12/14/94

TO: Distribution

FROM: Doug Arbuckle, NFLR Aero Response Team

SUBJECT: Langley response to NFLR Aeronautics Subcommittee regarding 757 issue

The attached package is provided to you FYI. It was faxed this morning to the NFLR Aeronautics Subcommittee meeting being held at Goddard. Please address any comments to Lee Beach, Jerry Creedon, or myself.

This package is available electronically as two Microsoft Word files and one Microsoft PowerPoint file by contacting Doug Arbuckle.

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KC
Dr. Earll Murman  
Chairman, Aeronautics Subcommittee  
NASA Federal Laboratory Review  

Dr. Murman:  

During your subcommittee's visit to Langley Research Center on December 6th and 7th, you and your team raised the issue of flight research activities at Langley versus Dryden, specifically with regard to the 757.  

As part of the discussion, you requested that Langley provide a histogram that showed the research flight operations schedule of the 737. This chart is attached. On the chart we have indicated the deployments of the 737 during the 3 year period -- as you can see, the deployments are periods of short and intense flight activity extending over a week or more. The remaining periods show our normal research flight operation involving a few research flights per week. The periods of no activity are aircraft "preparation" time (where experimental equipment is being installed on the aircraft) or aircraft maintenance/inspection/repair time.  

There are many factors to be considered in contemplating flight consolidation, including: research program content, technical expertise to rapidly redirect research programs, ability to provide suitable test conditions (e.g., ambient noise, weather conditions, etc.), ownership of facilities (versus sharing with another Government entity), customer location, and test range capability. Also attached you will find a white paper we have written that describes our perspective of how flight testing is used in aeronautics research -- this paper addresses the first two technical factors described above. In this white paper, short "case studies" are provided of our research experiences in the High Alpha Technology Program and the Wind Shear Airborne Sensors Program.  

Based on the discussions we had with your subcommittee, we have put together a team to study use of telemetry to allow ground monitoring of on-board experimental systems in an effort to determine the minimum number of personnel that must be aboard the TSRV to conduct experiments, as well as the implications of operating the 757 at Dryden while the researchers remain at Langley. This study is extensive and could not be completed in the short time since your visit. Preliminary results indicate that, although a very challenging task, most of the technology exists to develop a system allowing operation of the 757 at Dryden with researchers monitoring the tests at Langley, albeit at considerable cost (millions of dollars and years of schedule) since many capabilities now residing
only at Langley must be duplicated at Dryden. The study also has shown us that the technology exists to reduce the number of personnel aboard the TSRV, although it is not yet clear whether this would result in fewer personnel overall compared with our current approach. We are continuing to work on this study and will transfer the findings to our internal team responsible for modifying the 757 into a transport systems research vehicle. However, even if this capability is developed, for the reasons articulated in our white paper, we feel strongly that the NASA Aeronautics program is better served by maintaining operation of the 757 at Langley.

Earll, as your subcommittee deals with the issue of flight consolidation, we hope you can focus on what would be “fixed” in consolidating, with the goal of fixing only those things that are broken. We would be happy to discuss this further at the pleasure of your subcommittee.

Sincerely,

H. Lee Beach, Jr.

2 Enclosures
737 Research Flights (FY92-94 Histogram)

Research Flight Hours

FY92

FAA ILS Deployment, Los Angeles  Windshear Deployment, Denver  Windshear Deployment, Orlando

Research Flight Hours

FY93

CTAS Deployment, Denver

Research Flight Hours

FY94

CTAS Deployment, Denver

Langley Research Center
Research Process and Flight Testing

Research and development of an aeronautics technology typically requires skilled personnel, adequate facilities, and a program to focus the effort and fund it, leading to one or more technology products as shown figure 1. The personnel are usually the most important part of this combination, as well as the hardest to “measure” in terms of capability and expertise. Facilities consist of computers, simulators, laboratories, wind tunnels, and aircraft -- attributes of these are easier to measure and are often examined in making comparisons of different NASA Centers.

The people perform the research and development -- the facilities are “tools” in the hands of these personnel. Over a period of time, the people become expert at using their tools -- if tools exist but are not readily available, they tend not to be used by those personnel. Over the life of an institution, the people’s expertise is shaped by their experiences -- a history of the research programs and the tools used to accomplish each program.

