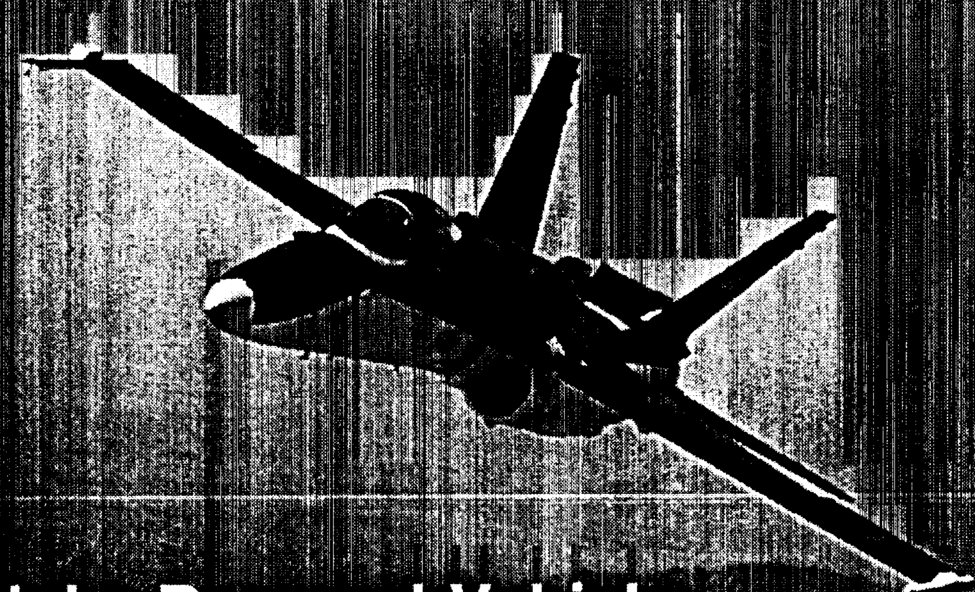

F-18 High Alpha ResearchVehicle: Lessons Learned

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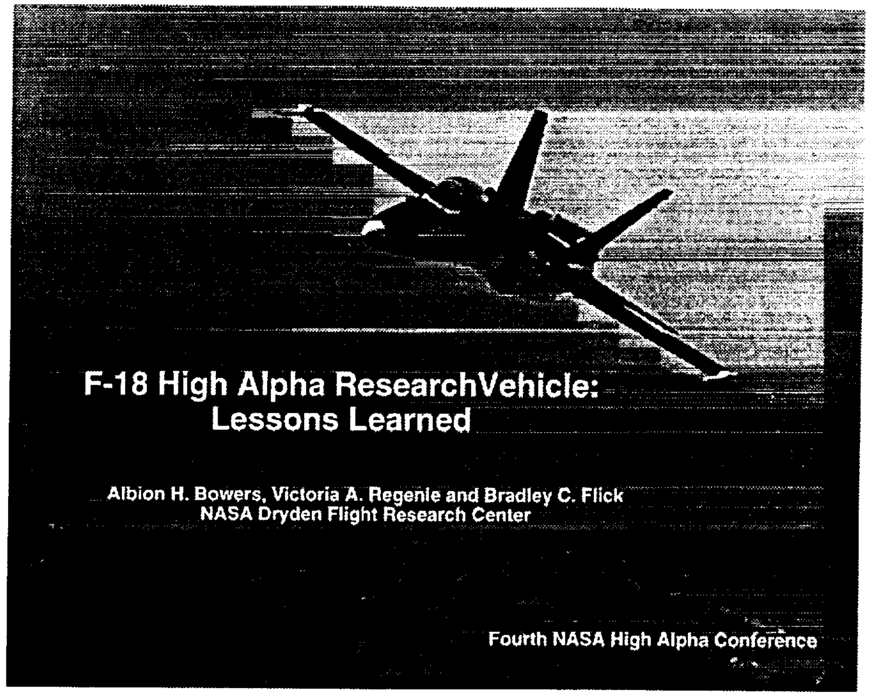
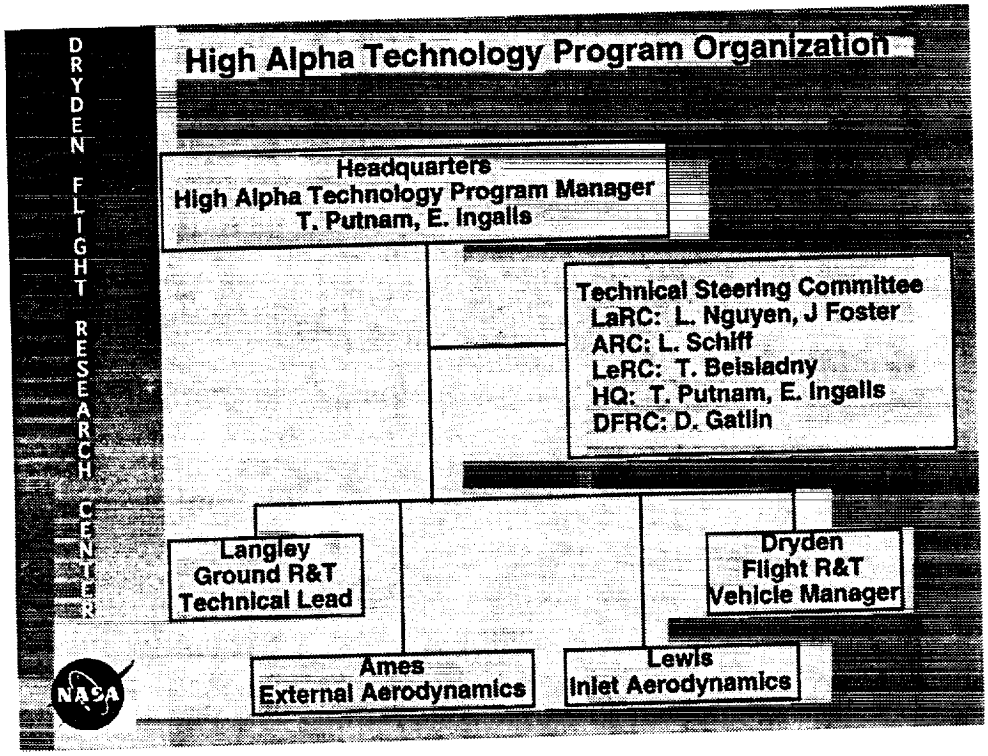
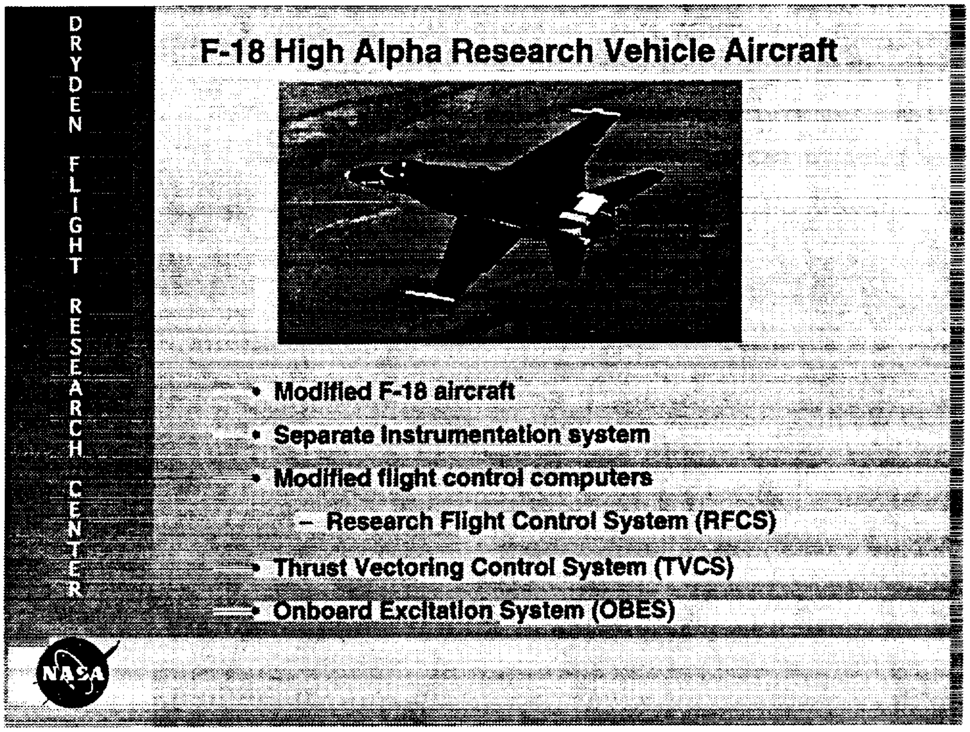


