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Gear Up 2000: Women in Motion

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Papers submitted to the second
Technical Paper Contest for Women

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INTRODUCTION

Two of the major concerns of the NASA Ames Research Center (NASA ARC) Advisory Committee for Women (ACW) are that recruitment of women scientists, engineers, and technicians needs to increase, and that barriers to advancement need to be removed to improve the representation of women in middle and upper management and scientific positions. One strategy that addressed this concern was the ACW sponsorship of the Technical Paper Contest for Women. The first Contest was held in 1992. This document contains the papers submitted to the second annual Tech Paper Contest for Women. These papers represent a wide range of research and personal development topics.

In 1992, the Contest increased the visibility of both the civil service women and the women who work for contractors at Ames. In 1993, the contest was again successful in increasing the visibility of its participants. The contestants were featured in Astrogram articles and commended for their support of the Center's Equal Opportunity efforts. The highest ranking winners, Lourdes G. Birckelbaw and Wendy Lanser, presented their papers to the Board of Directors. National recognition was received when the top five papers were presented at the 1993 Society of Women Engineers (SWE) National Convention and Student Conference at a special technical session. Three other participants were also able to attend the Convention.

The ACW plans to sponsor a third contest in fiscal year 1994. A number of other NASA Centers have used the Tech Paper Contest model to begin expanding their own participation in SWE and in supporting the publication of papers authored by women.

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PILOTED SIMULATION STUDY OF TWO TILT-WING CONTROL CONCEPTS

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Summary

A two-phase piloted simulation study was conducted to investigate alternative wing and flap controls for tilt-wing aircraft. The initial phase of the study compared the flying qualities of both a conventional (programmed) flap and an innovative geared flap. The second phase of the study introduced an alternate method of pilot control for the geared flap and further studied the flying qualities of the programmed flap, and two geared flap configurations. In general, the pilot ratings showed little variation between the programmed flap and the geared flap control concepts. Some differences between the two concepts were noticed and are discussed in this paper. The addition of pitch attitude stabilization in the second phase of the study greatly enhanced the aircraft flying qualities. This paper describes the simulated tilt-wing aircraft and the flap control concepts, and presents the results of both phases of the simulation study.

Introduction

Tilt-wing aircraft are a viable choice for vertical and short takeoff and landing (V/STOL) transports and other smaller V/STOL aircraft, because the tilt-wing concept lends itself well to reasonable efficiency in hover and to very good efficiency in cruise flight. A good technology base for tilt-wing aircraft exists. The first tilt-wing aircraft to transition from hover to forward flight was the Vertol VZ-2 in 1958. Other flight article tilt-wing aircraft included the Hiller X-18 (1958-1964), the Vought-Hiller-Ryan XC-142 (1964-1967), and the Canadair CL-84 (1965-1974). In particular, the XC-142 and the CL-84 flew military operational demonstrations.

Some significant issues associated with tilt-wing aircraft include wing buffet during decelerating or descending flight, a strong wing angle to speed dependence, wing generated pitching moments, and the requirement for a tail rotor or tail thruster to provide pitch control at low speeds and hover.

Renewed interest in tilt-wing aircraft from the military and civil communities resulted in the piloted simulation study at NASA Ames Research Center. This renewed interest includes use of tilt-wing aircraft for the U. S. Special Operations Command aircraft, the U. S. Air Force Advanced Theater Transport, NASA high speed rotorcraft studies, and proposed civil applications. A new look at tilt-wing aircraft was further motivated by advances in technologies such as propulsion, materials, and flight control systems which offer the potential to address shortfalls of previous tilt-wing aircraft.

Two piloted simulations of a transport size tilt-wing aircraft have been completed on the Ames Vertical Motion Simulator (VMS) (refs. 1–4). This paper presents the results of both simulations.

The first simulation evaluated and compared the flying qualities of two wing tilting concepts, a conventional programmed flap (where the wing is driven directly) and an innovative geared flap (where the flap serves as an aerodynamic servo to position the free-pivoting wing). The programmed flap was the control concept used by previous tilt-wing aircraft. The geared flap was first proposed by Churchill (ref. 5) and has the potential to eliminate the tail rotor or tail thruster required by previous tilt-wing aircraft in hover and low speeds for pitch control; this could result in a significant reduction in aircraft weight and complexity.

