Controlled Flight Beyond Stall

The X-31 Aircraft Program

Hannes Ross
Samara, May 2007

Lilienthal Hanggliding (1894)

Crash of Birgenair, 6.Febr. 1996

Nine months after the **crash of the Birgenair 757** off the coast of the Dominican Republic, the official accident report was published on November 8. The document states that the main reason for the disaster, which cost the lives of 178 passengers and 11 crew, was the failure of the crew to **interpret the signs of impending stall correctly and act accordingly.** The pilots were confused by false speed displays due to a blocked pitot.

Source:Flugrevue 10. Nov. 1996

Military Accidents

STALL / SPIN OUT - OF - CONTROL OPERATIONAL ACCIDENTS 1965 - 1986

Total losses (fighter / attack, bomber, trainer, etc): 566

Fatalities per accident: 0.85

Fighter / Attack

USAF		USN	
F-4	68	F-4	73
F-100	30	A-4/TA-4	54
F-111	17	F-8	35
A-7	14	A-7	33
F-5	10	EA-6	21
F-15	10	F-14	18
A-10	8	T-2	17
F-16	5	A-6	14

Total value of fighter / attack losses: $3.95 Billion

Poststall Landing Gear, Grashopper, 1973

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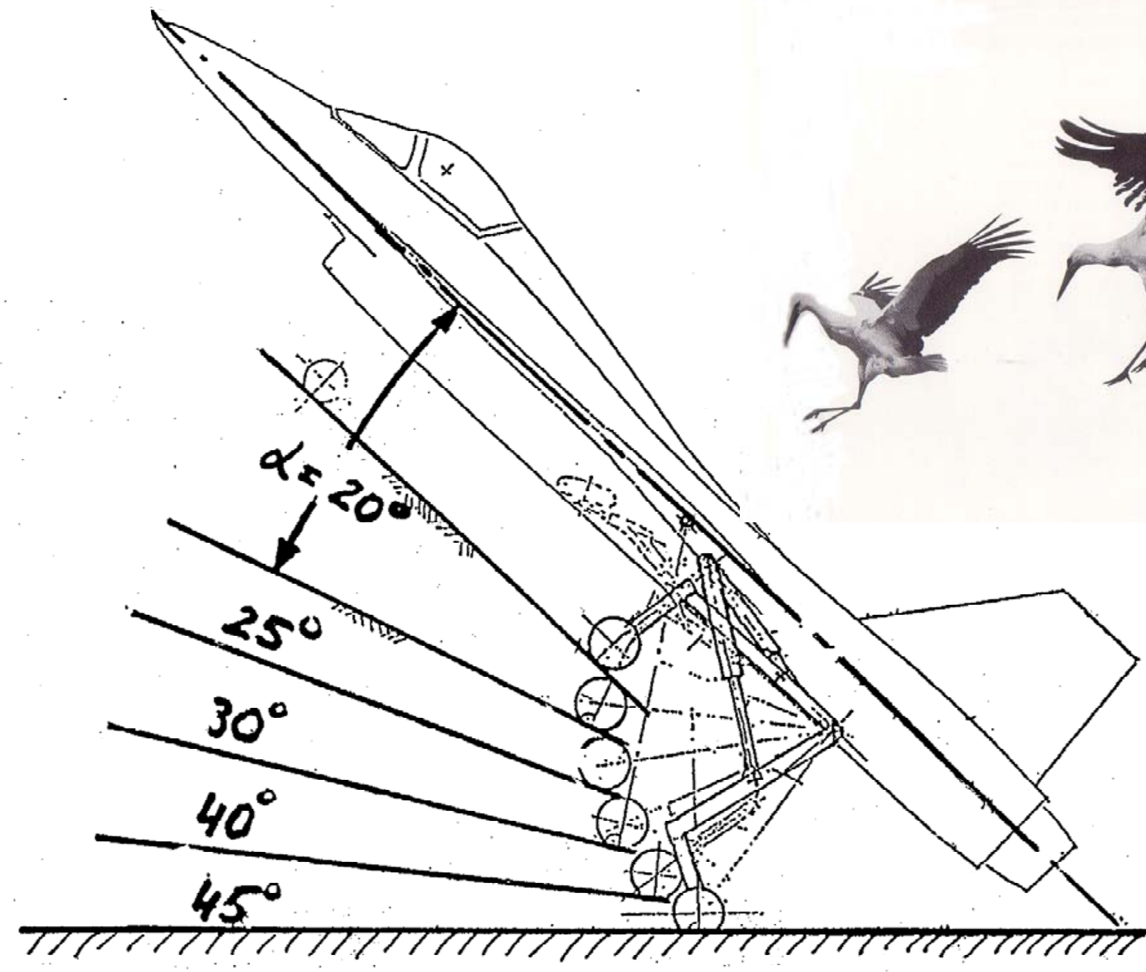
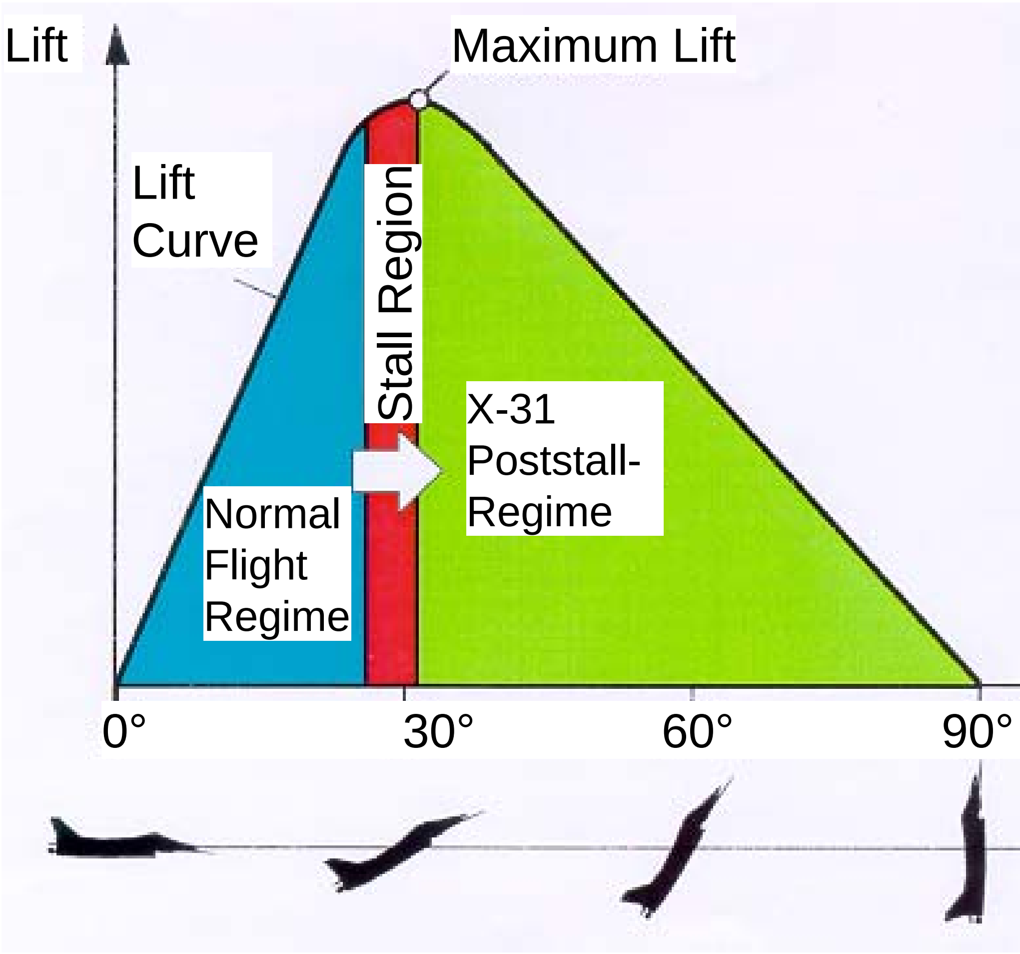


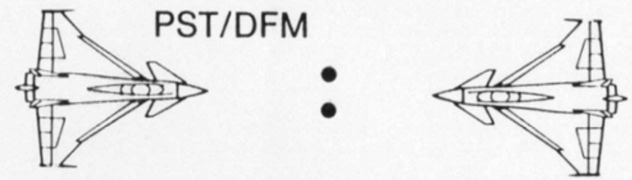
Lift vs. Angle of Attack

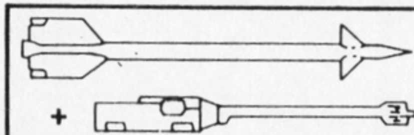
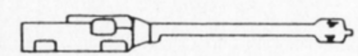


Dr. Wolfgang Herbst

IBR

Results from Manned Close-in Combat Simulations at IABG, Germany 1979



No. of Engagements: SRM + GUN: 331 Gun only: 125		
1. Time to first firing possibility	SRM + GUN 2:1	2,5:1
2. Time in shooting position	SRM 2:1	
	GUN 8:1	10:1
3. Engagement wins	5,4:1	4,2:1

