X-Vehicles Symposium/TGIR Conference

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X-36
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Tailless Fighter Agility Research Aircraft Program 1997
NASA Ames Research Center / Boeing Phantom Works

X-36 Tailless Fighter Agility Research Aircraft

28% Scale

Weights

Takeoff Weight	1,245 lb
Usable Fuel	162 lb
Thrust Class	700 lb
Density	28.3 lb/ft^3

Performance

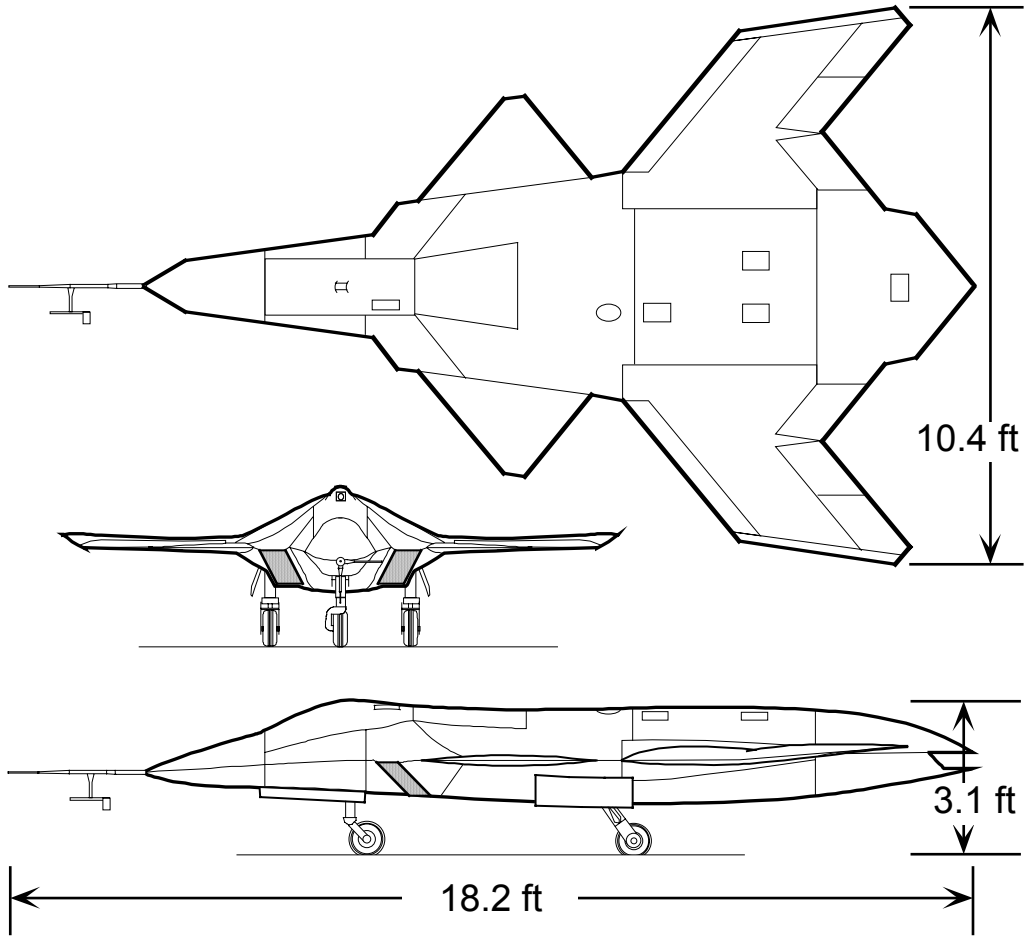
Mach Number	≤0.6
G Limit	5 g's
Landing Gear	14 fps
V Approach	112 KEAS
Max AOA	~40°

Stability Levels

C_{M_α}	+0.06 (Unstable)
C_{N_β}	-0.0015 (Unstable)