The F-18 High Alpha Research Vehicle has proven to be a useful research tool with many unique capabilities. Many of these capabilities are to assist in characterizing flight at high angles of attack, while some provide significant research in their own right. Of these, the thrust vectoring system, the unique ability to rapidly reprogram flight controls, the reprogrammable mission computer, and a reprogrammable On Board Excitation System have allowed an increased utility and versatility of the research being conducted. Because of this multi-faceted approach to research in the high angle of attack regime, the capabilities of the F-18 High Alpha Research Vehicle were designed to cover as many high alpha technology bases as the program would allow. These areas include aerodynamics, controls, handling qualities, and propulsion. To achieve these goals, new capabilities were developed to enable this research to occur. Some were outstandingly successful; others were not.



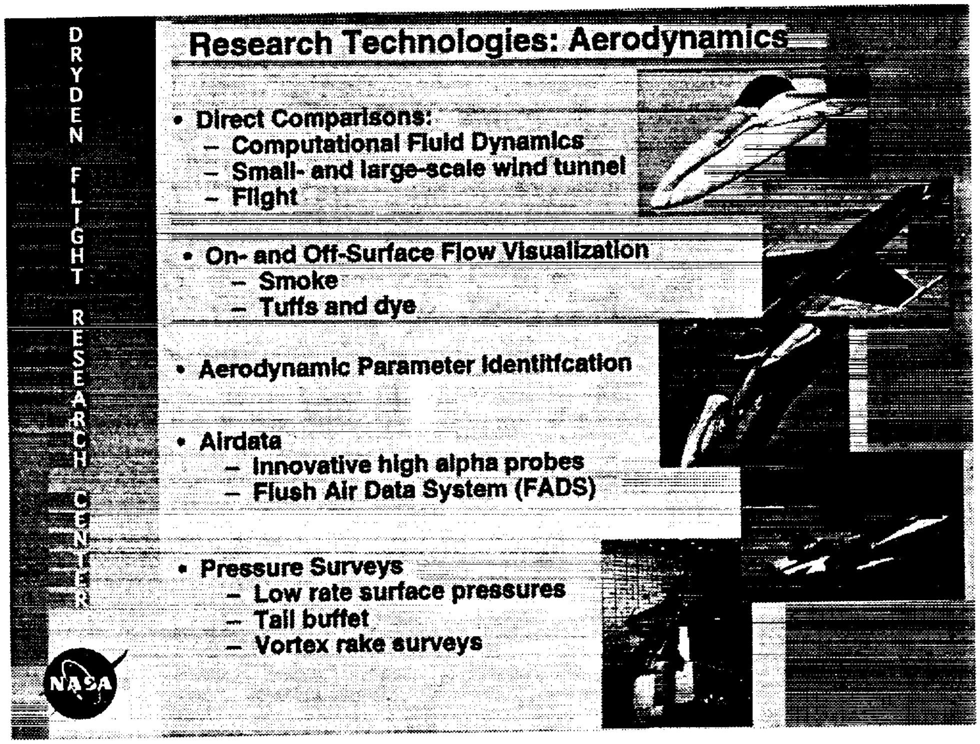
To better address the need for improved high angle of attack capability, NASA formed a High Alpha Technology Program (HATP). This program emphasized the need to provide a complete database of all available tools now used. To do this, close cooperation among all the NASA aeronautical centers was required.