Most programs are accomplished by a team of researchers and support personnel. Within this team, a single researcher will often lead the conduct of experiments in multiple facilities as the research program progresses. These progressions include from-CFD-to-tunnel-to-flight, from-CFD-to-tunnel-to-simulator, from-desktop-to-simulator-to-flight, etc. -- depending on the program objectives and the disciplines involved. These progressions are often (but not always) made easier when the research team is collocated and can access all the relevant facilities at a single site, and when the facilities are deliberately operated to be mutually supportive of each other in the research process.

Our experiences at Langley indicate that some research programs are better served when the flight testing is performed at Dryden and other research programs are more efficient/effective when the flight testing is conducted at Langley. We believe examination of two short case studies will illustrate our position.

High Alpha Case Study

The primary objectives of the NASA High Angle-of-Attack Technology Program (HATP) are: (1) to focus and accelerate the development and validation of design methodologies for high angle-of-attack conditions; and (2) to provide flight-validated concepts which provide unprecedented levels of agility at high angles of attack. The program was initiated in 1989 and will end in 1995. All four NASA aeronautics Centers (Langley, Ames, Lewis, and Dryden) have been involved in the planning and conduct of the program. Because flight validation is a key element, the High Angle-of-Attack Research Vehicle (HARV) was developed for flight testing at Dryden. The HARV is a highly modified F-18 that incorporates extensive instrumentation, a flexible research flight control
computer, and a multi-axis thrust vectoring control system. Dryden was chosen as the flight test site since the modifications to the F-18 to create the HARV were of a flight-critical nature, and Dryden has the world-class expertise and a long history of success in this type of testing. It is important to note that the HATP is an R&T Base research program and has been driven more by the desire to meet program objectives as stated above and less by a desire/need to meet a schedule for delivering technology products. This permitted greater flexibility in working the ground/flight research efforts.

To date, HATP activities involving both ground and flight research fall into two general areas: aerodynamics (= 2/3) and controls (= 1/3). Overall, the ground and flight research efforts have been well coordinated and are producing very good results. Much of this success is due to the efforts of the personnel at the Centers to work as a team to overcome the inherent limitations of not being collocated. An additional important factor is that these research efforts did not involve a strong coupling of the ground and flight activities, and the communication mechanisms for achieving the required coupling are straightforward and well-known. This coupling in the aerodynamics area is illustrated in figure 2. Here, the efforts were primarily focused on comparison of ground predictions (analytical {CFD} and experimental {wind tunnel}) with flight results. The ground activities were conducted by Langley researchers using Langley facilities. In parallel, the flight effort was conducted by Dryden researchers using a Dryden facility -- the HARV. The required level of coupling of the two activities was low because the ground results did not directly impact the conduct of the flight tests and vice versa. The only requirement was for careful coordination of the activities so that consistent data (measurements, test conditions, etc.) were obtained and transferred. For example, a Langley researcher developing a CFD method was able to proceed almost independently of the flight activity at Dryden. The researcher's only concern was to coordinate with a counterpart at Dryden to assure that the flight data needed to test/validate the code would be consistent (test conditions, airplane configuration, measurement locations, etc.) with the CFD calculations. This coordination could be effectively accomplished by telephone, videocon, and electronic data transfer, and the information communicated was well-known parameters used in all forms of aerodynamic testing (both wind tunnel and flight). Consequently, most of the Langley HATP aerodynamics researchers have never been to Dryden to participate in HARV flight testing.

![Diagram](image)

