COLLEGE OF ENGINEERING
KEVIN T. CROFTON DEPARTMENT OF
AEROSPACE AND OCEAN ENGINEERING
VIRGINIA TECH.

AOE 4144: Applied CFD

A series of 12 lectures by Prof. Raj (course co-instructor)

Reflections on the Effectiveness of Applied Computational Aerodynamics for Aircraft Design

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Advanced Development Programs

LOCKHEED MARTIN

Lecture 8

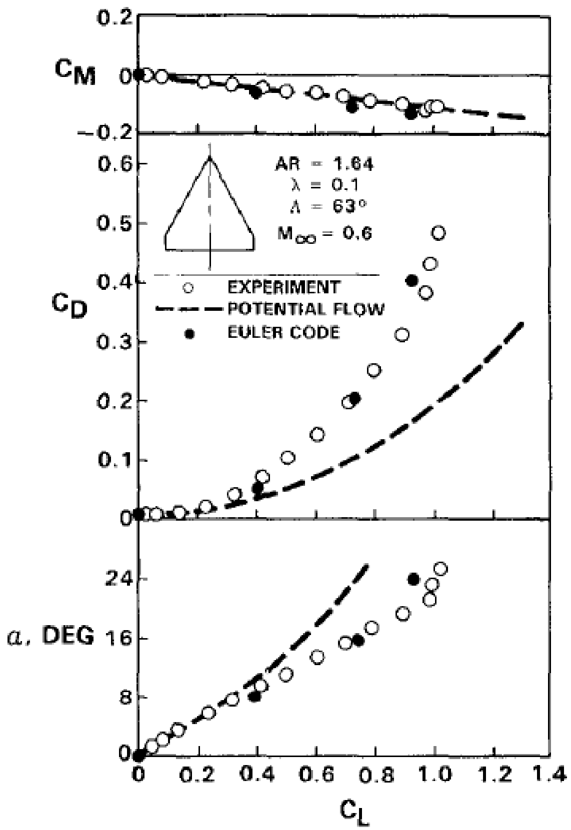
Topic 5: Evolution of Applied Computational Aerodynamics (Part 4 of 5)

List of Topics

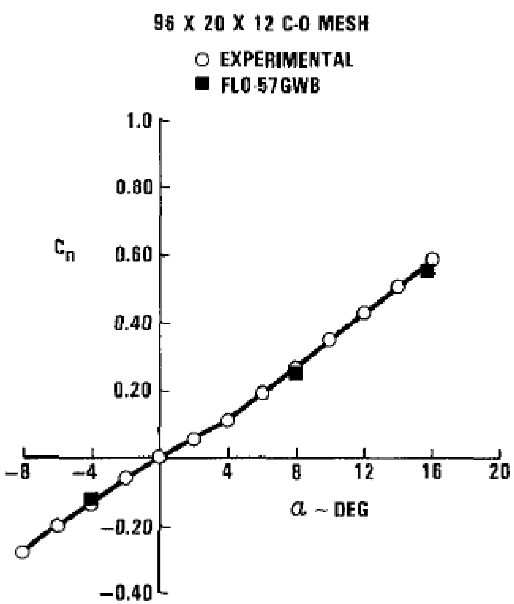
Free-vortex Flow Simulation Using Euler Codes

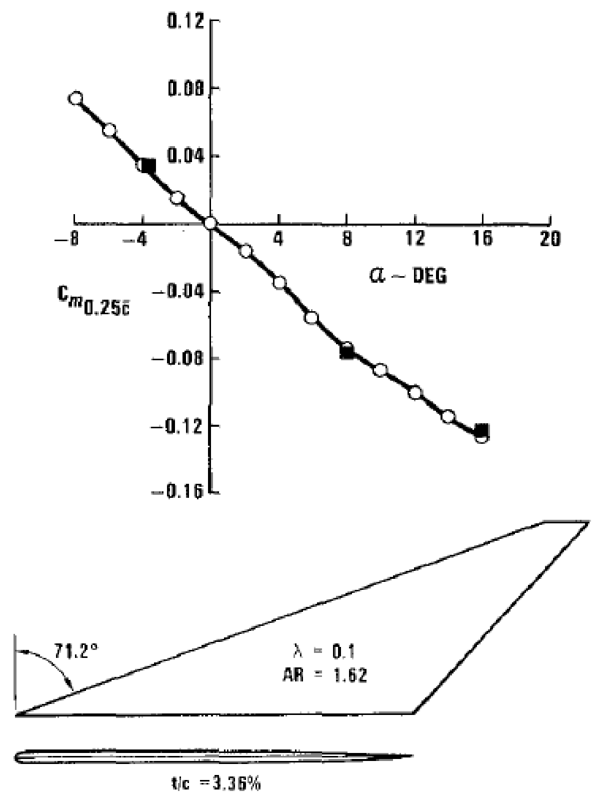
- **Eriksson and Rizzi (1981); Hitzel & Schmidt (1984); Murman & Rizzi (1986)**
  - Euler equation solutions on delta wing at 0.9 and 1.5 Mach numbers and α = 15º; free vortices captured automatically—*1981 IV GAMM Conference*
  - 1984: *Journal of Aircraft*, 21 (10); 1986: *AGARD Symposium*, Aux-Ed-Provence, France
- **Raj and Sikora (1984)—*Recent Encounters with an Euler Code** * (FLO-57GWB)**

Sharp-edged cropped delta wing (M = 0.6)



Arrow wing (M = 0.85)