The second simulation introduced several refinements, including a variation to the pilot control of the geared flap, a redefinition of the pilot evaluation tasks, and control law refinements.

The combined objectives of both simulations were to: (1) simulate a representative tilt-wing aircraft, (2) develop control laws for the programmed flap and the geared flap control concepts, (3) evaluate and compare the flying qualities of the flap control concepts, and (4) determine the feasibility of eliminating the tail rotor or tail thruster using the geared flap concept.

This paper describes the simulated tilt-wing aircraft, the flap control concepts, and the experiment design including the simulation facility and the pilot evaluation tasks of both simulations. Results of the simulations are presented, including flying qualities comparisons between the flap control concepts for both piloted simulations and a discussion of the tail thruster pitch control power usage by each flap configuration during the second simulation.

Simulated Tilt-Wing Aircraft

The conceptual tilt-wing aircraft of this study was a mid-sized V/STOL transport aircraft, sized at about two-thirds the weight of a C-130. A tail thruster was included to provide pitch control during hover and low speeds. A sketch of this conceptual aircraft is shown in figure 1. The aircraft had an overall length of 92 ft, a gross weight of 87,000 lb, and a payload capability of 10,000 lb. It had four engines with 26 ft diameter propellers. The thrust to weight ratio was 1.15. The wing span was 109 ft with an aspect ratio of 9. The low horizontal tail was fully movable from 0° to 28° and was scheduled with wing incidence. The wing loading was 66 lb/ft^2 and the disk loading was 40 lb/ft^2.

Aircraft Control Effectors

During hover and low speed flight, longitudinal control was provided by the tail thruster and wing incidence, and pitch control was provided by the tail thruster. Pilot preference and choice of longitudinal control technique near hover was somewhat configuration dependent and will be discussed in the results of the second simulation. During conversion, the elevator, horizontal tail, and tail thruster provided pitch control. The throttle controlled altitude during hover and conversion. During airplane mode, all effectors worked conventionally.

Simulation Math Model

The longitudinal rigid airframe aerodynamic and dynamic characteristics were modeled completely. The aerodynamic model used a component buildup method to develop total forces and moments. Momentum theory was used to calculate propeller slipstream velocities which were then used with the "power-off" aerodynamics data to obtain "power-on" aerodynamic characteristics. Other elements in the math model included coupled-wing-body equations of motion, engine and propeller dynamics, programmed flap and geared flap controls, a generic landing gear model, and a buffet boundary model. Pitch axis stabilization was augmented in rate only during the first simulation and rate plus attitude during the second simulation. The first simulation did not include a ground effects model, however the second simulation did include a developmental ground effects model. During the first simulation, the simulation model cycled real-time at a frame rate of 15 msec on a CDC 875. During the second simulation, the simulation model cycled real-time at a frame rate of 10 msec on a Vax 9000.

Wing buffet is a significant issue of all tilt-wing aircraft. The buffet onset was defined from wind tunnel data and was a function of the effective wing angle-of-attack and the flap setting. The progressive deterioration of the flying qualities as deeper buffet was encountered was not modeled. A typical buffet boundary for the simulation is shown in figure 2 for a glideslope of –7.5°. It should be noted that as tilt-wing aircraft transition from forward flight to hover, aerodynamic lift is replaced by powered lift and buffet onset becomes a ride quality issue. Recovery from buffet is immediate with the application of power.

The lateral/directional dynamic characteristics were modeled using stability derivatives. The dominant features were high roll damping and the addition of turn coordination above 30 knots. This study concentrated on longitudinal flying qualities, hence, accurate modeling of the lateral-directional dynamics was considered less critical to the study. A description of the math model can be found in reference 4.

Flap Control Concepts

The programmed flap control concept uses a flap schedule that is basically a function of the wing incidence, although the pilot is provided an attenuation control. The pilot sets a desired wing incidence by using a beeper switch on the throttle grip which, in turn, sets the programmed flap deflection through cam or electrical control. The wing is directly driven by a hydraulic actuator, as shown in figure 3.