Materials

Skin - Carbon Epoxy and Aluminum
Bones - Machined Aluminum
Assembly - Mechanical Attachment
Nozzle - Cast Chem Mill Titanium



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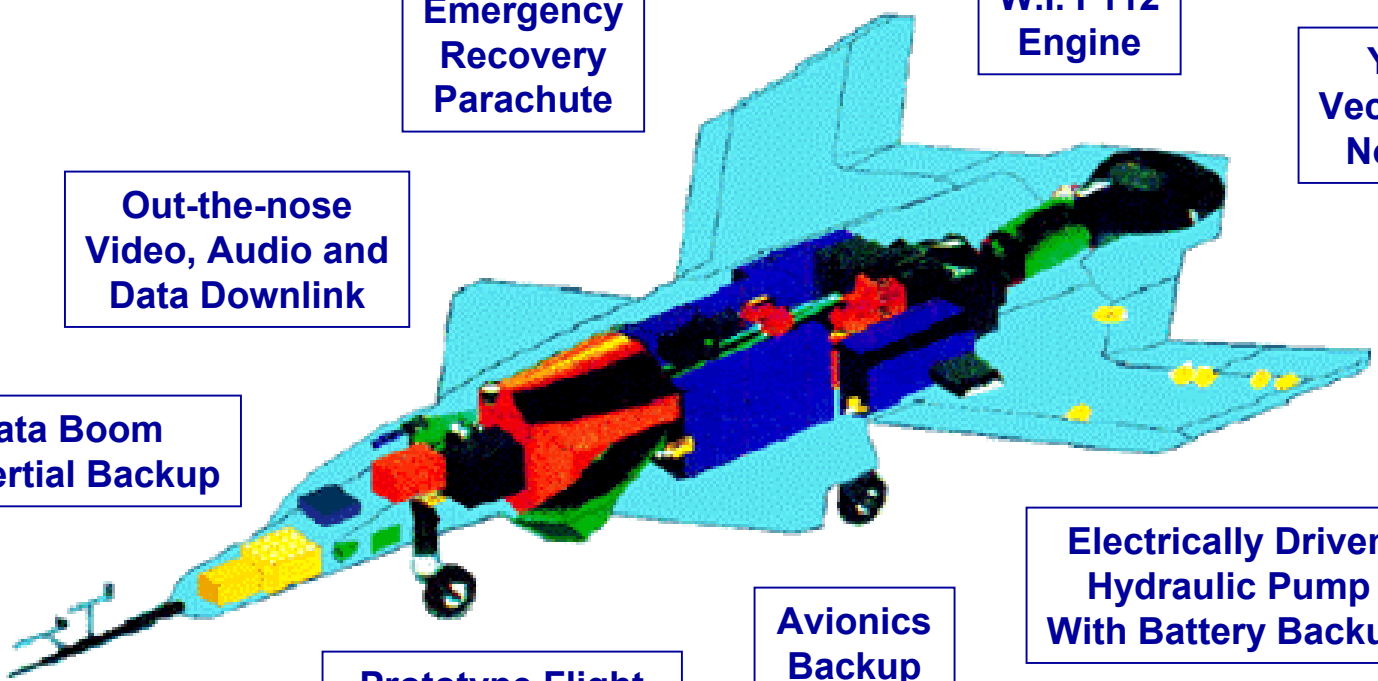
X-36 Features



14 fps Emergency Recovery Parachute

W.I. F112 Engine

Yaw Vectoring Nozzle

Out-the-nose Video, Audio and Data Downlink

High Bandwidth Hydraulic Actuators

Airdata Boom With Inertial Backup

Electrically Driven Hydraulic Pump With Battery Backup

Avionics Backup Batteries

Prototype Flight Control Computer With 100 Hz Frame Rate

Navigation Computer With IMU & GPS

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X-36 Video

X-36 Technology Evolution and Transfer

1989-93: Technology Definition And Maturation

- Tailless Fighter Requirements
- Tailless Aircraft Configurations
- Vectoring Nozzle Concepts
- Control Systems and Simulation
- Analysis and Testing