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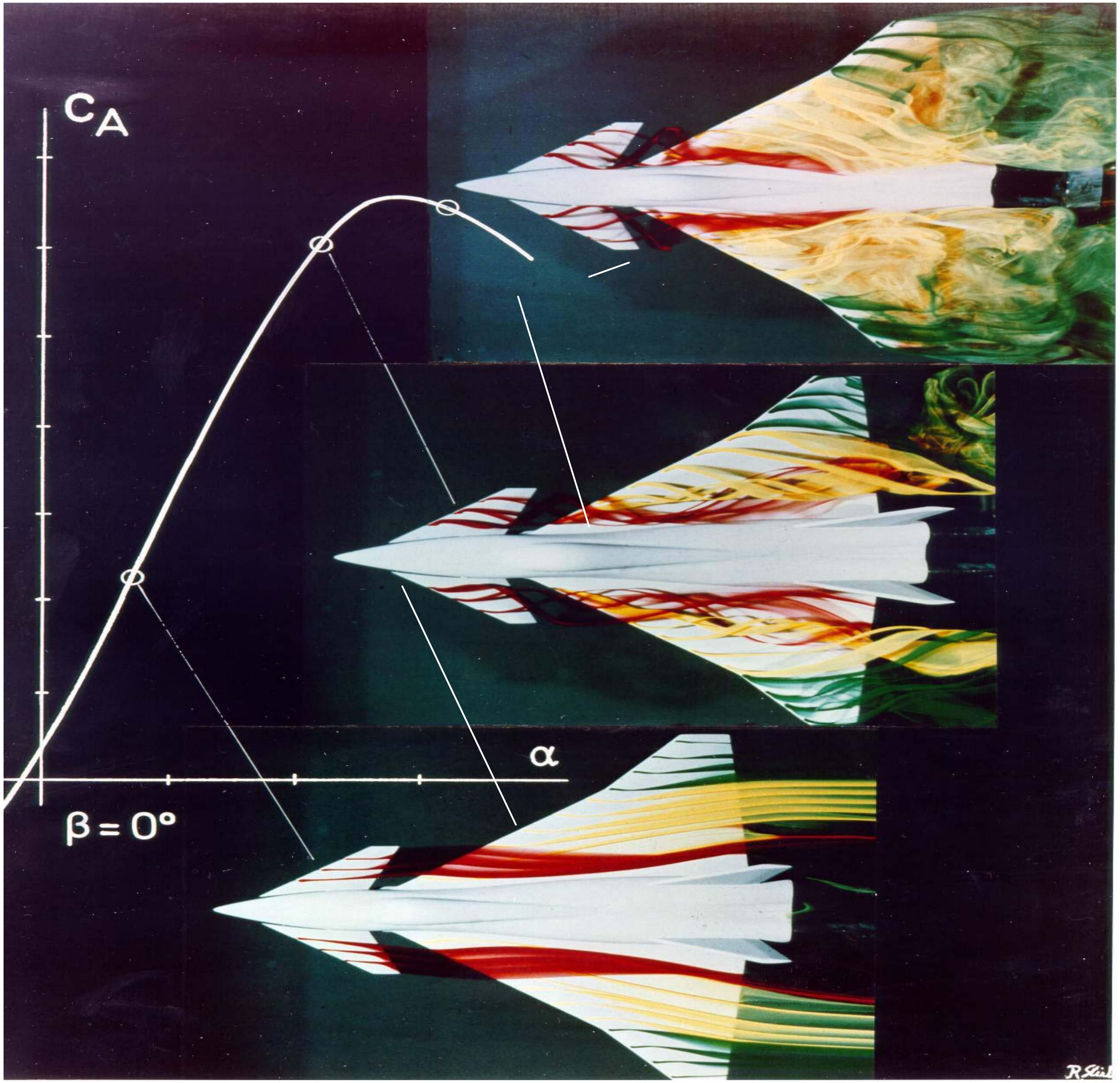
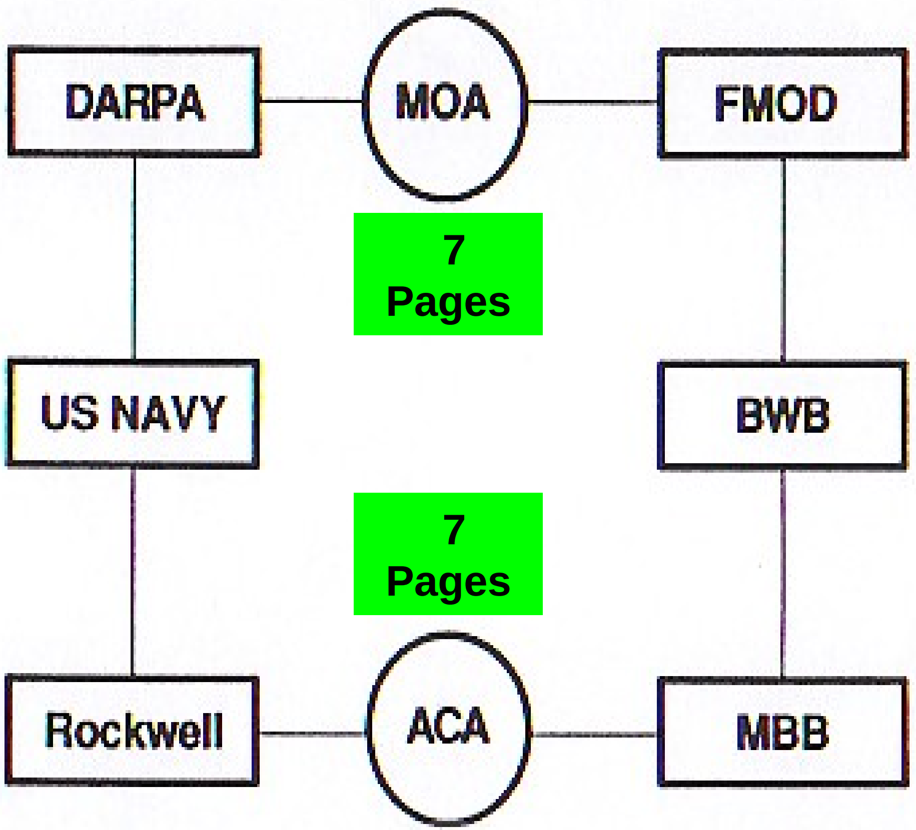
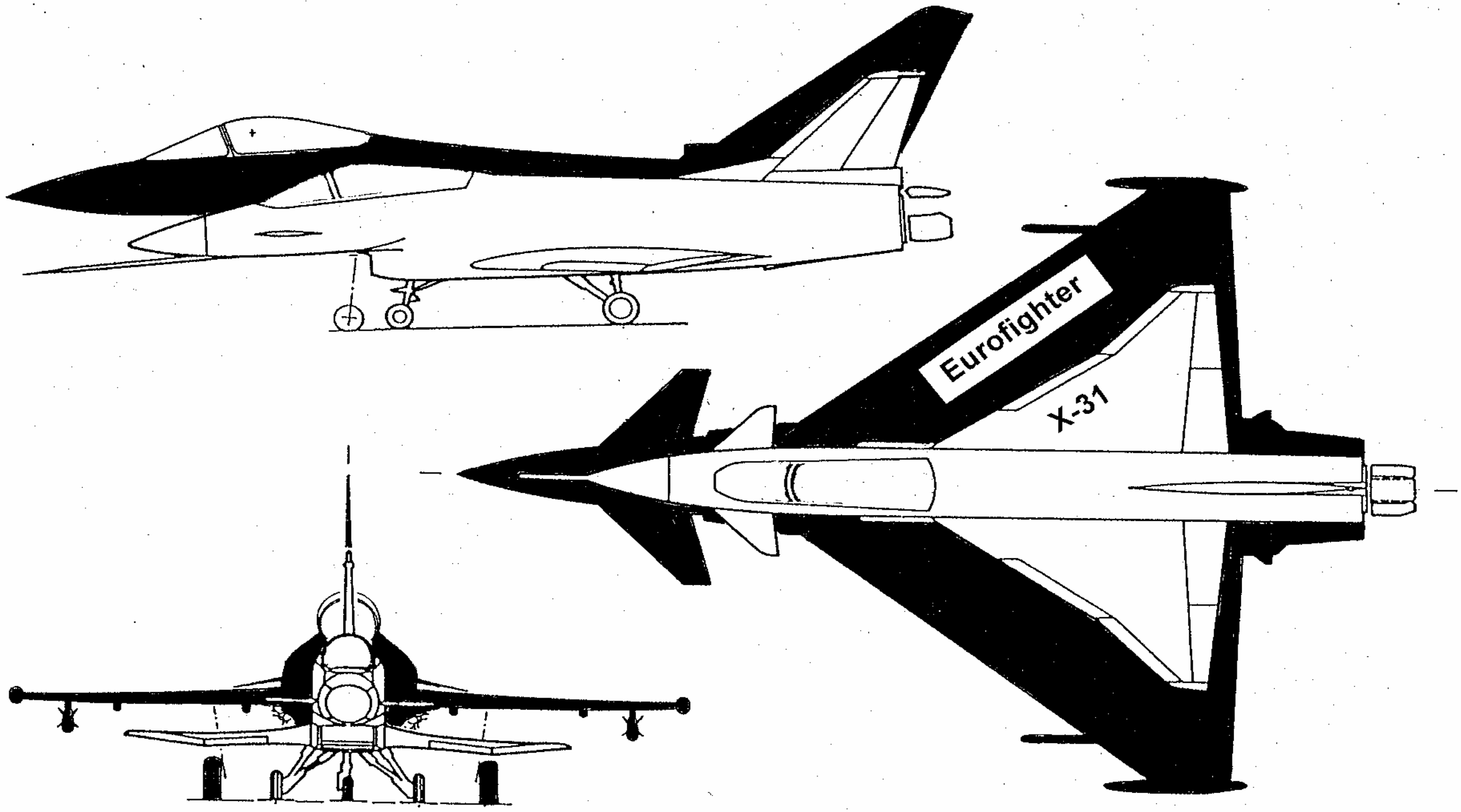


Government / Industry Organization & Program Objectives

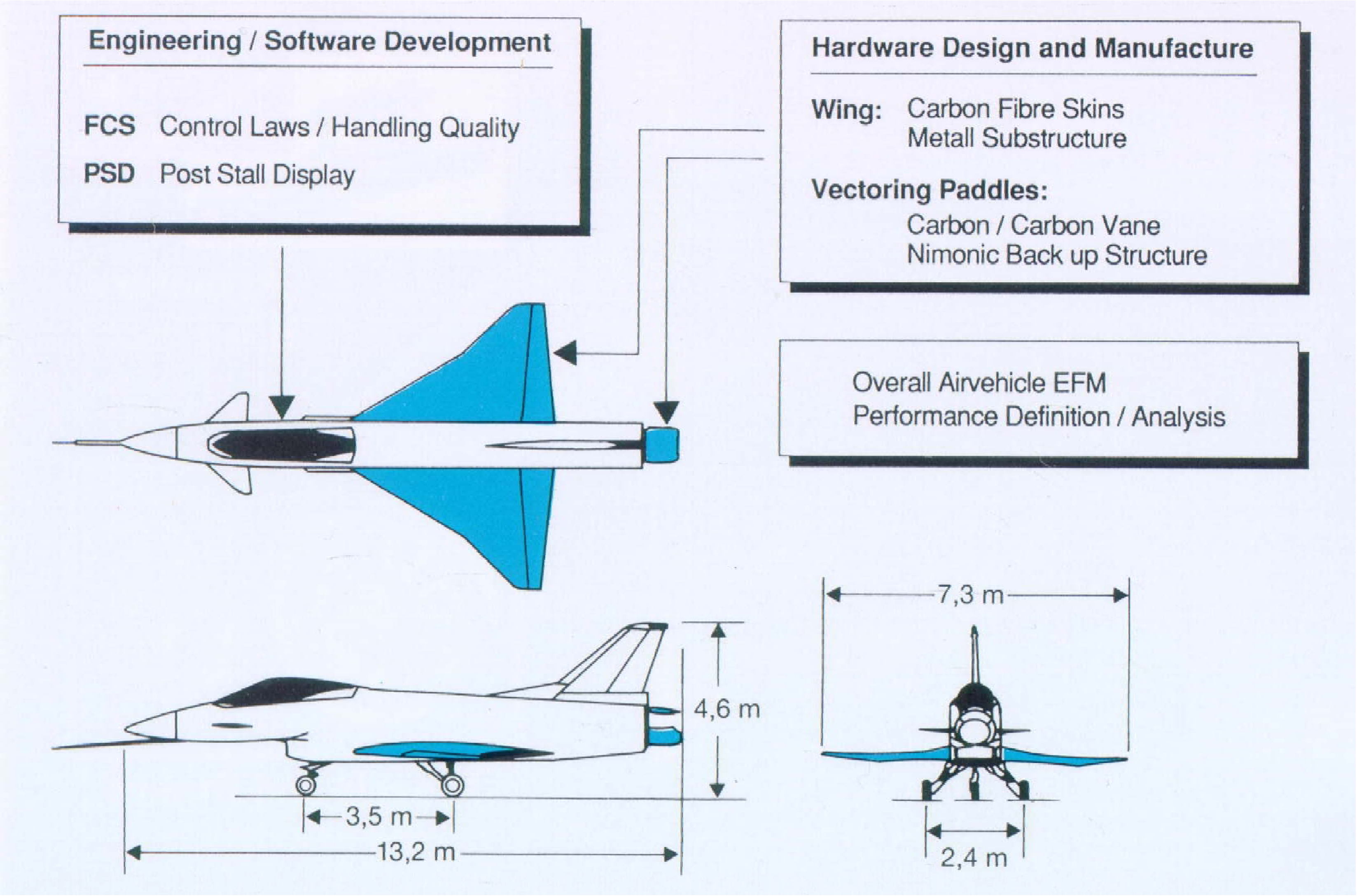


1. **Design, develop, build two “low cost” demonstrator aircraft**
2. **Demonstrate the technical feasibility of Post-Stall maneuvering**
3. **Demonstrate the tactical utility of Post-Stall capability**