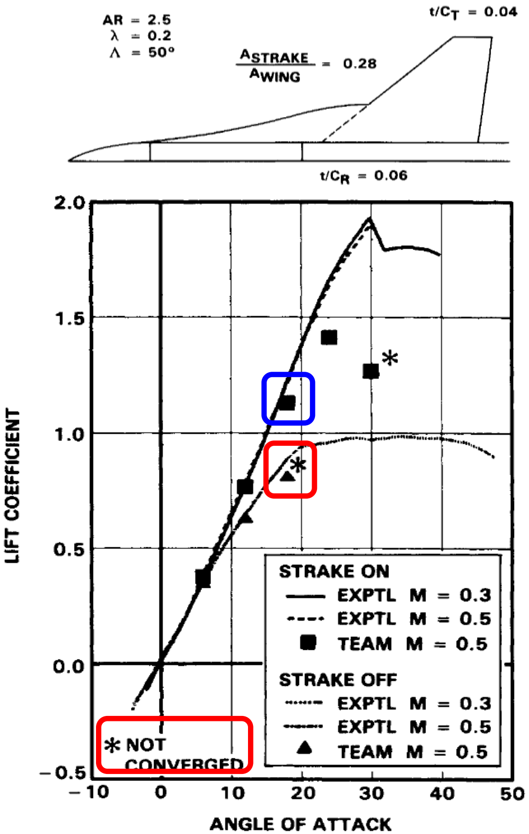
inspired by Steven Spielberg's <u>Close Encounters of the Third Kind</u>—a 1977 American SciFi classic—he wrote and directed

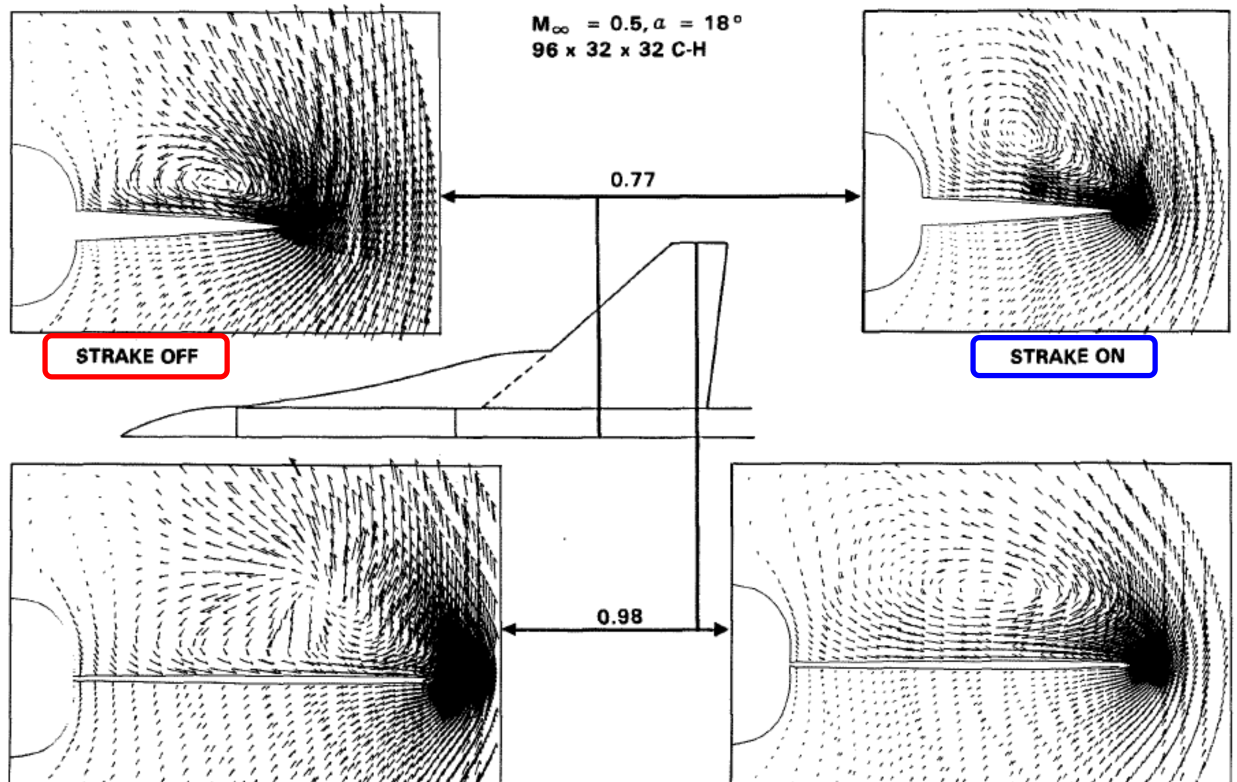
Source: Refs. 5.2.18 – 5.2.25

TEAM (Euler) Validation

Strake-Wing-Body Configuration – *Free-Vortex Flows*

- **Raj, Sikora and Keen (1986) -** ***ICAS 86-1.5.2***





"…generation of vortices about sharp-edged wings due to the total pressure losses is quite insensitive to the actual magnitude of numerical dissipation, *as long as there is some*."

Euler Codes More Effective Than The-then RANS Codes

Source: Refs. 5.2.21

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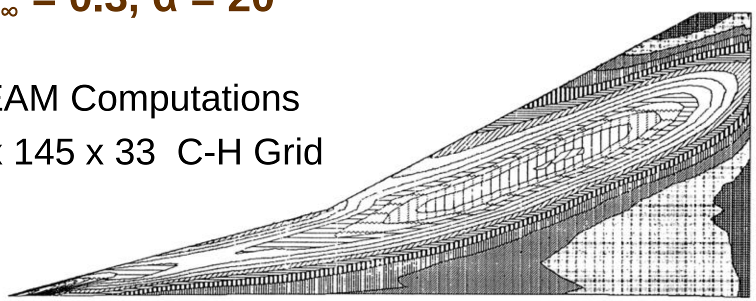
TEAM (Euler) Validation

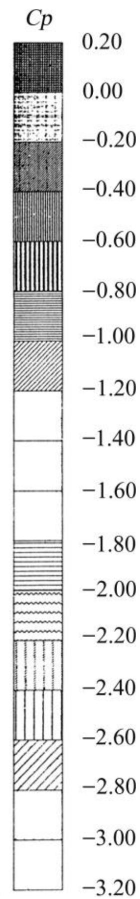
75º/62º Double-Delta Wing Body Configuration - *Free-Vortex Flows*

