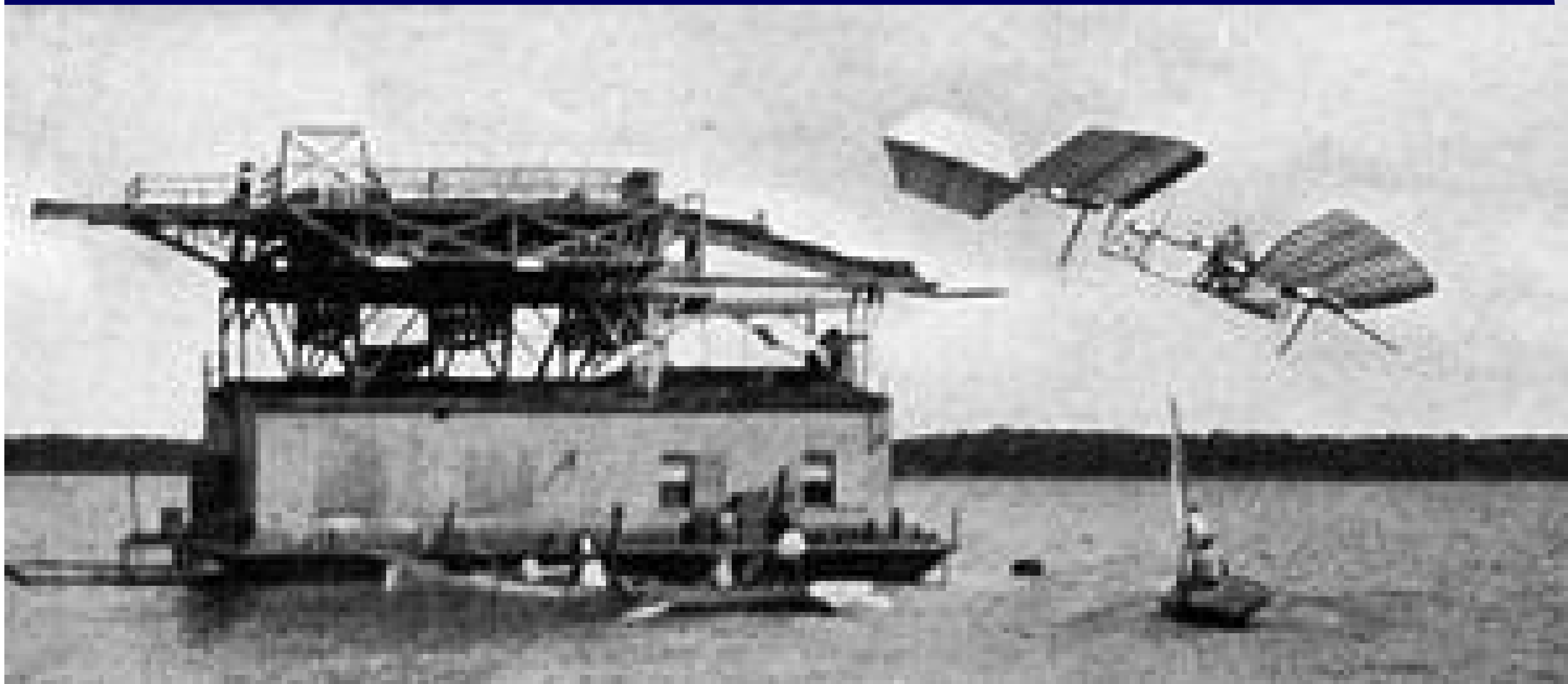
Lilienthal “Vorflügelapparat” 1895:
•Active camber control
•Active leading edge surfaces
•All-movable “drag control” devices

Lilienthal Active Leading Edge Control Surface Patent 1995

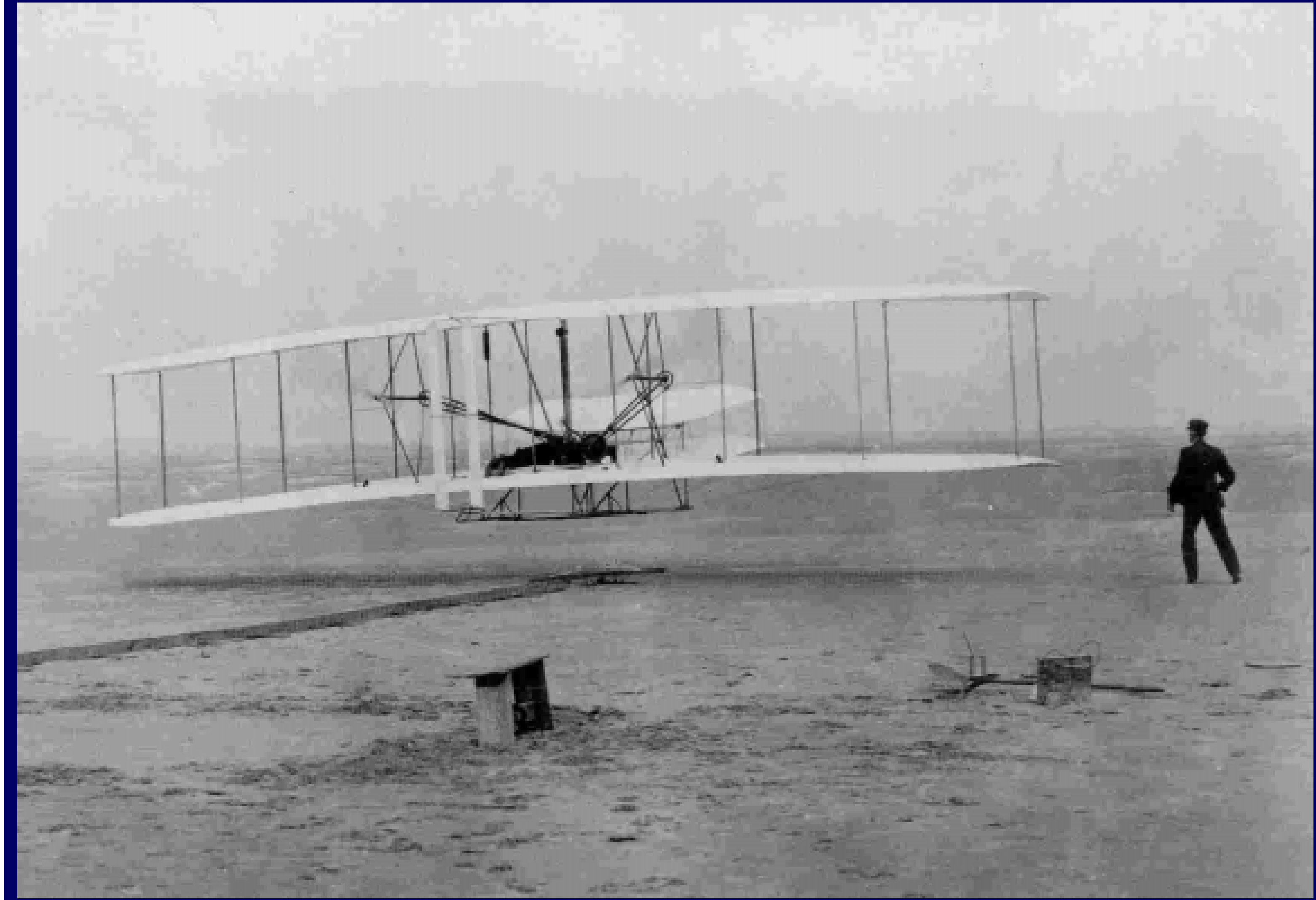


Lilienthal's "Normalflugapparat" 1894
- the first production aircraft -

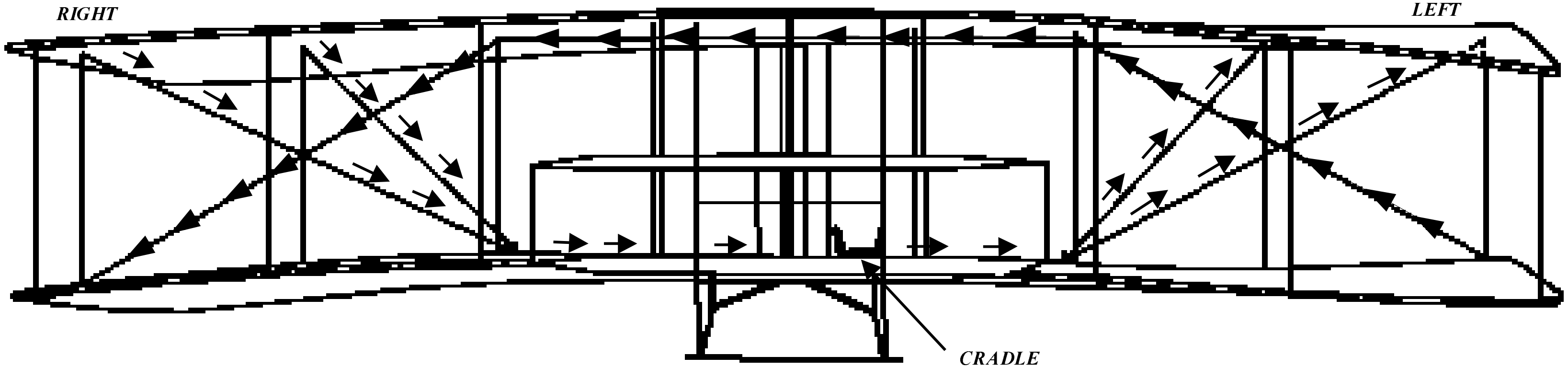
Aeroelastic impacts on aircraft performance
- The early years -



Aeroelastic impacts on aircraft performance
- The early years -



Roll control of the Wright Flyer-I by wing twist

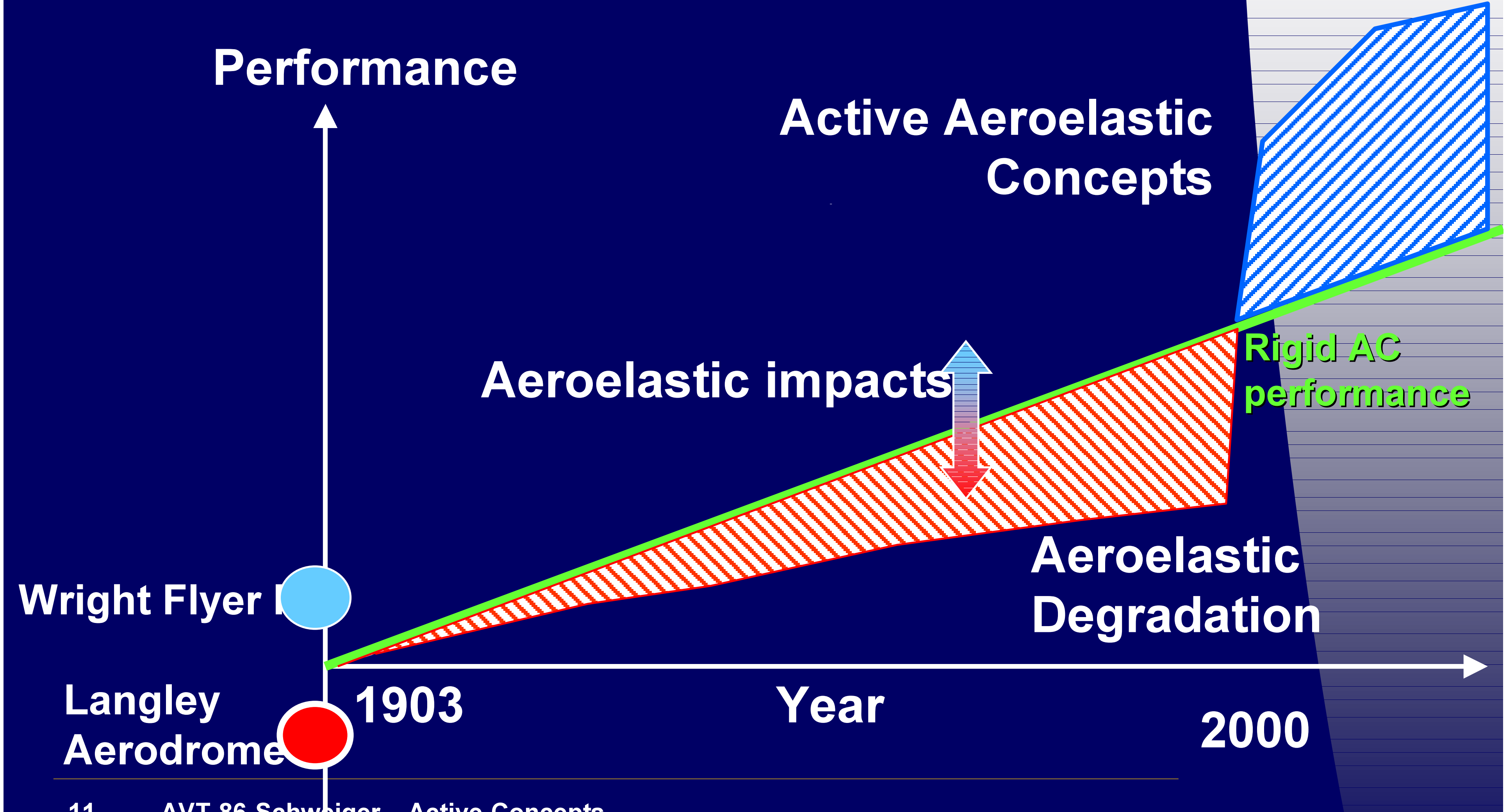


CABLES ATTACHED TO CRADLE - SLIDING CRADLE TO LEFT OF MACHINE PULLS TRAILING EDGE OF RIGHT WING DOWNWARD

CABLE (NOT ATTACHED TO CRADLE) IS MOVED AUTOMATICALLY BY DOWNWARD MOVEMENT OF RIGHT WING

The accompanying picture of the Wrights' powered machine (with motor and propellers removed) shows the method of twisting the rear of the wings. A movement of only an inch or two, to the left or right, of the operators' hips resting on the little cradle was enough to give greater lift to whichever wing needed it, and to restore sidewise balance.

