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The F-15 Forebody Vortex Control (FVC) Program was initiated to improve the high angle of attack controllability of the F-15. The F-15 has more-than-adequate nose-down recovery margin, however it would be desirable to increase the yaw control available at high angles of attack in order to improve departure resistance as well as maneuverability.

The goal of the program is to develop a production FVC system for the F-15. The system may consist of either a mechanically actuated device such as the strakes developed for the HARV program, or a pneumatic device such as the port blowing system tested on the X-29. Both types of systems are being evaluated under this program.

F-15 FOREBODY VORTEX CONTROLS

Integration of a Mechanical Forebody Vortex Control System Into the F-15

by

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Background information on the F-15 aircraft will be presented, followed by a description and overview of forebody vortex controls (FVC) technology. Then the status and future plans of the F-15 Forebody Vortex Controls Program will be discussed.

Discussion Overview

F-15 FOREBODY VORTEX CONTROLS

- Background
- Results of Phase I: Concept Exploration Study
- Results of Phase II: Concept Validation Study
- Status of Phase III: FVC Integration Study
- Future Plans

The F-15 flight control system consists of a mechanically controlled, hydraulic surface actuation system, supplemented by a high authority Control Augmentation System (CAS) which is implemented through the Flight Control Computer (FCC). The CAS is the primary means for implementation of flight control changes in the F-15. Early models of the F-15 utilized an analog FCC, whereas the F-15E has a digital FCC which is more adaptable to flight control changes.

Outer mold lines are similar for all F-15 models, with the major exception of the canopy. The A and C models have a single place canopy, and the B, D, and E models have a two place canopy. The models also have somewhat different main landing gear bumps, as well as different protuberances.

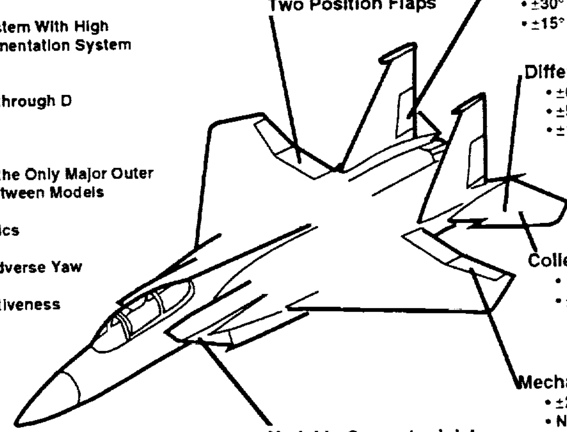
High angle of attack characteristics of the F-15 are similar to many other aircraft. At high angles of attack, the ailerons tend to produce adverse yawing moment. For the F-15, the adverse yawing moment makes it necessary to wash-out the aileron authority at high angles of attack. The rudders also lose effectiveness at high angles of attack due to tail blanking by the wing and fuselage.

A Short Course on the F-15

F-15 FOREBODY VORTEX CONTROLS

Main Features

- Mechanical Control System With High Authority Control Augmentation System (CAS)
- Analog FCC on F-15 A through D
- Digital FCC on F-15E
- Canopy and CFT's are the Only Major Outer Mold Line Changes Between Models
- High AOA Characteristics
  - Ailerons Produce Adverse Yaw
  - Rudders Lose Effectiveness



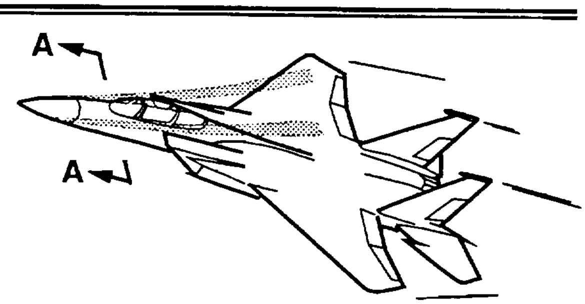
More Control Power Is Desired At High AOA