Raj, Keen, and Singer
AIAA paper 88-2517, 1988

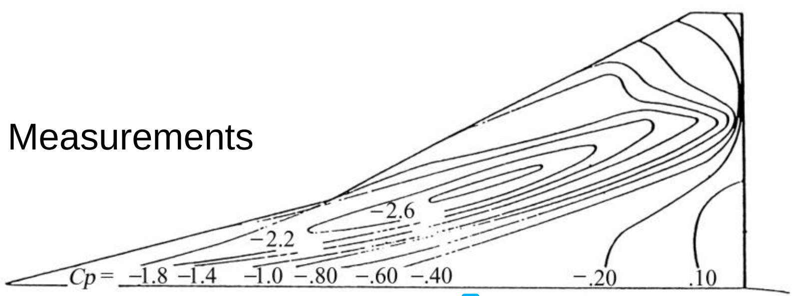
$M_\infty = 0.3$, $\alpha = 20^o$

TEAM Computations
49 x 145 x 33 C-H Grid





Measurements



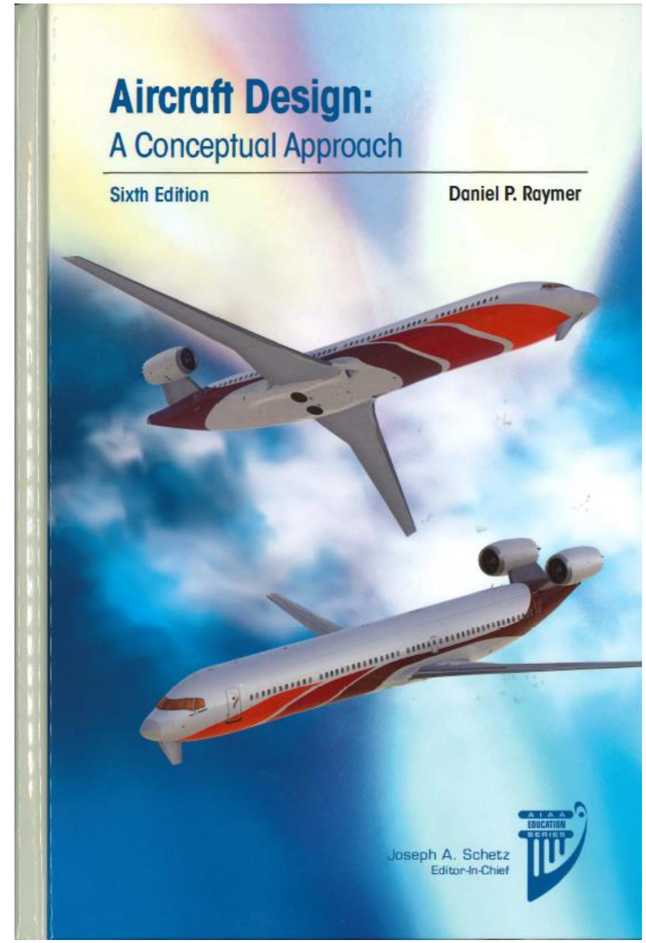


Fig. 12.42 (p 457)

"Recognition" by Aircraft Designer—Doesn't Get Better Than That!

Image Source: Ref. 5.2.23 and Internet

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TEAM Capabilities Evolution Summary

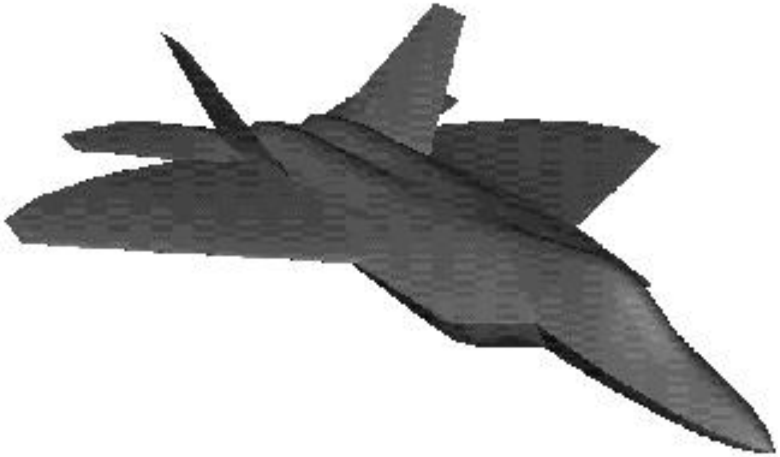
	Configuration Geometry	Grids	Free-stream Mach number	Flow Model
1984	• Wing • Wing-Body	• Single Zone (Block) • C-H, C-O, O-O topologies	Subsonic Transonic Supersonic	Inviscid (Euler)
1986	• Wing • Wing-Body • Wing-Body-Tail/Canard	• Single Zone (Block) • C-H, C-O, O-O • O-H, H-H topologies added	Subsonic Transonic Supersonic	Inviscid (Euler)
1988	• Wing • Wing-Body • Wing-Body-Tail/Canard • Full Aircraft with Inlet and Exhaust Systems	• Single Zone (Block) • Patched Multi-Zone (Multi-Block) • C-H, C-O, O-O, O-H, and H-H topologies	Subsonic Transonic Supersonic Hypersonic	• Inviscid (Euler) • Viscous (RANS with only Baldwin-Lomax turbulence model) • Equilibrium Real Gas

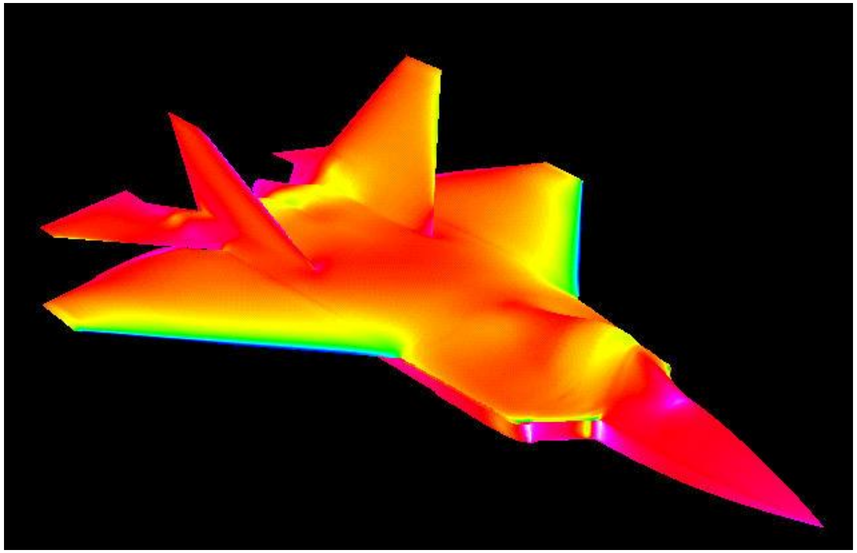
USAF/WRDC/Lockheed TEAM Code Offers Full Aircraft Aerodynamic Analysis Capability in 1988 for ATF Application (Inviscid Euler Much More Effective than Viscous RANS)