Aeroelastic impacts on aircraft performance



Active Structures Concepts for Aircraft Control
- Applications -

•Aerodynamic drag
- induced
- friction (reduced area)

•Aerodynamic control effectiveness
(conformal shape control surfaces)
&
•Aeroelastic control effectiveness

•Stabiliser effectiveness

•Load control

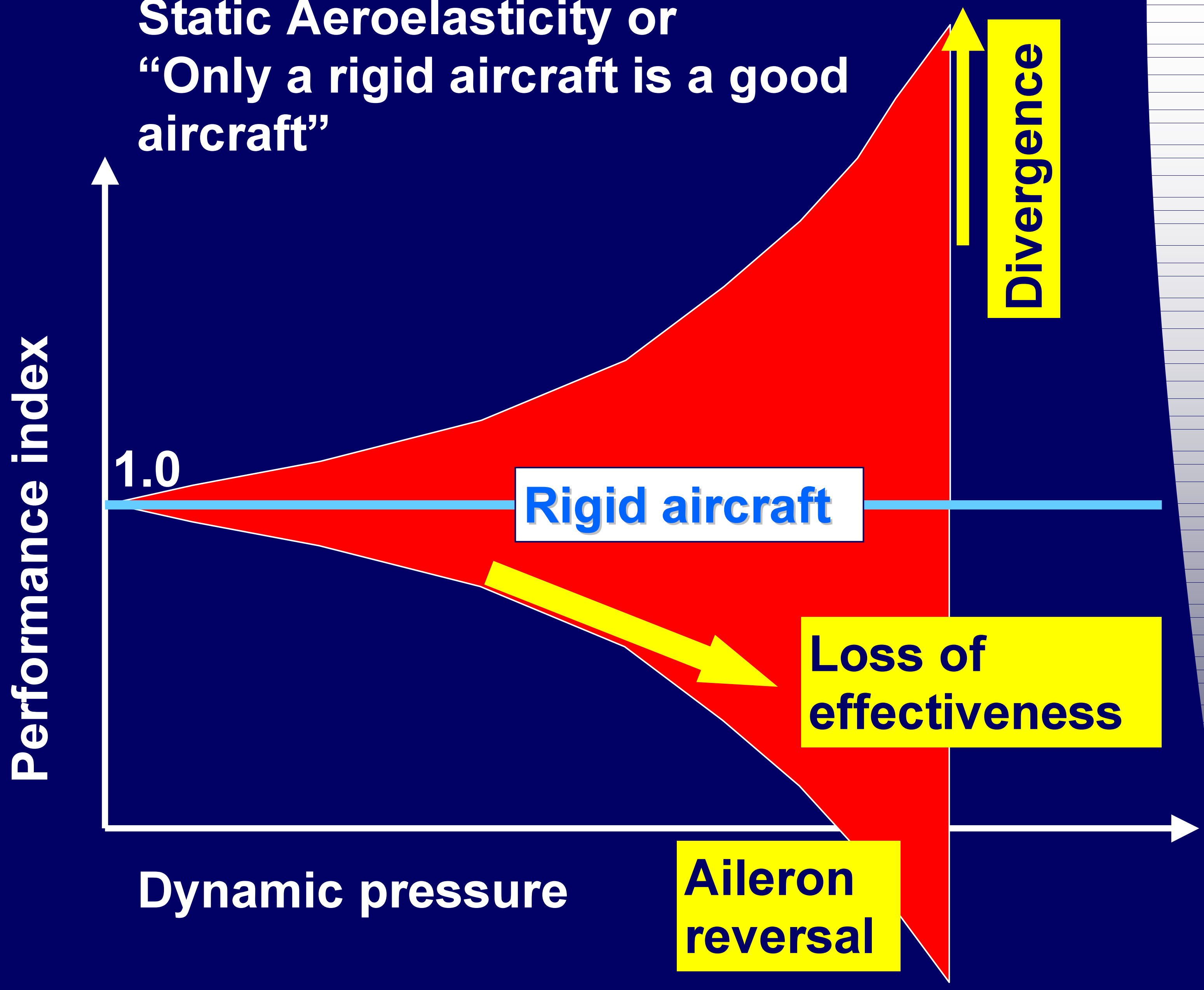
Active Structures Concepts for Aircraft Control
- by types of activation -

- Conventional and new aerodynamic control surfaces, acting as tabs

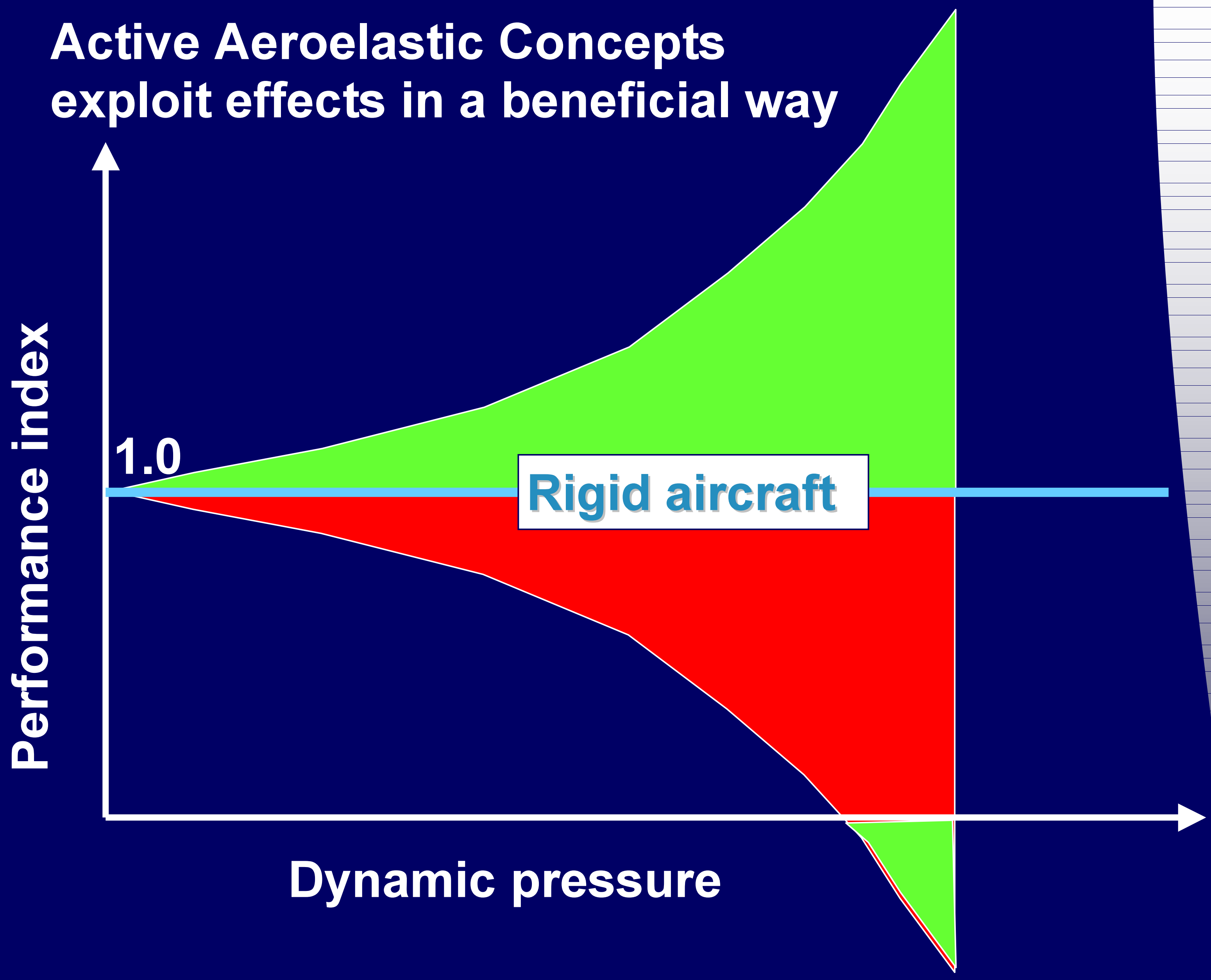
- Active structural components
  - based on smart materials
  - based on conventional technology

- All- movable surfaces (stabilisers) with adaptive attachment/actuator stiffness

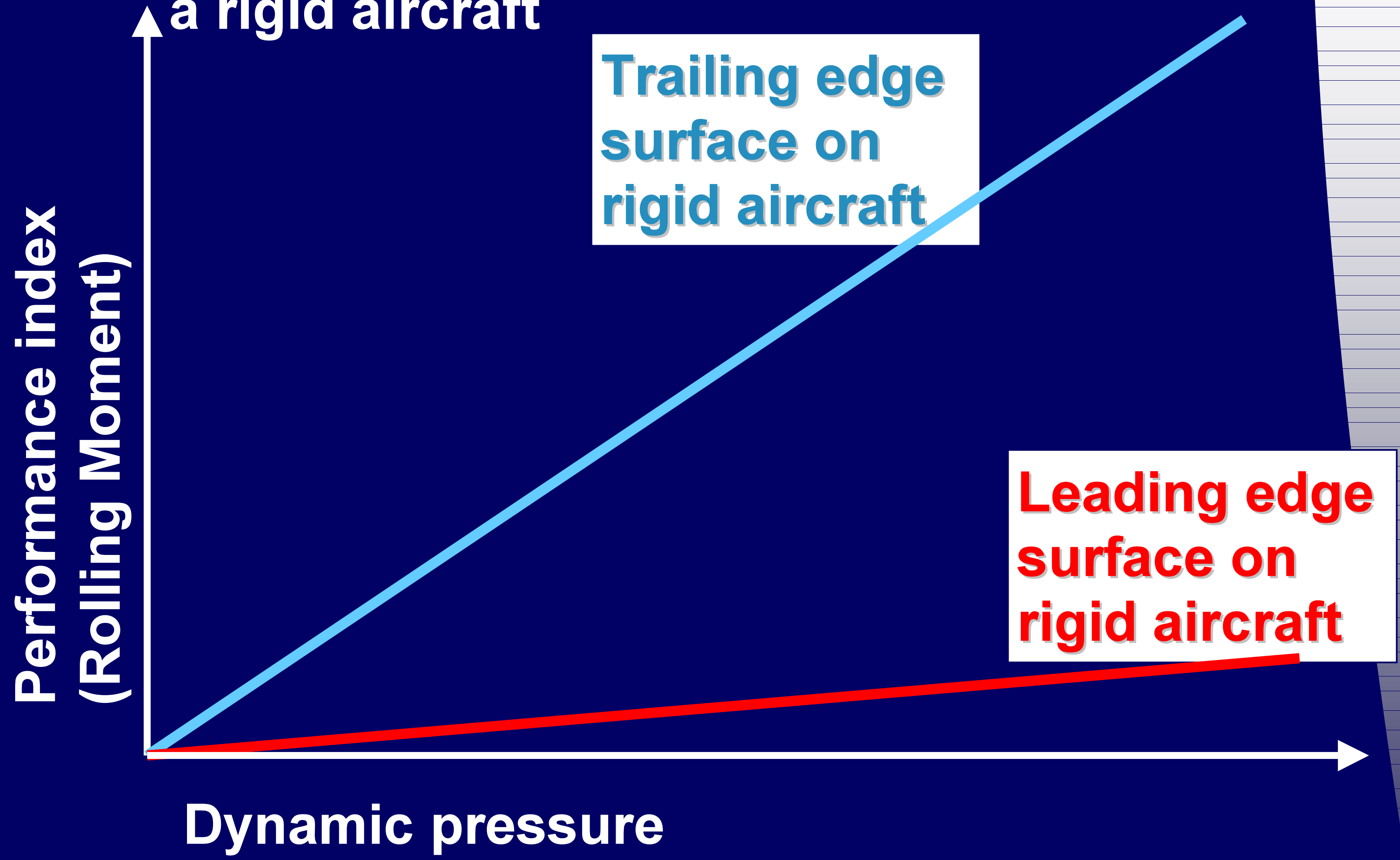
Static Aeroelasticity or "Only a rigid aircraft is a good aircraft"