Early in the development of a program, it was found that the Steering Committee was a most valuble asset to the project and the program as a whole. The steering committee was composed of a representative of each Center involved (plus a NASA Headquarters representative). Leaders of diverse disciplines were called upon to be members of the steering committee. The job of the steering committee was to provide vision for the HATP. In this way, the technical people at the Project levels did not need to worry about long range advocacy. Technical individuals could influence the direction of the program through their representatives, but the planning of the program was made at the highest level with input from the various projects to produce the most cohesive package of CFD to wind tunnel to flight database available.

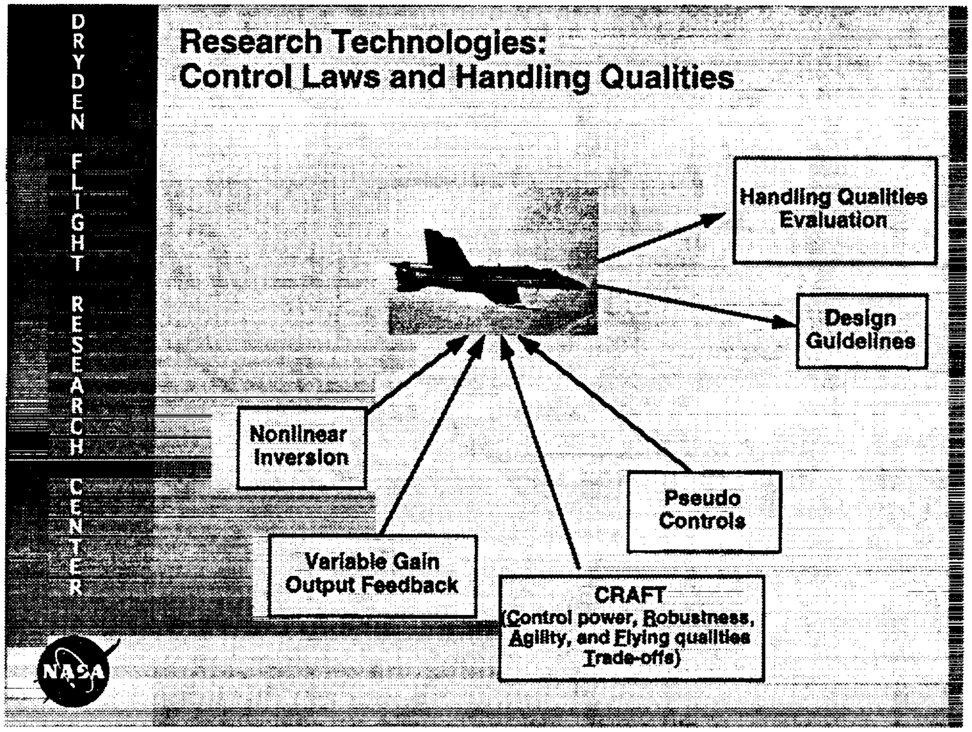


The focal point of this program was selected to be a highly modified F-18 airframe. This aircraft was originally know as Full Scale Development (FSD) Ship 6, but now bears the NASA call sign 840 or also the NASA F-18 High Alpha Research Vehicle (HARV). The decision to use an F-18 aircraft was rooted in the knowledge that the F-18 (or F/A-18 as the production aircraft are known) was the finest high angle of attack airframe testbed available. The aircraft was extensively modified to include thrust vectoring, a unique instrumentation system, highly modified aircraft systems, additional emergency systems, and a special flight control computer.

The TVCS was designed as a set of add-on vanes that were never meant for a production type system. As such, they were heavy, crude and unsophisticated. They were simply a boiler-plate research system with which to gather the data. Despite this they were effective, easily maintained, and robust. Since the time they were designed and installed, thrust vectoring has become much more sophisticated. We have since begun calling our implementation the first generation of thrust vectoring systems. First generation being represented by the X-31 Enhanced Fighter Maneuverability aircraft, with an integrated vane approach and second generation being represented by the F-16 Multi-Axis Thrust Vectoring (MATV) aircraft with axi-symmetric nozzle vectoring.