X-31/Eurofighter Size Comparison

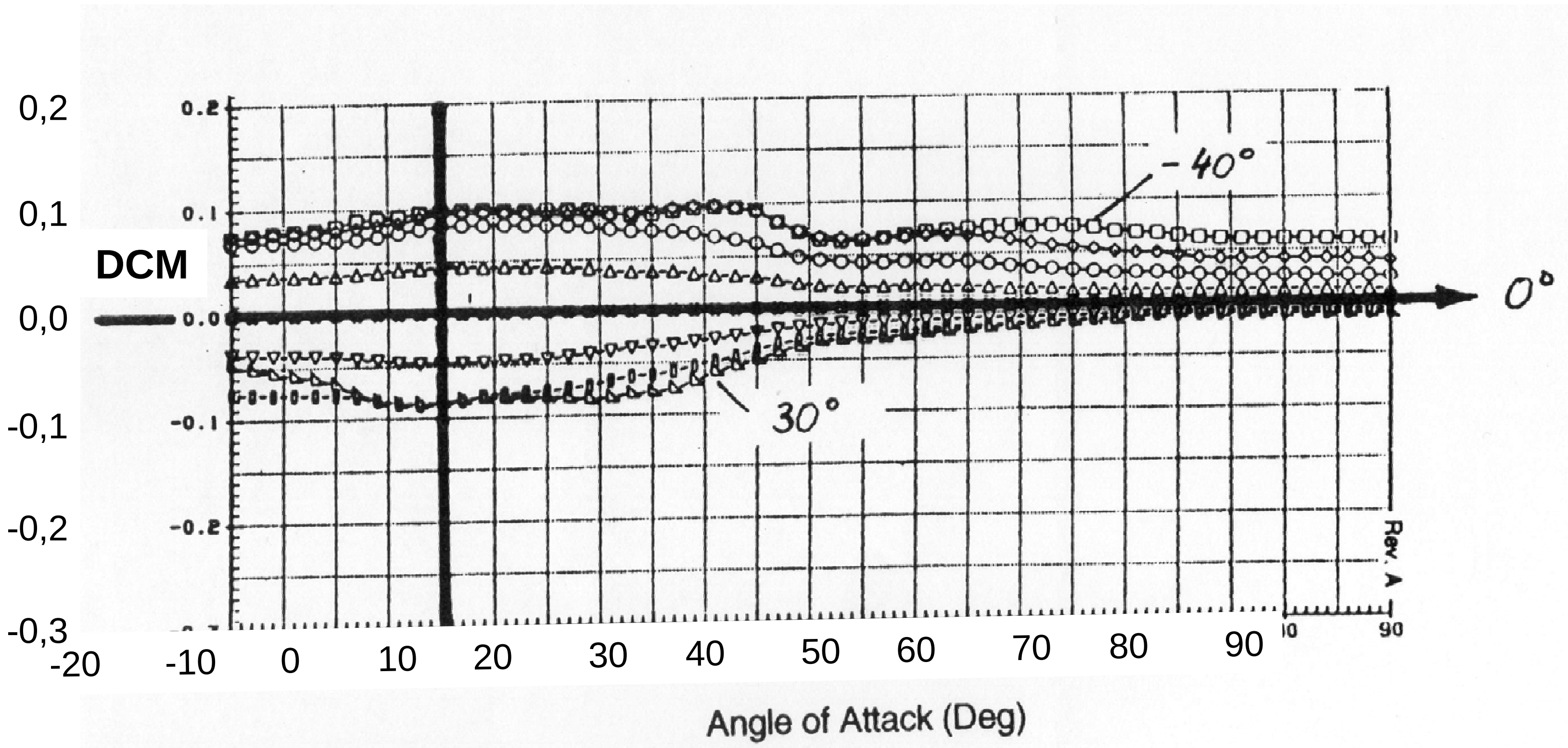


EADS Workshare

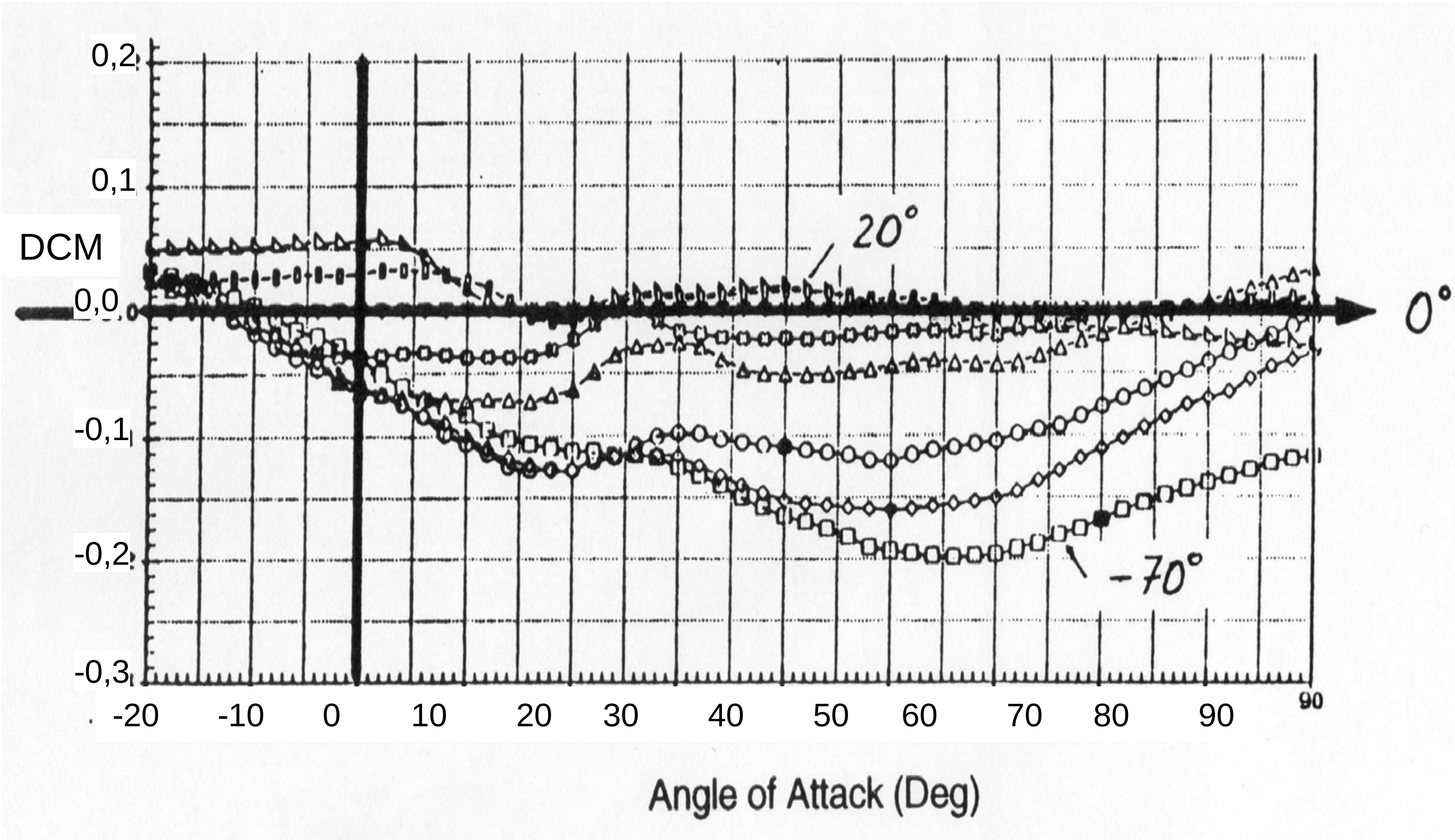


Trailing Edge Trim Power vs. Angle of Attack

IBR



Canard Pitch Moment vs. Angle of Attack



Rudder Effectiveness vs. Angle of Attack

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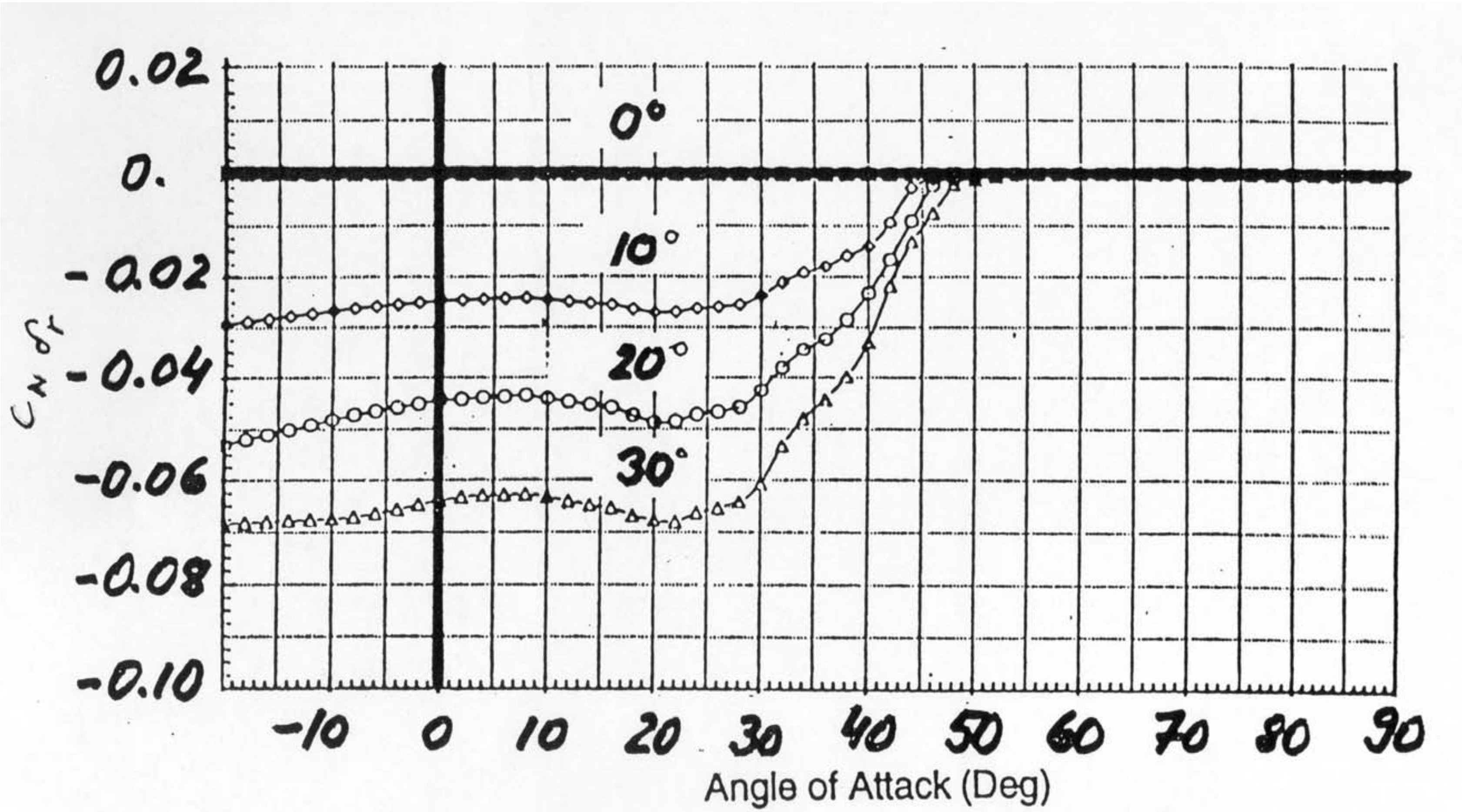

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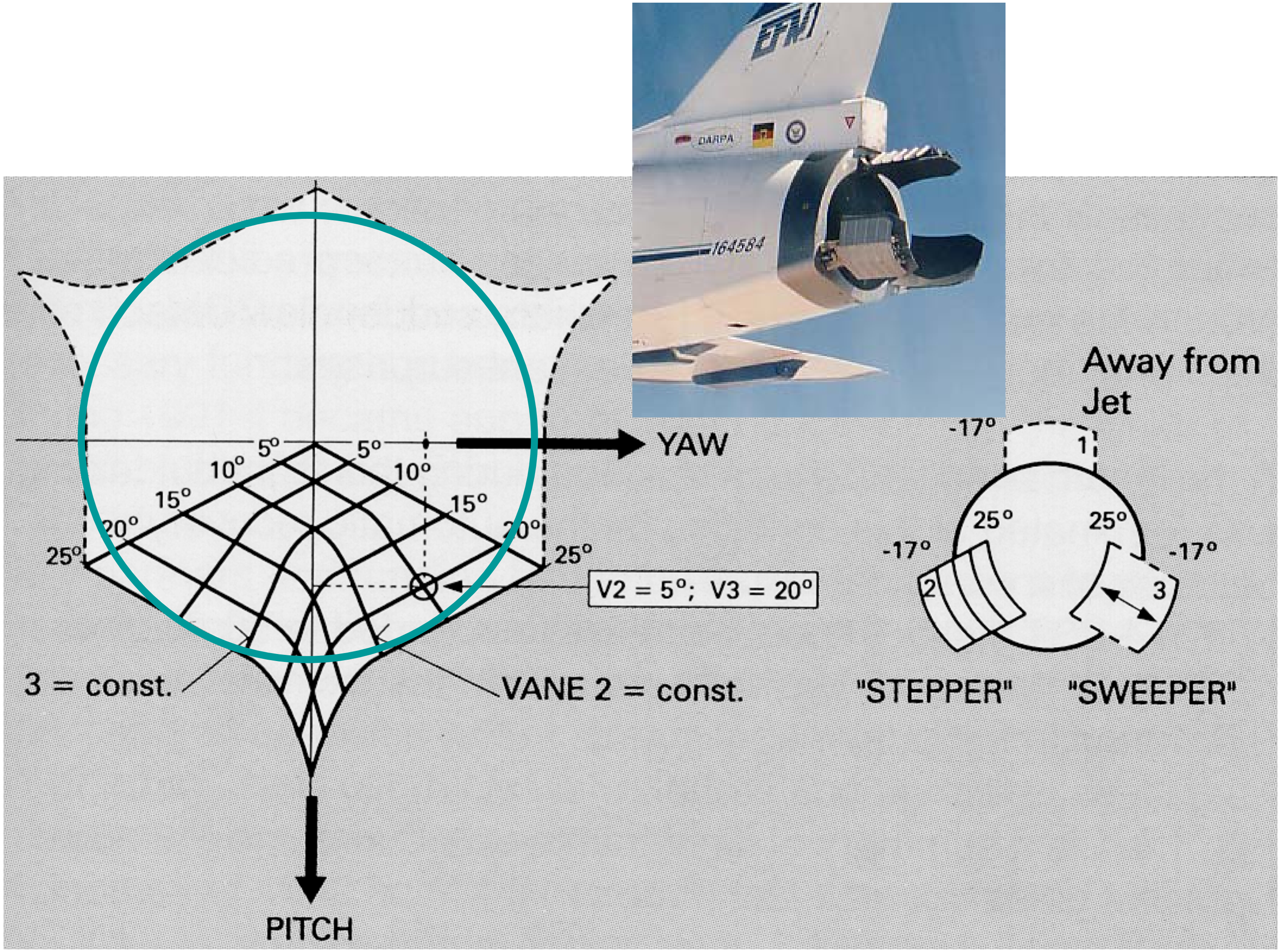
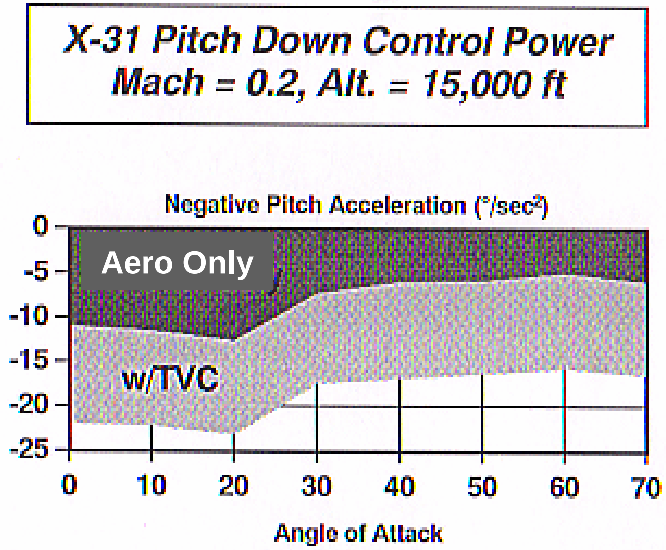
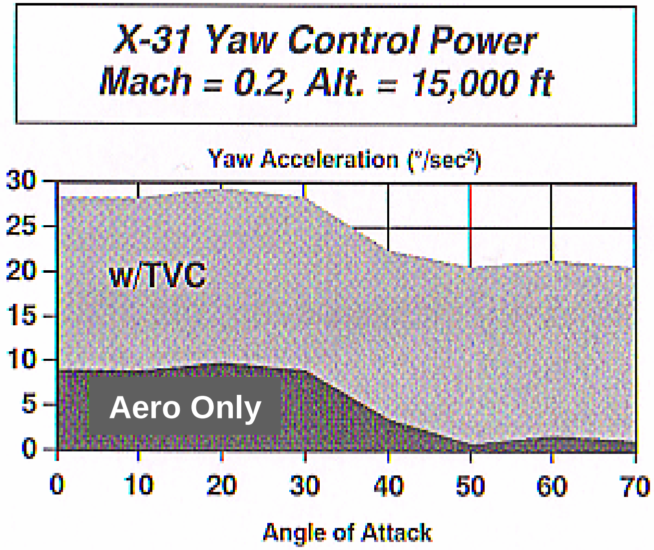
Side Force Generation by Thrust Vectoring System