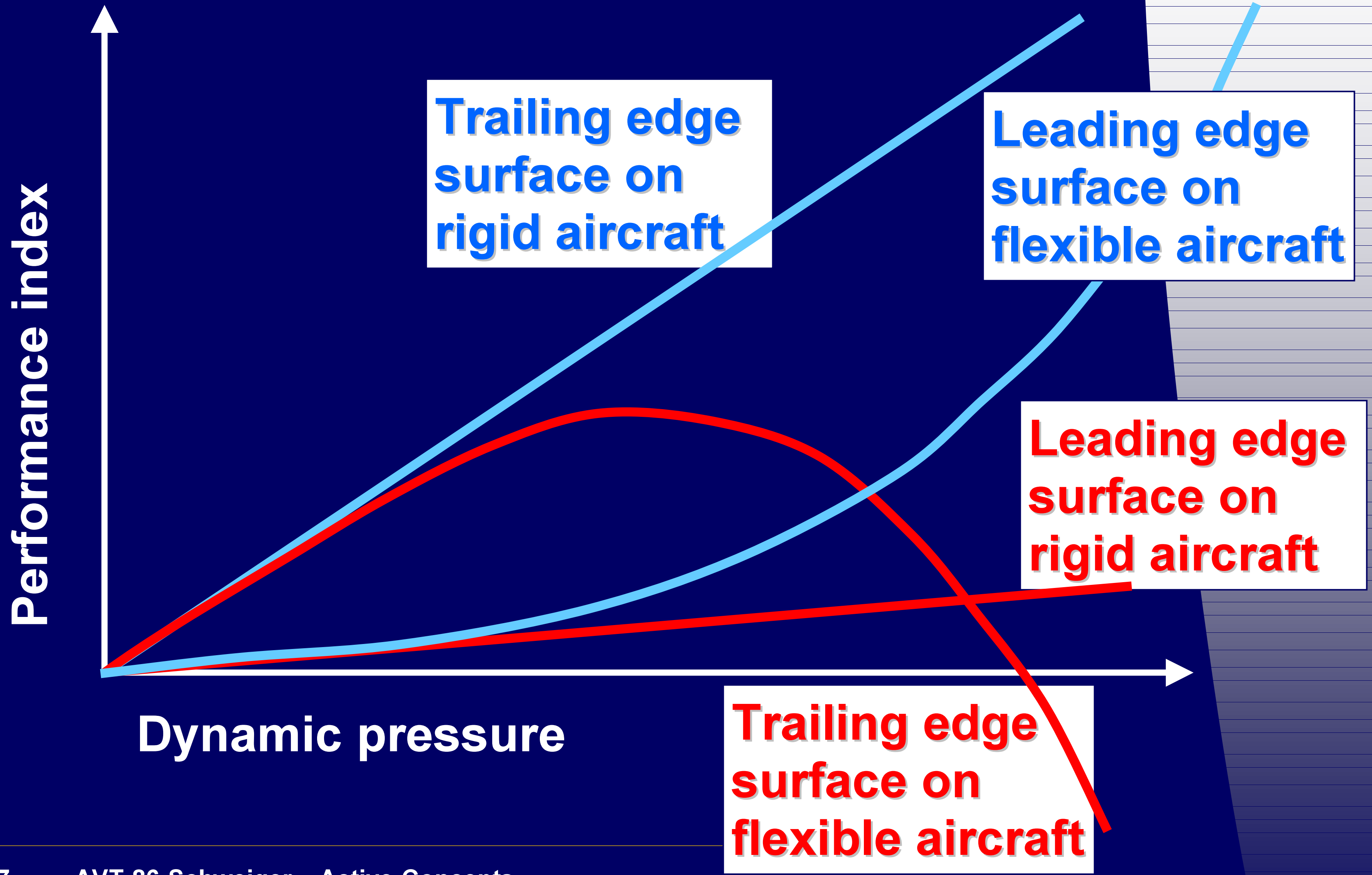
Active Aeroelastic Concepts exploit effects in a beneficial way



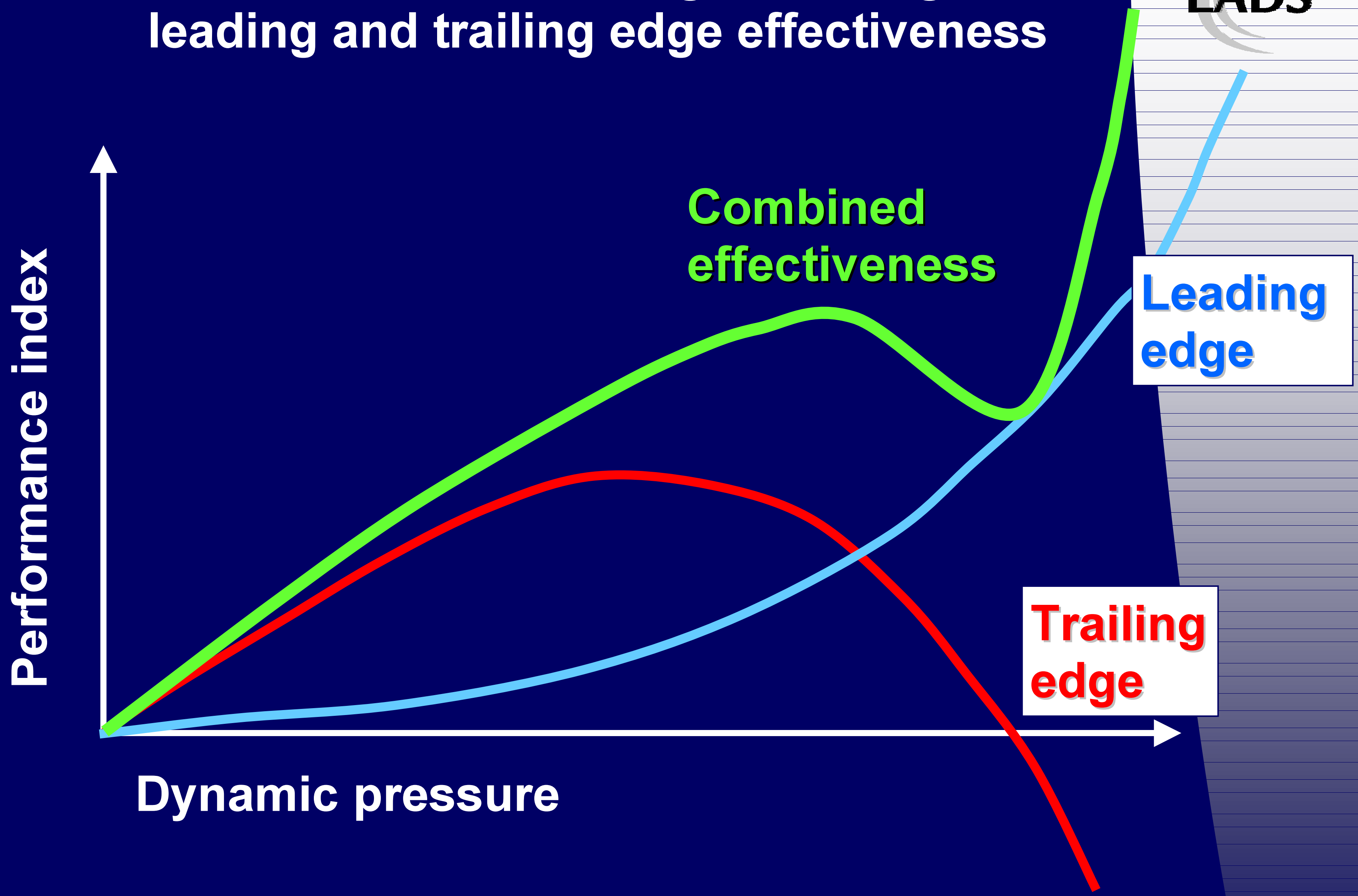
Aerodynamic effectiveness of leading and trailing edge control surfaces for a rigid aircraft



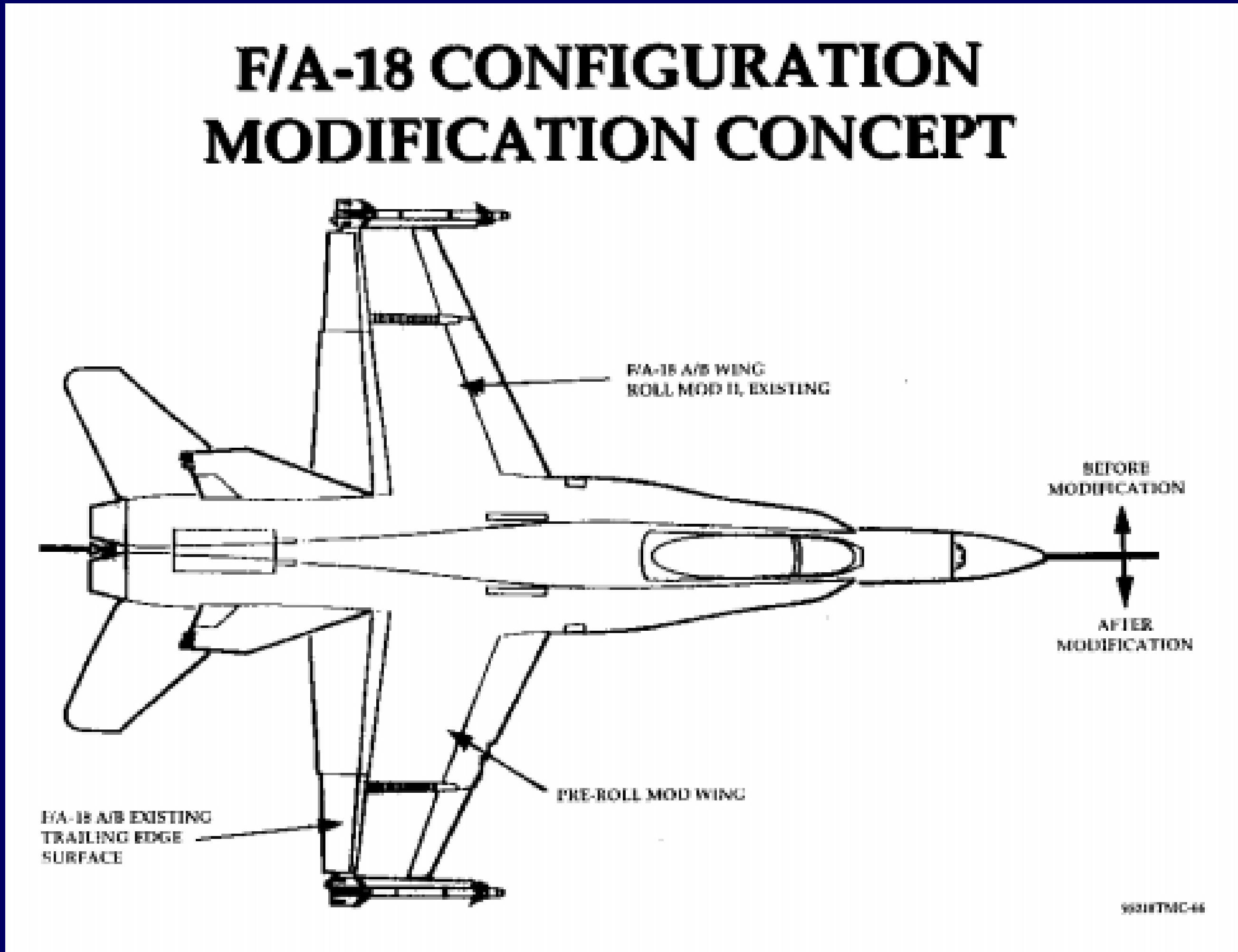
Aerodynamic effectiveness of leading and trailing edge control surfaces