The geared flap control concept (ref. 5) uses the flap as an aerodynamic servo tab to control the wing incidence relative to the fuselage. A schematic of this flap control concept is shown in figure 4. The pilot input is done through a beeper switch located on the throttle grip or through a combination of the beeper switch and the longitudinal stick. Either way, the pilot input results in a flap deflection which in turn drives the wing incidence. The wing is essentially free pivoting (some damping is required) and is driven primarily by the forces generated by the flap deflections within the propeller slipstream. For example, an increase in flap deflection causes an unbalanced aerodynamic moment about the wing pivot, which is balanced when the wing rotates down canceling the moment via mechanical feedback to the flap through the wing/flap linkage. Aerodynamic moments generated by aircraft motion, friction and artificial damping also affect the pivoted wing response.

With the programmed flap concept, the aircraft needs a tail rotor or tail thruster for pitch control in hover and at low speeds, since elevator effectiveness is not sufficient at lower velocities. Note on figure 5 that the upsetting aircraft pitching moments are caused by the thrust offset from the fuselage center of gravity as the wing tilts.

The geared flap concept, may potentially be used to eliminate the tail rotor or tail thruster (or at least to significantly reduce the pitch control power required from these auxiliary tail devices) by using the essentially free-pivoting wing driven by the geared flap to provide both longitudinal and pitch control.

Simulation Experiment

Simulation Facility

Both simulations were conducted on the NASA Ames VMS. The VMS operational limits are ±22 ft of vertical motion and, depending on cab orientation, ±15 ft of longitudinal or lateral motion. Both simulations used the longitudinal orientation to focus on the longitudinal flying qualities of the aircraft. In the VMS the pilots can experience accelerations of up to ±22 ft/sec^2 vertically, ±13 ft/sec^2 longitudinally, and ±10 ft/sec^2 laterally. A sketch of the VMS is shown in figure 6.

Cockpit Layout

The same basic cockpit instruments were used for both simulations, although several instruments were arranged differently for the second simulation at the pilots' request. Glideslope and localizer information were added for the second simulation and were displayed around the attitude direction indicator (ADI). A new instrument was also added for the second simulation which combined both wing incidence and flap angle information. In addition to the analog instruments, the first simulation displayed wing incidence digitally, and the second simulation displayed both wing incidence and speed digitally. For both simulations the cockpit controls consisted of a center stick with a trim button, a left-hand throttle with a spring return rotary beep switch, rudder pedals, and a flap lever located to the left of the pilot and aft of the throttle. The flap lever was used only with the programmed flap configuration; the lever was graduated to produce 0-100% gain on the programmed flap schedule. During the first simulation, a stick shaker was installed to cue the pilot when buffet was encountered. During the second simulation, a seat shaker (no stick shaker was used) and an angle-of-attack warning light were installed to cue the pilot when buffet was encountered.

Experiment Configurations

During the first simulation, two flap control configurations, programmed flap (PF) and geared flap on the beep (GFB), were evaluated by the pilots. In the GFB configuration, the pilot controlled the geared flap using the beep switch on the throttle grip only. During the second simulation, a third flap configuration was added, geared flap on the stick (GFS). The GFS configuration allowed the pilot to control the geared flap using a combination of both the longitudinal stick and the beep switch.

All three flap configurations used the spring return rotary beep switch embedded on the throttle grip. Release of the beep switch resulted in a constant value of the last resulting wing incidence. In the PF configuration the pilot beep switch input generated a wing rate command. In the GFB configuration the pilot beep switch input generated a reference (desired) wing incidence which through the control laws resulted in a flap setting that drove the wing incidence towards the desired wing incidence. In the GFS configuration the pilot beep switch input and the longitudinal stick input were combined to generate a reference wing incidence which through the flap control resulted in the desired wing incidence. For the latter configuration the pilot had full authority of wing tilt on the beep switch and a limited authority on the longitudinal stick. The stick authority translated to about 2° of wing per inch of longitudinal stick for wing incidences of 25°–105° and was gain scheduled to 0° for wing incidences less than 25°. It should be noted that with no longitudinal stick activity, the GFB and the GFS configurations yield the same aircraft characteristics.