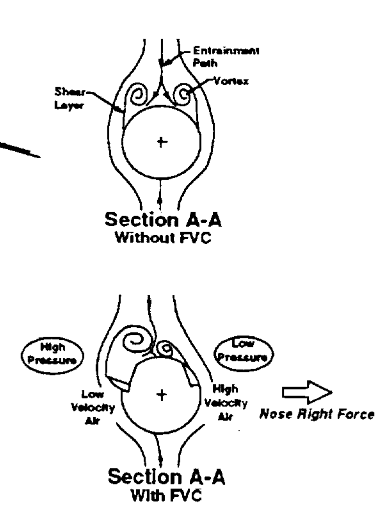
The aerodynamic benefits of forebody vortex control have been demonstrated under the HARV and X-29 programs, as well as many other studies. For vehicles such as the X-29, F-18, and F-15, forebody vortex controls produce primarily yaw control.

At high angles of attack, the tail surfaces are blanked by the wing and fuselage resulting in reduced stability and control. In contrast, the forebody flow field remains in a highly energized flow field throughout the angle of attack range, making forebody vortex control an attractive option.

Forebody vortex control utilizes small perturbations which modify the shear layer separation point and restructure the forebody vortex system. The perturbations may be accomplished through either a mechanical or pneumatic device, but the magnitude of the perturbation required to produce a given force increases rapidly as the perturbation is positioned at greater distances from the nose. Forebody vortex control has also been found to be controllable which means that the magnitude of the resulting force is proportional to the magnitude of the perturbation.

FVC Improves Hi-α Departure Resistance and Maneuverability





- Forebody Flow Field Remains Highly Energized at High Angles of Attack
- Forces Are Controlled By Manipulating Shear Layer Separation Point
- Perturbations Can Be Relatively Small . . . Perturbation Requirements Increase Aft of Nose
- Resulting Force Is Proportional to the Size of Perturbation (ie. Forces are Controllable)
- Forebody Vortex Control Can Be Accomplished Either Mechanically or Pneumatically

F-15 FOREBODY VORTEX CONTROLS

The first phase in the FVC development program for the F-15 was to determine whether FVC would improve flying qualities and could be implemented without a substantial modification to the airframe. The results of a maneuverability analysis showed that FVC can provide a substantial improvement in maneuverability and controllability. A concept layout also demonstrated the feasibility of various mechanical FVC concepts.

During Phase I, the assumption was made that the yawing moments produced by FVC on the F-15 will be similar to those produced by FVC on the HARV aircraft. The goal of Phase II was therefore, to verify the validity of this assumption. A good correlation resulted and proved that the F-15 flow field is conducive to FVC.

FVC can be accomplished through either a pneumatic or a mechanical system. Within these categories, candidate concepts include port blowing, slot blowing, actuated conformal strakes, sliding strakes, rotatable nose cones, or rotatable radomes. The objective of Phase III is to determine which concept is best for the F-15. After the best concept is selected, the next task is to perform a cost benefit study, to determine if FVC makes sense for the F-15.

After passing these critical tests, the next step is to develop and flight test a production FVC system.

F-15 FVC Program Was Designed to Answer Six Important Questions

F-15 FOREBODY VORTEX CONTROLS

1) *Will FVC Significantly Improve Flying Qualities? . . . . Yes!*
   - PHASE I: Concept Exploration Study
     - Literature Search, Maneuverability Enhancement Study, and Simulation

2) *Can It Be Done Without A Major Re-build? . . . . Yes!*
   - PHASE I: Concept Exploration Study
     - Concept Layout

3) *Is The F-15 Forebody Flow Field Conducive to FVC? . . . . Yes!*
   - PHASE II: Concept Validation Study
     - MDA Low Speed Wind Tunnel Testing

4) *What's The Best FVC Technique for the F-15? . . . . TBD 1994!*
   - PHASE III: FVC Integration Study
     - Aero Optimization, Trade Study

5) *Is FVC a Good Value for the F-15 Program? . . . . TBD 1994!*
   - PHASE III: FVC Integration Study
     - Manned Simulation, Cost/Benefit Analysis

6) *How Do We Put It Into Operational Use? . . . . TBD 1995!*
   - PHASE IV: Flight Test Program
     - Detailed Design and Fabrication, Flight Test

To develop FVC for the F-15, a team was assembled which combines the expertise and resources of highly experienced organizations. At the present time Wright Laboratories is the only organization which has flight tested FVC. Wright Labs also has experience from the STOL Demo and MUSIC programs and are highly knowledgeable of pneumatic FVC technology.