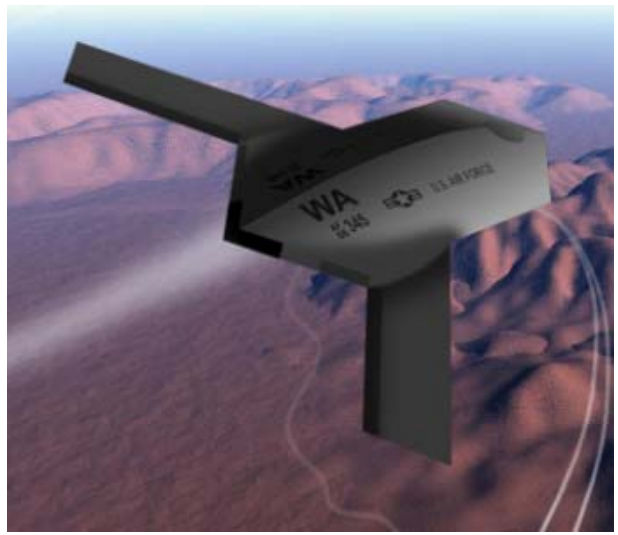
1994-95: Technology Application

- Subscale Demonstrator Development
  - CFD Design and Analysis
  - Wind Tunnel Testing
  - Nozzle Development/Testing
  - Aircraft Design and Fabrication

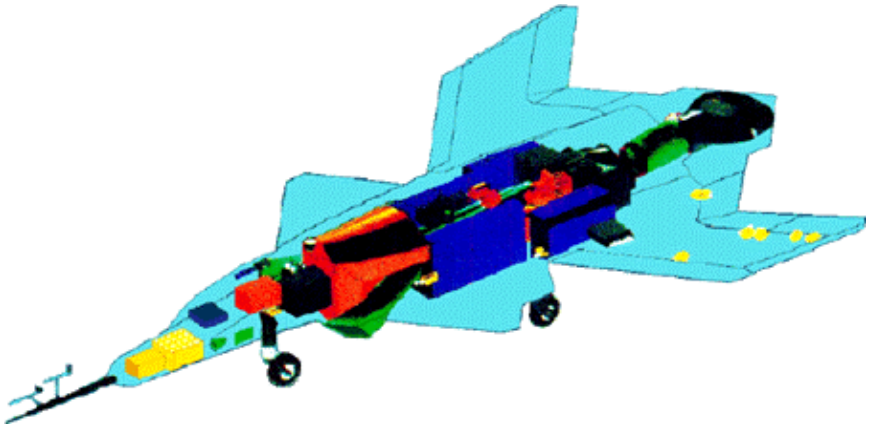
1996-97: Technology Demonstration

- X-36 Ground and Flight Testing

1998+: X-36 style vectoring nozzle used on X-45



X-36 Propulsion System



Thrust Vectoring Nozzle

- Rapid Vectoring Response
- Large Plume Movement
- Cast Ti Construction
- Airframe Mounted