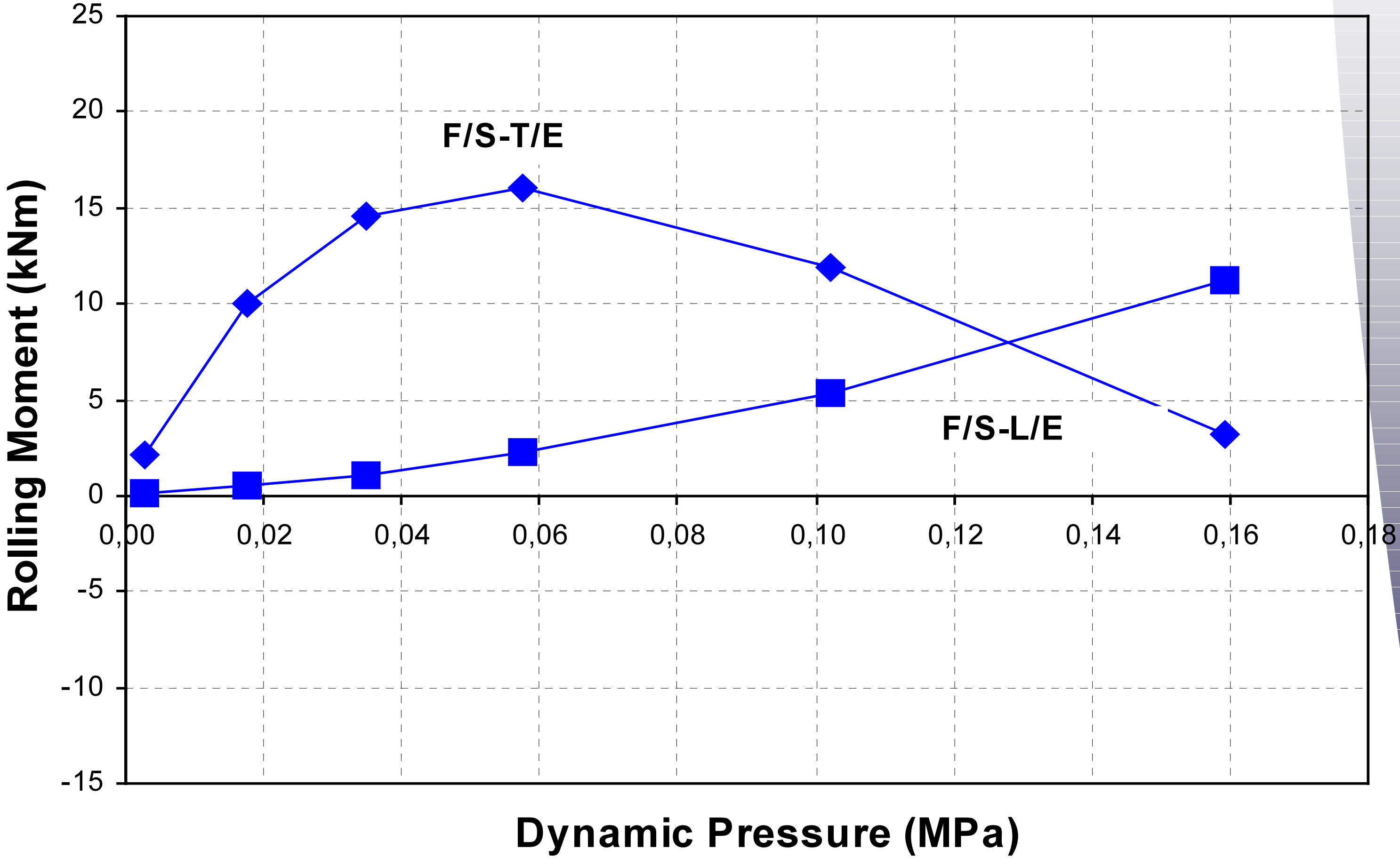
Active Aeroelastic Wing: Blending of leading and trailing edge effectiveness



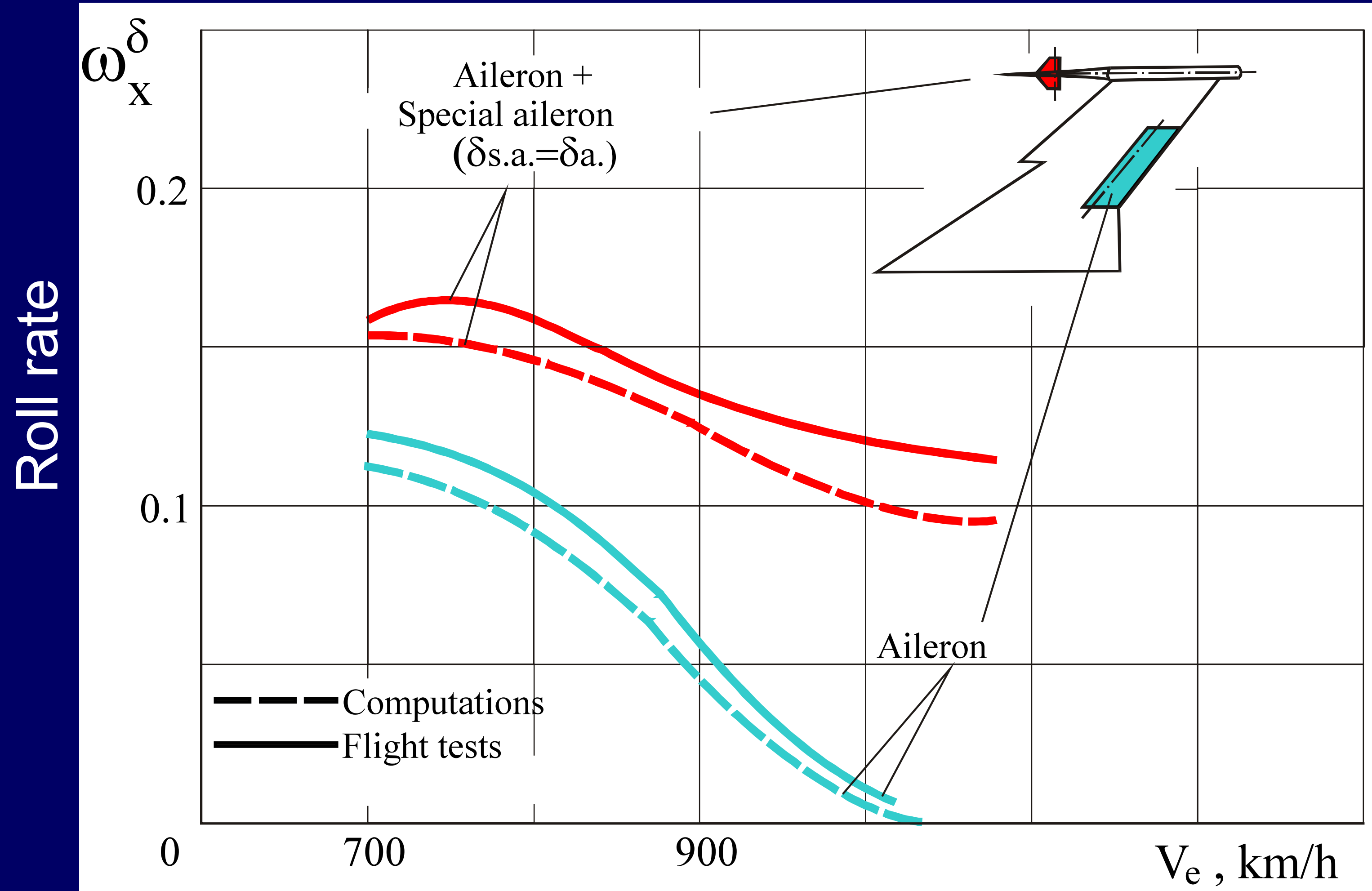
F-18 Active Aeroelastic Wing Flight Test Demonstrator



Result for a low aspect ratio fighter wing (static design)

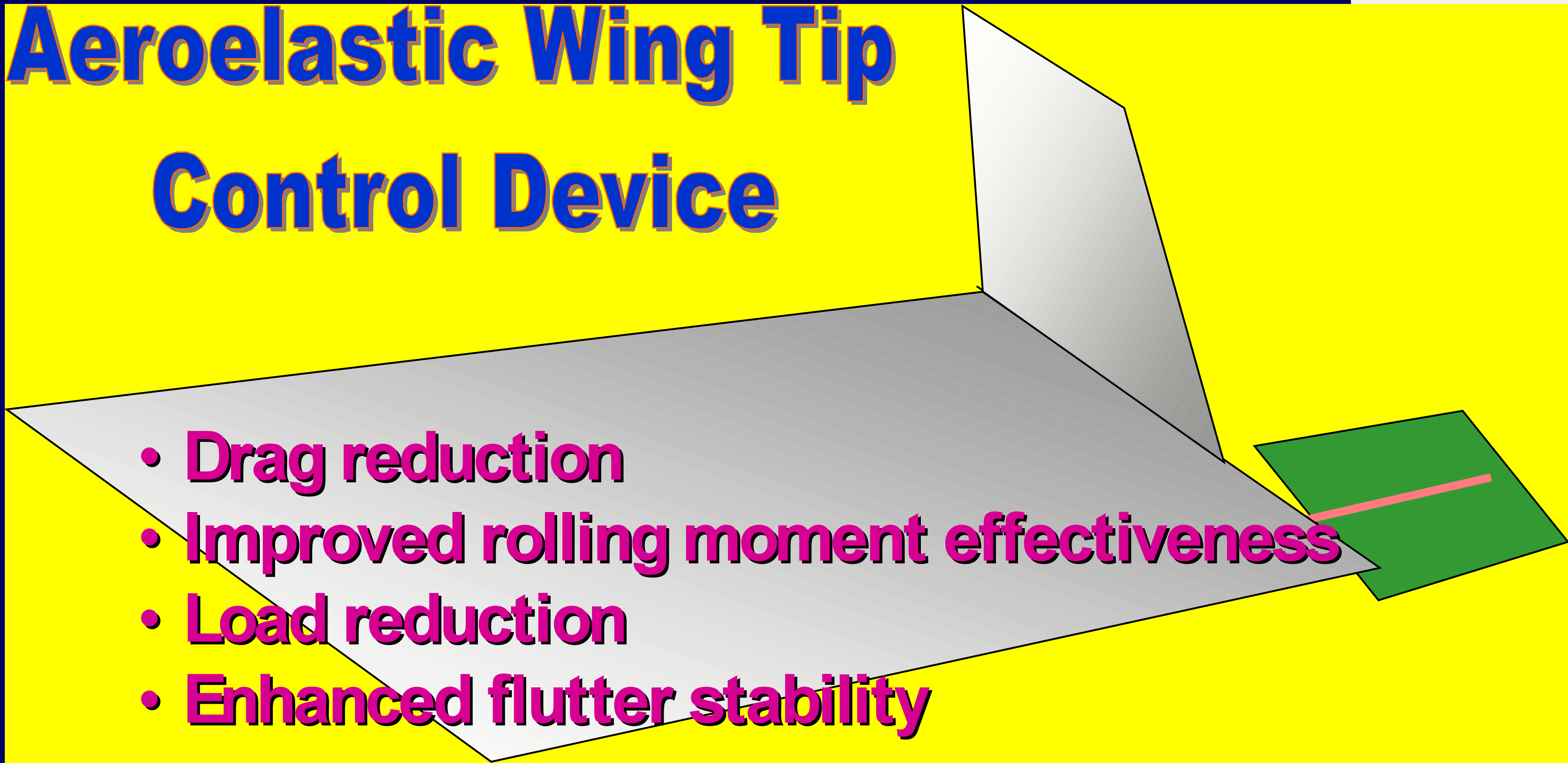


New aerodynamic control surface concept: computational and and flight test results (courtesy of TsAGI)



New aerodynamic control surface concept for a transport aircraft wing with winglets

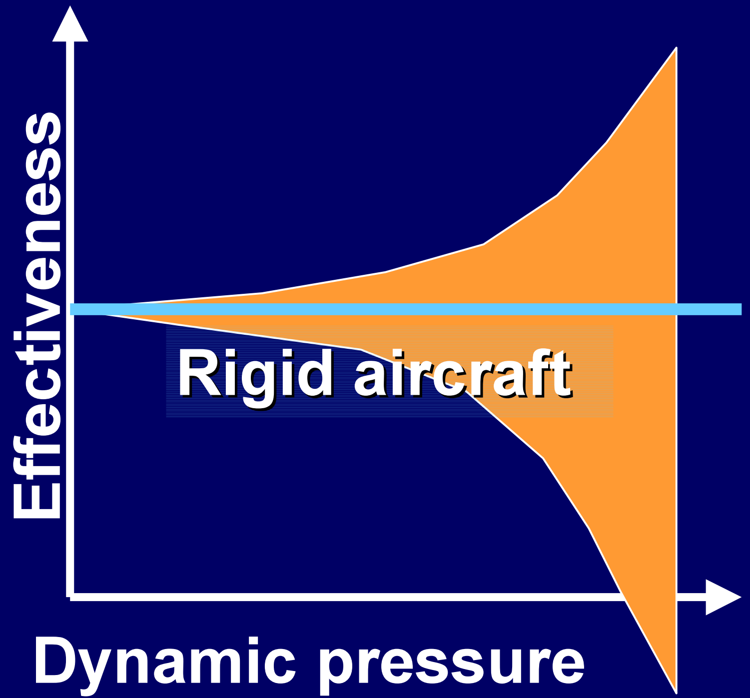
Aeroelastic Wing Tip Control Device



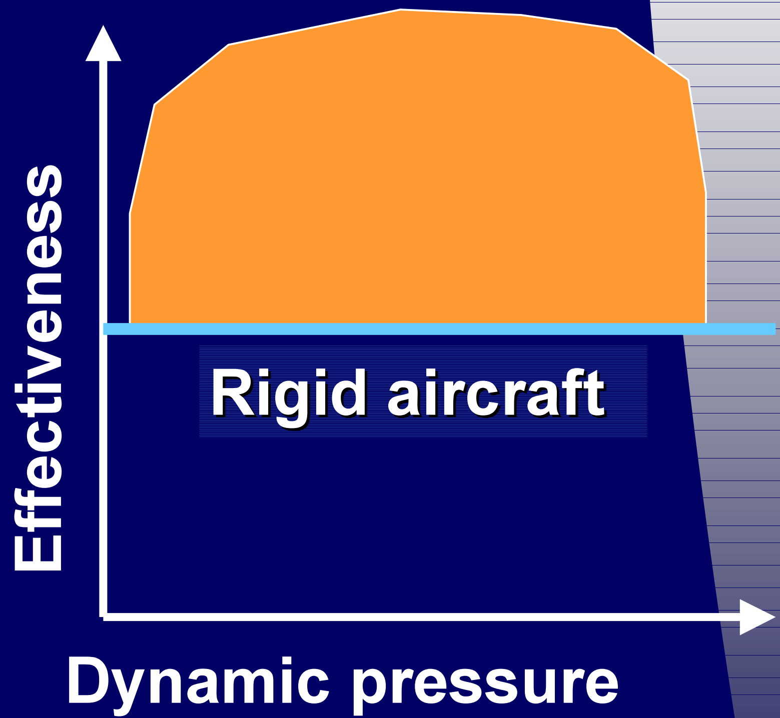
- Drag reduction
- Improved rolling moment effectiveness
- Load reduction
- Enhanced flutter stability