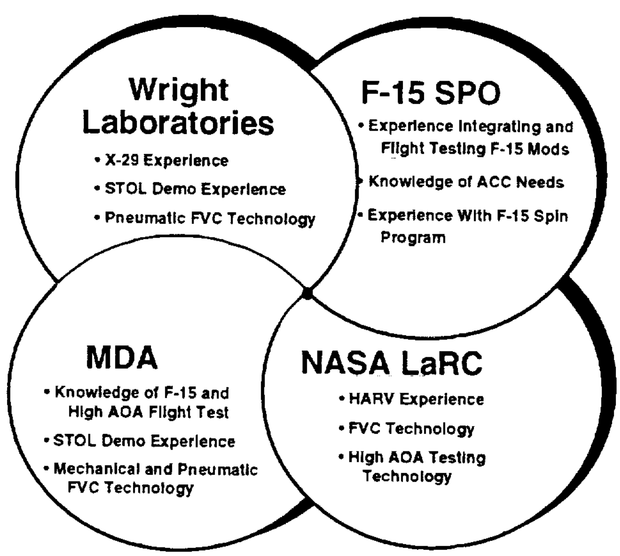
The F-15 System Program Office (SPO) is a critical link for the team, providing insight into the needs of the Air Combat Command (ACC) which is the primary user of F-15's. The F-15 SPO is also an experienced manager of F-15 modifications and is currently managing an F-15 high angle of attack flight test program.

NASA LaRC has gained considerable experience with FVC and high angle of attack technology through the HARV program. NASA LaRC is also an excellent source of high angle of attack testing technology.

MDA brings to the team an unparalleled knowledge of the F-15 system. MDA has experience from the STOL Demo and MUSIC programs, as well as production integration of high angle of attack control systems. MDA also has several years of both pneumatic and mechanical FVC research experience.

Teaming Adds Synergy to FVC Development Program

F-15 FOREBODY VORTEX CONTROLS



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Phase I: Concept Exploration Study

- Results Summary -

Will FVC Significantly Improve Flying Qualities?
Can It Be Done Without A Major Re-build?

- Concept Layout
- VECTOR Maneuverability Analysis

The High Strake concept offers a relatively simple structural integration challenge. These strakes will mount conformally on the top of the nose barrel with no impact upon radar performance. Actuators and other hardware will mount inside of a ballast bay, and minimal structural redesign is required.

The main drawback to the High Strake concept is the impact upon pilot visibility. In order to achieve the desired aerodynamic performance, the strakes must be made relatively large compared to a strake mounted closer to the tip of the radome. Concerns over blanking of critical visibility sectors are being investigated

High Strakes Offer Relatively Simple Structural Integration

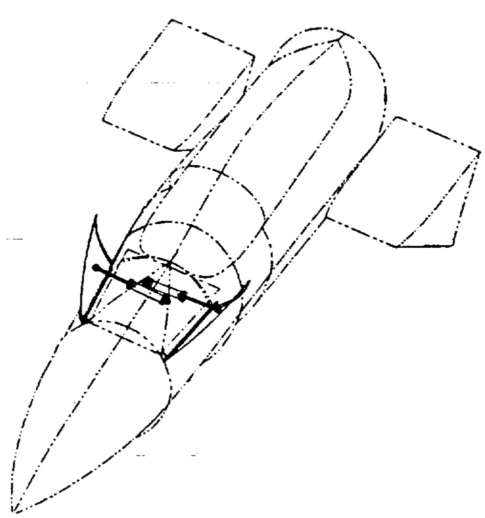
F-15 FOREBODY VORTEX CONTROLS

Pros:

- Structural Attachment on Current Load Path
- Actuators/Systems Inside Ballast Bay
- Same Access to Avionics Suite