W.I. F112 Cruise Missile Engine

- 700 lb Thrust Class
- Moderate BPR Turbofan
- Supplied as GFE

Bifurcated Diffuser

- Contracting Area
- Separation Free
- Designed With CFD

Side Mounted Inlets

- 2-D Shaping
- Subsonic Design Features

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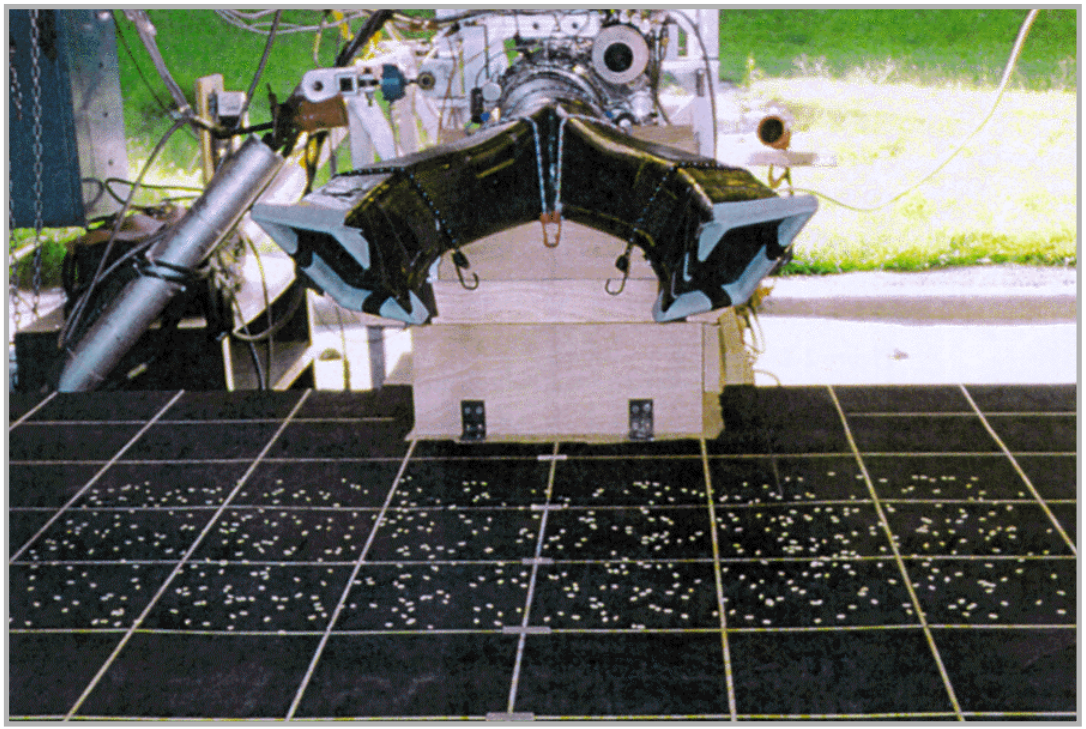
Inlet/Engine Test at Williams International