X-31 TV Vane Arrangement

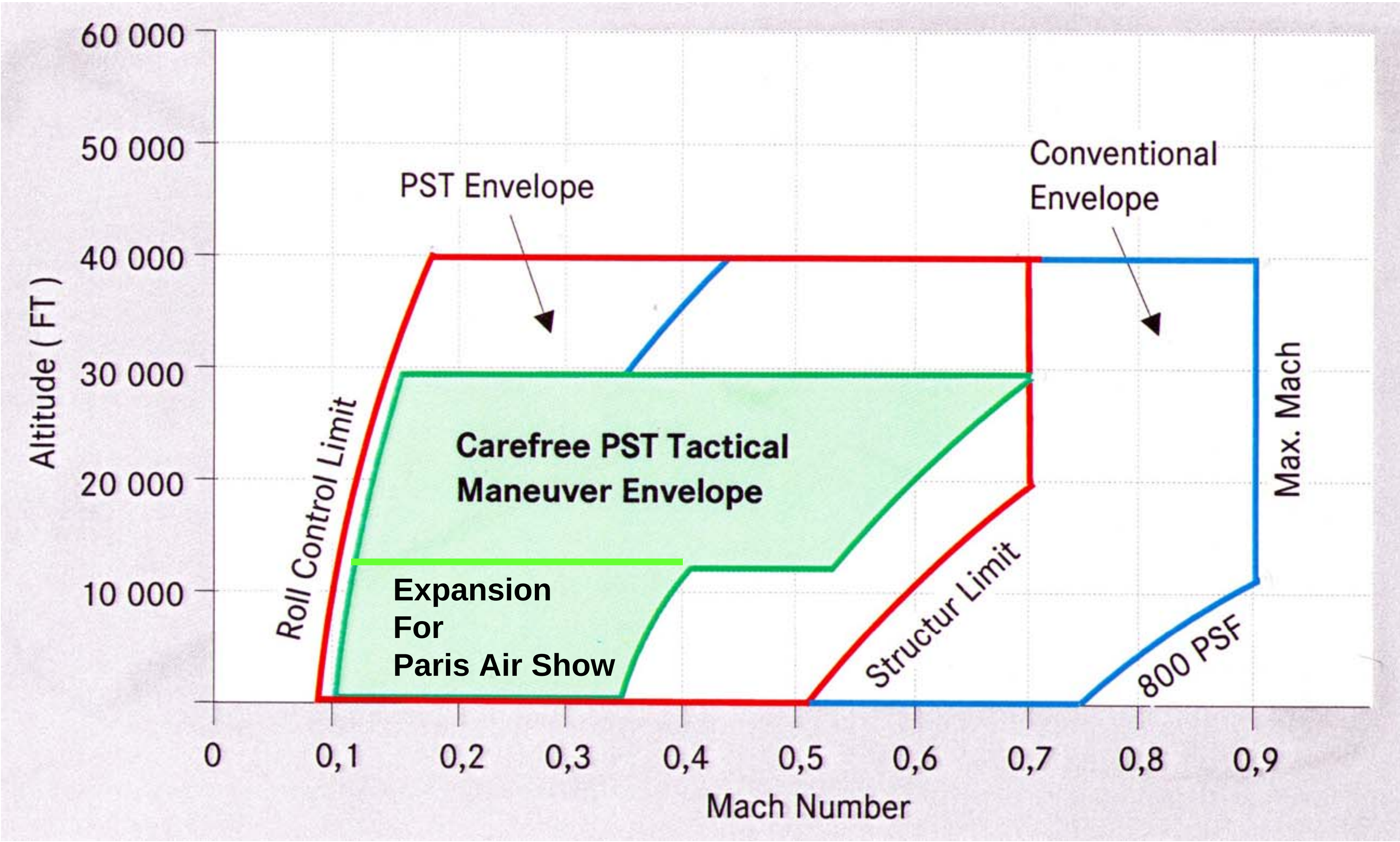
Thrust Vectoring Control Authority



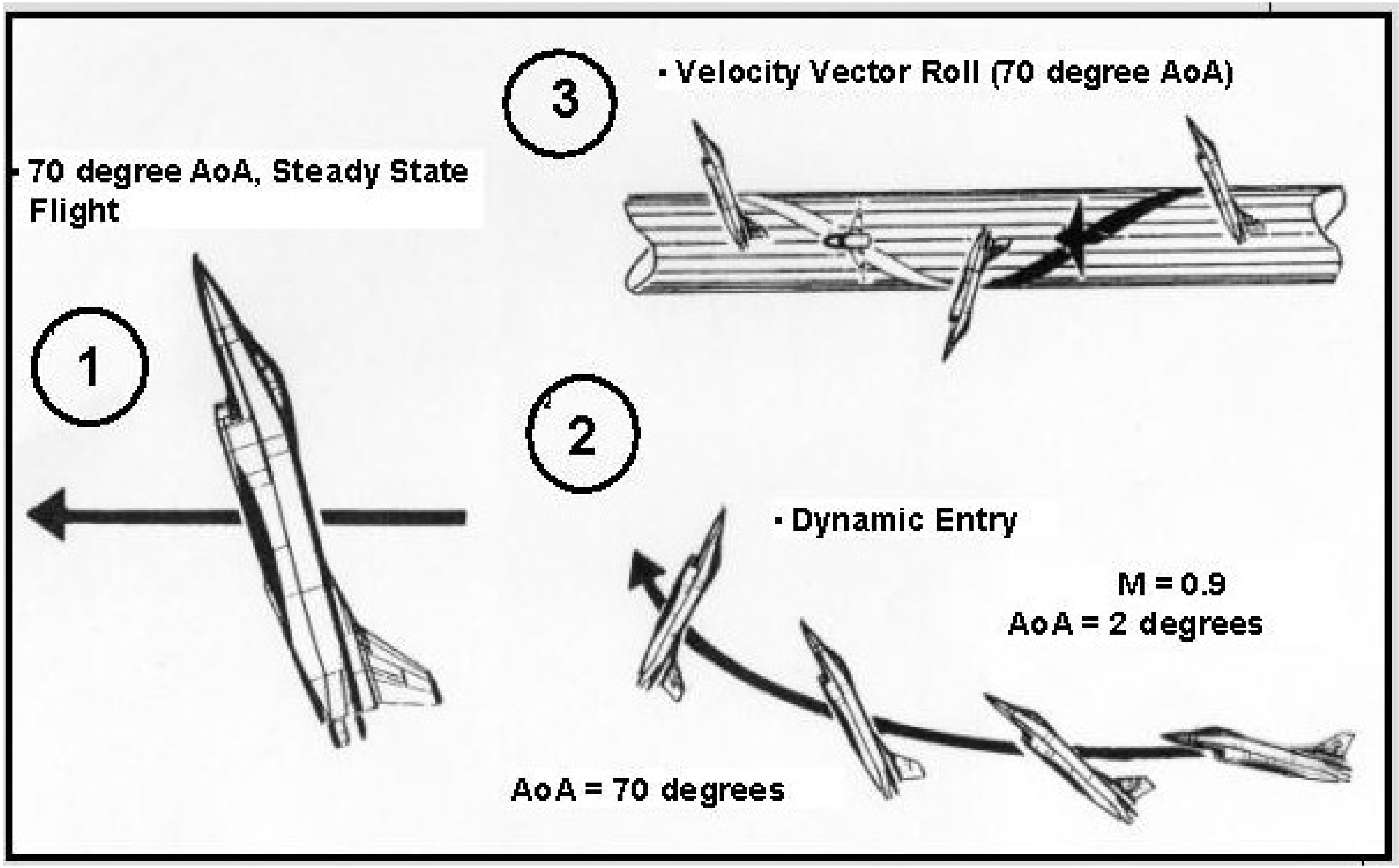


- Improved control authority provides increased safety
- Eliminates inherent design problems such as deep-stall
- Provides for higher yaw accelleration to reduce departures/allow for graceful exit from spin
- Allows for unique entry conditions for additional emergency training

X-31, Post-Stall Envelope

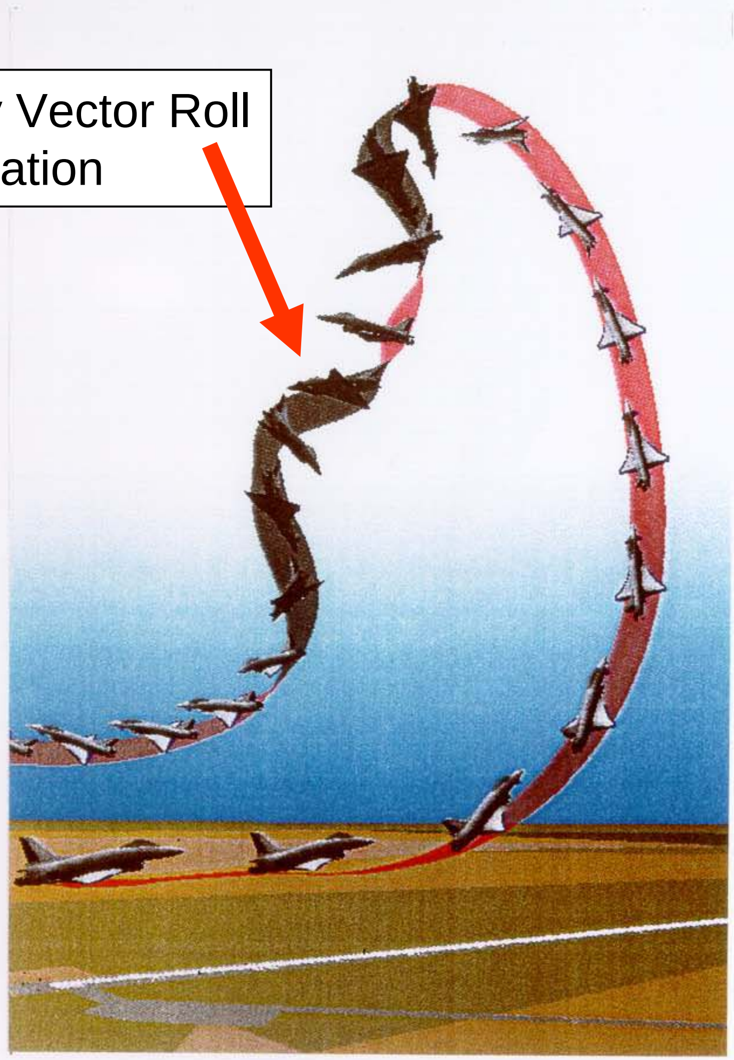


PST Flight Test Milestones



High Angle of Attack Manoeuvring

- Velocity Vector Roll
- Deceleration



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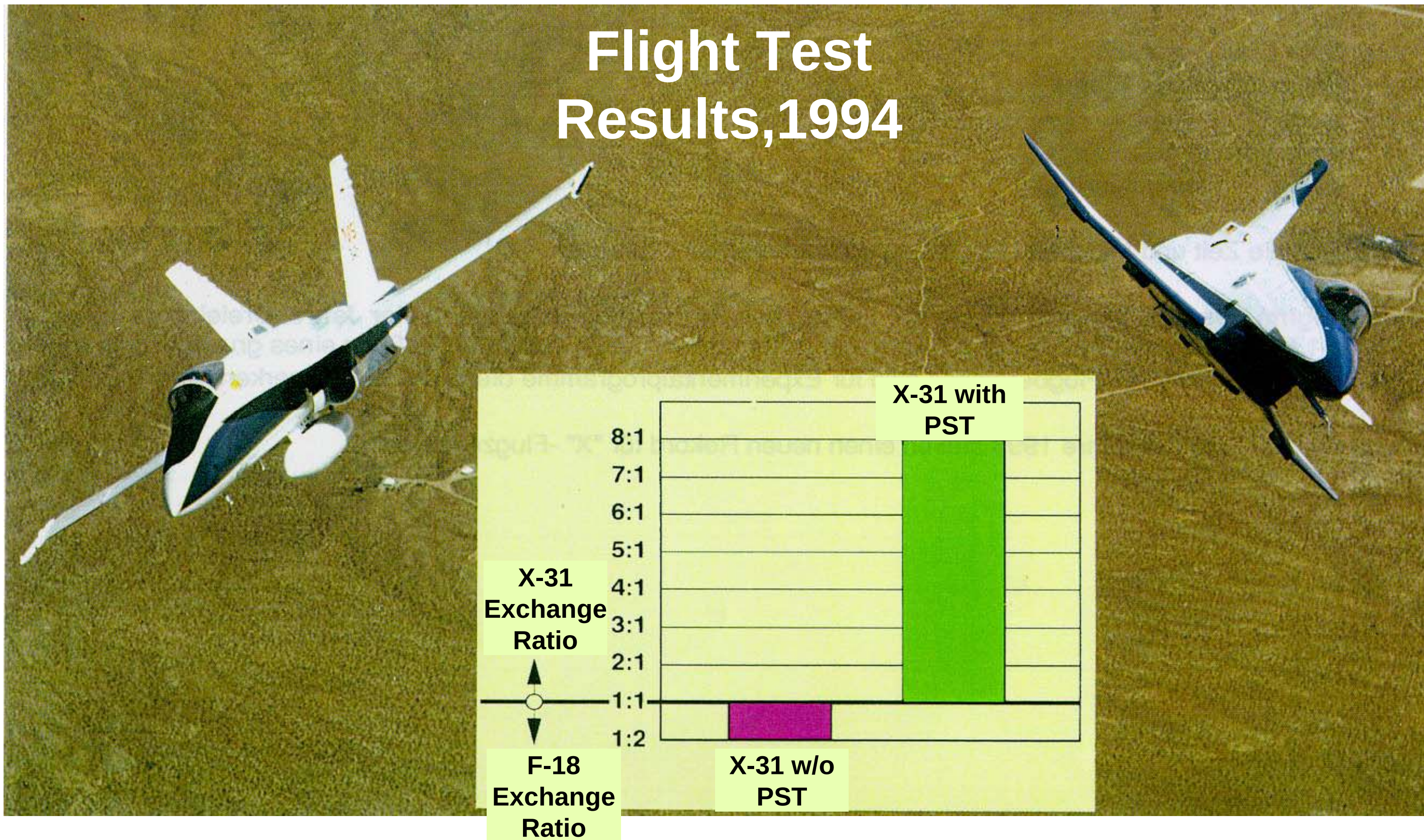
Close-in Combat Effectiveness: Simulations vs. Flight Test