**Figure 2 - High Alpha Aerodynamics Research Process**

For the second HATP major activity -- controls -- the ground/flight coupling is illustrated in figure 3. As indicated in the figure, the coupling/communication for this activity is higher than for the aerodynamics activities. In addition to the requirement for test coordination discussed previously, there was also a direct transfer of ground results to the flight effort. The control laws were initially developed in Langley's Differential Maneuvering Simulator (DMS) -- once Langley researchers
were satisfied with the control laws, the block diagrams and specifications were sent to Dryden where software was developed to implement the control laws in a suitable form for implementation on the HARV. Since we knew at the genesis of the program that there would be researchers at two locations, an attempt was made to divide the work accordingly in a rational way. However, Dryden’s responsibility for flight safety, and the strong role the control laws have with regard to this responsibility, made a clean division of the work more difficult. Fortunately, the communication mechanisms for describing control laws and aircraft state data are sufficiently straightforward that the activities were possible to conduct individually within each Center without a significant requirement for resources (people and facilities) from the other Center. Thus, the ground research was accomplished by Langley researchers using Langley facilities, while the flight element was conducted predominantly at Dryden by Dryden researchers using Dryden facilities. Most of the communication/coordination activities were conducted electronically -- this was workable since the major elements being exchanged were block diagram descriptions of control laws and aircraft state data time histories. However, in contrast to the aerodynamics situation, Langley researchers did travel to Dryden during critical periods to participate in the checkout and flight testing of the control laws. Nonetheless, the key point is that although Langley personnel were involved, it was in a support role to the Dryden team that actually ran the flight research program.

In summary, the required coupling between ground and flight research activities in the HATP was not high and could be accomplished with diligent use of electronic communications and relatively limited travel of researchers between Langley and Dryden. Consequently, the separation of the Langley researchers from the test airplane did not significantly impair their ability to effectively accomplish the goals of the program.

**Wind Shear Case Study**

The Wind Shear Airborne Sensors Program began at Langley in 1986 as a response to the increasingly apparent hazard of microburst wind shear to commercial aviation. Over the subsequent six years, in cooperation with the FAA and the U. S. avionics industry, and capitalizing on Langley’s broad experience in atmospheric and aircraft simulation modeling, sensor technologies, and transport aircraft operations, Langley researchers conducted a program now hailed as a model for research and development efforts. Not only was a successful solution to the wind shear problem identified and proven, the program was completed under budget and ahead of schedule. Given such performance, lessons learned in this program should be applied to future efforts.
We believe this program would not have been successful without the collocated aggregation of skilled personnel, flight simulation and other ground-based facilities, and the TSRV 737 research aircraft. It is true that a program in wind shear research could have been funded at a location without such a confluence of resources, but we believe that comparable results would have taken years longer, cost millions more, and as a result, the program might not have been attempted.

This last point addresses timeliness of research and development -- the Dallas-Ft Worth wind shear accident caused the FAA to require that all commercial airliners be equipped with reactive wind shear alerting systems by the end of 1992. This rule was made even though the limitations of the reactive systems technology -- which only warns the crew when the aircraft is already in the wind shear -- were understood. The rationale was that the reactive systems were the only technology available and they would provide additional crew awareness resulting in fewer accidents than if nothing was done. However, it was recognized that wind shears occurred of sufficient strength to cause a crash if an aircraft penetrated it; therefore, predictive systems were desired that provided the crew with sufficient advance warning to execute an "escape" procedure (see below). Based on progress in the Wind Shear Program as of 1989, the FAA agreed to grant a rule exemption to three airlines (American, Continental and Eastern) that were pursuing predictive wind shear system development. This exemption allowed those airlines to delay making a final implementation decision on whether to purchase reactive or predictive wind shear systems until the end of 1993. The Wind Shear Program had to produce useful results by this time if technology readiness was to be demonstrated in time for systems to be installed in the U.S. airline fleet. The program completed flight testing in late FY92, terminated at the end of FY93, and on November 30, 1994, a Continental Airlines 737-300 made the first flight with a certified predictive wind shear system made by Allied-Signal (Bendix Division). Hundreds of these systems are now on order.

The Wind Shear Program capitalized on Langley's unique combination of expertise in atmospheric and aircraft simulation modeling, sensor technologies, and transport aircraft operations. The initial focus was on understanding and modeling the microburst wind shear phenomenon and characterizing its effect on a transport aircraft. In 1988, piloted simulation evaluations were conducted at Langley which showed that just a few seconds advanced warning of an impending event was enough time to safely avoid the hazard. This knowledge was used to define requirements for airborne sensors and flight management strategies that could potentially provide this advanced detection and warning. Langley researchers then designed and developed candidate sensor systems (a NASA-unique capability) and defined flight management concepts for crew use of the information these sensor systems provided. From 1990 through the summer of 1992, the main thrust of the program effort was invested in preparing for and conducting a series of research flights which tested the viability of these sensors in actual microburst conditions.