Evaluation Tasks

First Simulation

The evaluation tasks during the first simulation were hover station keeping, outbound transition, descending decelerating inbound transition to hover, and a short takeoff and landing (STOL) landing task.

Hover station keeping– The aircraft was positioned over a checkerboard pattern to the right of the runway at 50 ft altitude in hover. The pilots attempted to maintain position and altitude for 3 minutes.

Outbound transition– The aircraft was positioned over a predetermined location on the runway at 50 ft altitude in hover. The pilots smoothly increased power and ascended to 100 ft altitude, then incrementally lowered the wing while trying to maintain altitude. The task ended at 180–200 knots and 500 ft altitude.

Descending decelerating inbound transition to hover– The aircraft was positioned initially downwind of the runway at 500 ft altitude and 12,000 ft to the left of the runway with 200 knots velocity. The pilots slowed the aircraft velocity to about 180 knots and lowered the landing gear on the downwind leg. On the base leg, the pilots descended to 300 ft altitude, slowed the velocity to about 100 knots and raised the wing incidence to 10°. On the final approach, the pilots incrementally raised the wing, adjusting power accordingly, and slowed the velocity to about 35 knots. A desired glideslope was not specified, the pilots were allowed to use whatever glideslope they preferred. As the pilots approached the hover position above the touchdown point, they descended to 50 ft altitude and continued to raise the wing as appropriate. The task ended when the pilots brought the aircraft to a hover and landed.

STOL Landing– The aircraft was positioned initially at 500 ft altitude and 5,000 ft to the left of the runway with 60 knots velocity and with the landing gear down. The task ended when the aircraft landed at the target position.

Second Simulation

The evaluation tasks were redefined for the second simulation to emphasize the flying qualities differences between the control concepts during conversion and hover within the boundaries permitted by the math model (i.e., primarily longitudinal flying qualities). The baseline altitude was chosen at 70 ft to avoid configuration-specific ground effects. The tasks were bounded by specific performance standards, thereby permitting a better application of the Cooper-Harper pilot rating method (ref. 6). The four tasks and their performance standards are described below.

Hover station keeping with turbulence– The aircraft was positioned over a predetermined location on the runway at 70 ft altitude in hover. The turbulence level was severe at 8 ft/sec rms in all three axes. The pilot attempted to maintain position for 70 sec, using whatever technique the pilot preferred (wing incidence, pitch attitude adjustment, or a combination of the two). Desired performance was defined as ±10 ft altitude, ±25 ft longitudinal position, ±25 ft lateral position and ±10° heading. Adequate performance was defined as ±20 ft altitude, ±50 ft longitudinal position, ±50 ft lateral position and ±15° heading.

Level inbound transition to hover– The aircraft was positioned initially short of the runway threshold at 70 ft altitude with 93 knots velocity (this initial velocity corresponded to 9° wing angle in the PF configuration and to 16° wing angle in the geared flap (GF) configurations—for the same velocity, the wing angles are different because of different flap settings). The pilots decelerated the aircraft to arrive at a hover over the designated end position while trying to maintain 70 ft altitude, level pitch attitude, and avoiding buffet. Desired performance was defined as ±10 ft for altitude, ±2° for pitch attitude, and less than 3 sec total buffet time. Adequate performance was defined as ±20 ft for altitude, ±4° for pitch attitude, and a total buffet time greater than 3 seconds.

Descending decelerating inbound transition to hover– The aircraft was positioned initially 6,000 ft short of the runway at 800 ft altitude. The initial wing incidence (46° for PF and 52° for GFB and GFS) was selected to yield a speed of 40 knots, hence investigating only the final stages of deceleration where buffet considerations were minimized (see fig. 2) and where differences among the control configurations were maximized. The pilots captured the –7.5° glideslope using both electronic guidance (glideslope and localizer guidance on the ADI) and the visual approach slope indicator (VASI) lights on the runway and established a nominal sink rate of 550 ft/min. At 400 ft altitude, the wing incidence was increased, and power was added as necessary to maintain flightpath. The pilots decelerated the aircraft to a hover at 70 ft altitude while maintaining level pitch attitude and avoiding an overshoot of the designated end position. The pilots were to avoid buffet as much as possible by using low deceleration rates and by avoiding low power settings. Desired performance was defined as ±1/2 dot (a dot is a glideslope guidance marker on the ADI) at altitudes greater than 200 ft and ±1 dot at altitudes less than 200 ft, ±2° pitch attitude, no overshoot of the final hover position, and less than 5 sec total buffet time. Adequate performance was defined as ±1 dot at all attitudes, ±4° pitch attitude, one overshoot of the final hover position, and more than 5 sec total buffet time.