IBR

1979 Simulation Results

	Guns + SRM	Guns
Engagement Wins	5.4:1	4.2:1



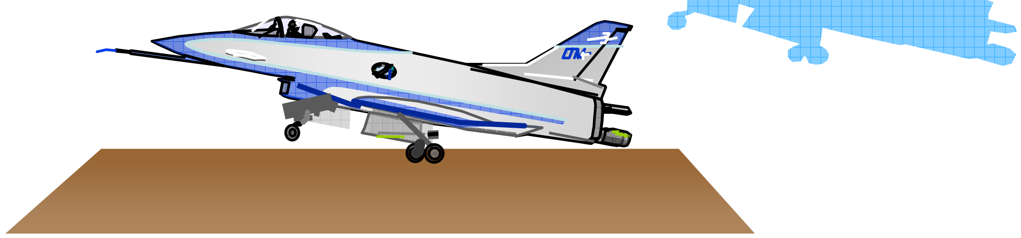
Extremely Short Take-Off and Landing (ESTOL) using Thrust Vectoring

Objective

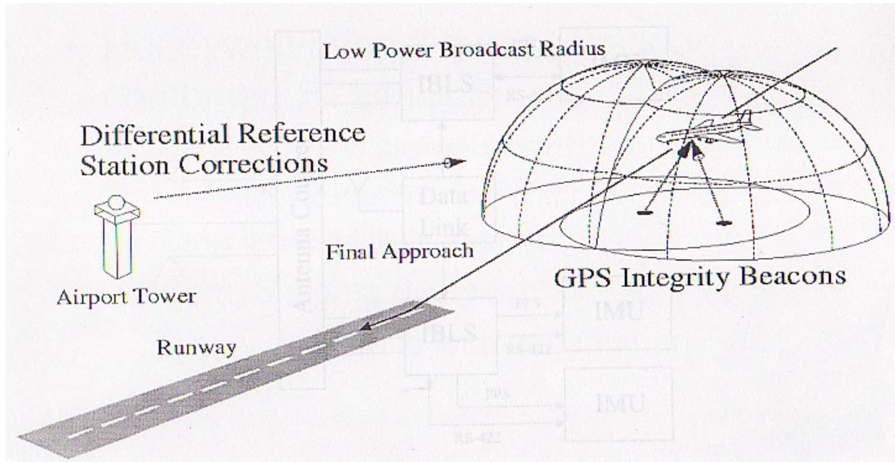
- ESTOL experiments shall demonstrate a reasonable, minimum energy during touch-down and landing

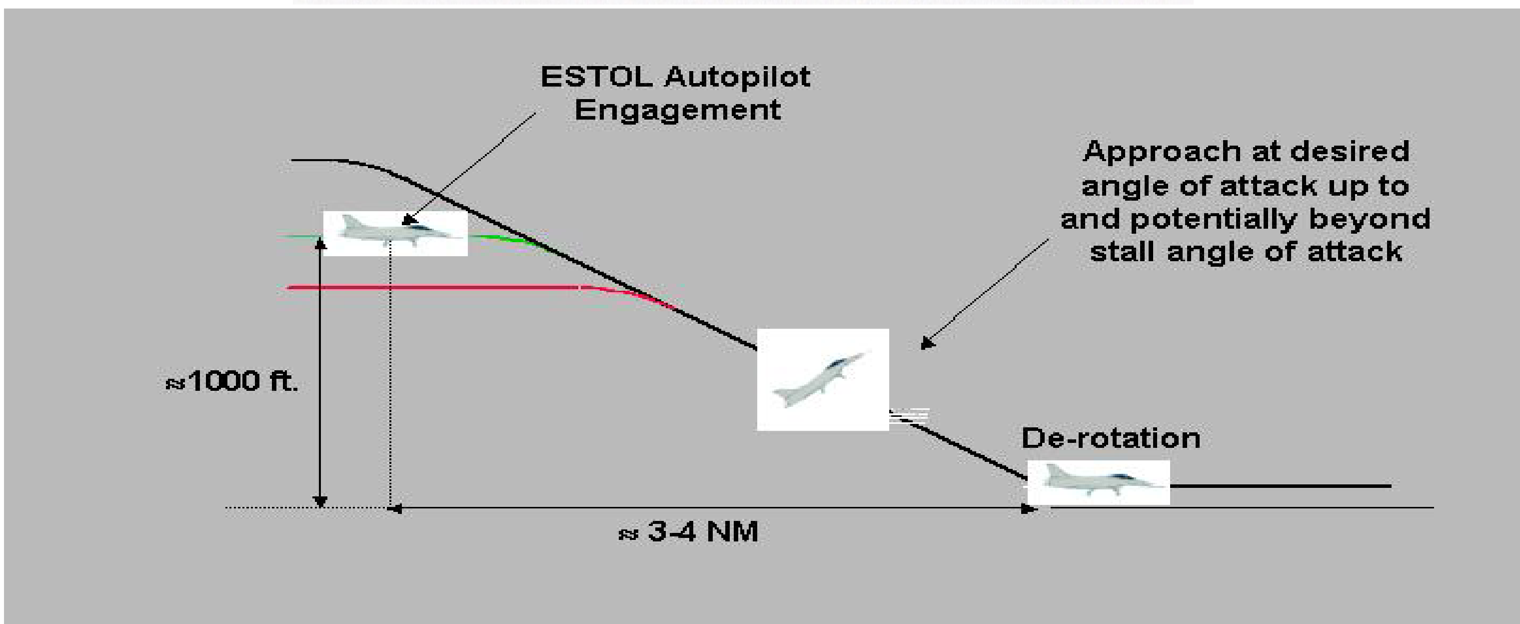
Concept

- High Angle of Attack (AoA) Approach using Thrust Vectoring for Precise Low Speed Control
- Derotation to Land (Reduced Pitch Angle)
- Thrust Vector-Assisted Rotation for High AoA Fly-Away

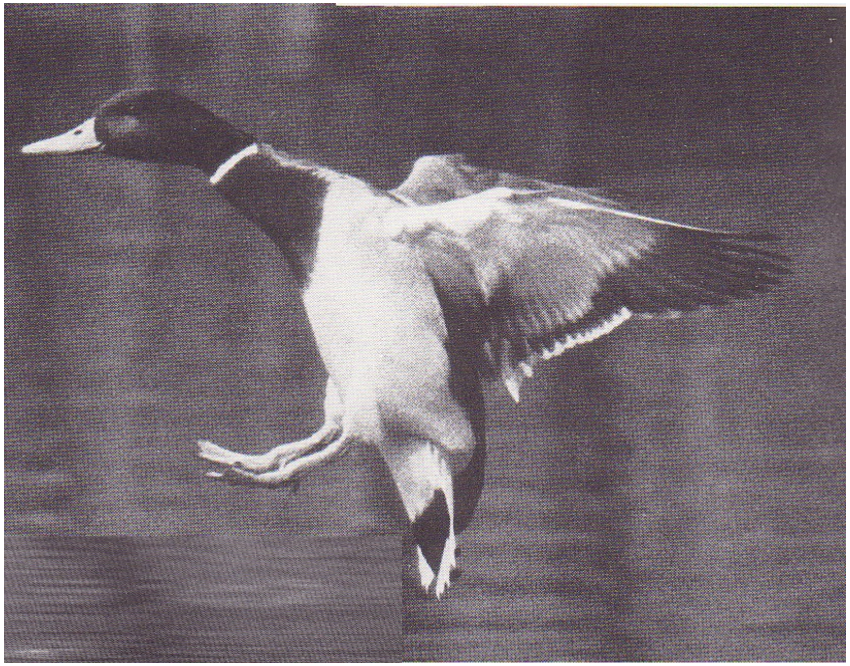


Approach Trajectory





Natural and Man-Made Landing Approach



Data Sharing with Universities, Institutions:

- AC Geometry for CFD calculations
- AC Geometry for WT modell
- Trajectory optimization Well, Stuttgart
- FCS design, Uni Stuttgart
- DLR, program üarticipation, Parameter identification

X-31 Experimental Aircraft - Exploitation of Configuration and other Project-relevant Data in external Cooperations

Project	Description	Main Partners	X31 – Data used	RESULTS
Frontier (1996-1998)	EU-Research Project on development and verification of multidisciplinary optimisation methodologies	BAe Systems EADS-M – Univ. of Trieste Univ. of Newcastle	Wing lofting	Multipoint optimisation of dimensioning of wing t.e. flaps for supersonic roll performance
JULIUS (1998-2000)	EU-Research Project on development and verification of multidisciplinary simulation analysis tools in HPC environment	BAe Systems EADS-M Dassault Aviation – Univ. of Swansea FhG -IPK	Complete Aircraft CAD Model Structural models of wing and of complete aircraft	Test of CAD-repair procedure Aeroelastic Simulation of flight manoeuvres (e.g. rapid roll, 5g-pull up)
FASTFLO II (1999-2000)	EU-Research project on development and verifacation of fast CFD analysis tools	NLR DLR EADS-M Saab - FFA	Complete Aircraft CAD Model	Simulation of flow characteristics at high angle of attack by an unstructured Naviers-Stokes solver
TA15 (2002 – 200x) (proposed)	EU research project on vortex flow phenomena	NLR EADS–M Alenia DERA	Complete Aircraft CAD Model	Validation of CFD Methodology wrt to unsteady vortical flow phenomena

Andreas Schütte, Gunnar Einarsson, Axel Raichle, Britta Schöning

Prediction of the Unsteady Behavior of Maneuvering Aircraft by CFD Aerodynamic, Flight-Mechanic and Aeroelastic Coupling

The main objective of this paper is to focus on the necessity for developing an interactive, multidisciplinary engineering tool for predicting the unsteady critical states of complex maneuvering aircraft. Such a simulation environment has to bring together aerodynamics, aeroelasticity and flight mechanics in a time-accurate simulation tool. In order to deliver such a tool in the near future, the DLR Project SikMa-"Simulation of Complex Maneuvers" has been initiated to combine these three disciplines into one simulation environment [18][19].

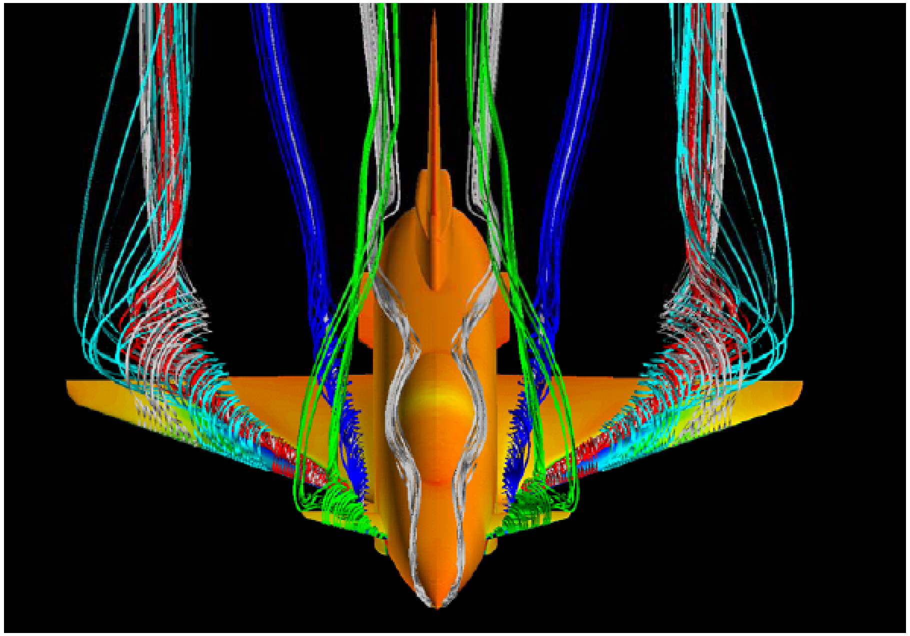


Figure 14: 3D flow field over the X-31 configuration at 18° angle-of-attack.