Source: Ref. 5.2.13

TEAM (Euler) Application

YF-22 Dem/Val Configuration (1988)





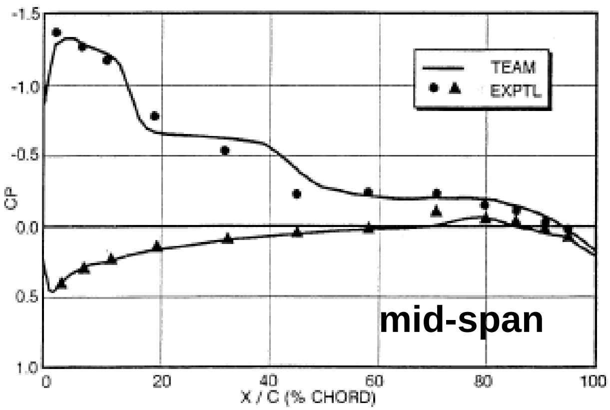
USAF/WRDC & Lockheed Investment Pays Off!

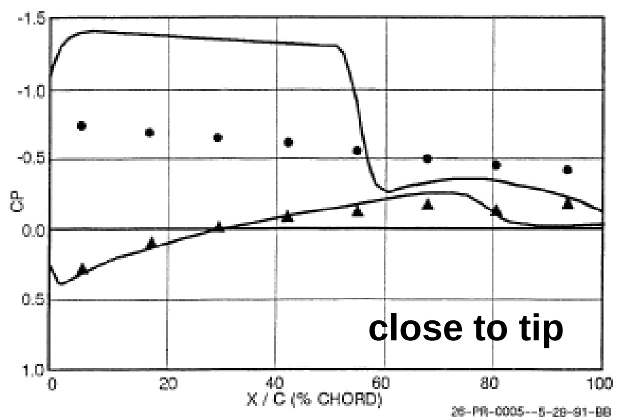
TEAM (Euler) Application: *YF-22 Dem/Val*

1988: Full-aircraft Analysis for Airloads Prediction (Reaser and Singer)

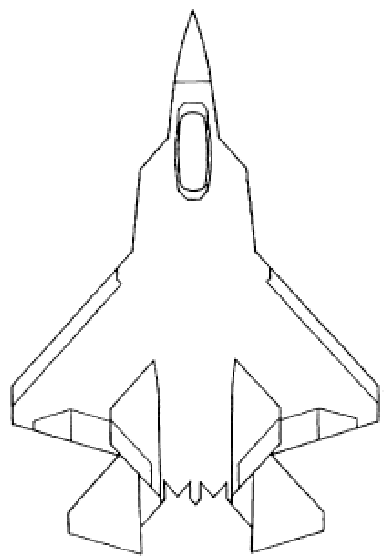
- Several transonic and supersonic Mach numbers
- Symmetric and asymmetric flight conditions
- Flow-through as well as powered nacelles

α = 8°





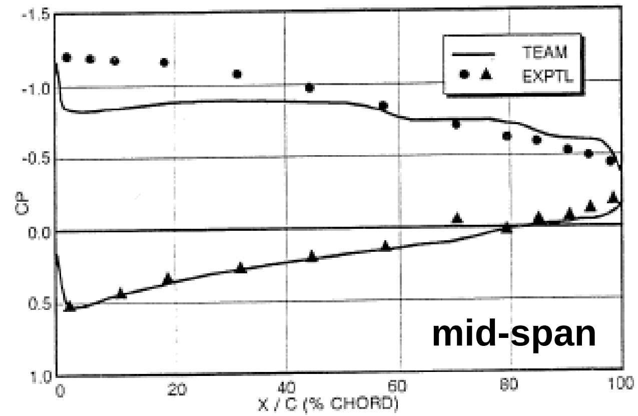
Transonic flow

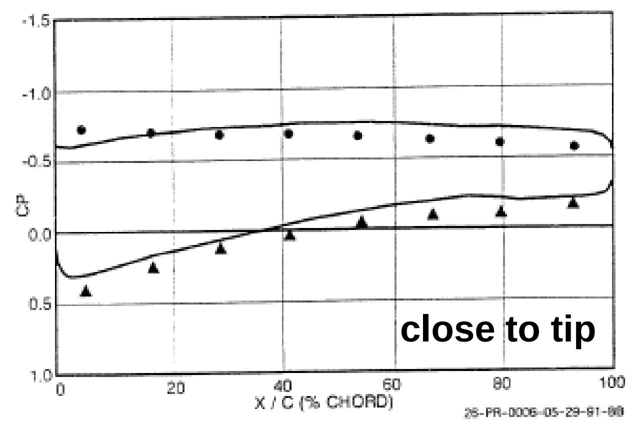


43-zone H-H grid

1.5 million grid points

α = 16°





TEAM results generated *before* wind-tunnel pressure model test

Code used in *predictive mode**; no grid adjustments made for 'better/improved' correlations!