Active Aeroelastic Concepts

Range of aeroelastic effectiveness on conventional designs

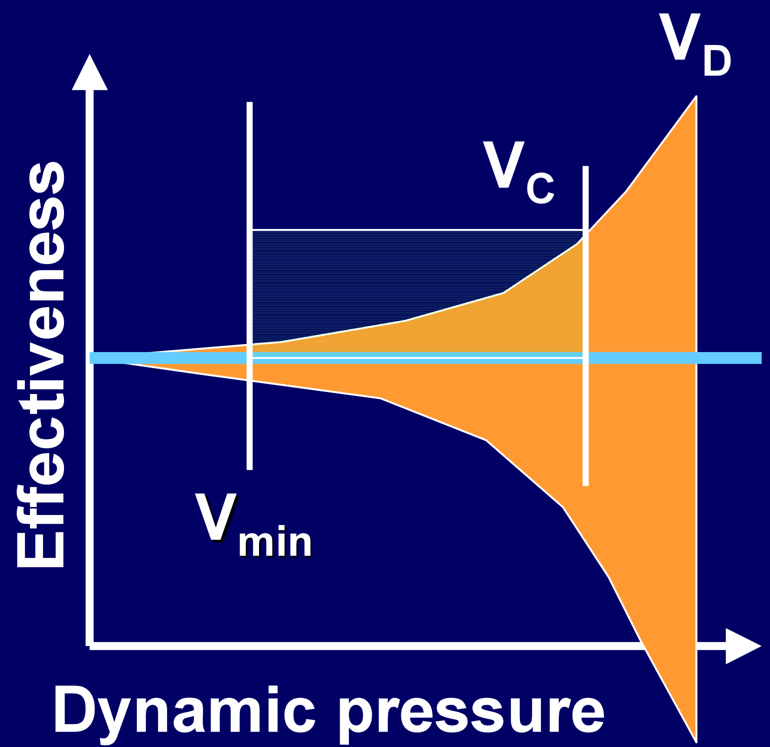


Desired range for advanced active aeroelastic concept

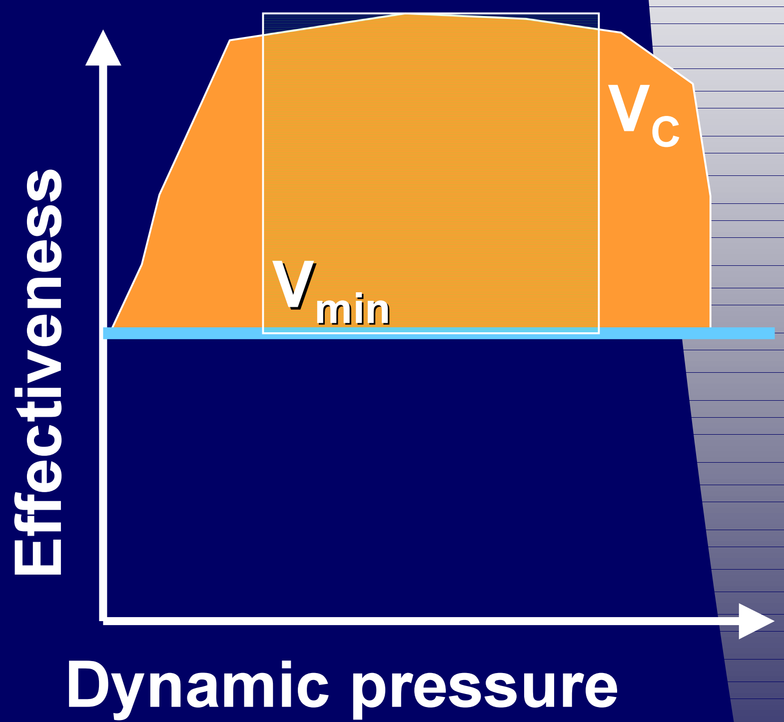


Usable range of aeroelastic effectiveness by flight envelope

for conventional active aeroelastic concepts



for advanced active aeroelastic concept



Active Structures Concept, based on Active Materials

- Energy requirements
- Concepts
- Analytical design methods
- Structural strength and stiffness considerations
- Examples
- Scaling effects
- Applicability for real aircraft

Fictitious control surface concept (Khot, Eastep, Kolonay)

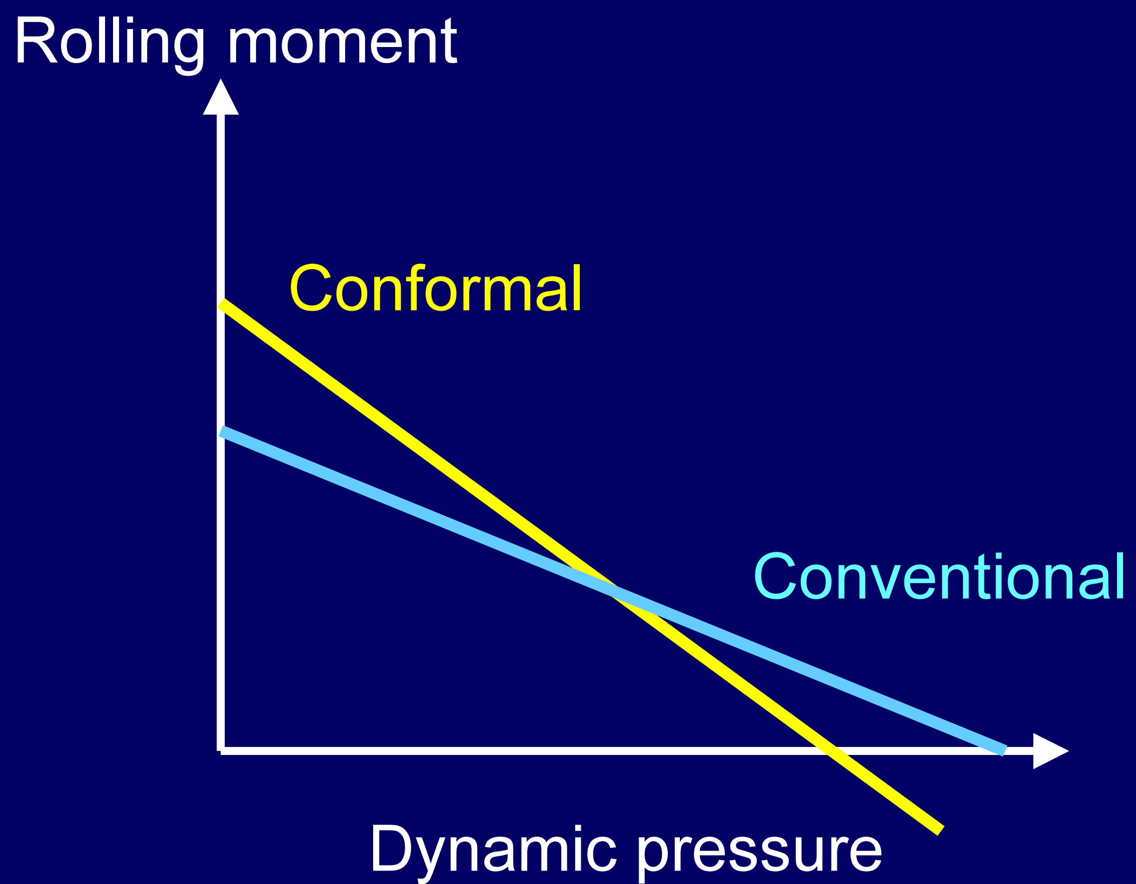
- It is used to derive the required energy
- A conventional trailing edge aileron is used to deform the wing
- The same energy is supplied to re-twist it and establish the “rigid aircraft” performance

- The results give only a rough idea about the required energy
- Other kinds of deformation are easier to achieve

Active materials concepts

- Only very few actual applications (analytical and experimental)
- Mainly based on SMAs
  - torque tube
  - SMA wires for conformal control surfaces
- Weak points:
  - speed of deformation
  - thermal aspects (energy supply, insulation)
  - stiffness of passive structure
- Examples
  - NASA Smart Wing Program (part of Aircraft Morphing Program)

Example for experimental results for a conformal trailing edge with SMA wires



Example for a passive structure which enables large deformations

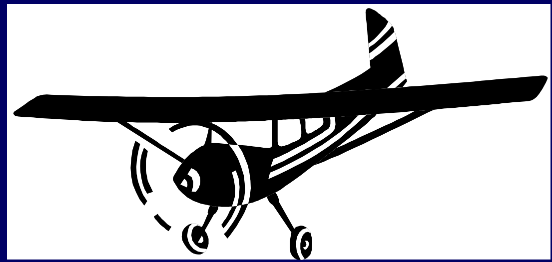
Selectively Deformable Structure (SDS)
Prof. Amiryants, TsAGI, Russia

Should we again try to imitate nature in Aviation?

- Birds
- Insects
- Plants

- Scaling laws
- Technical design elements and equivalents in nature
- Genetic algorithms in optimization?
- Other vehicles