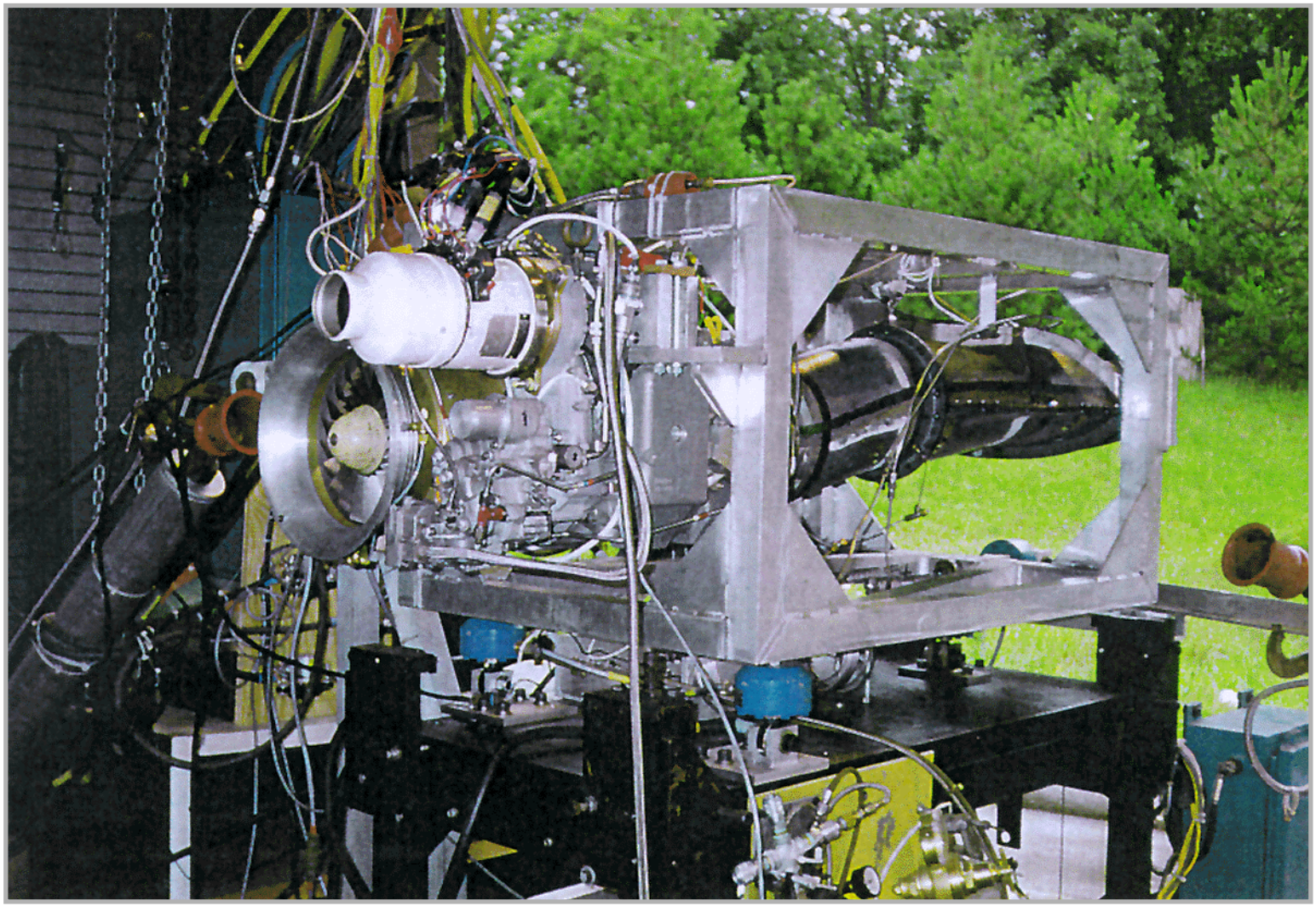
Test Summary

- Inlet and F112 Engine
- Ground Board to Simulate Ground Plane
- Rice Krispies™ on Ground Plane
- Full Power Operation
- Lip Ht. Above Ground = 15.9 in.

Conclusions

- Some Movement on Ground Board, But No Evidence of Ingestion
- Stable Engine Operation With the X-36 Inlet
- Low-Risk of FOD

X-36 Engine/Nozzle Test Set-Up at Williams International

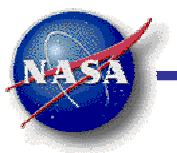


Remotely Piloted Vs Autonomous Flight?

- **Full pilot-in-the-loop remote operation**
  - Quickly notices differences from simulation
  - Rapid problem recognition
  - Response to unforeseen events
  - Flexibility during the flight operation

- **Fully autonomous operation**
  - Safe flight with certain system failures
  - Human error “eliminated”?

- **Hybrid approach of piloted flight with autonomous capability worked very well on the X-36 Program**