Longitudinal reposition– The aircraft was positioned initially short of the runway threshold at 70 ft altitude in hover. The pilots began a forward translation, achieving a wing angle that was 40 deg less than the initial wing angle at hover, then started decelerating back to a hover, and ended the task in hover at 70 ft altitude over the designated end position. The pilots were to maintain 70 ft altitude and level attitude, avoid buffet, and arrive at the end position without overshoot. Desired performance was defined as ±10 ft altitude, ±2° pitch attitude, less than 3 sec total buffet time, and no overshoot of the final hover position. Adequate performance was defined as ±20 ft altitude, ±4° pitch attitude, more than 3 sec total buffet time, and one overshoot of the final hover position.

Task Environment and Visual Cues

First Simulation

All the tasks were evaluated in daytime calm conditions and were performed visually without the aid of a flight director. No visual enhancements were added to the computer generated database.

Second Simulation

The tasks were evaluated in daytime calm conditions with the exception of the hover station-keeping task which included turbulence. The tasks were performed visually, except for the descending decelerating transition to hover, which could be performed both visually and with the aid of the glideslope and localizer information displayed on the ADI.

In addition to an improved visual system, several visual cues were added to aid the pilots. VASI lights were added to help the pilots maintain glideslope. Runway cracks and tire marks were added to aid in depth perception and to add realism. Several vertical pylons consisting of stacked color-coded 10 ft cubes were added along the edge of the runway to provide height information. STOL runway markings were superimposed over the main runway and used to define task end positions.

Evaluation Pilots

First Simulation

Nine evaluation pilots participated in the study. Six pilots had experience with fixed wing aircraft, and three had experience with helicopters. Three pilots also had experience with powered-lift aircraft; one of these pilots also had experience flying the XC-142 tilt-wing.

Second Simulation

Six evaluation pilots participated in the study. They all had extensive experience with fixed wing aircraft and helicopters; five also had powered-lift aircraft experience. Four pilots had experience flying the XV-15 tiltrotor; one of these pilots also had experience flying the V-22 tiltrotor. One pilot also had experience flying the CL-84 tilt-wing.

Results

The flying qualities results of both simulations are summarized in figure 7 on a Cooper-Harper scale. The symbols and brackets in figure 7 indicate the mean pilot ratings and the maximum and minimum pilot ratings, respectively. The three dashed brackets in the figure indicate one pilot rating in each case that was markedly different from the other ratings (and will be discussed later). Individual task results are discussed further in this section.

During the first simulation, the pilot ratings exhibited large variations, as seen in figure 7. This was probably due to loose constraints on task performance definitions and to different levels of pilot training.

During the second simulation, the evaluation tasks were defined more completely and desired performance standards were identified for each evaluation task. Aircraft and simulator familiarization tasks were defined and practice runs were monitored to assure that each pilot attained a similar training level. This, coupled with better instructions on general tilt-wing characteristics, led to better trained pilots; consequently, the pilot ratings exhibited less variation.

During the first simulation, pitch axis stabilization was augmented in rate only and rate plus attitude during the second simulation. Attitude augmentation was an improvement which greatly alleviated the pilot pitch-axis-control workload. This effect can be seen in the pitch activity in figure 8. With the addition of pitch attitude stabilization in the second simulation, the pilots rarely reported any pitch axis control problems.

During hover, the initial response of the geared flap configurations to a forward wing command was a longitudinal aircraft acceleration transient in the rearward direction. The rearward acceleration transient is caused by a transient increase in force (lift) on the wing caused by the initial flap deflection in the propeller slipstream. Damping about the wing pivot was increased in the second simulation to reduce this adverse response. Although still noticeable to the pilots, time histories showed that the magnitudes of the rearward acceleration transients were reduced to about a third.