Flight in nature and similarities with airplanes

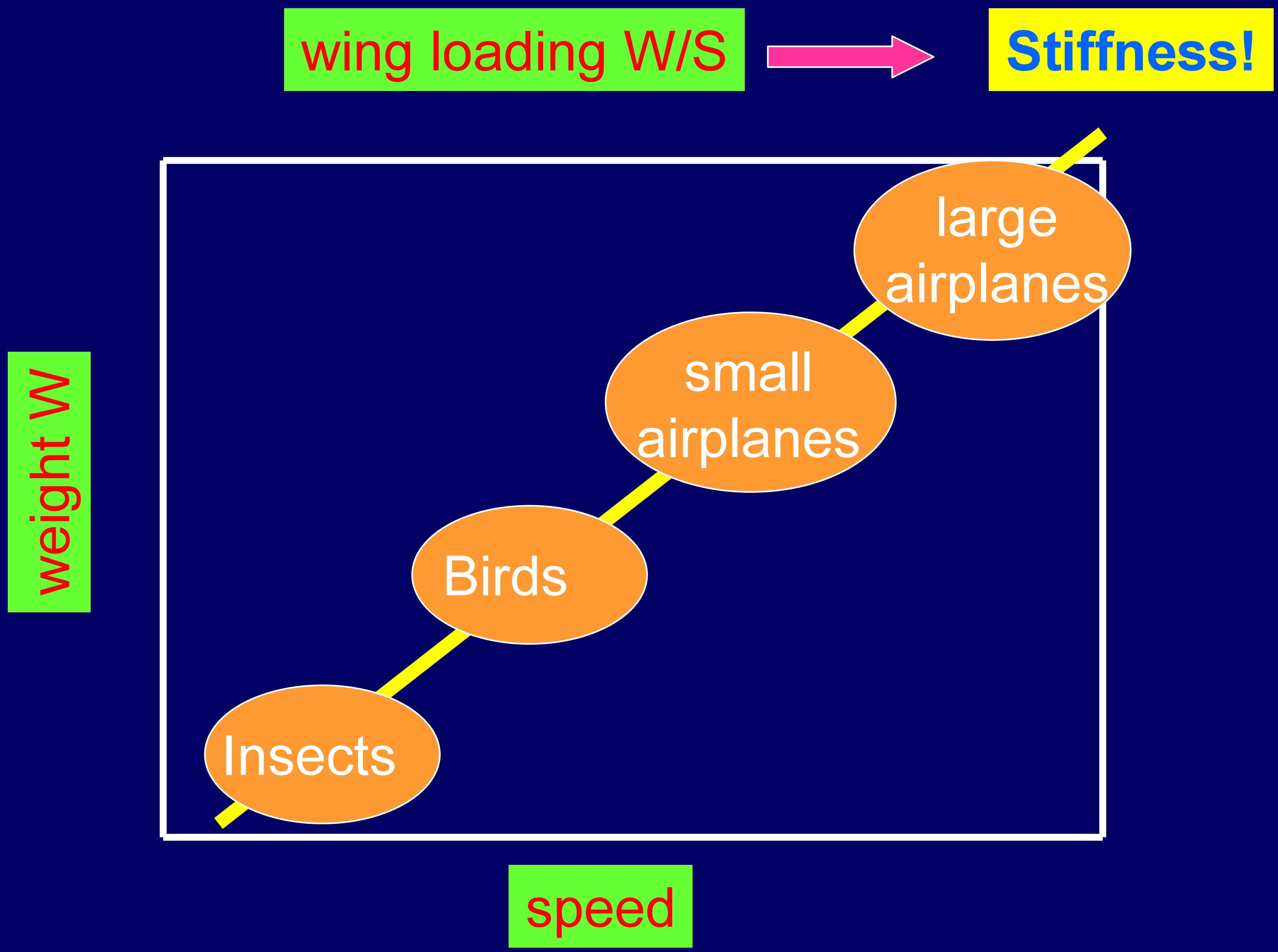


Birds

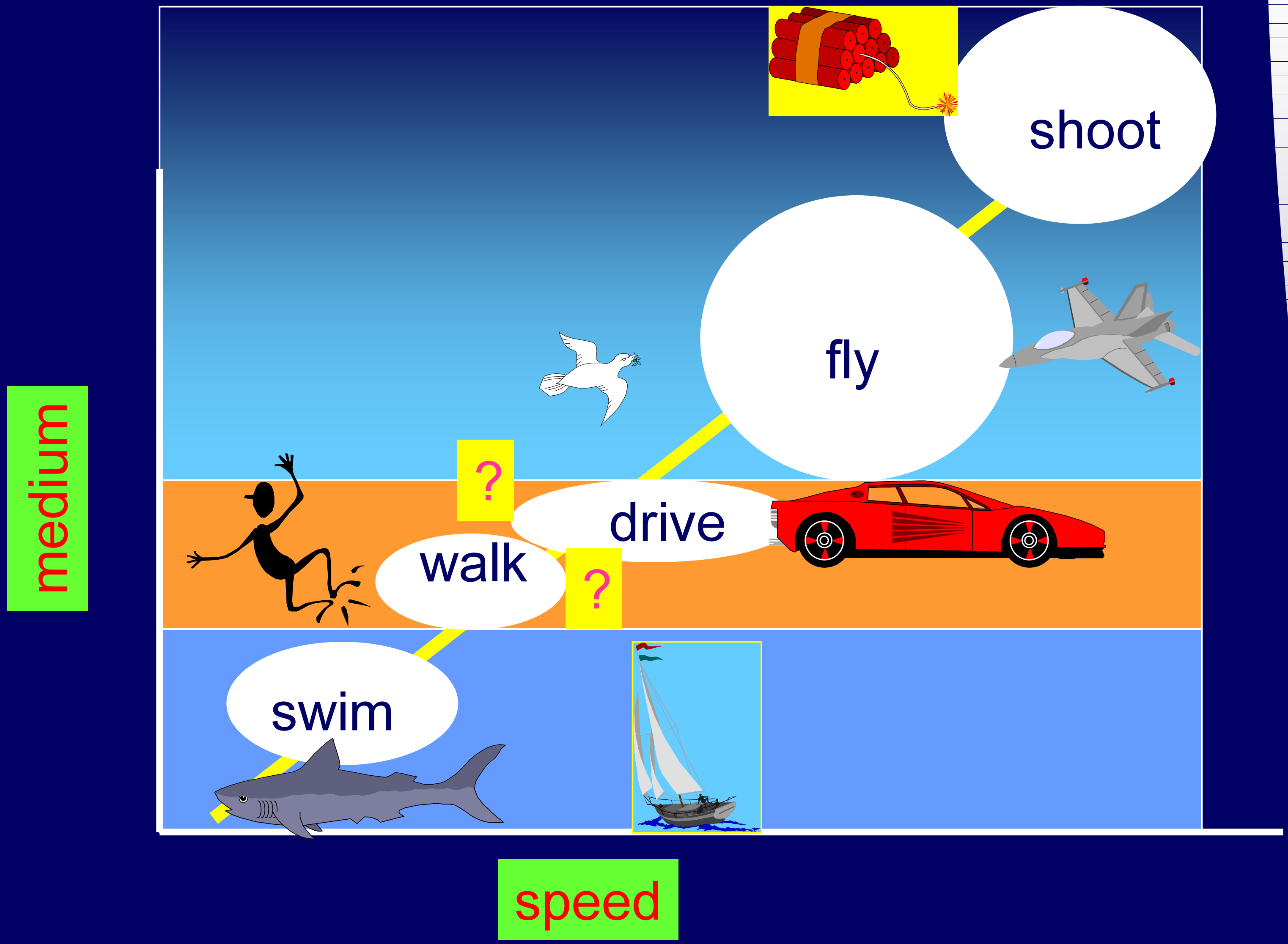
Insects

- Aerodynamics
- Structures and materials
- Cycles in evolution

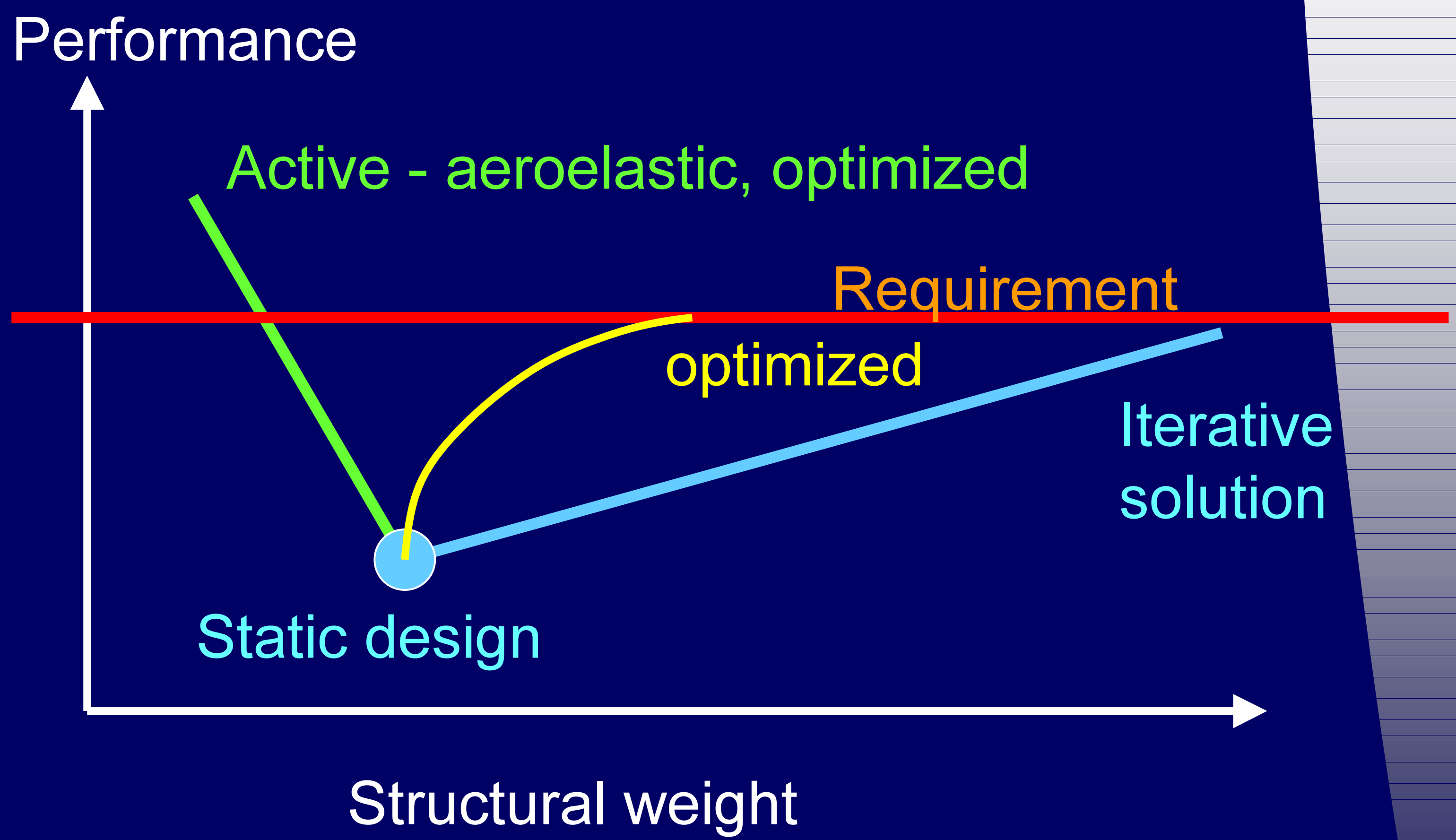
The great flight diagram (adapted from "Energy requirements of micro air vehicles")



The diagram of motions

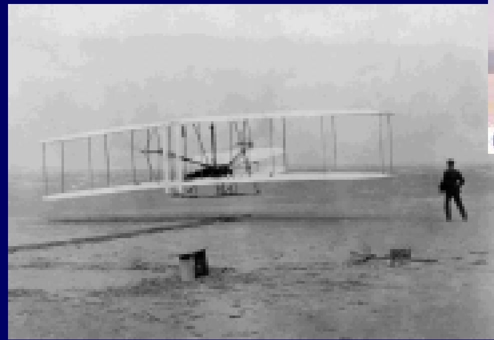


The importance of efficient analytical design tools (structural optimization and MDO)

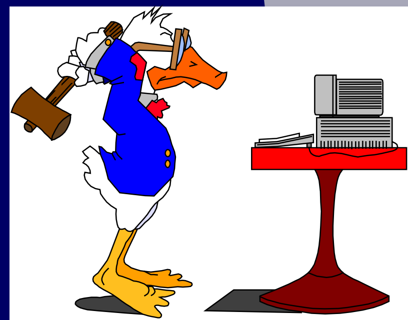


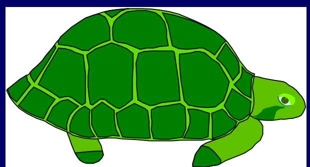
Evolution and genetic optimization (inspired by a remark from Dr. Venkayya)

80 years



100 000 000 years





Can we wait that long for technical improvements?

Is a more flexible aircraft a better aircraft?

Das Flugzeug, das wie ein Adler flattert

Schwalbenflügel
Spezielle Kunststoffe lassen die Flügel weich schwingen wie bei einem Adler.

Material
Wie durch das Gefieder eines Vogels werden die Luftströme geleitet.

Stützgelenke
Künstliche Gelenke stützen den Flügel, halten ihn in seiner Form.

Software
Sensoren auf den Tragflächen ermitteln Luftwiderstand und Auftrieb.