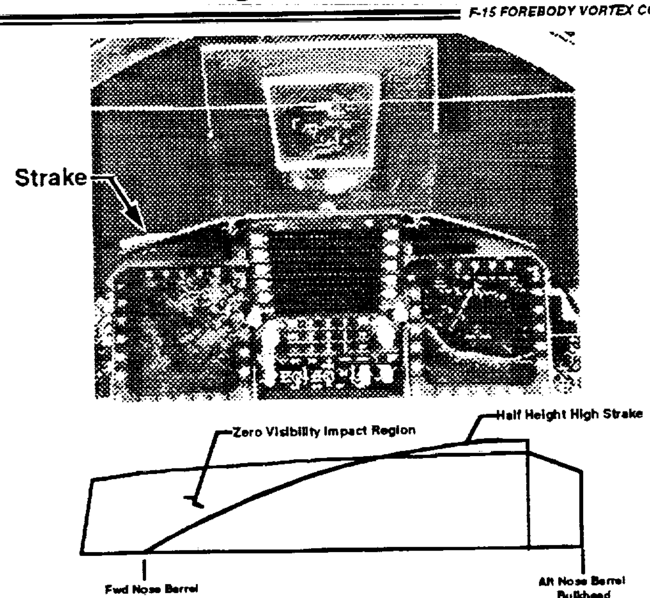
Cons:

- Visibility Impact?



To address the visibility concerns with the high strake concept, several analysis methods are being used. To gain an early look at the visibility impact of the High Strake concept, mock-ups were used to gather pilot comments. Based upon these studies, the strake shape was redesigned to minimize the intrusion of the strake into the pilot's visibility region. Later in the program, flight simulation will be used to help address the visibility concerns.

Visibility Impact Will Be Considered During Strake Testing



The Rotatable Radome is the second mechanical FVC concept being evaluated. It promises greater aerodynamic performance relative to the High Strake concept and will have a minimal structural impact. A remove and replace installation is expected, with only minor avionics repositioning required.

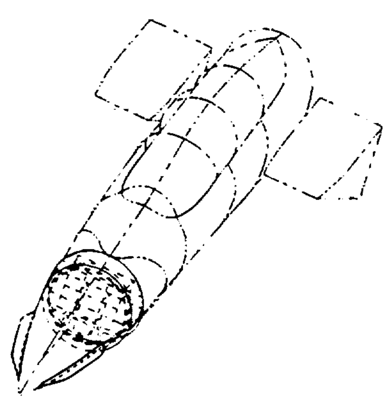
The greatest concern with this concept is radar performance and system complexity. The inclusion of fixed strakes on the radome is expected to present a considerable radar design challenge. Additionally, the mechanism to actuate the system is expected to be complex and could have a significant impact upon reliability and maintainability.

Rotatable Radome Offers Unique Control Opportunities

F-15 FOREBODY VORTEX CONTROLS

Pros:

- *Strake Can Be Small*
- Improved Low AOA Directional Stability
- Remove and Replace Radome Installation
- Minimal Changes to Airframe Structure and Systems
- Minimal Effect on Avionics Access



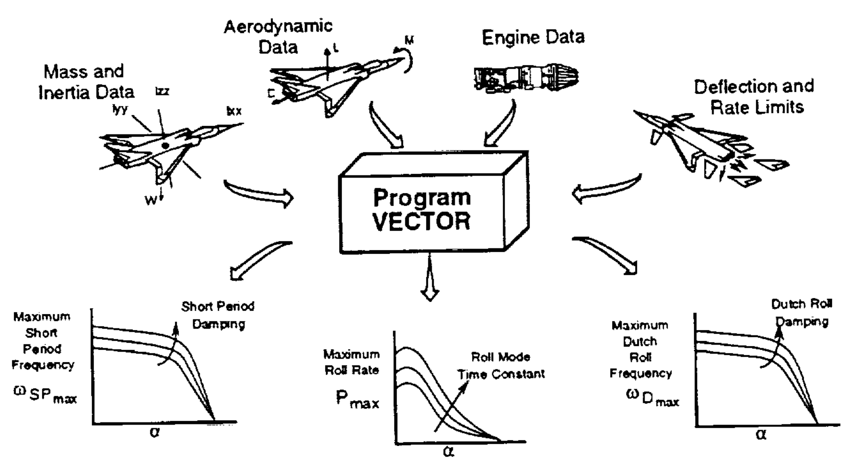
Cons:

- *System Complexity*
- Radar Performance Impact
- Actuation Rates?