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RTO-MP-AVT-123

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X-31, Eurofighter, und Tornado, Paris 1995

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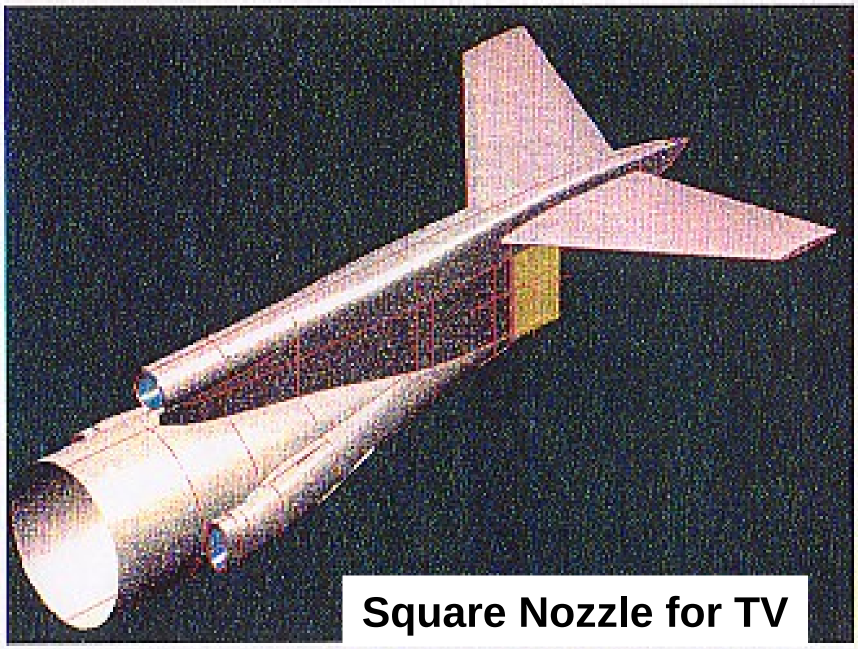
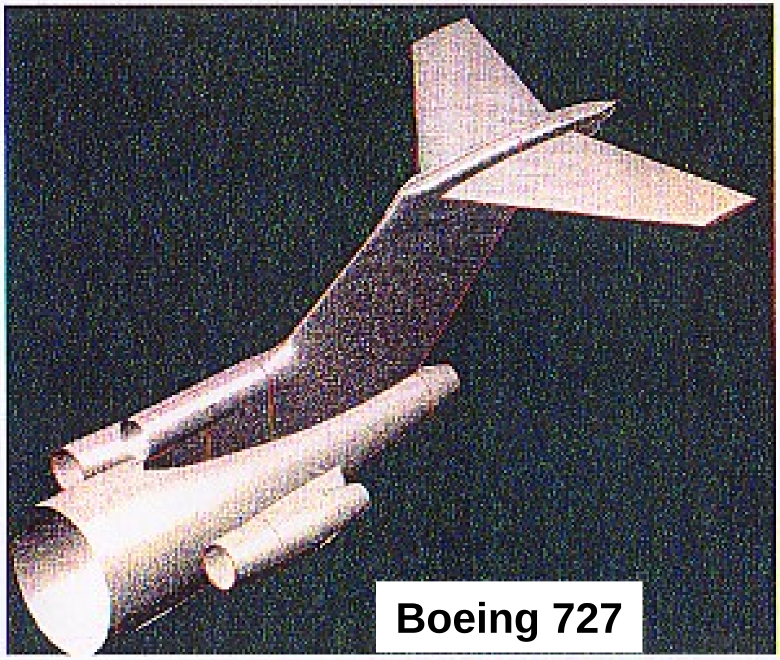
Reserve Slides

Thrust Vectoring for Civil Aircraft?





- **T/W ratio for commercial aircraft: 0,25 – 0,35**
- **Primarily wing mounted engines: no lever arm for for pitch and yaw**
- **Fixed engine nozzle, no variable exit area**

Application of TV for commercial aircraft doubtful.
Blended Wing body concepts could offer a new opportunities.

Program Pay-off's

Development/Demonstration of new technologies:

- **Application of the CCV F-104 approach to control law development**
- **Fully integrated thrust vectoring into the digital FCS System**
- **Pathfinder for the NARMCO carbon fiber material for the EF**
- **Opening of a new flight regime: Post Stall Arena**

- **Demonstration/evaluation of new operational capabilities (PST for CIC)**

- **Demonstration of precision short field landing techniques**
- **Development of a microminiaturized Air Data System**

Development and Test of a new aircraft

- **Training of a new generation of engineers from conceptual design through flight test**

Development of a Vector nozzle for the EJ 200 engine by ITP in Spain

What we did not (yet) achieve:

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Thrust Vectoring For Eurofighter

But the Competitors have TV already!

Elements of the VECTOR Program

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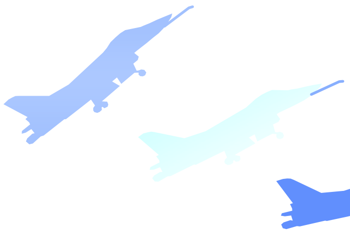
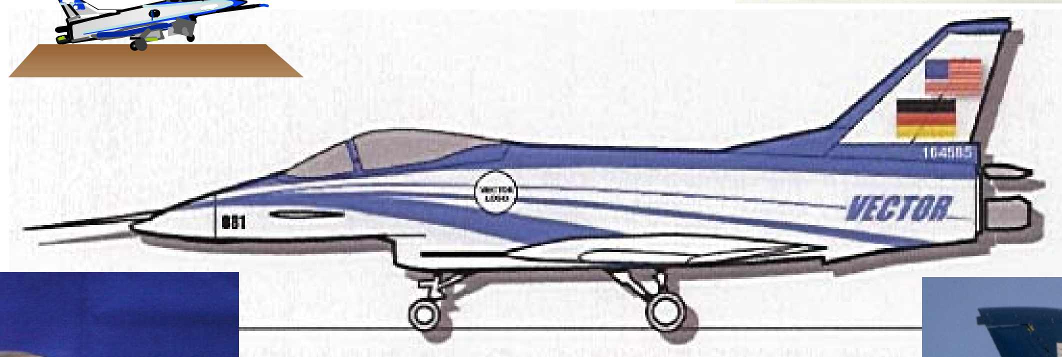
ESTOL

Extremely
Short Take-Off
and Landing



TAILLESS

Reduced Tail/Tailless



AADS

Advanced Air Data System

Thrust Vectoring

Vanes developed for the X-31 EFM program

Options for High Alfa Landing

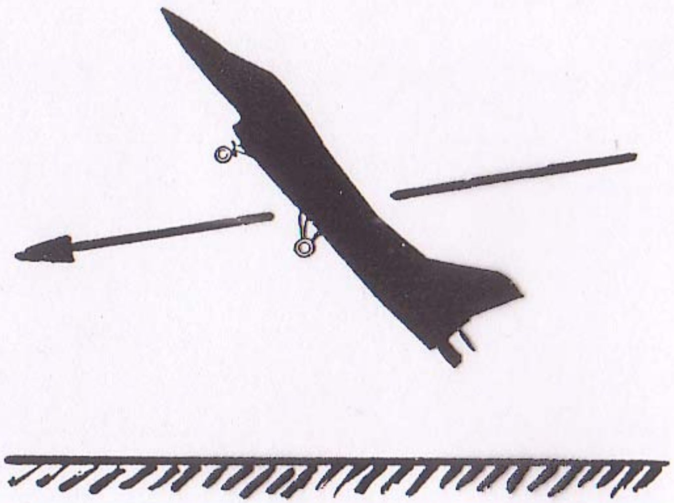
High attitude

Normal approach angle

Low speed

Normal sinkrate

High Thrust



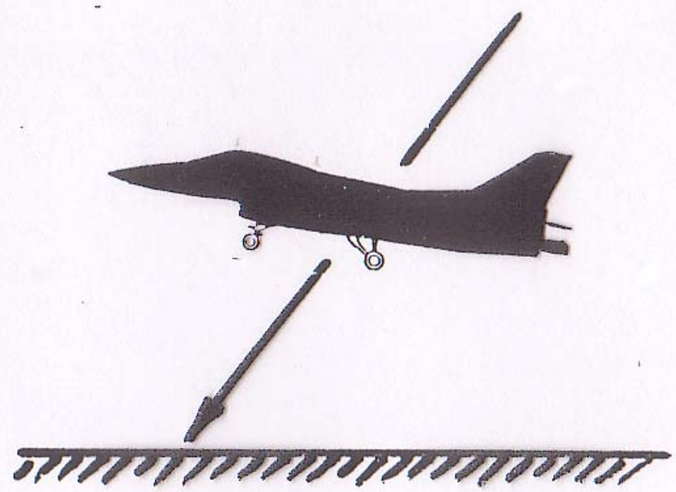
Normal attitude

Steep approach angle

Low speed

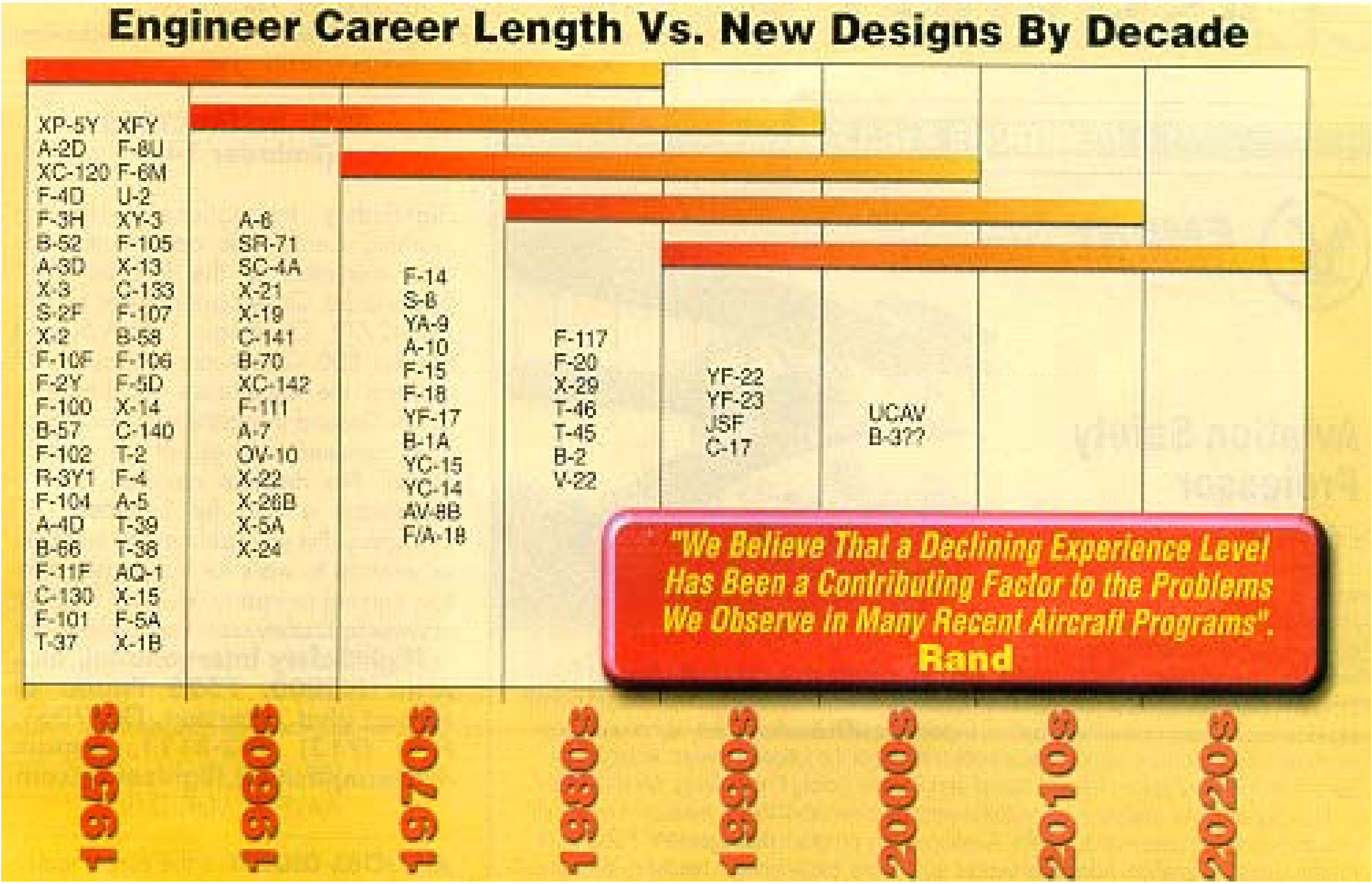
High sinkrate

"Low" Thrust



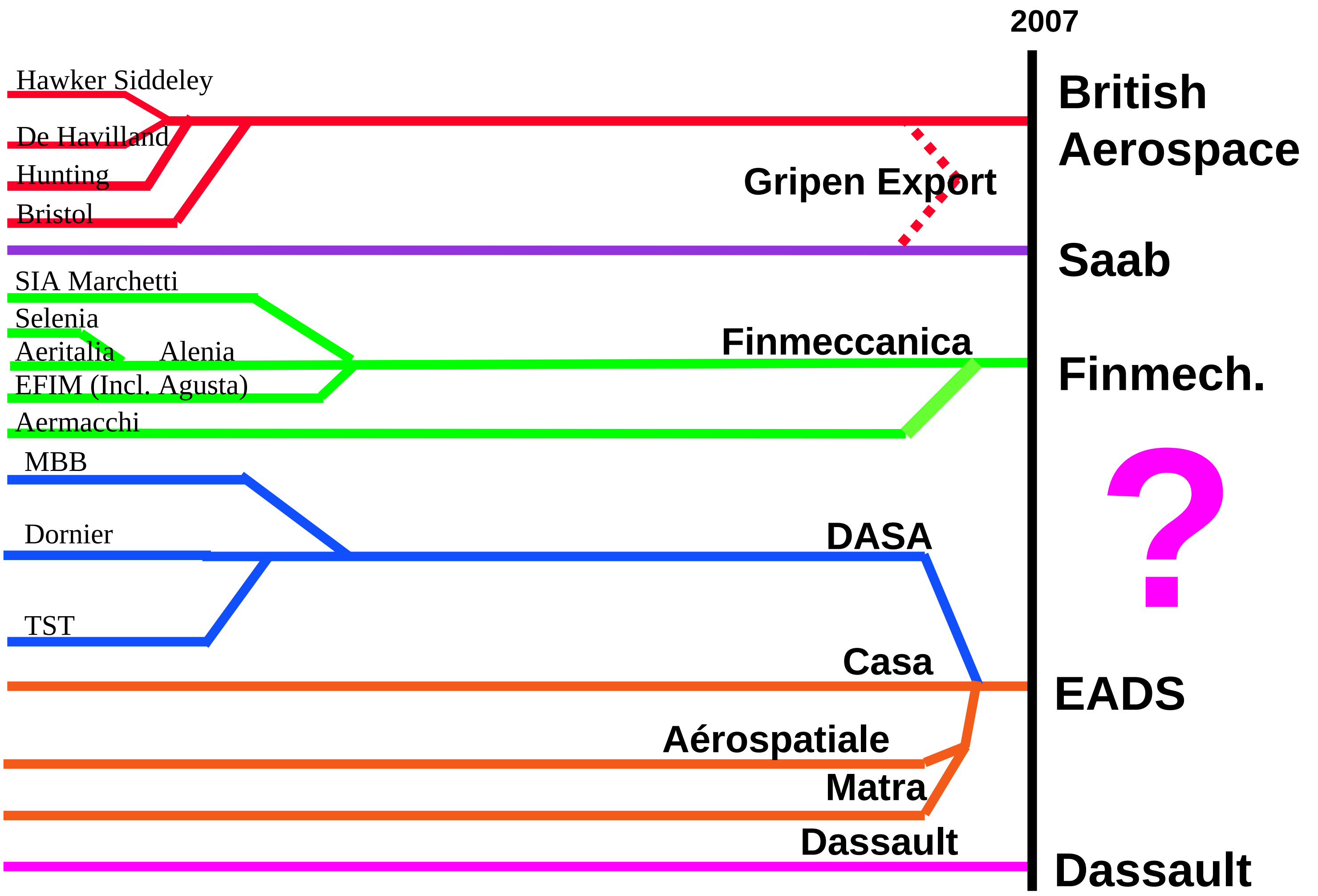
How Do We Maintain the Knowledge Base?