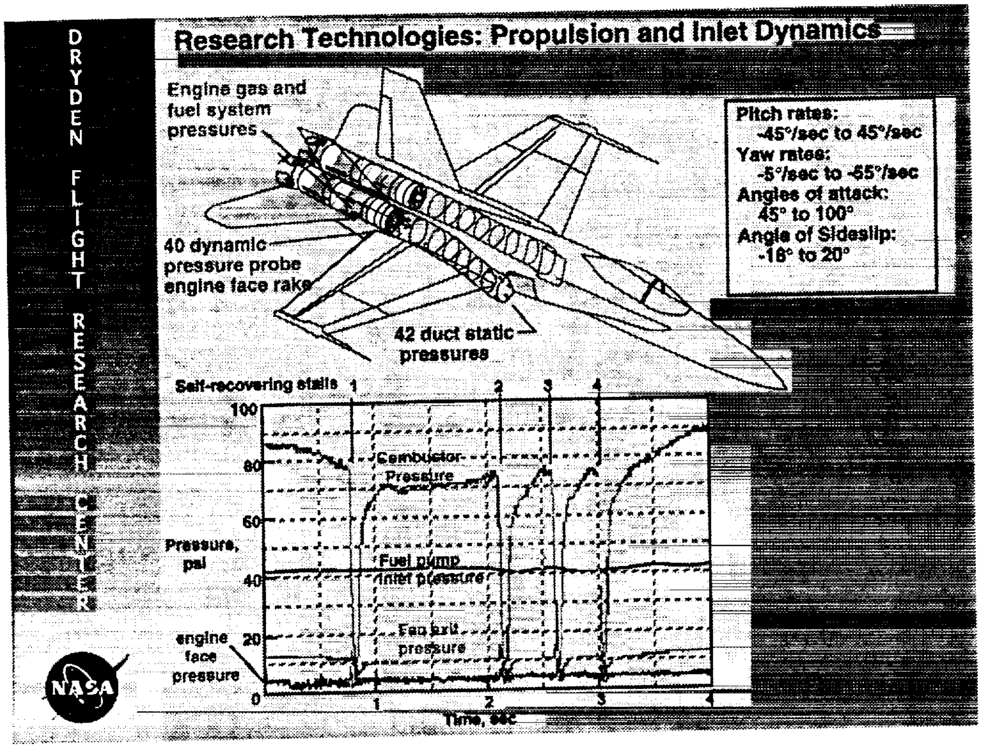


Aerodynamic research has included static pressures, unsteady pressures, on and off surface flow visualization, as well as innovative parameter identification techniques. Static pressures have been taken around the forebody, leading edge extensions (LEX), wings, a vertical tail and the fuselage. Unsteady pressures and accelerometer data are being used to characterize the unsteady aerodynamic flow field over the verticals. A special traversing wake rake was made to investigate the off-surface vortex flow field over the LEX. All of these pressures are being used to characterize the flows at high angles of attack. An aerodynamics related piece of research is being done in the area of parameter identification. Three innovative techniques are being used to generate maneuvers at high angles of attack which are being analyzed using traditional techniques.

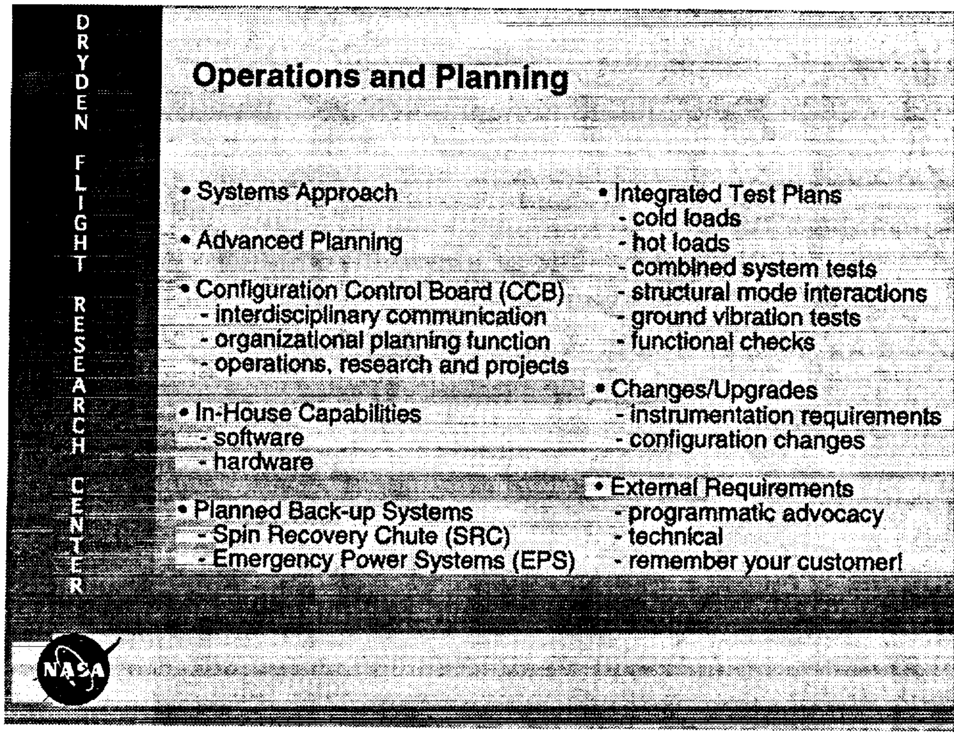


Controls research is being conducted by having several different control laws being independantly designed for the aircraft. Of the five differnt control law sets designed for the aircraft, all which will be flown and evaluated. The digital flight control computers on-board the aircraft allow rapid reconfiguration. With each research control law set flown on the aircraft, the baseline aircraft control laws are retained for normal operation of the aircraft. This parallel control law set have allowed more rapid verification and validation of software than would have been possible. The baseline set of control laws allowed the research control laws to undergo a less complete, thorough and exhaustive verification and validation allowing for more rapid changes.

Handling qualities research is concentrating on the unique control effector aspects of the aircraft. Thrust vectoring allows control in corners of the envelop that do not lend themselves easily to conventional aerodynamic controls. Evaluation of handling qualities at high angles of attack are developing guidelines for criteria to be used for future generations of high performance fighter type aircraft.



Propulsion research has been expanded using the F-18 High Alpha Research Vehicle because of the aircraft's ability to explore corners of the envelope that have been unobtainable with any repeatability or what had been transient at best. Special instrumentation to characterize the distortion and flow in the inlet, measure the thrust loss at high angles of attack, and baseline various thrust measurement systems are being flown on the aircraft.