For an early look at performance improvements, the computer program VECTOR was used to determine the maximum achievable dynamics for the F-15 with FVC. VECTOR requires aerodynamic, propulsion, mass and inertia, and actuator data, and returns the maximum achievable aircraft dynamics. In short, the program outputs the capabilities of an aircraft assuming that the aircraft has a "perfect" flight control system.

Program VECTOR Was Used To Gage Maneuverability Improvements

MDA's Program VECTOR Quickly Determines Maximum Achievable Dynamics Across the Flight Envelope

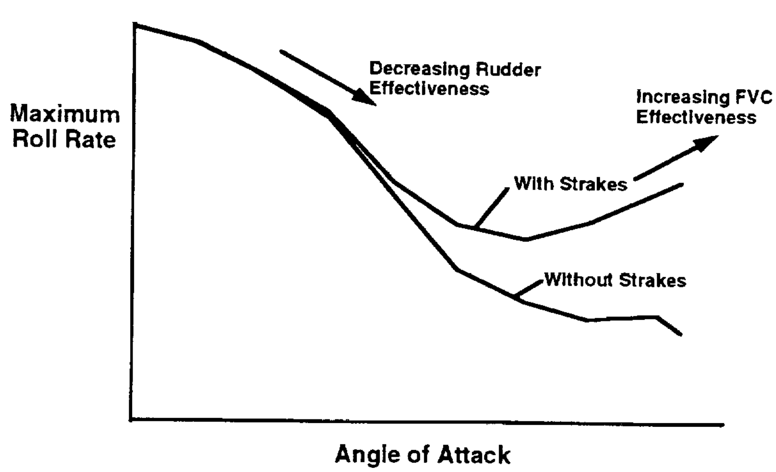


Wind tunnel data for FVC on the F-15 was not available for this early study, requiring the FVC control powers to be estimated. The F-18 HARV FVC database formed the basis of the estimates which was later found to provide an excellent representation of the F-15 FVC characteristics.

Maximum roll rate was found to be significantly improved by FVC. For the baseline aircraft, as with most conventional aircraft, the attainable roll rate drops as angle of attack increases. With FVC, at low angles of attack the roll rate still drops as angle of attack is increased, but as FVC gains effectiveness, the roll rate begins to increase dramatically. The increased yaw control from FVC not only improves roll performance, but will substantially improve departure resistance.

VECTOR Predicts Substantial Roll Rate Improvement At High AOA

F-15 FOREBODY VORTEX CONTROLS



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F-15 FOREBODY VORTEX CONTROLS

Phase II: Concept Validation Study

- Results Summary -

Is The F-15 Forebody Flow Field Conducive to FVC?