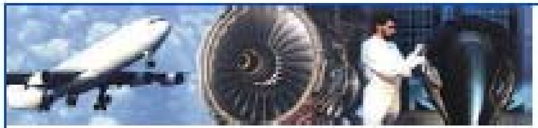
(US Data)



Source: Rand Corporation

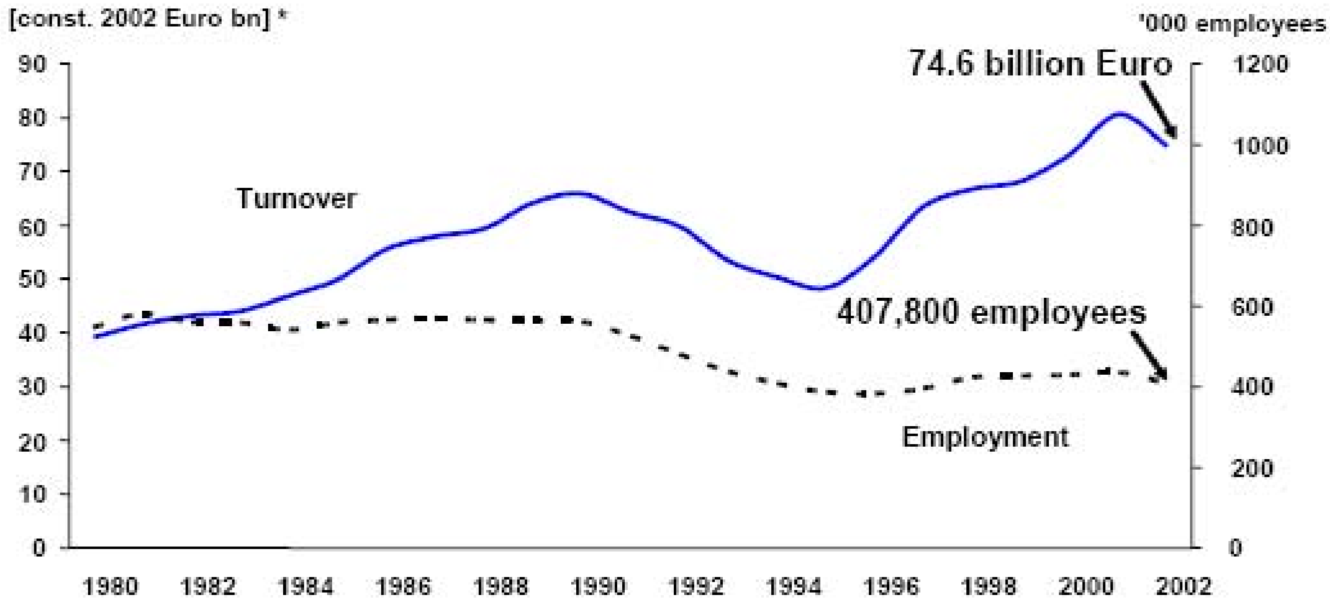
Consolidation of European Aerospace Industry !?





EU Aerospace Industry

Turnover * and Employment⁺



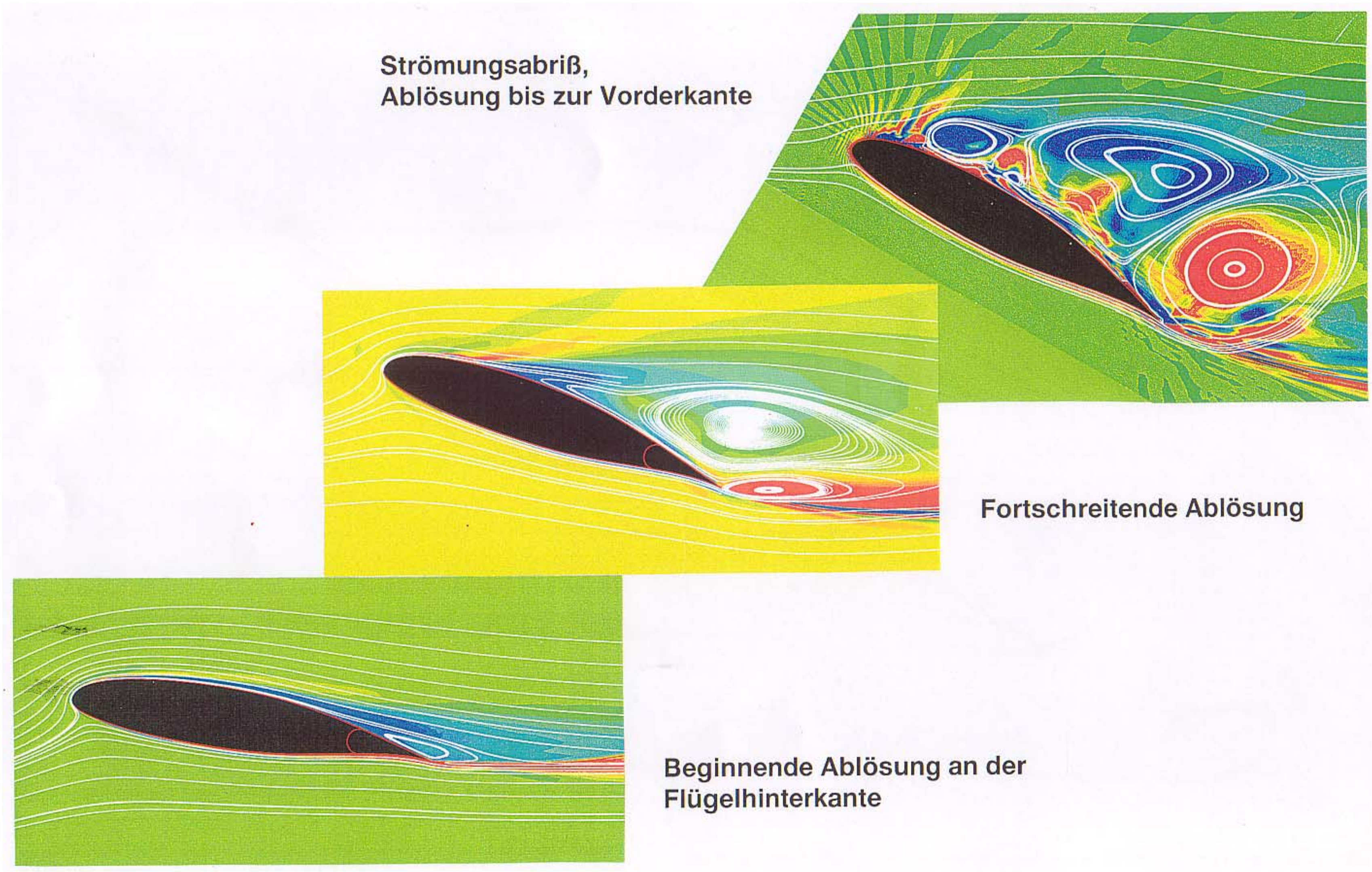
AECMA

*) based on EU consolidated turnover

+) incl. estimates for Sweden until 1992 and non-AECMA companies until 1996

Source: AECMA

Stall (2 Dimensional Calculations)