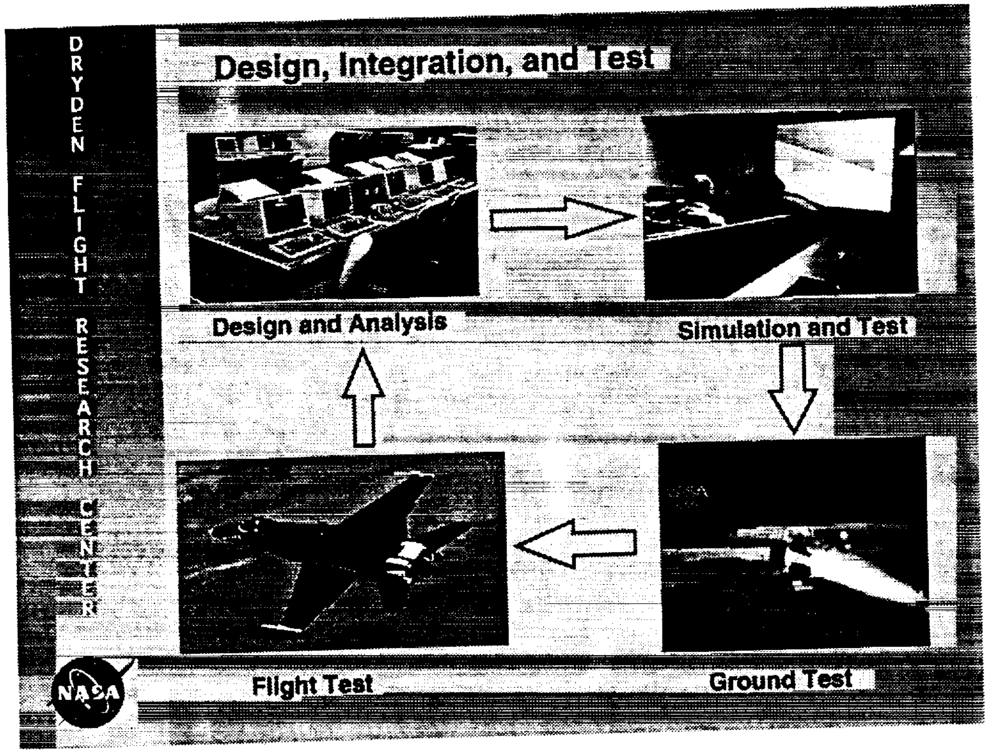


Many actions were found to assist the project greatly in its inception. Certain planning groups were instrumental, not only for program inception, but throughout the program. Other actions were much more simple, and while easily stated, made a significant impact to later operational aspects of the flight phase. Certain other actions were painful to the project, but were found to have long term payoffs far in excess of their setbacks. Along with estimates for changes, be sure to define, well in advance, deletion of envelope expansion hardware, e.g., Spin Recovery Chute (SRC) and Emergency Power Systems (EPS).

This goes hand-in-hand with planning in advance as much as possible. While this is a simple statement to make, it is very difficult to execute. In many cases, it is difficult to visualize the complexity of the complete system, especially when one is concentrating on the discipline at hand. The more advanced planning one is able to complete, the more quickly and smoothly the test project can advance.

At the project level, strong interdisciplinary communication was a must. A part of this was a configuration control board (CCB) process that worked.

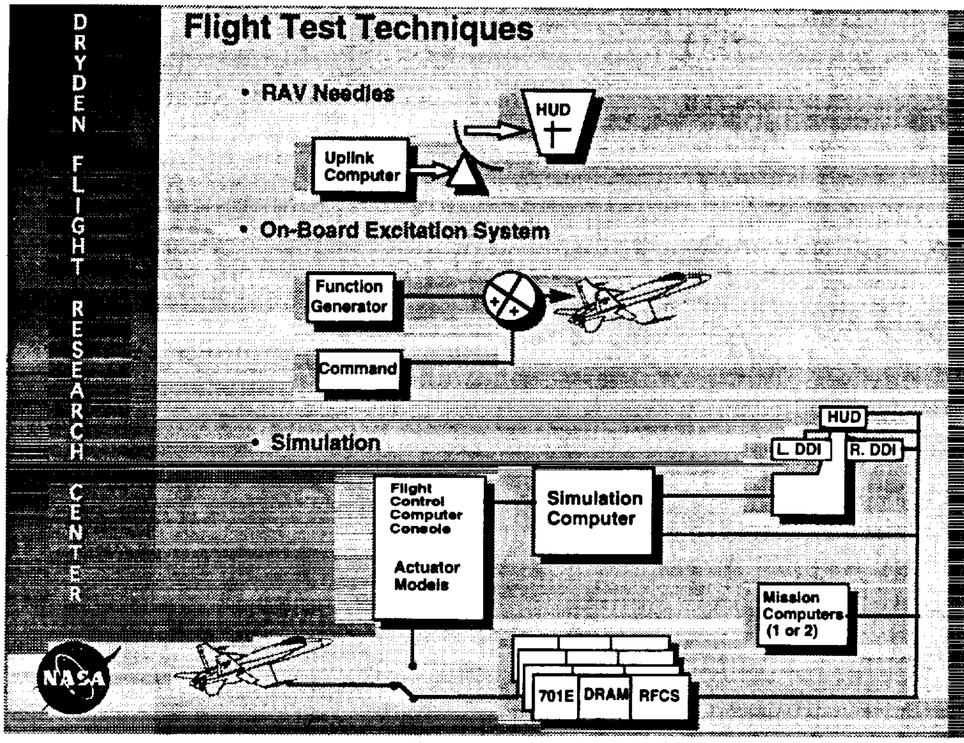
As the system approaches flight testing, ground testing is performed. During this ground testing, be sure to include enough time for contingencies. Thrust vectoring is a difficult problem, causing a level of engine to airframe integration that has not been experienced before. The flight test plan is only that, a plan. Contingencies inevitably arise, forcing quick rethinking of individual flight plans. Use the data of opportunity as the situation arises.



Major modifications, even if expected to be used for limited time periods, require design to facilitate physical access to as many systems as possible for maintainability. Elegant engineering solutions are not necessary, but maintainability is required. Significant schedule slips for simple failures can be expected if access is not designed into systems. Remember the cause and effect during modification of any system. Keep the entire aircraft in mind and use a systems approach as much as possible.

Along with maintainability, testability is required. The ability to test systems in the aircraft must be designed into the complete system and into each component of each system as early as possible. This greatly simplifies any troubleshooting later in the schedule.