- MDA Low Speed Wind Tunnel Test

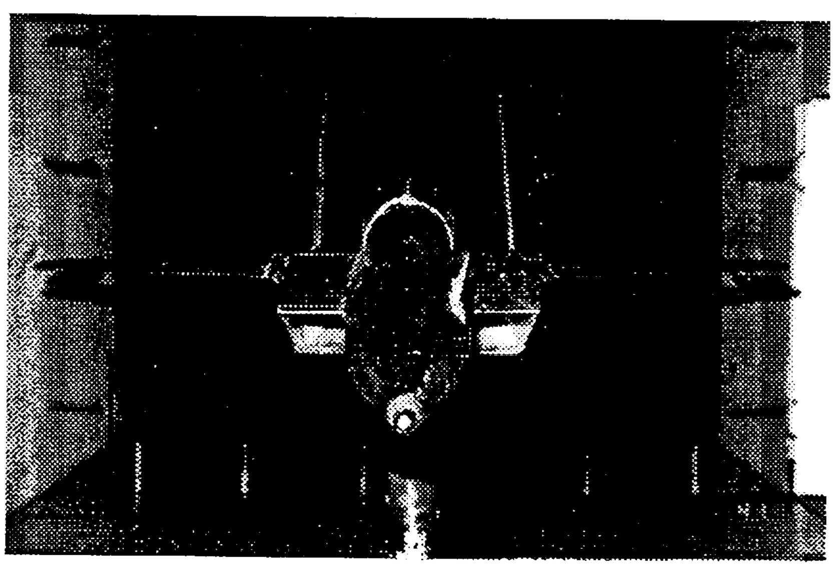
F-15 FOREBODY VORTEX CONTROLS

Testing was conducted in the MDA Low Speed Wind Tunnel using the 13% F-15 model. Angle of attack range was limited to approximately 35° for this model due to the mounting mechanism. A variety of deflectable strake sizes and positions were evaluated including large strakes to form an upper bound on FVC effectiveness. A curved lead-edge strake shape was used for this initial exploratory test because it provided a generic shape which is less dependent upon local flow characteristics.

The rotatable radome was not evaluated at this time due to the complexity of the required model modifications. The high strake position, shown in the photograph, was found to be the most effective and provided substantial yaw control.

Strake Data Were Acquired in MDA Low Speed Wind Tunnel

F-15 FOREBODY VORTEX CONTROLS



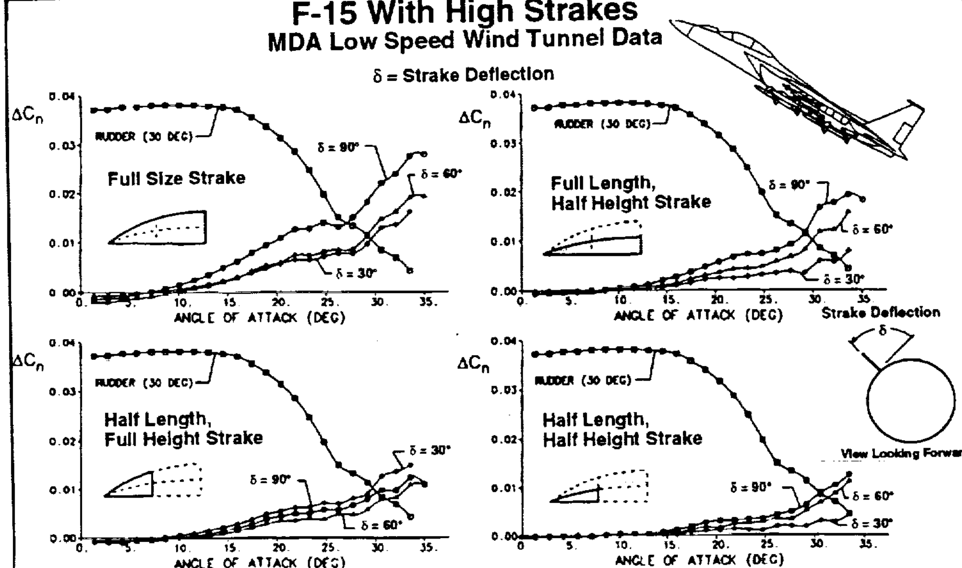
One of the key characteristics of the high strakes is that reduced strake height still provides significant yawing moment control through strake deflection. The full size strake was expected to produce good yawing moments, but in order to minimize visibility impact, it was desired to reduce the strake size.

The data show that the full length, half height strake does result in an yawing moment reduction relative to the full size strake, but the strake still produces a substantial yawing moment. In contrast, the half length, full height strake loses even more yawing moment relative to the full size strake.

Strakes Remain Effective When Height is Reduced

F-15 With High Strakes

MDA Low Speed Wind Tunnel Data



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F-15 FOREBODY VORTEX CONTROLS