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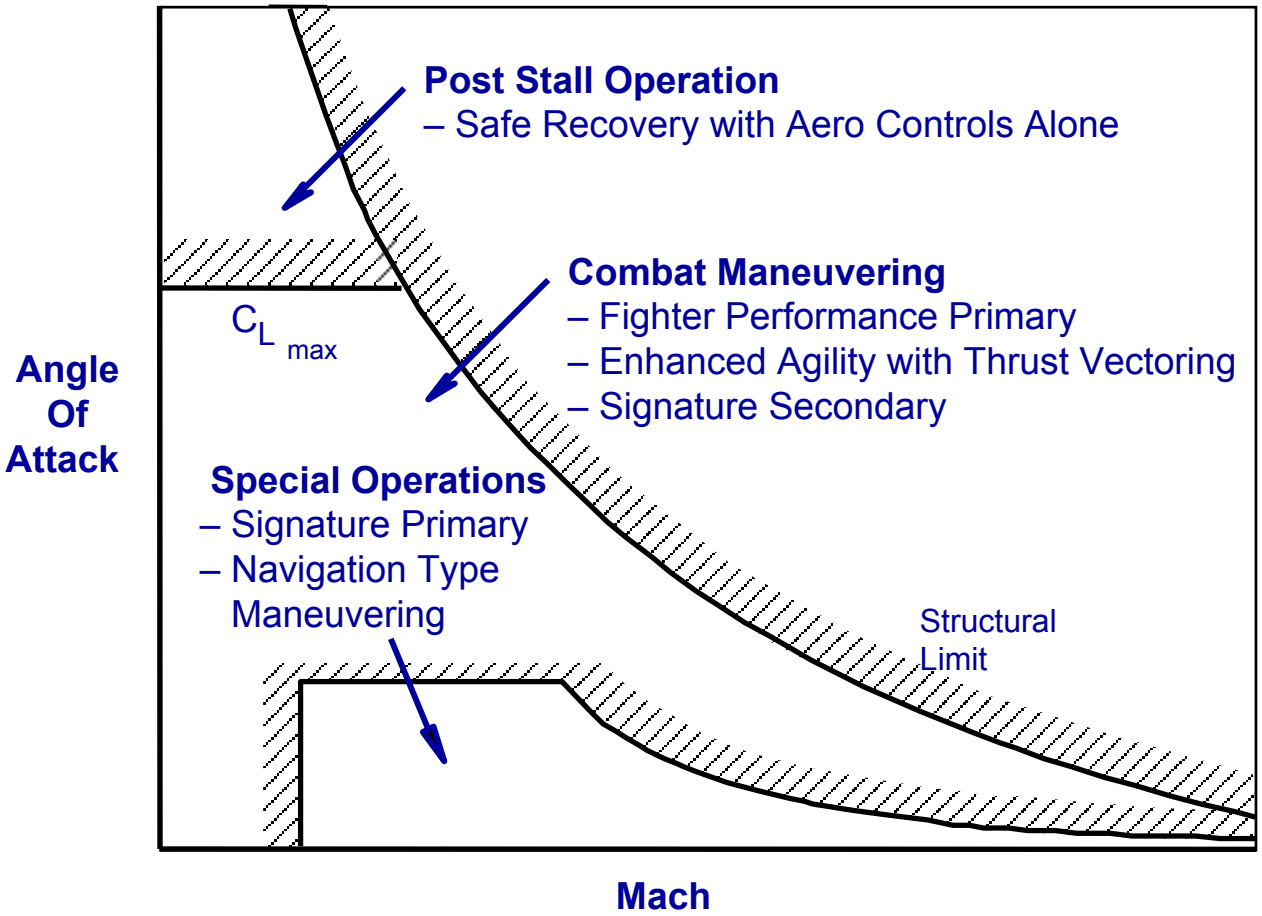