In-house support for each system must be maintained in order to capitalize on the accessability, maintainability and testablity of these systems. This extends to the specialized systems installed, like instrumentation, or modifications like the TVCS. Also the hardware and software that might be used `off-the-shelf' should be able to be modified in-house as late requirements arise. All these little pieces could become major stumbling blocks should a necessary change be required but is unavailable.

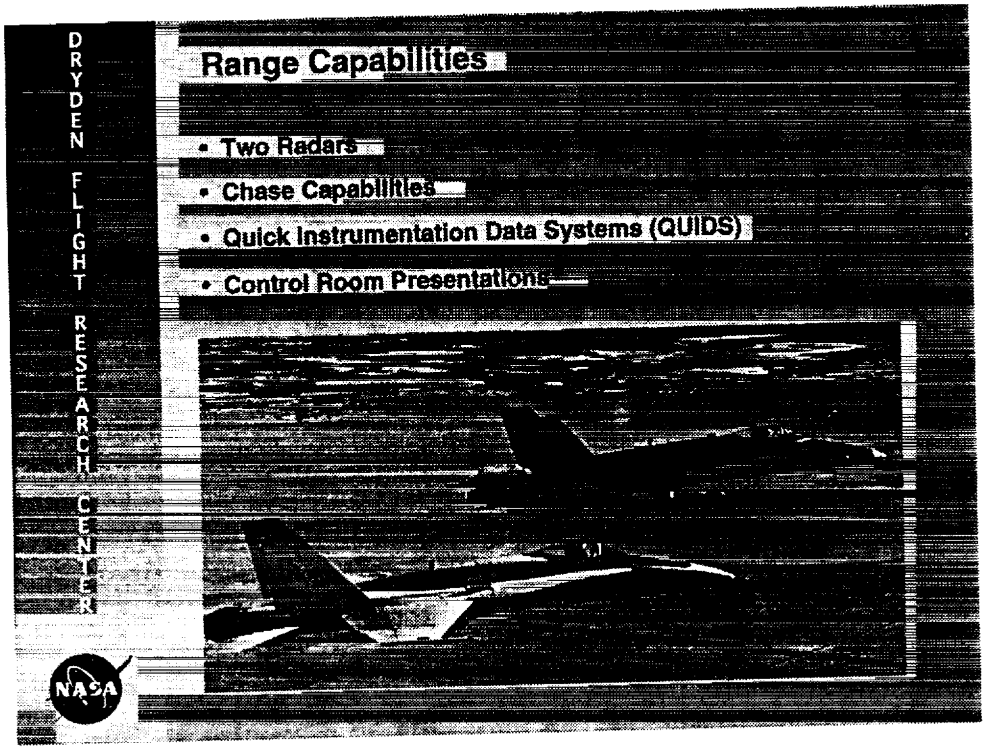


Consideration should also be given to flight test techniques. If the simulation is accurate, it can prove to be a most valuble tool for assessing the workload of a particular maneuver. New maneuvers can be designed for handling qualities, or control law evaluation, or performance in this way as well. Excellent examples abound in the HARV project, such as High Alpha Nosedown Guidelines (HANG), or the various handling qualities work performed in the HARV flight tests.

One flight test technique that was planned on from very early on in the program was the On Board Excitation System (OBES). This was a piece of software located in the RFCS that allowed independant excitation of individual flight control surfaces. While its original intent was to provide for structural excitation for aeroservoelastic clearance, later uses included inner-loop control law parameter identification, aerodynamic derivative extraction manuvers, and to vary static stability recovery charateristics (HANG).

A Remotely Augmented Vehicle (RAV) capability was incorporated on the aircraft. This allowed guidance to be uplinked to the pilot to assist in the flying of a maneuver or initial condition. Consequently, unusual or very precise and complex maneuvers could be flown more easily.

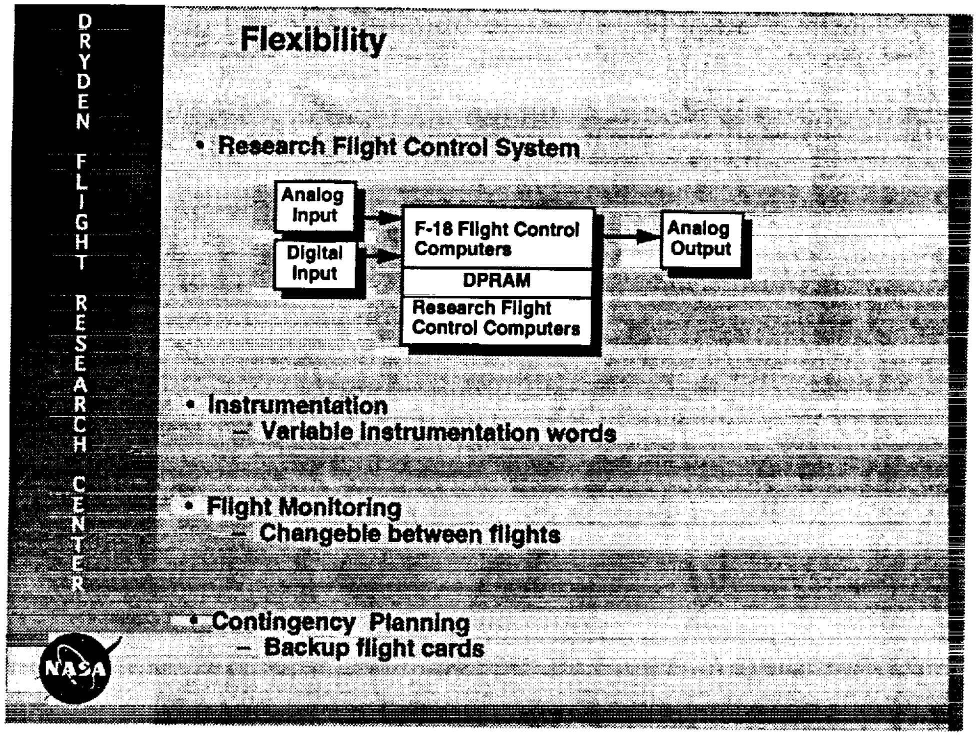
A great help in early development work was the hardware-in-loop (HIL) simulation. Having the hardware available to test software releases early, and to perform verification and validation on, assisted in solving problems with software/hardware. This was long before such software or hardware were on the aircraft. This prevented costly and extensive downtime in the flight schedule.