**not necessarily by choice!!!*

Source: Ref. 5.2.26

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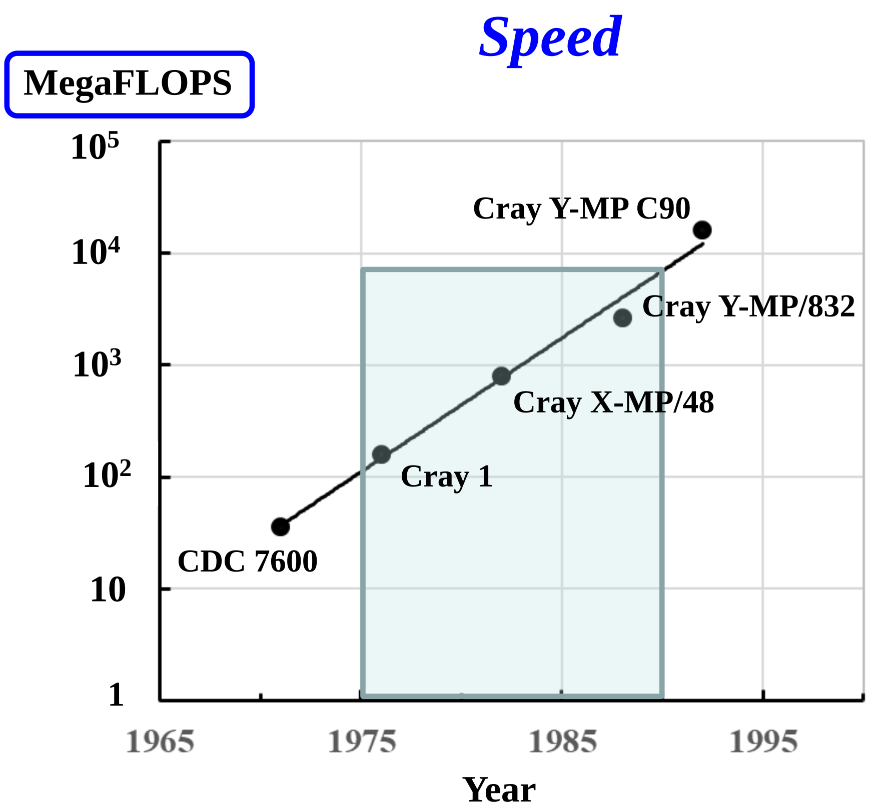
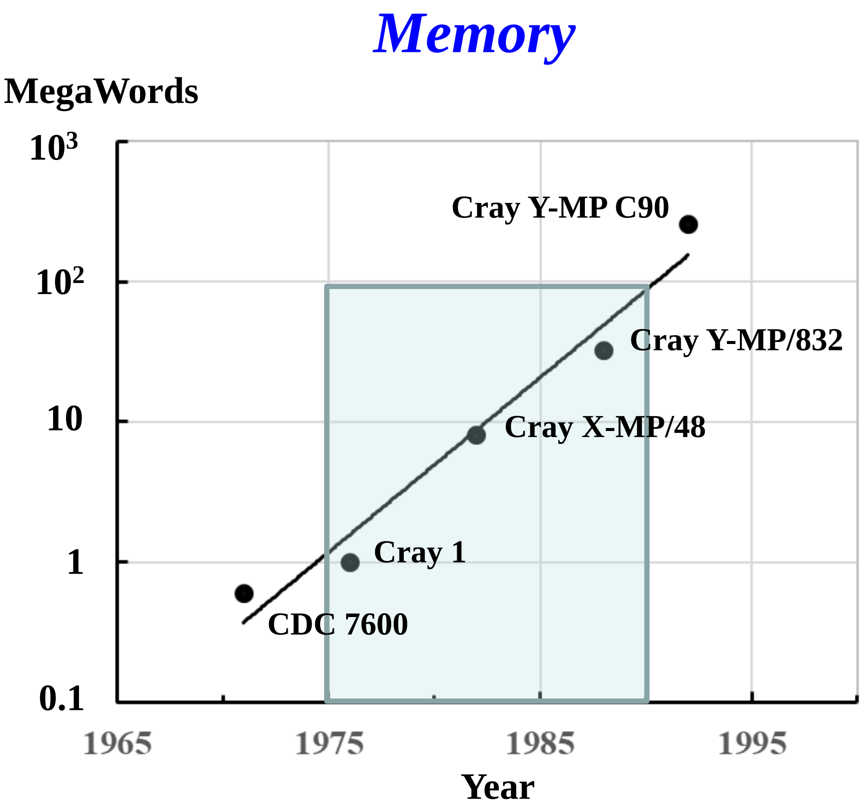
Computing Advances: *Key to Success*

1975-1990: More than 2 orders of magnitude improvement in speed and memory





TEAM Computational Speed

Cray Y-MP/832: 15 to 30 seconds per time step for a million cell grid

TEAM Computational Memory

Cray Y-MP/832: About 40 times the maximum number of grid cells

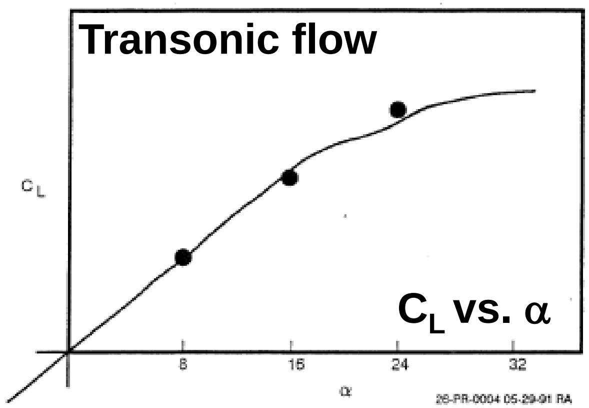
By 1990, Euler Solutions on Million-cell Grid in 6 to 8 Hours…But Weeks of Grid-Generation Time Hampers Effectiveness!

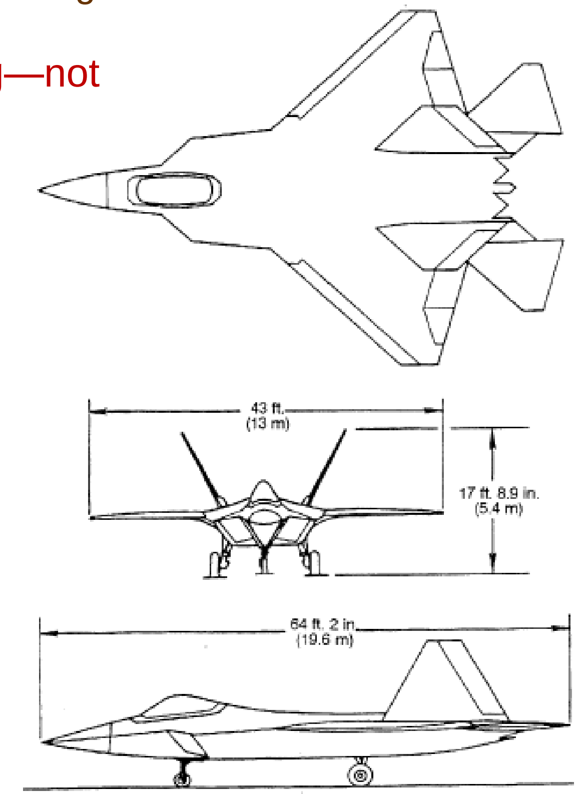
TEAM (Euler) Effectiveness *(1988-1989)*