Pilot compensation and workload comments in this paper are based on the pilot subjective comments. Pilot performance (desired or adequate–as defined in the task definitions) during the second simulation was measured during evaluation runs. Comments on the task performance are based on actual data and not on pilot comments.

First Simulation Results

Hover Station Keeping

Although some pilots could not detect a difference in height control between the PF and the GFB configurations, others felt that height control was less precise with the GFB configuration. With both configurations the pilots had difficulty visually holding position over the checkerboard pad and tended to drift about 50 ft and sometimes as much as 100 ft.

Outbound Transition

The first difference noted by the pilots between the PF and the GFB configurations during this task was the initial longitudinal aircraft response to a forward wing command from the hover position. The initial response with the GFB configuration was a rearward acceleration transient which resulted in a delayed longitudinal response compared to the PF configuration.

During mid-conversion, the aircraft experienced large pitch down moments with both the PF and the GFB configurations; however, the majority of the pilots felt that the pitch down attitudes encountered with the GFB configuration were not as severe as those encountered with the PF configuration. At lower wing incidences, wing movements resulted in an aircraft heave response which was similar for both flap configurations. One pilot, who was a former XC-142 project pilot, noted that both the pitch down moments and the aircraft heave response were similar to the XC-142 aircraft behavior.

The pilot workload was associated with altitude control and with trying to minimize the pitch down attitudes encountered during mid-conversion. Pitch oscillations were sometimes encountered while trying to correct this problem. Throttle sensitivity and heave damping were low, and sometimes caused overcontrol while monitoring altitude.

Descending Decelerating Inbound Transition To Hover

The aircraft heave response to wing movements was noticed again with both configurations. At the higher wing incidences, wing movements produced less heave and more drag. Some pilots felt that the altitude changes due to the heave response were more exaggerated with the GFB configuration than with the PF configuration. Buffet was encountered with both configurations during mid-wing angles.

The pilot workload was associated with controlling pitch attitude, altitude and glideslope. Pilot compensation was required with power to offset the heave response to wing movements.

Stol Landings

The pilot workload was higher with the GFB configuration than with the PF configurations and was associated with trying to avoid buffet which was encountered more often with the GFB configuration. There was some initial maneuvering in altitude and velocity, but the overall approach was fairly smooth. Pilots controlled glideslope and velocity by a combination of throttle adjustments and pitch commands.

Second Simulation Results

Hover Station Keeping With Turbulence

As mentioned in the task definition, the pilots were allowed to use whatever technique they preferred (wing incidence, pitch attitude, or a combination of the two) to regulate longitudinal position in hover. With the PF configuration the majority of the pilots preferred controlling their longitudinal position with wing incidence. This preference has been noted before by CL-84 pilots, "For forward and aft translation the pilots preferred to use wing tilt while holding the fuselage level. This was smoother, easier and more natural than tilting the whole aircraft" (ref. 7).

With both GF configurations most pilots preferred using pitch attitude over wing incidence to control longitudinal positioning. One pilot evaluated this task using both techniques and gave the pitch attitude technique a 5 and the wing incidence technique a 7 where the degradation was primarily attributed to a delay in longitudinal response leading to oscillatory longitudinal characteristics. This delay stems from a characteristic of the GF configurations mentioned earlier, where the initial response to a forward wing command results in a rearward acceleration transient. This response characteristic was also responsible for degraded speed predictability near hover with the GF configurations compared to the PF configuration.

One pilot evaluated this task with the GFB configuration on three separate runs: one with turbulence in all three axes, one with no lateral turbulence, and one with no turbulence. The pilot flying qualities ratings were 3, 2.5 and 1.5, respectively.

One hypothesis concerning the GFS configuration was that it would reduce pitch control requirements, and hence, pitch activity might be lower than with the

GFB configuration. However, examination of data did not show reduced pitch activity compared to the GFB configuration. This is probably due to the current level of control law development which allowed insufficient wing authority on the longitudinal stick (about ±10% only).

The workload and pilot compensation associated with height and position control with both GF configurations were similar to the PF configuration, except that the lag between wing movement and perceptible longitudinal aircraft response required moderate to considerable lead compensation.