Special requirements extended well beyond those of the HARV aircraft. A Quick Instrumentation Data System was used for the chase aircraft so that special maneuvers where the chase could maneuver as a target for the HARV aircraft. This QIDS data was telemetered to the control room, and in concert with two radars, formed the ability to evaluate maneuver set-ups and minimize loss of data. Special displays were also developed for the control room so that research engineers could quickly evaluate the quality of a particular maneuver.

The number of instrummented channels and the high data rate at which the data was to be gathered neccessitated the use of two instrumentation systems in the telemetry stream, and a third instrumentataion stream was recorded on board the HARV aircraft. With the QIDS system being flown on a chase, this resulted in yet another data stream. The ability to quickly and easily accommodate requirements such as these contributed greatly to the success the HARV has enjoyed.

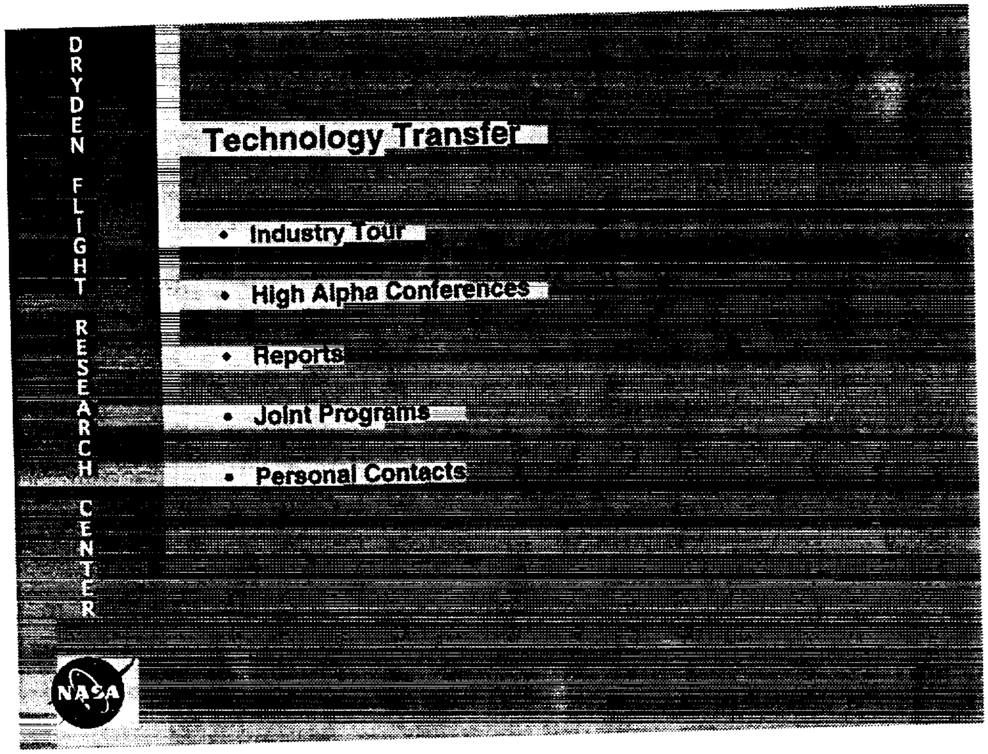
However, beware of possible instrumentation overkill. It is very easy to continue adding more and more capability, without exploring the possibility of using an existing sensor on the aircraft.



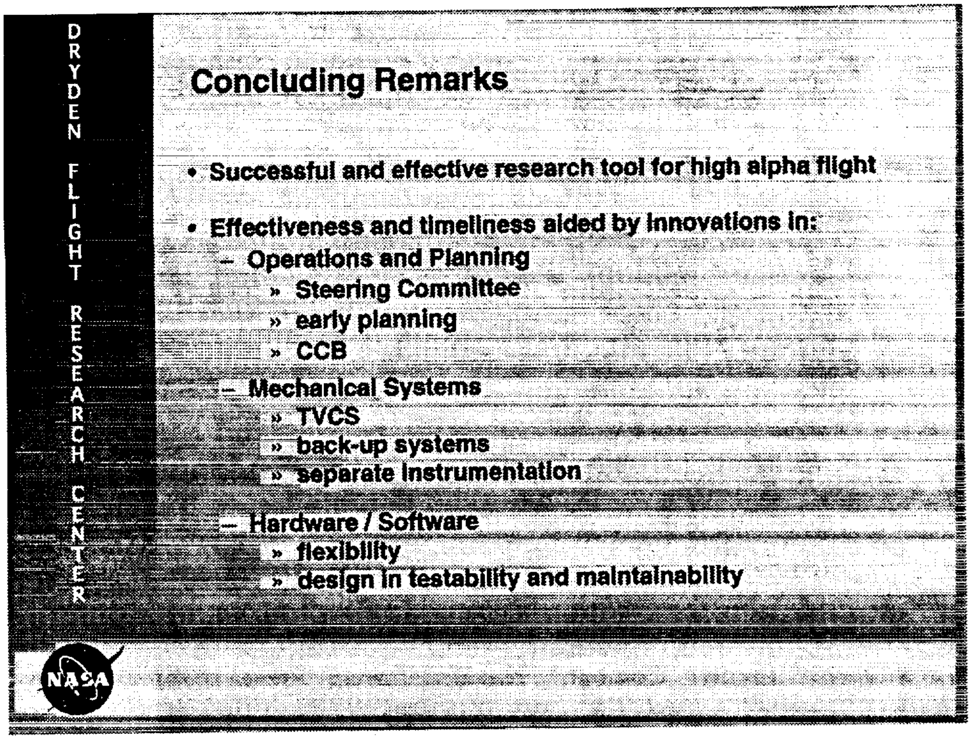
A research flight control system. where only control laws were operated, was of great value to be able to execute the program goals in a timely fashion. Part of that asset was assisted by having built in testability as well. This meant that many changes could be effected only with simple software changes. In all cases, it was desired to add more analog Input/Output (I/O). Sufficient I/O was always beyond the grasp of the project. No sooner was the design fixed, when new requirements would spring up driving the need for yet more I/O. Any flexibility that can be designed into the system is of great advantage at all levels (simulation, aircraft systems, instrumentation, control room capabilities, uplink systems, etc).