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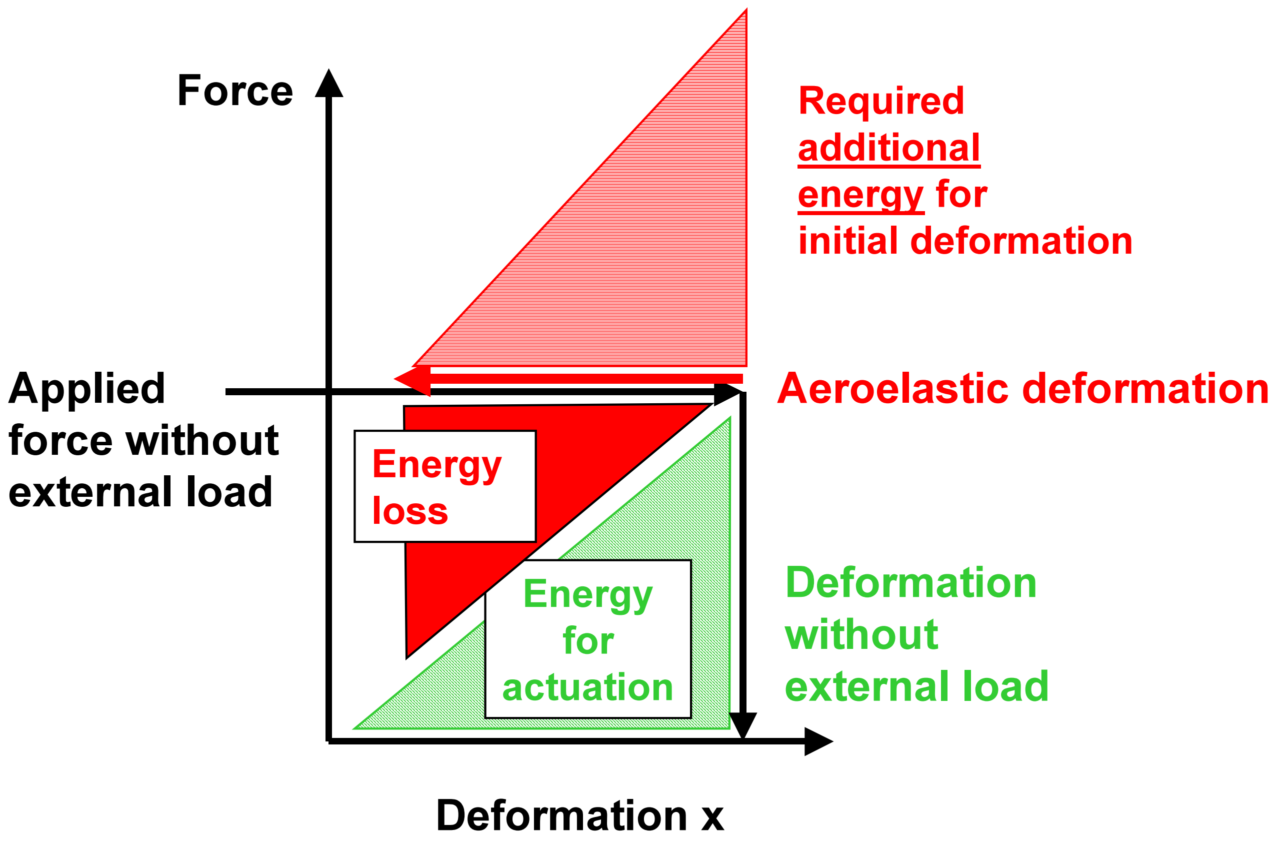
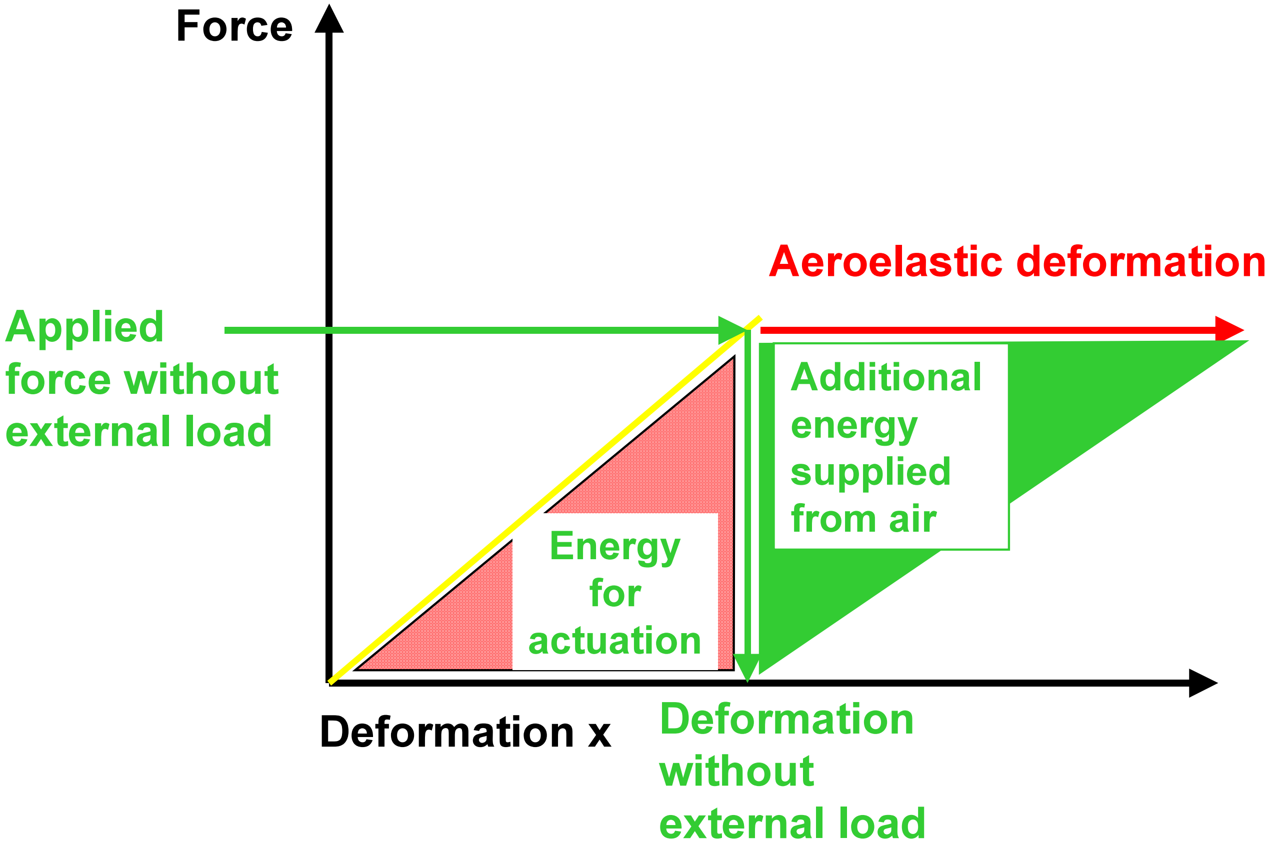
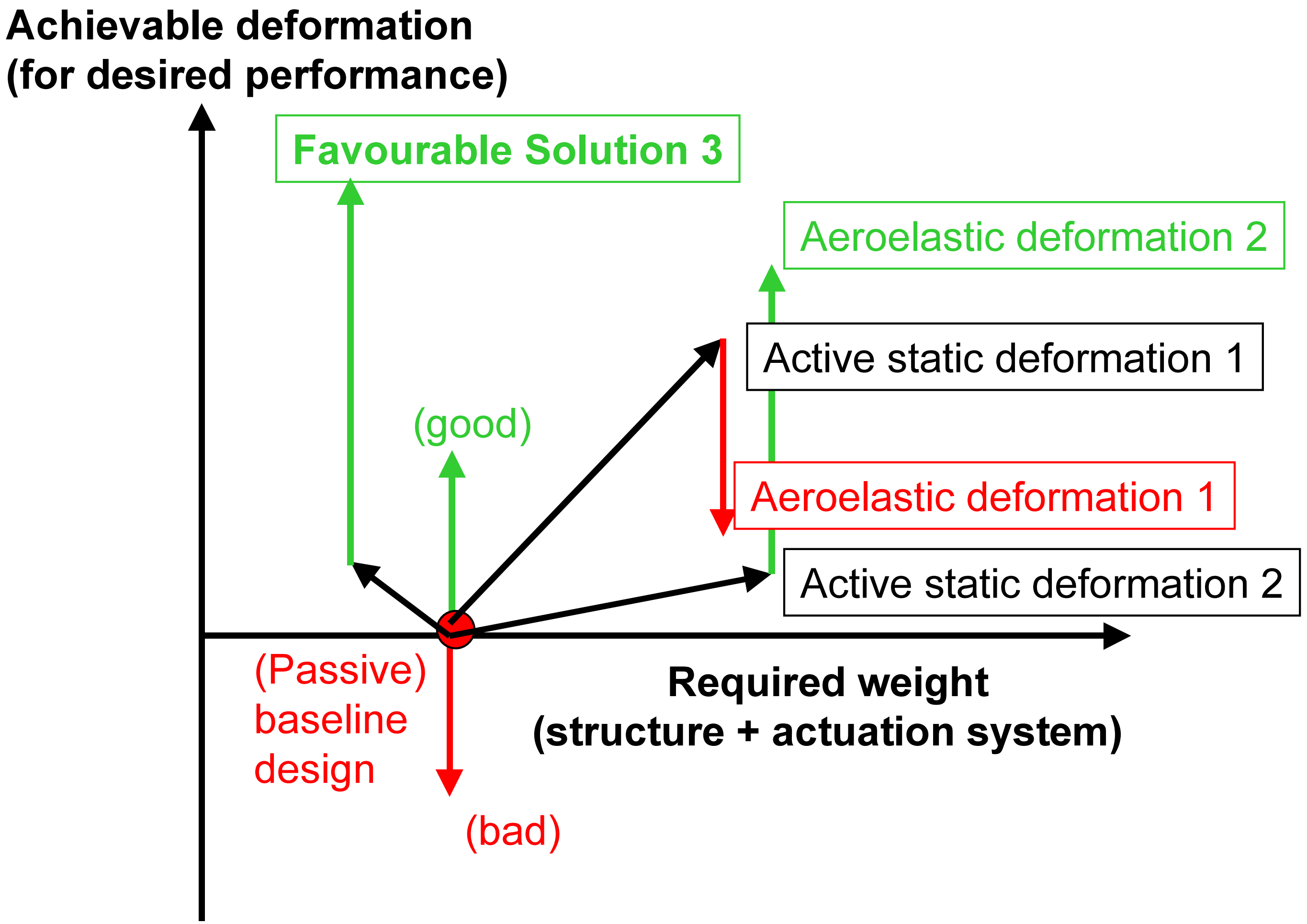
Forced deformation and aeroelastic response - Case 1 -



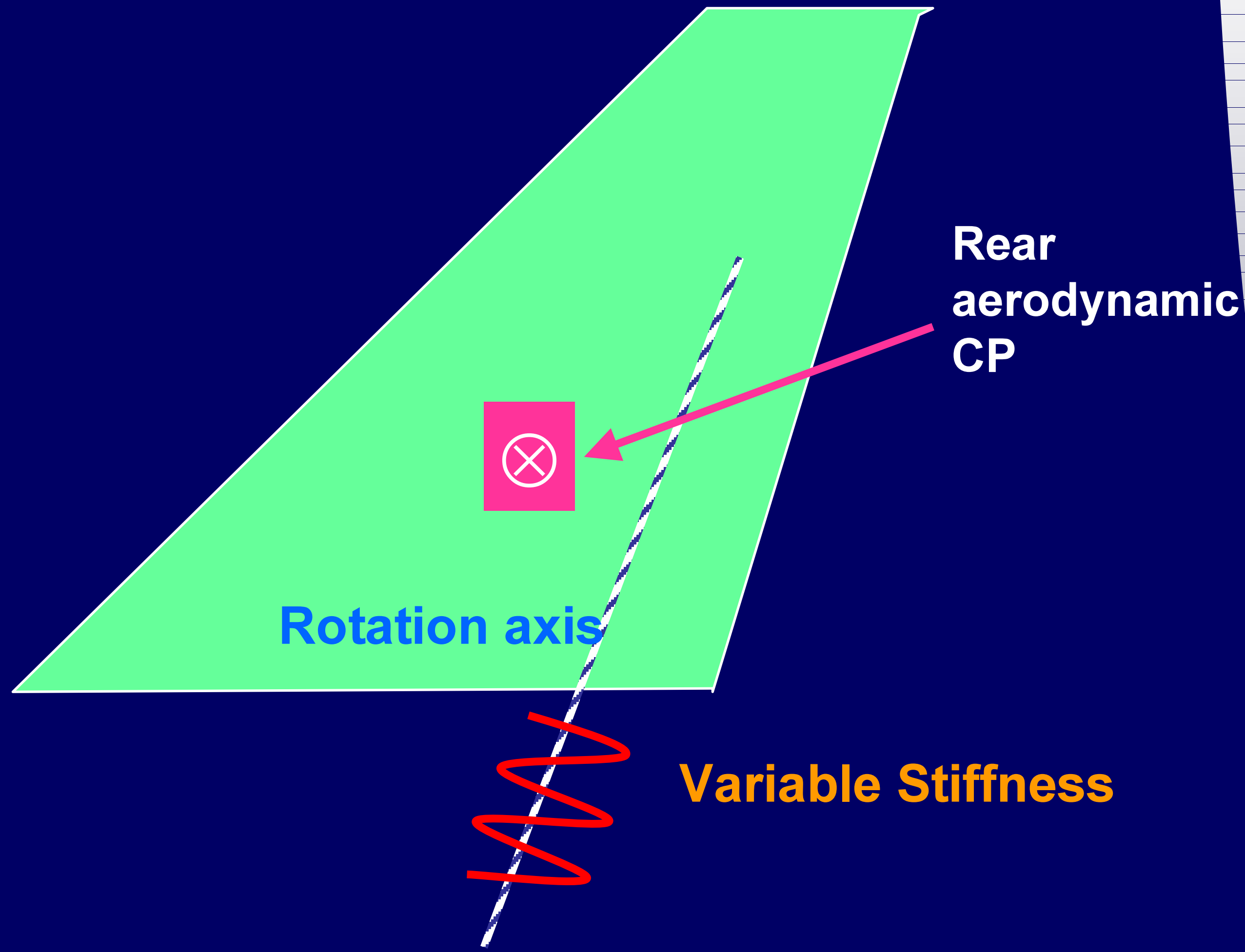
Forced deformation and aeroelastic response - Case 2 -