In general, the pilots achieved desired performance standards for altitude, lateral position, and heading, and adequate performance for longitudinal position. Average longitudinal drifts were –14 ft to 51 ft with the PF, –13 ft to 38 ft with the GFB, and –5 ft to 38 ft with the GFS. In most cases the pilots were unable to perceive the longitudinal drift because of limited visual cues.

Level Inbound Transition To Hover

At low wing incidence, the short term response to wing movements was an aircraft heave response. Some pilots felt the heave response to initial wing change was reduced with the GFB configuration compared to the PF configuration; one pilot noted that the "have response to initial beep (wing tilt) was much better than (the) programmed flap, coupling (was) not as bad." Another pilot felt the throttle usage to control the heave response was lower with the GFB configurations and thus an "improvement over the programmed flap." The heave response with the GFS configuration was similar to the GFB configuration.

All pilots agreed that the time spent in buffet increased with the GFB and the GFS configurations compared to the PF configuration (an average total buffet time of 8.0 sec for the GFB and 8.4 sec for the GFS vs. 2.1 sec for the PF).

Power management was required by the pilots to offset the heave response to a wing change and to avoid buffet (especially with both GF configurations). Pilot compensation was also required to predict speed towards the hover end position.

In general, the pilots achieved desired performance for altitude and pitch attitude with all three flap configurations, desired performance for buffet with the PF configuration, but only adequate performance for buffet with both GF configurations.

Comments on buffet– The increased time spent in buffet with the GF configurations is most likely due to lower flap settings than the PF configuration for similar wing angles. Examination of time histories showed that buffet was encountered during the mid-wing-incidence range of 35°–60° for both the PF and the GFB configurations. During this mid-wing-incidence range, the flap range was 20°–40° for the PF and 5°–20° for the GFB.

Increase in leading and trailing edge flap deflections on the CL-84-1 improved the buffet boundary of the aircraft (ref. 8). Also, one of the methods proposed to alleviate buffet from results of flight investigations of the VZ-2 was larger flap deflections (ref. 9).

Descending Decelerating Inbound Transition To Hover

The differences among the three flap configurations were minimal during this task. Most pilots felt the workload was low because the task was slow and glideslope control required only power regulations. However, with the PF configuration, two pilots noticed a coupling between wing movement and vertical response and felt that the workload was high due to poor heave predictability. Examination of the strip charts showed that the reported heave control difficulties were associated with large abrupt wing movements.

With the GF configuration one pilot noted that he "felt glideslope tracking was the tightest so far" compared to the other two flap configurations; another pilot said "height control was easier than with the PF configuration." Since the task definition required a level pitch attitude, longitudinal stick activity was minimal, and the GFS configuration showed only subtle differences from the GFB configuration.

Largely because of the task structuring, no buffet was encountered with any of the flap configurations. In general, the pilots achieved all the desired performance standards with all three flap configurations.

Longitudinal Reposition

As noted previously, the short term response to a wing incidence change at the lower wing angles was a heave response with all flap configurations. Again, the pilots noticed that the initial longitudinal response to a forward wing command from the hover position was sluggish with both GF configurations compared to the PF configuration; hence, the resulting degraded speed predictability near hover of both GF configurations was noted by the pilots.

Using the wing incidence technique for final hover acquisition with the GFB configuration, one pilot got into a divergent position pilot induced oscillation (PIO) "that could not be suppressed with any amount of compensation" (the rating was a 7). Time histories showed that the flap was at the lower limit during most of the hover acquisition, which caused a distorted wing flap response.

Initially, the tail thruster pitch control power of the GFS configuration was ±0.3 rad/sec^2, which was half the pitch control power of the other two flap configurations. Several pilots evaluated this configuration without encountering any tail thruster pitch control power limits. However, one pilot, using an aggressive wing tilting technique, did encounter loss of aircraft control because of tail thruster control power saturation, "...an overshoot was developing which required continuous wing beep (wing movement). As power was increased to account for the loss of wing lift, the power-pitch coupling response became apparent and objectionable. It was countered with stick input but when the flaps reached the deflection limit a divergent pitch PIO rapidly developed that resulted in loss of control after two oscillations." This resulted in the flying qualities rating of 10. The tail thruster pitch control power of the GFS configuration was increased to ±0.6 rad/sec^2 (the same as the other two configurations), and the problem did not occur again. The same pilot using the same aggressive wing tilting technique evaluated the task again and the rating was a 5.