Throughout this time period, we believe the close proximity of the TSRV B737 research aircraft, the "support" personnel, and facilities to the researchers leading development of the test systems was critical to the success of the program -- the process relationship of these elements is shown in figure 4. This process is in contrast to the processes shown in figures 2 and 3, which involved much weaker coupling of the ground and flight efforts. For the wind shear program, the flight test hardware and software were developed in ground facilities at Langley and then installed on the TSRV. Many of the systems developed required unique expertise that is only available at Langley. The 737 simulation model (unique since it has been "tuned up" by Langley personnel to more accurately simulate the behavior of our 737-100 prototype) was used both in the TSRV simulator -- a replica of the research flight deck in the airplane -- and to support experimental systems checkout in the TSRV experimental avionics systems integration lab. The major difference between the High Alpha research processes shown in figures 2 and 3, and the Wind Shear research process shown in figure 4, is that a single group of people collocated with one set of facilities performed all of the research involved to accomplish the Wind Shear program.
The following are examples of how coupling occurred during the conduct of the Wind Shear program:

- Types and locations of equipment designed and installed for the program included:
  - research radar control system and operator’s console
  - research radar receiver/transmitter units
  - research radar antenna
  - video cameras (forward flight deck and research flight deck)
  - laser radar (lidar) data system and operator's console (rear cabin)
  - research laser system, laser control pallet, hull penetration and aiming turret (cargo bay)
  - cooling system modifications for laser and other systems (cargo bay and throughout aircraft)
  - Research Flight Deck display monitors
  - infrared sensor, window penetration, and control unit installations (cabin)
  - ground radar data link

Determining the location and design for each of these aircraft installations typically involved the researchers and “support” personnel walking out to the aircraft, evaluating potential options, and then deciding on a workable installation that met research requirements. This process happened continuously as designs and equipment developed, were modified, and then modified again over the almost two years preparing for the initial program deployments. Much of this equipment was operated and maintained by researchers and their technicians rather than dedicated support personnel, minimizing training cost/schedule and maximizing flexibility in the research system.

![Figure 4 - Wind Shear Research Process](image)

- The lidar system was developed by a contractor and delivered to Langley for installation on the airplane. The system performed well during ground tests at Langley, but showed multiple anomalies when installed on the aircraft. Most of these difficulties arose since the contractor had conducted extensive ground tests, but did not have a lot of experience with aircraft equipment installations. Another factor was that this was the first lidar system ever installed on an airplane. The entire system installation was removed, modified, re-tested, and re-installed in the aircraft at least three times over a five month period. Most of the contractor’s expert personnel were located on the West Coast. The cost of having these personnel “deployed” to Langley was not trivial. Our experience here was that having the experts who designed and built the system located across the country from the facility where the system was being tested created a set of obstacles that made a challenging technical problem harder to overcome.
• The radar installation was developed and tested by Langley researchers and "support" personnel in the NASA-unique radar laboratories at Langley. On multiple occasions, the 737 radome was removed from the aircraft, trucked down the street, and subjected to tests in Langley's far-field anechoic chamber to verify the transmissibility characteristics of the radome. This procedure was conducted within a few days, and scheduled around normal research flight operations. We believe that arranging for and conducting these tests at a remote site from the aircraft would have been more expensive and lengthy, or fewer tests would have been done -- adding technical risk to the program.

• During the months preceding the first field deployments (and actual microburst penetrations), weekly, then daily, communications and interactions were held amongst the researchers and "support" personnel to develop operational plans and procedures for the tests. Many simulation sessions were held in the TSRV simulator (a duplicate of the TSRV research flight deck) to evaluate wind shear display concepts, practice microburst wind shear encounters, validate recovery maneuvers and verify flight safety margins. Many valuable communications and interactions occurred informally, as hallway meetings, lunch time conversations, etc., where ideas were proposed, practicality limits checked, and relationships established. We believe that the teamwork built up by this entire group due to these interactions was the foundation on which the program became a success.