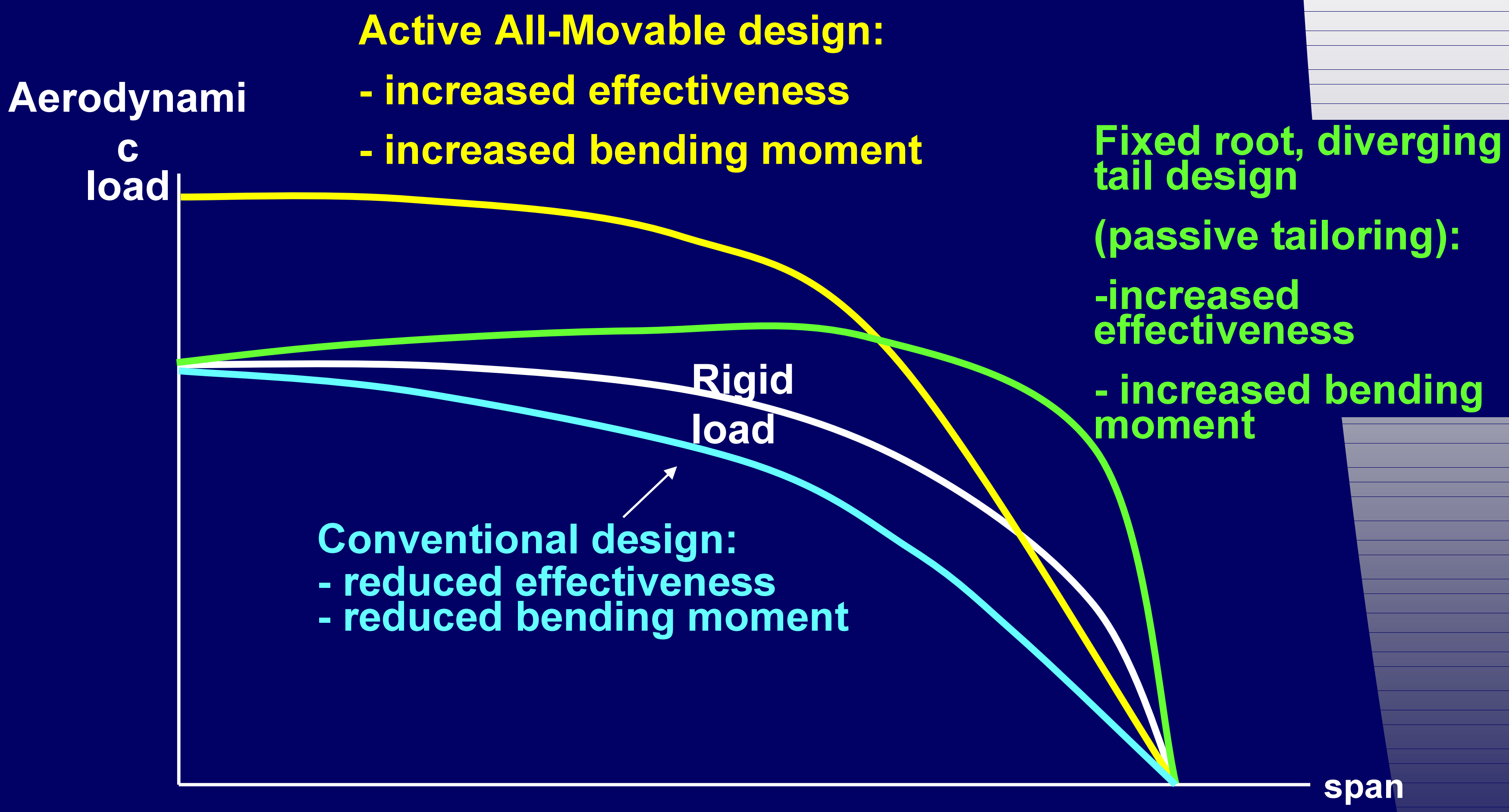
Concepts Performance



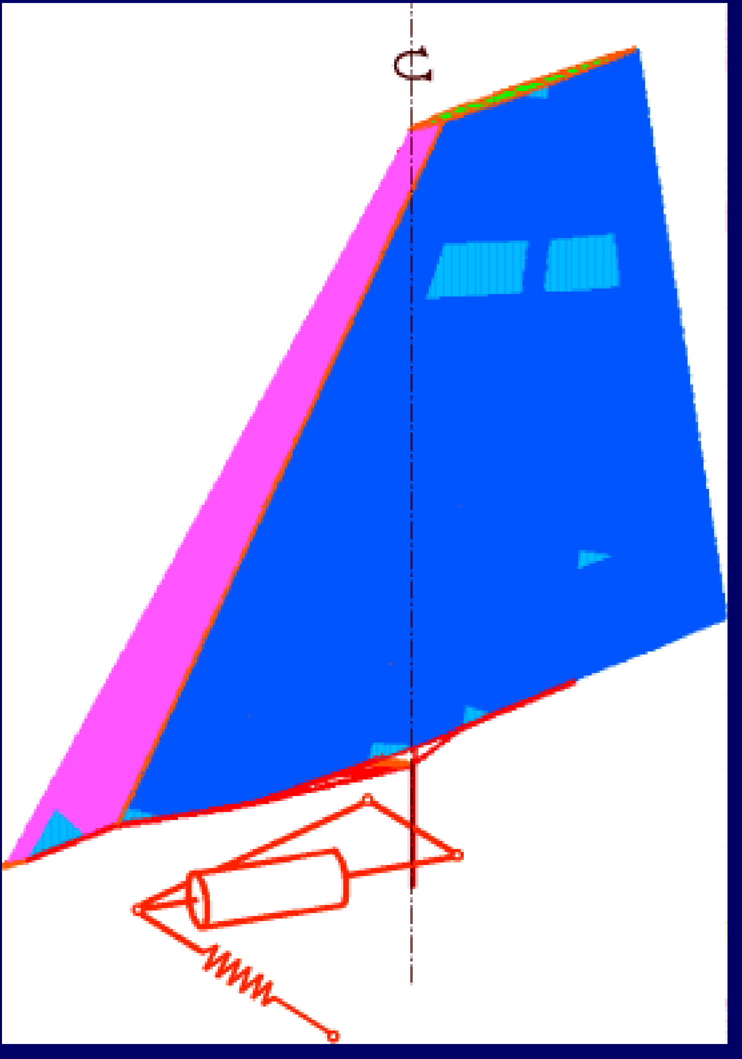
Basic concept for Active Aeroelastic All-Movable Surfaces

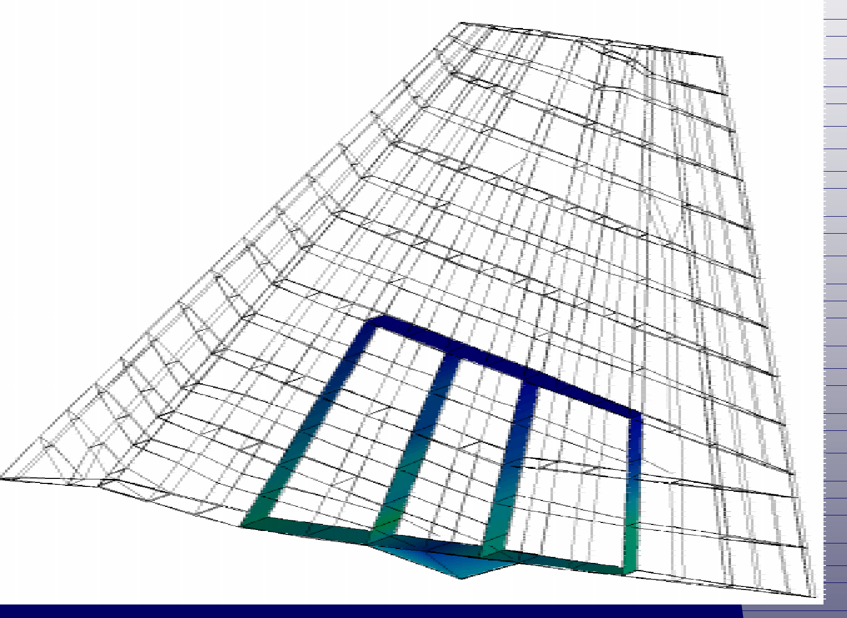


Fin load distribution for different design approaches



Analysis model for All- movable tail

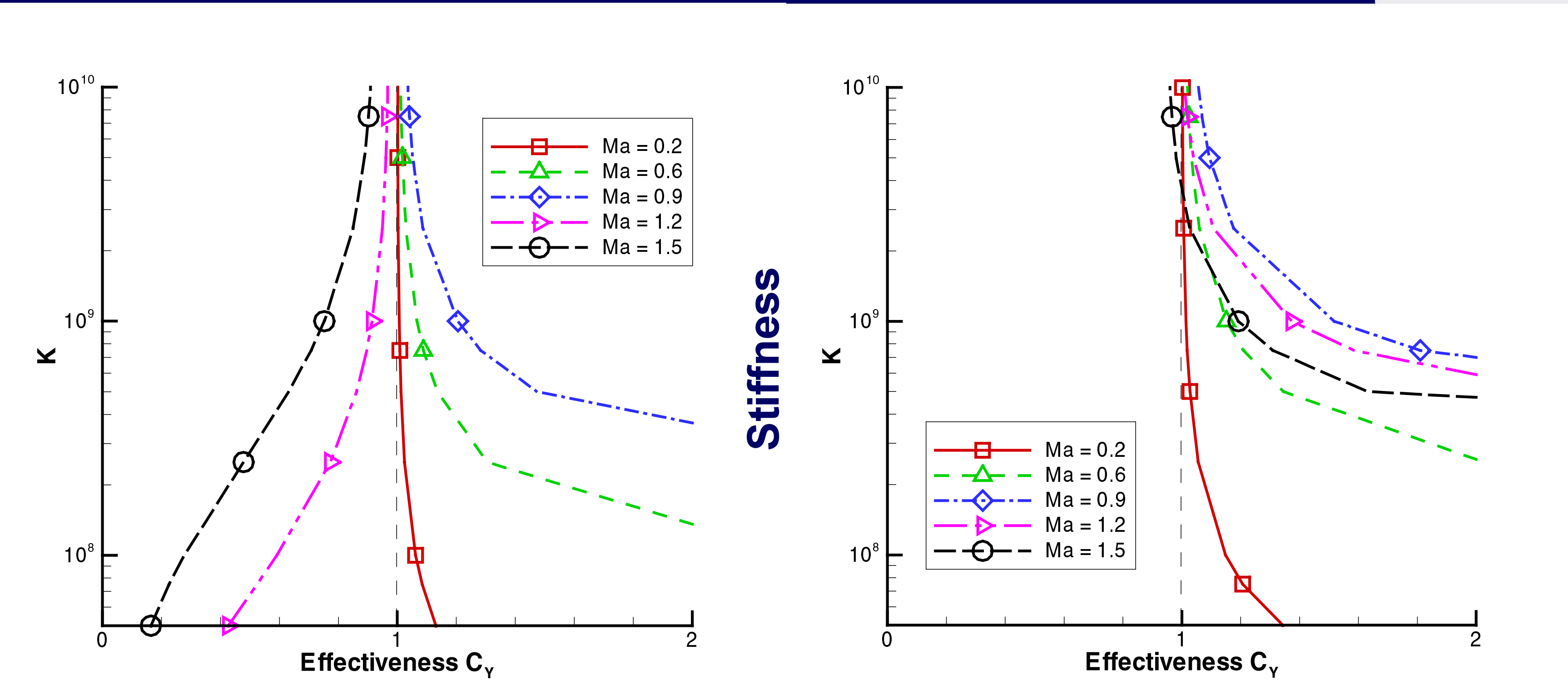




Actuator position and stiffness variation for aeroelastic effectiveness

HL at 35% chord

HL at 47% chord



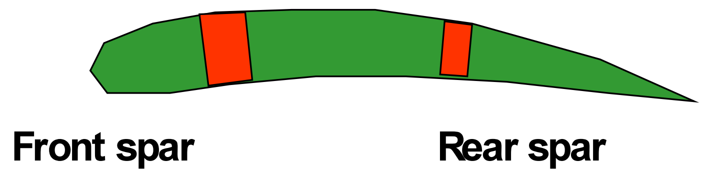
Effectiveness

Other active structures concepts

- Piezoelectric materials?
- Variable stiffness substructure
- Pneumatic?

Goodyear Inflatoplane (1950s)

Fokker D-VIII: Adding stiffness makes not always a better airplane



The Tasks

- Do not try to deform a rigid structure by internal forces
- Place flexibilities where they do not hurt the load capacity (and aeroelasticity)
- Exploit aeroelastic servo effects
- Enlarge aeroelastic sensitivities at lower speeds (without structural weight penalties)
- Do not damage flutter stability

Predictions- I
The reliability of predictions

Niels Bohr:
**”Prediction is very difficult,
especially about the future.”**

Predictions- II
Some experts predictions

- ”The [flying] machines will eventually be fast; they will be used in sport but they should not be thought of as commercial carriers.”
  – Octave Chanute, Aviation Pioneer, 1910.

- ”The energy produced by the breaking down of the atom is a very poor kind of thing. Anyone who expects a source of power from the transformation of these atoms is talking moonshine.
  – Ernest Rutherford, Physicist, ca. 1910.

Predictions- III
Another expert's prediction

”Fooling around with alternative currents is just a waste of time. Nobody will use it, ever. It's too dangerous . . . it could kill a man as quick as a bolt of lightning. Direct current is safe.”

– Thomas Edison, Inventor, ca. 1880.

Predictions- IV
Personal predictions and conclusions

- Active aircraft structures will only work efficiently, if static aeroelastic effects are included as an integral part of the design process to activate the the deformations.
- (Distributed) Smart Materials are not suitable to initiate structural deformations for aircraft control functions.
- There is a strong need for more powerful, compact (hybrid) actuators, exploiting the high energy density of Smart Materials.
- Depending on the type of aircraft and mission, different active structures concepts will be more or less effective.