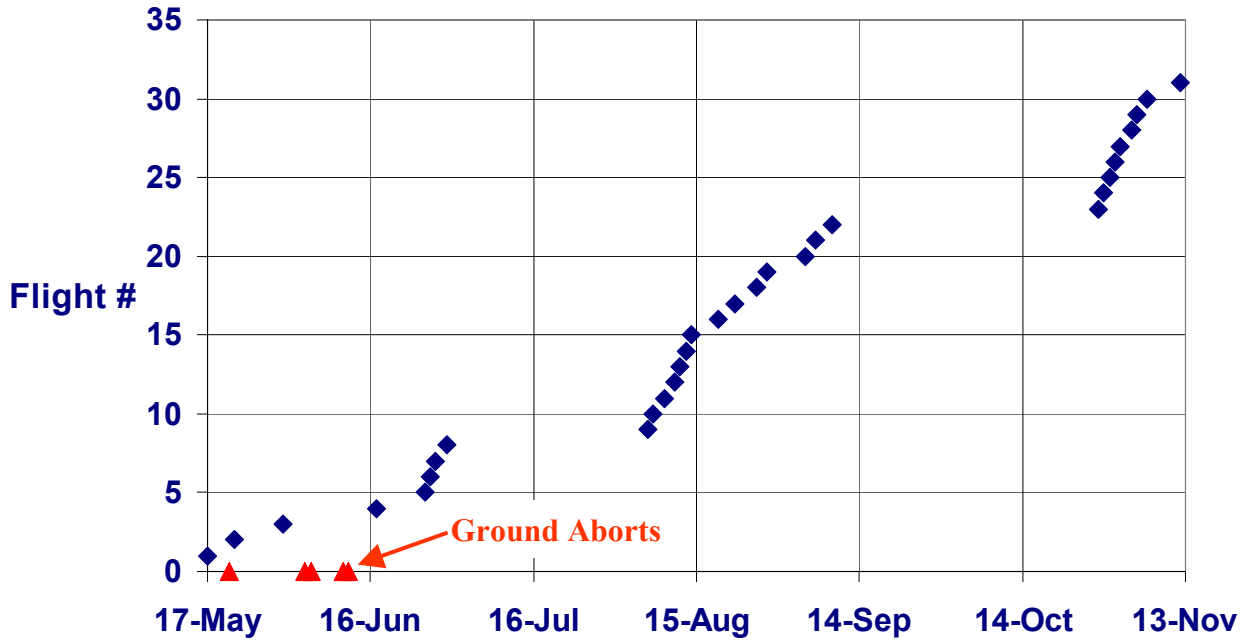
X-36 Flight Control Operational Philosophy