Evolution of Thrust/Weight Ratio

Fighter and VTOL Aircraft

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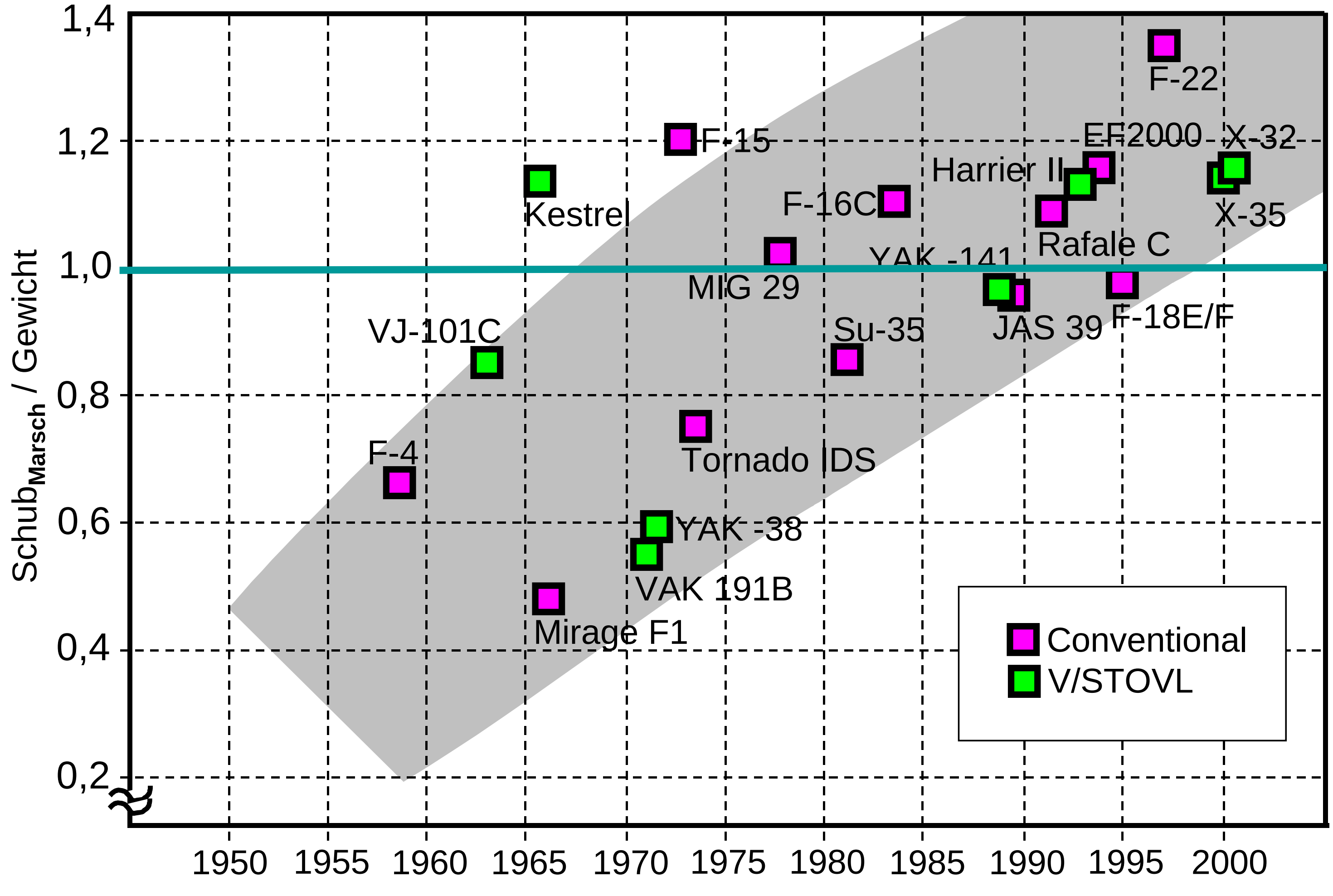
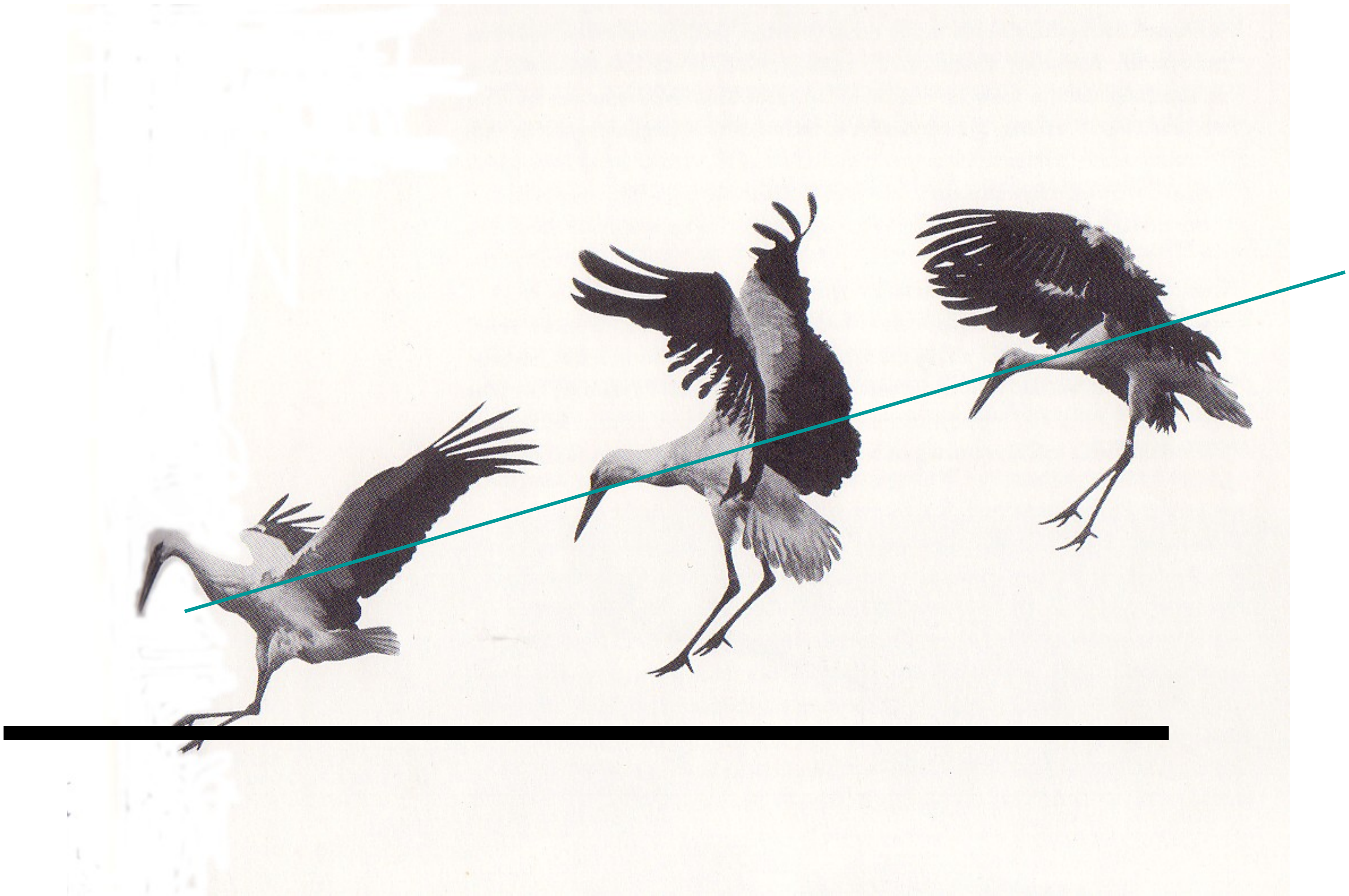
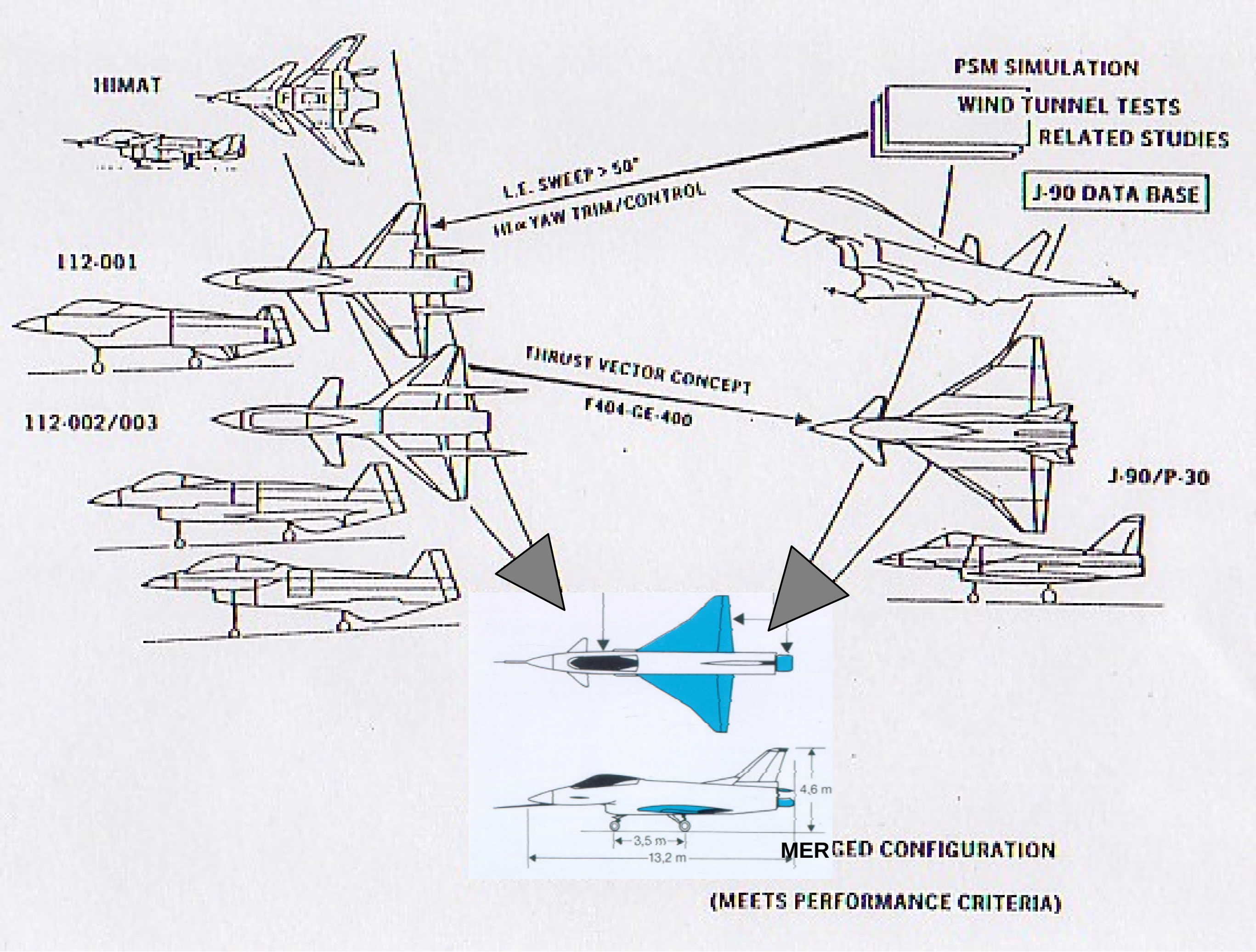


Hannes Ross
Samara, May 2007

Das Langbein Fahrwerk



Configuration Selection



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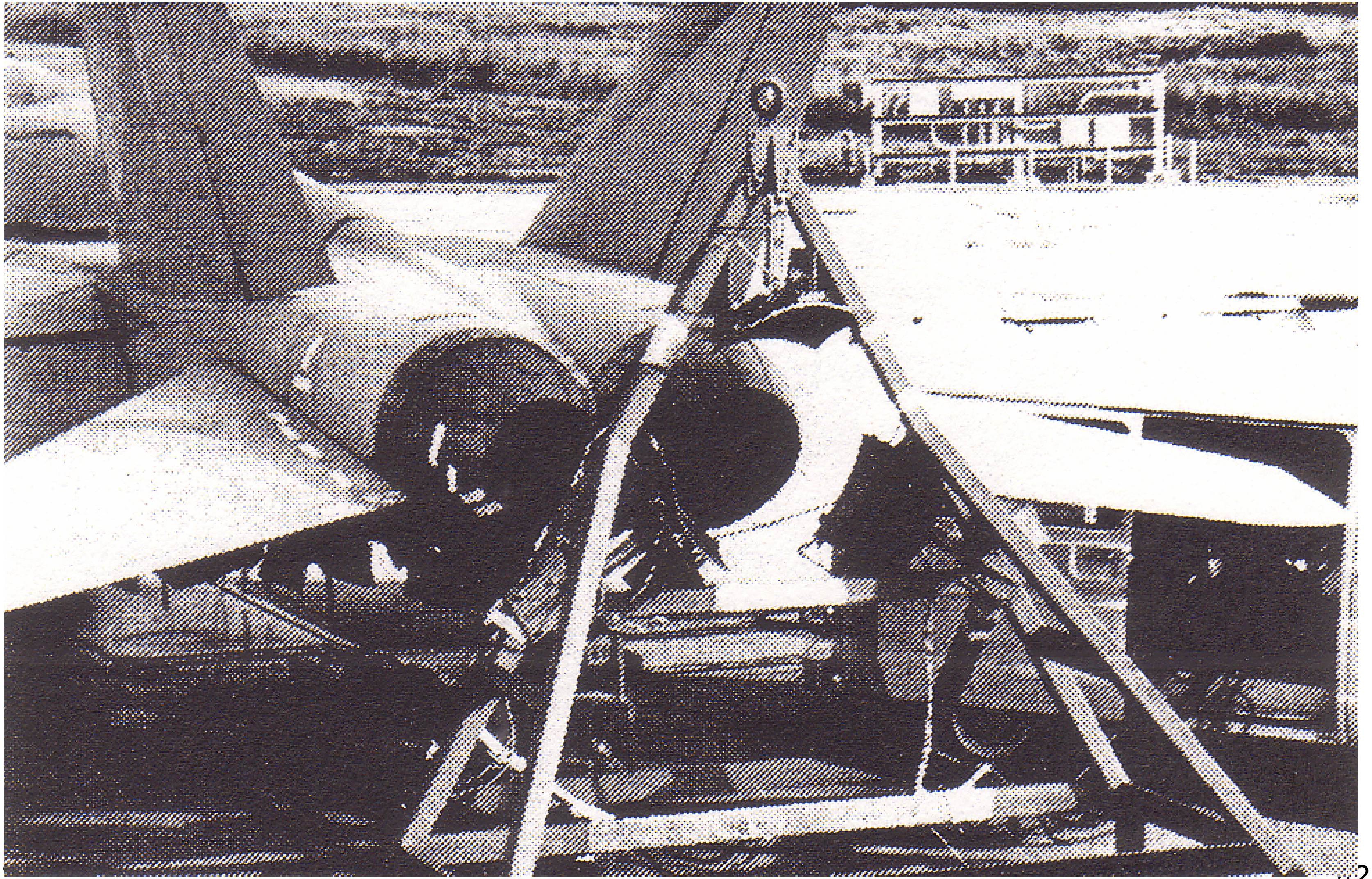
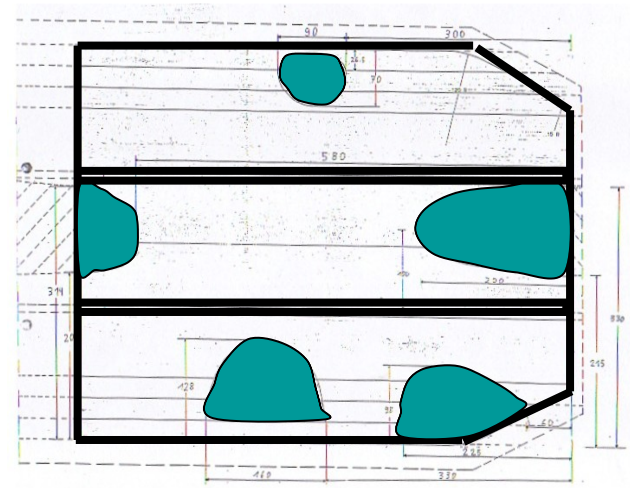
Full Scale Thrust Vectoring Test



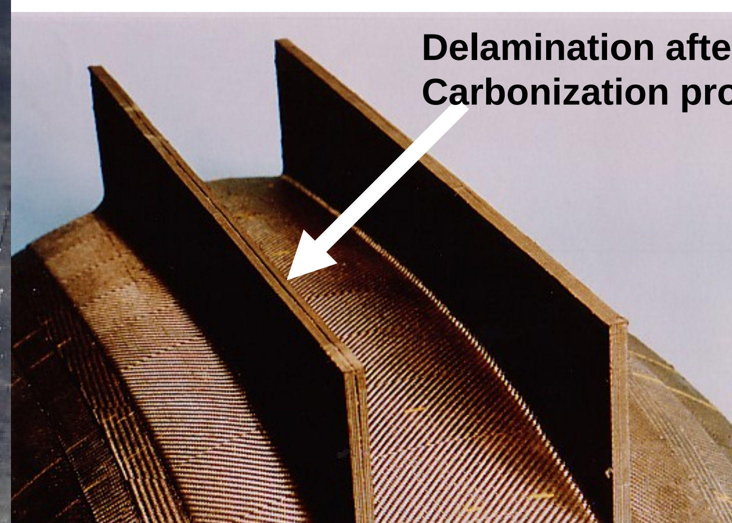
Vane Manufacturing

Gewicht der C/C Ablenkschaufel: 6kg
Gewicht der Metallstruktur: 10kg



Thrust Vector Vane Delaminations

Vane 1 after Green Core Process



Delamination after first Carbonization process

Comparison X-31 vs. F-18 HARV

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X-31, Thrust Vector Vane Attachment Scheme

Drove Aft Fuselage Changes

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Booms for
Vane Attachment
And Actuation

Initial Flight
Configuration:
No booms!

Added Trim
Surface

Nosecone Strakes

EWADE

IBR