Assessment Based on YF-22 Dem/Val Application

- ***(-) Long Turnaround Time:*** Tedious and time consuming grid generation
  - Two engineers spent ***few hundred man-hours*** over ***several weeks*** to build a **43-zone H-H topology hexahedral grid** with approximately **1.5 million nodes** for half the configuration
- ***(-) Only Inviscid Drag:*** Program personnel want total drag—not getting it is one of their key complaints

Lift reasonably well predicted for transonic flight conditions





- ***(+) Detailed Surface Pressures Useful:*** for structural design as well as thermodynamics groups
  - ***Structural Design group*** wants force, moment, and surface pressure increments due to control surface deflections

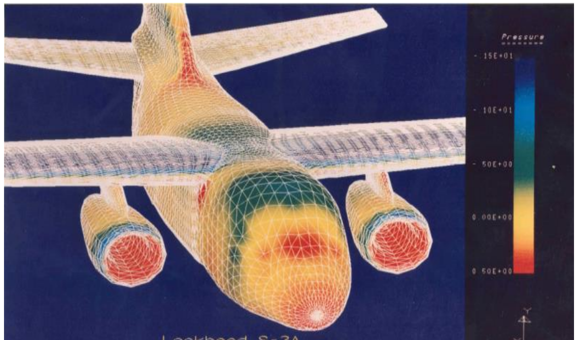
Challenge: ***Too Many Grids, Too Little Time!***

TEAM Run Times 'Reasonable', but Effectiveness Too Low to Meet the Needs of F-22 EMD that Lockheed Hoped to win in 1991

Efforts to Increase TEAM Effectiveness

1989 – 1991

- **Total (Absolute) Drag:** ***add viscous effects for increased realism***
  - Coupling with integral boundary-layer codes? *Not well suited for fighter analyses*
  - Extend TEAM by adding N-S viscous terms? *In-house TRANSAM efforts initiated in 1986*
- **Grid Generation:** ***make it faster and less labor-intensive***
  - **Multi-block hexahedral grids**
  - **Overlapping grids**
  - **Cartesian grids**
  - **Unstructured tetrahedral grids**
    - **AIRPLANE Code:** Lockheed procured unstructured tetrahedral grid Euler code in 1990 from Jameson's Intelligent Aerodynamics, Inc., Princeton, NJ



AIRPLANE Solution

Key Challenge:

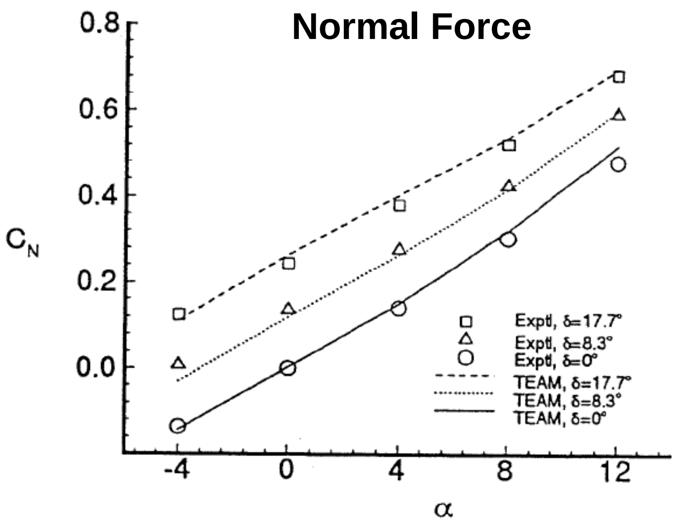
How to develop requisite level of competency and confidence in brand new methods in order to lower the risk enough by early 1991 for F-22 EMD applications?

In 1990, aerospace industry went into depression leading to (a) reduction in the number of qualified engineers, and (b) significant reductions in R&D funding!

- **Interim Path Forward: make maximum use of multi-zone structured grid—*once it's built*—since structured grid generation methodology was then the most mature**
  - *Use surface transpiration concept to "simulate" the effect of control surface deflection by appropriately changing the no-normal-flow surface boundary condition*

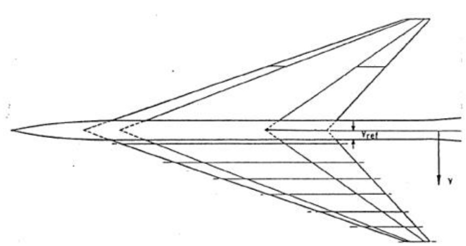
Innovative Approach to Estimating Incremental Loads Due to Control Surfaces

- **Customer's Problem:** Estimate incremental aerodynamic forces, moments, and surface pressures due to control surface deflections for multiple settings and flight conditions to support structural design
- **Solution:** Use *surface transpiration concept* to "simulate" the effect of control surface deflection by appropriately changing the no-normal-flow surface boundary condition
  - NO NEED TO CHANGE THE INITIAL GRID!
  - The concept—originally proposed by Lighthill—had enjoyed great success in simulating the effect of boundary layer on inviscid flow modeled using potential or Euler methods



M_∞ = 0.85

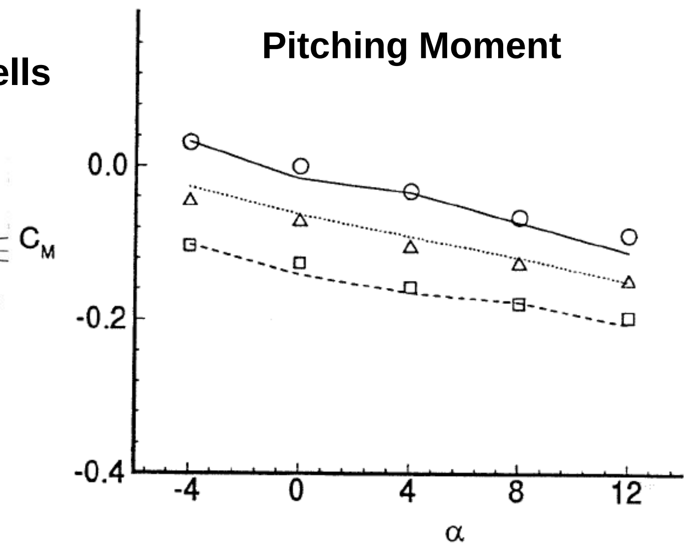
14-zone grid; ~235,000 cells



AR = 1.65

Λ = 71.2°

λ = 0.1



Solution developed and implemented in 1989-90; published in 1993, AIAA Paper 93-3506

Results Improved Confidence in Meeting Customer Needs

Source: Ref. 5.2.32

The Exciting Eighties!