X-36 Flight Test Highlights

- 31 Flights from 17 May – 12 Nov 1997
- 20,200 ft MSL max altitude
- 15 Hr 38 Min flight time
- 4.8g max
- 3 – 40 deg AOA
- 52 – 206 KEAS
- 3 pilots



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Technical Challenges

Datalink System

- Poor aircraft antenna coverage
- Multipath telemetry interference
- Datalink drops - Flights #2 - 4

Subsystems

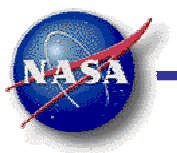
- Landing gear retraction difficulties
- High nozzle bay temps - Flight #1
- Fuel tank blockages

Propulsion System

- Unreliable engine ignition
- Engine fan overspeed
- Engine compressor stalls

Flight Control System

- Structural Mode Interactions
- Undesired longitudinal commands



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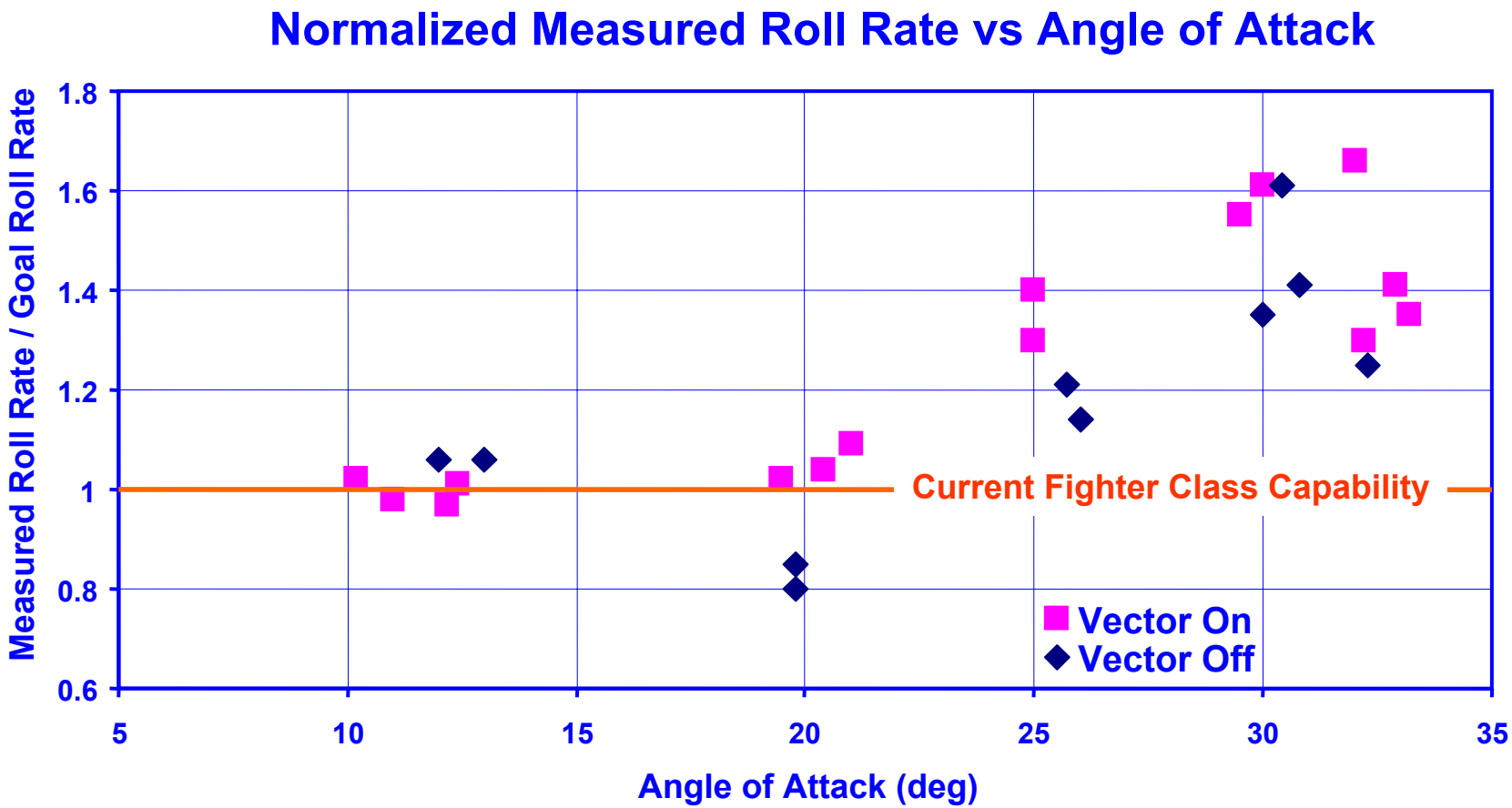
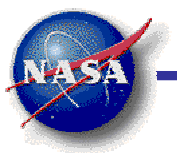

Normalized Measured Roll Rate vs Angle of Attack
Measured Roll Rate / Goal Roll Rate
1.8
1.6
1.4
1.2
1
0.8
0.6
5
10
15
20
25
30
35
Angle of Attack (deg)
Current Fighter Class Capability
Vector On
Vector Off

Significance of Test Results

- Fighter-class agility is possible without vertical tails
- The thrust vectoring nozzle is a breakthrough technology
- Subscale, remotely-piloted aircraft can be effectively used as technology demonstrators



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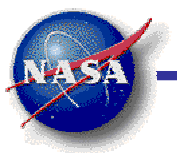
Keys to Our Success

- Mature technology base
- Integrated NASA / Boeing team & cost shared program
- Select, co-located team with personnel continuity
- Limited program visibility & no micro-management
- Rapid software turnaround and a high fidelity simulation
- Designed, built, and operated like a real aircraft
- Remotely piloted flight with autonomous capability



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