For a research effort, more data out of the flight control system (FCS) would have been highly desirable. Control law development and inner-loop parameter identification of control laws would have been highly desirable. The limited number of channels that were designed were rapidly overwhelmed by the later desires of research in the controls group, especially with the later control law designs.

Before embarking on an ambitious research data instrumentation system, be sure that the range data processing is capable of supporting displays, strip charts and timely data availability. Many fast response research instrumentation systems (such as used to measure and quantify data for engine/inlet stalls) have a bit rate that will tax most range telemetry systems. Also be aware of possible constraints operationally with the range, as rapidly reconfigured aircraft may not be supportable as the range may not be as rapidly reconfigured to keep up. Schedule changes to minimize changes, if possible. However, back to back control law comparisons, or other requirements, may require rapid range support changes.



Last, and most imperative, is technology transfer. The HATP has sponsored a set of conferences and workshops. These are excellent methods for disseminating information to the respective industry groups. The HARV and HATP have also performed an industry tour, to encourage participation in the program. These have proved to be the most effective means of distrubuting the complete databases to interested parties.

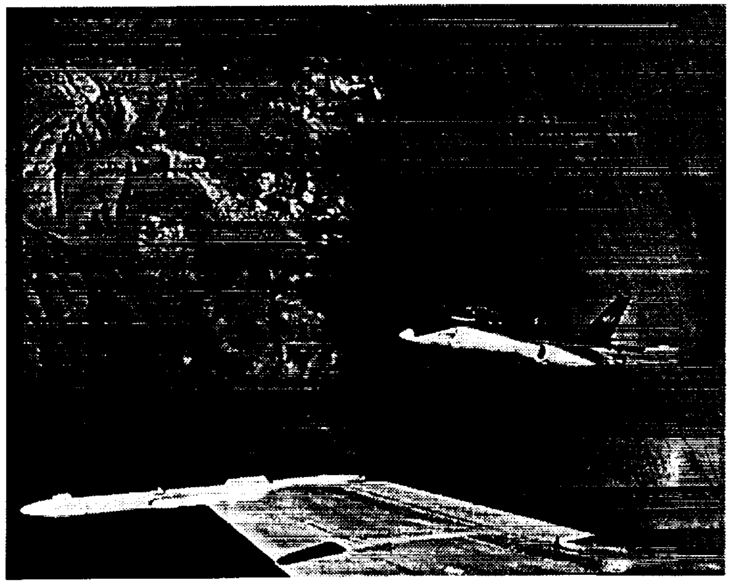


The NASA F-18 High Alpha Research Vehicle project, as a part of the NASA high Alpha Technology Program, proved to be a most effective tool to perform research in the high alpha regime. Research has been accomplished in aerodynamics, controls, and propulsion.

The effectiveness and timeliness of the project was greatly aided by innovative thinking and execution in three areas. These three areas that assisted in making the project as successful as it has been were operations and planning, in mechanical systems, and hardware and software.

The F-18 High Alpha Research Vehicle has proven to be a flexible, capable research tool to investigate the high angle of attack regime with particular emphasis in the areas of aerodynamics, propulsion, control law research, and handling qualities. Many of these capabilities were essential to the performance of the project, and to the assistance to the program.

REFERENCES



Shaw, Robert: ``Fighter Combat," Naval Institute Press, 1985.

Chambers, Joseph R.: ``High-Angle-of-Attack Technology: Progress and Challenges," NASA CP 3149, Part I, Vol. I, 1992.

Gilbert, William P., and Gatlin, Donald H.: ``Review of the NASA High-Alpha Technology Program," NASA CP 3149, Part I, Vol. I, 1992.

Kempel, Robert: "F-18 High Alpha Research Vehicle Description," NASA Contractor Report, 1993.

Regenie, Victoria, Gatlin, Donald, Kempel, Robert, and Matheny, Neil: "The F-18 High alpha Research Vehicle: A Hihg-Angle-of-Attack Testbed Aircraft," NASA TM 104253, 1992.

Ogburn, Marilyn E.; Foster, John V.; Nguyen, Laut T.; Breneman, Kevin P.; McNamara, William G.; Clark, Christopher M.; Rude, Dennis D.; Draper, Marjorie G.; Wood, Craig A.; and Hynes, Marshall S.:``High-Angle-Of-Attack Nose-Down Pitch Control Requirements for Relaxed Static Stability Combat Aircraft," NASA CP 3149, Part II, Vol. I, 1992.

Pahle, Joseph W.; and Wilson, Joe: ``Preliminary Flight-Test Results with Multi-Axis Thrust Vectoring," NASA CP 3137, 1992.

Wilson, R. Joe; and Pahle, Joseph W.: ``Results of High Yaw Rate Expansion Flights," NASA CP 3137, 1992.

Klein, Vladislav: ``Aerodynamic Charateristics of High Angle of Attack Research Vehicle (HARV) Determined from Flight Data," NASA CP 3149, 1992.

Bowers, Albion H.; Noffz, Gregory K.; Grafton, Sue B.; Mason, Mary L.; Peron, Lee R.: ``Multiaxis Thrust Vectoring Using Axisymmetric Nozzles and Postexit Vanes on an F/A-18 Configuration Vehicle," NASA TM 101741, 1991.