- **April 12, 1981: Launch of the First Space Shuttle Mission**
  - Mission Commander **John Young** had already flown in space four times, including a walk on the Moon in 1972
  - **Bob Crippen**, the pilot, was a Navy test pilot who would go on to command three future shuttle missions
- **June 1981: USAF ATF Request for Information (RFI)**

- **September 26, 1981: Boeing 767 First Flight**
  - September 8, 1982: original 767-200 entered service with United Airlines
  - October 1986: 767-300 followed by 767-300ER in 1988

- **February 19, 1982: Boeing 757 First Flight**
  - January 1, 1983: original 757-200 entered service with Eastern Airlines
  - Compared with 707 and 727, it consumed approx. 40% less fuel per seat, on typical medium-haul flights

- **December 14, 1984: Grumman X-29 First Flight**
  - Experimental aircraft that tested forward-swept wing, canard control surfaces, and other novel technologies

- **September 1985: USAF ATF Request for Proposal (RFP)**
- **October 1986: Lockheed and Northrop Awarded 50-month Prototype Dem/Val Contracts**
  - First Flights: YF-22 (29 Sep 1990); YF-23 (27 Aug 1990)

- **February 22, 1987: Airbus 320 First Flight**
  - 18 April 1988: entered service with Air France

The Exciting Eighties (for the Author!)

Personal

1980

- **Granted US Permanent Resident status**
- **And…**

1981
1st son

1985
2nd son

1985
Naturalized US Citizen

Professional

- **AIAA & SAE**
  - AIAA ASM: St. Louis (1981), Reno (1983, 1984, 1987)
  - AIAA APA: Danvers (1983), Williamsburg (1988)
  - AIAA Euler Solvers Workshop: Monterey (1987)
  - SAE Aerospace Tech Conf. & Expo: Anaheim (1988)
  - Two AIAA Technical Committees: *Fluid Dynamics (1985-88)* and *Applied Aerodynamics (1988-91)*
- **ICAS* Congress**
  - Toulouse (1984), London (1986), Stockholm (1990)
- **3rd Intl. Congress of Fluid Mech., Egypt** (1990)
- **After-hours teaching** *(1985-1990)*
  - Lockheed Employee Edu. Pgm. (*Aerodynamics for Designers*)
  - UCLA Continuing Education (*Introduction to Aerodynamics*)
  - Lockheed Tech Institute (*Computational Fluid Dynamics*)
- ***Lockheed consolidation*** *(1987)*
  - ***Three companies into one: Lockheed Aeronautical Systems Company (LASC) headquartered in Burbank, California***
  - *Loss of CFD and ACA talent and expertise in Georgia*
- **Appointed *Comp Aero Technical Lead*** *(1989)*
  - Represented LASC on Corporate Task Force on Advanced Computing Methods (ACM)

*International Council of the Aeronautical Sciences

The Exciting Eighties (for the Free World)

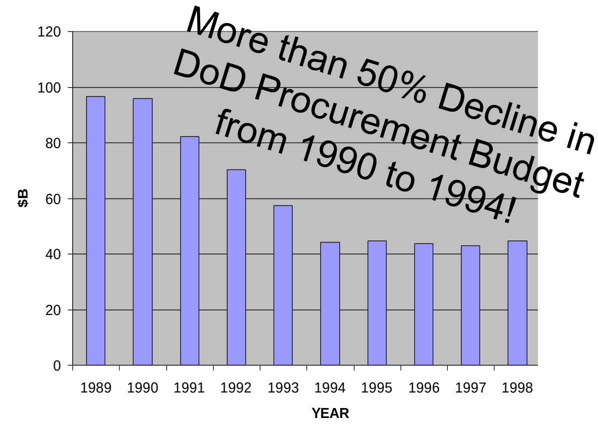
Final Collapse of the USSR & Emergence of the New World Order

A Pivotal Event in World History: November 9, 1989

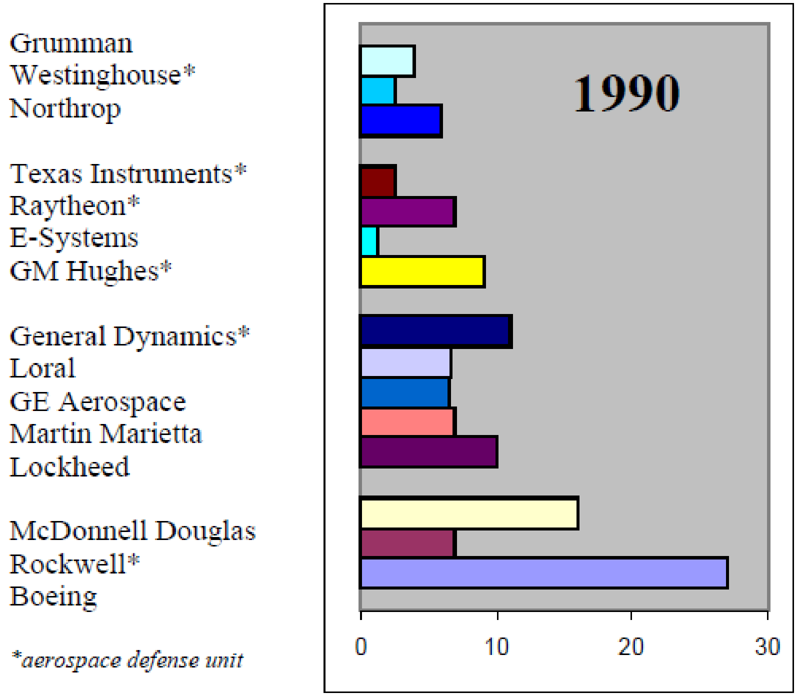
Fall of Berlin Wall Created New Geo-political Realities

The Nasty Nineties Followed the Exciting Eighties!

