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/ft³

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

Stability Levels
$C_{M\alpha}$ +0.06 (Unstable)
$C_{N\beta}$ -0.0015 (Unstable)

Materials
Skin - Carbon Epoxy and Aluminum
Bones - Machined Aluminum
Assembly - Mechanical Attachment
Nozzle - Cast Chem Mill Titanium
X-36 Features

- Yaw Vectoring Nozzle
- W.I. F112 Engine
- 14 fps Emergency Recovery Parachute
- Out-the-nose Video, Audio and Data Downlink
- Airdata Boom With Inertial Backup
- Navigation Computer With IMU & GPS
- Prototype Flight Control Computer With 100 Hz Frame Rate
- Electrically Driven Hydraulic Pump With Battery Backup
- Avionics Backup Batteries
- High Bandwidth Hydraulic Actuators
- Emergency Recovery Parachute

NASA

Boeing
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
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
X-36 Flight Control Operational Philosophy

Post Stall Operation
- Safe Recovery with Aero Controls Alone

Combat Maneuvering
- Fighter Performance Primary
- Enhanced Agility with Thrust Vectoring
- Signature Secondary

Special Operations
- Signature Primary
- Navigation Type

Structural Limit

Mach

Angle Of Attack

$C_L_{\text{max}}$
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
Technical Challenges

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

**Propulsion System**
- Unreliable engine ignition
- Engine fan overspeed
- Engine compressor stalls

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

**Flight Control System**
- Structural Mode Interactions
- Undesired longitudinal commands
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
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