• With great regularity during the preparation for flight, and during the locally-based initial flight evaluations, the research group conducted system checkouts on the aircraft and the TSRV experimental avionics systems integration lab. These checkouts, particularly software evaluations for various research flight deck displays, were critical in iterating toward a final system design which met the researcher needs. The morning phone call asking a researcher to come by the lab or airplane after lunch to check out the latest software installment or display was a regular and invaluable occurrence. In our experience, this type of communication and development does not happen by telephone or videoconference, and can slow development or result in less design iterations. The difference in display development between a one-day turnaround of idea to test and a two-week or more cycle is tremendous.

• Prior to the major field deployments for the program, three to six months of flight testing for system development and evaluation occurred in both 1991 and 1992. During these flights, the primary researchers for each sensor system flew on-board the aircraft, operating and continuously observing sensor system performance (as they also did during the actual deployments). The benefits of such experience (aside from the cost/time savings and flexibility benefits of not automating every control function of the experimental equipment) included: the ability to observe system anomalies from start-up to shut-down (not just during "data on" times); researcher awareness of the entire flight environment affecting system performance (not just reading pre-selected parameters of telemetered data); and the development of a team spirit by the on-board crew. The cost of having such a lengthy preparation period for a remotely-sited aircraft, where the entire crew can only be involved if a significant number of them are on travel, would have been significant for the size crew we used in these experiments. Yet without this preparation, we do not believe the systems would have worked in time for the scheduled deployments and the flight test program would have been significantly delayed. Since flights had to occur during a four month period in the summer (to maximize likelihood of encountering an event), missing this window would mean delaying testing for a year. Especially during the time before the second year's deployments, absolutely every minute of preparation time was essential since the systems were not fully working until just weeks prior to the field deployments.

During the 30 months for which the Wind Shear Program was a TSRV aircraft customer, there were other flight programs conducted on the aircraft. Each of these programs used, to varying degrees, all of the access, resources, proximity, and interaction with the research aircraft as did the Wind Shear Program. In our view, each of these programs was successful on its own and the pace of juggling tests, requirements, schedules, and installations, all intermingled, all changing in real time due to uncontrollable variables, was a notable accomplishment. We believe that if the aircraft were
located 2000 miles away, this quick reaction, adjustment, and pace could not have happened. Due to long-distance logistics, these projects would have needed rigid, serially-sequenced schedules and anything close to the above listed results would have required more time to produce, would have therefore cost more, and would have achieved less.

Summary and Conclusions

Based on our experiences in conducting flight tests using "local" research aircraft and remotely-sited research aircraft, we believe that a legitimate case can be made for both. Our experience is that it is inherently most efficient (for the program) to collocate the people and facilities required to conduct a given program. For various reasons, this choice is not always possible. Dryden offers unique capabilities and facilities that are not available elsewhere in this country (and in some aspects, the world). Using these capabilities and facilities from across the country can be easy or difficult, depending on the nature of coupling among the people and facilities required to accomplish the program (as we have discussed above) and the expertise at Dryden for the tasks required.

We believe that all available evidence continues to support the Aeronautics Roles and Missions decision that all flight research activities will be conducted at Dryden unless programmatic considerations (including but not limited to cost and/or schedule) require the testing to be conducted at one of the other Aeronautics centers. In the case of the 757 replacement for the TSRV (B-737), we believe that Langley's track record in operating the TSRV for research, and our research program plans for using the 757 in a similar way, supports the decision to site the 757 at Langley.

If NASA intends to continue the type of research conducted using the TSRV over the last twenty years and meet AST and HSR program commitments (NASA would seem to be highly motivated in this direction since flight deck automation complexity and pilot performance are by far the leading causes of today's airline accidents), then the research process from conception-to-simulation-to-flight must be efficient, available, and utilized. Separation of any link in this chain is nearly equivalent to eliminating this type of research altogether. For the reasons itemized in this paper, we believe small flight projects would not be attempted, fewer large projects would get tested, and those that were tested would not be performed as efficiently (or effectively) as would be the case if the researchers and their testbed aircraft were collocated. Our belief in this regard is not a reflection of the quality of personnel at a remote site, but simply a reflection of the large logistical, communication, and integration barriers that inevitably result.