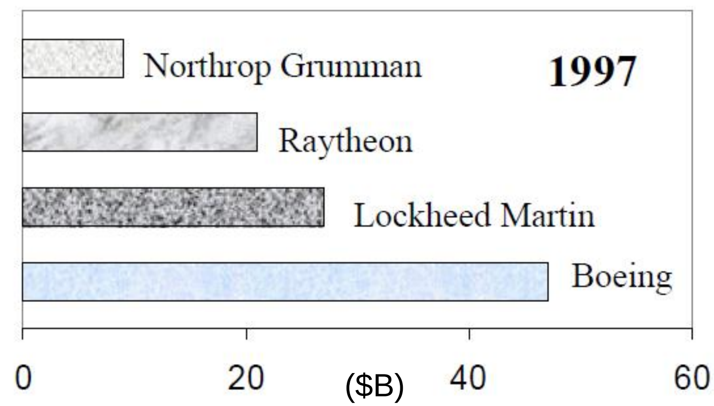
- **"Peace Dividend"—*Major Contributor to Depression in US Aerospace Industry***
  - Loss of 495,000 people (37% of workforce) in just five years (1990-1994)
  - Overall sales down 9% in 1994 after single-year 10% drop in 1993
  - Aerospace industry dramatically reduced R&D funding in response to DoD budget decline



- **Consolidations, Mergers, and Reorganizations—*To Reduce Capacity & Cost***
  - Dec 1992: *Lockheed acquires GD military aircraft division*
  - Mar 1995: *Lockheed and Martin Marietta formally merge*
  - Dec 1996: *Boeing and McDonnell Douglas announce merger*



(size of the bar represents sales volume)



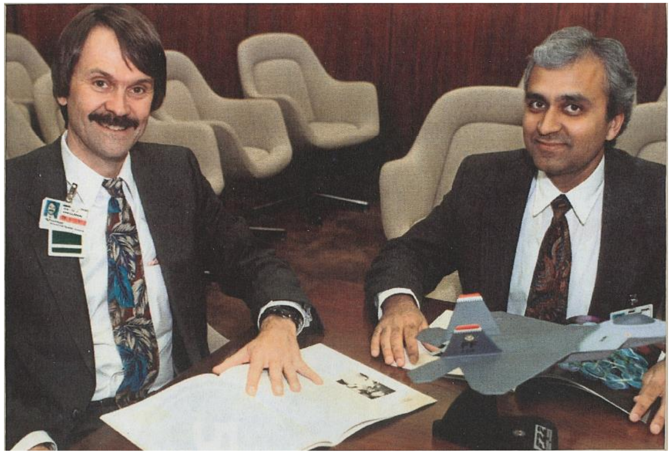
15 down to 4 in 7 years!

Source: Ref. 1.3

New Opportunities: *1990-91*

- **May 1990: Lockheed Reorganization—*one company into two!***
  - Decides to vacate Burbank—split operations between Palmdale and Marietta
    - Lockheed Advanced Development Company (LADC), Palmdale, California
    - Lockheed Aeronautical Systems Company (LASC), Marietta, Georgia
- **23 April 1991: *YF-22 is the winner!***
  - Secretary of the US Air Force Donald Rice announced Lockheed's **YF-22** as the **winner**
  - LASC to work the **F-22 Engineering and Manufacturing Development (EMD)** contract in Georgia
  - ***Raj relocates to Georgia in August 1991***

- **13 December 1991: *LASC selects two Technical Fellows in the inaugural year***
  - **Chellman (Structures)** & **Raj (CFD)**
  - Most Senior Rank in Technical Track
  - Increased Emphasis on Mentoring and Technical Leadership
  - **Key Challenge:** *Rebuild Capabilities in Georgia*



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Lecture 8: Key Takeaways

- **1985-1988: TEAM validation using many configurations and a range of flow conditions**
- **1988: TEAM (Euler) analysis of full YF-22 Dem/Val configuration**
- **1988-1989: Assessment of TEAM (Euler) Effectiveness based on YF-22 Dem/Val application**
  - **Grid Generation**: Tedious and time consuming
  - **Extensive Validation**: Limited value (***Lesson Learned: validation must be done for geometries and flow conditions that aren't substantially different from the intended application***)
  - **Total Drag**: Unable to predict using inviscid Euler code
  - **Surface Pressures**: Deemed useful for structural design…but increments for deflected control surfaces would be really useful
- **Many promising technologies to increase Effectiveness, but none mature enough to meet the anticipated needs of F-22 EMD effort in 1991**
  - **Interim Path Forward:** Make maximum use of the multi-zone grid for the baseline configuration—once it is built
- **1990: Innovative Approach to estimation of incremental loads due to control surface deflections for multiple settings**
  - **Surface transpiration concept** incorporated in TEAM to simulate control surface deflections

Lecture 8: Key Takeaways (contd.)

- **The Exciting Eighties**
  - Launch of the **1st Space Shuttle** *(April 12, 1981)*
  - USAF Advanced Tactical Fighter (**ATF**): *RFI (Jun 1981); RFP (Sep 1985); 50-month Dem/Val contract award to Lockheed and Northrop (Oct 1986)*
  - Boeing: ***767*** *first flight (Sept 26, 1981);* ***757*** *first flight (Feb 26, 1982)*
  - Grumman **X-29** First Flight *(Dec 14, 1984)*
  - Airbus **320** First Flight (Feb 22, 1987)
- **The Nasty Nineties**
  - "Peace Dividend" from the fall of the USSR contributed to US aerospace industry depression resulting in **mergers and consolidations*: 15 down to 4 in 7 years!***
- **1990-91: New Opportunities**
  - Lockheed reorganization—one company into two
  - Lockheed awarded F-22 EMD contract
  - Raj selected Tech Fellow

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Topic 5

5. Evolution of Applied Computational Aerodynamics *(1950-2000)*

5.2 Pursuit of Effectiveness (1980–2000)

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Topic 5.2 (contd.)

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