Phase III: Concept Integration Study

- Status and Future Plans -

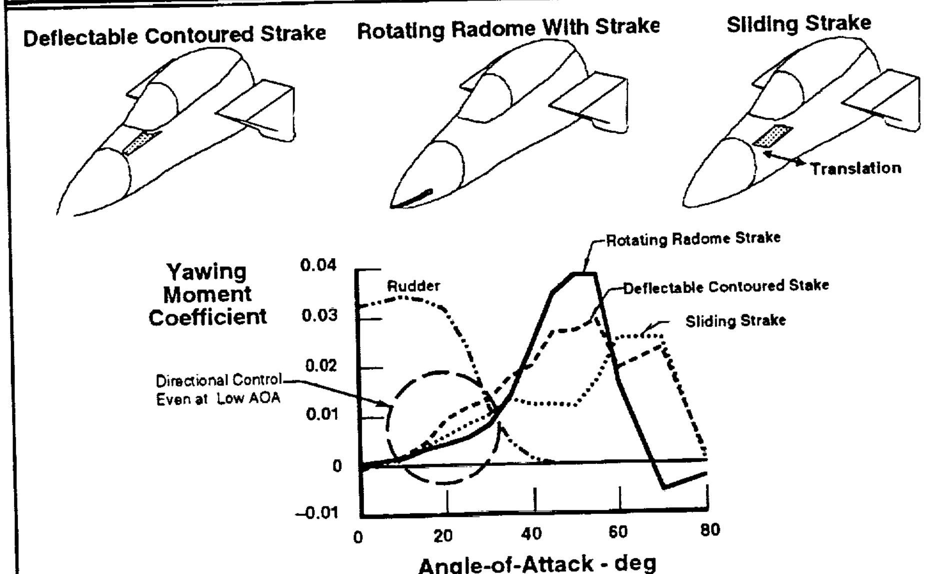
What's The Best FVC Technique for the F-15?

- Aero Optimization
  - Wind Tunnel Testing of Mechanical Devices
- Manned Simulator Evaluation

Having proved the desirability and feasibility of FVC on the F-15, the next step was to determine the best FVC concept. Wind tunnel testing was conducted cooperatively with NASA LaRC to develop a database for the mechanical FVC concepts. The strake shape was redesigned for the High Strake concept in order to maximize the strake size, while minimizing the intrusion into the pilots visibility region.

The results showed that both the High Strakes and the Rotatable Radome provide good yaw control.

Mechanical FVC Concepts Were Tested In The NASA 30x60 Ft Tunnel



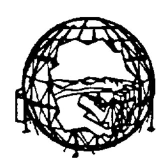
A manned simulation will provide necessary feedback on the desirability of FVC. Both test pilots and operational pilots will be invited for the simulation to provide a diverse perspective. Pilot comments will constitute a major portion of the benefit scale for a cost/benefit analysis.

A vortex control concept will be selected for database development, and an aerodynamic database will be assembled using the NASA LaRC 30x60 Ft Wind Tunnel Data. A limited implementation will be used for the simulation as a cost saving measure. A limited number of configurations and flight conditions will be evaluated in order to simplify control law development and reduce testing time. In addition, no failure modes will be analyzed.

ACC Pilot Manned Sim. Evaluation Will Demonstrate Need For FVC

F-15 FOREBODY VORTEX CONTROLS

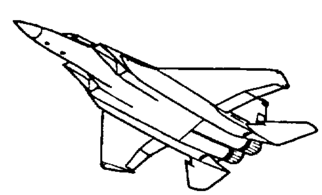
Manned Simulation Will Provide



- An Early Look At Expected Performance
- An Opportunity to Gain Feedback From Air Combat Command (ACC) Pilots
  - New Uses for the Improved Capability
  - Adequacy of Control Power Enhancements
  - Departure Resistance and Spin Recovery Capability

Implementation Plan

- FVC Effectiveness From LaRC 30x60 Ft Wind Tunnel Data
- Mach Effects From HARV Database
- Limited Configurations
- Limited Flight Conditions
- No Failure Modes
- Pilots From ACC . . . Other?



Development of FVC concepts will continue as control laws are developed for a manned simulator evaluation. This will provide the information necessary to conduct trade studies to weigh the benefits of mechanical and pneumatic devices and to conduct a cost/benefit analysis.

The F-15 FVC Program is focused on development of a production FVC system. Flight testing of a near production system will provide an opportunity to further develop tactics to exploit the new flight capability and allow for a smooth transition to production.

Future Plans

F-15 FOREBODY VORTEX CONTROLS

- Complete Aero Optimization for FVC Concepts
- Complete Control Laws and Conduct ACC Pilot Manned Simulator Evaluation
- Pursue:
  - Trade Study to Weigh Benefits of Mechanical and Pneumatic Devices
  - Cost / Benefit Analysis of FVC for F-15
  - Flight Test
  - Production/Retrofit