Pilot compensation was required to lead the heave response with throttle and to predict speed towards the end of the task. The workload was primarily in the vertical axis trying to maintain altitude. One pilot noted that, "...conditions were ideal and that any complications due to wind, turbulence or visibility would significantly add to the workload."

In general, with the PF configuration the pilots achieved all the desired performance standards. With both GF configurations, the pilots achieved desired performance standards for altitude and buffet, and desired to adequate performance for pitch attitude.

Tail Thruster Pitch Control Power Usage

The maximum tail thruster pitch control power was 0.6 rad/sec^2 for both the PF and the GFB configurations. As previously discussed, the maximum pitch control power of the GFS configuration was initially 0.3 rad/sec^2, and was later increased to 0.6 rad/sec^2. The V/STOL Handling Qualities Criteria (ref. 10) recommends that available pitch control power be in the range of 0.4–0.8 rad/sec^2 in hover and 0.4–0.6 rad/sec^2 STOL mode.

The following discussion on pitch control power usage refers to results obtained during the second simulation only. The pitch control power commanded is a result of the pilot's longitudinal stick input and the SAS (stability augmentation system) input. The longitudinal stick input to tail thruster command logic was the same for each of the three configurations. The SAS input was added to the longitudinal stick input, and the combined pitch control power was limited to 0.6 rad/sec^2. The tail thruster was not phased out at the higher velocities.

The maximum pitch control power used during all runs evaluated for each task is summarized in table 1. For the hover case, the maximum pitch control power used with the PF and the GFB configurations is broken down according to pilot longitudinal positioning technique (i.e., wing or stick).

Table 1. Maximum pitch control power encountered (rad/sec^2)

	Longitudinal reposition	Level inbound	Descending decelerating
PF	0.24	0.18	0.13
GFB	0.34	0.36	0.18
GFS	0.34	0.31	0.22
	Hover in turbulence		
PF (wing)[a]	0.18		
PF (stick)	0.26		
GFB (wing)[b]	0.22		
GFB (stick)[a]	0.14		
GFS (wing and stick)	0.45		

[a]Preferred technique for controlling longitudinal position.

[b]One evaluated run only.

It is important to note that in most cases the maximum pitch control power encountered was an isolated "spike" in the data, often resulting from aggressive wing tilting. This occurred especially in the case of the geared flap configurations where aggressive wing tilting drove the flap into a position limit (0° if tilting up or 60° if tilting down) which then resulted in a large spike increase in pitch control power. Aggressive wing tilting also increased the pitch control power usage of the programmed flap, but because the programmed flap was scheduled, flap position limits were never encountered and the increases in pitch control power were not as large as with the geared flap.

Comparison of the values shown in table 1 does not show a reduction in pitch control power used by the geared flap configurations compared to the programmed flap configuration. However, the values in table 1 are pitch control power results of the flap concepts at the current stage in development. Further control law development and more study on the treatment of flap stops and wing pivot location are needed to address the pitch control power issue.

Summary of Results

1. The pilot ratings and comments showed that in general, the programmed flap and the two geared flap configurations had similar flying qualities (in the level 1–2 range). Hence, the geared flap concept is feasible for tilt-wing aircraft.

2. Two main differences between the programmed flap and the geared flap configurations were the amount of time spent in buffet and the longitudinal aircraft response in hover. The amount of time spent in buffet was greater with both geared flap configurations than with the programmed flap configuration because of lower flap deflections for similar wing incidences. With both geared flap configurations, the initial longitudinal aircraft response to a forward wing command from hover was a rearward acceleration transient. This acceleration transient resulted in sluggish longitudinal aircraft response and hence in degraded speed predictability near hover with both geared flap configurations compared to the programmed flap configuration. The transient response was reduced in the second simulation with the addition of damping about the wing pivot.

3. The pitch attitude stability augmentation system (SAS) added to the flap configurations during the second simulation was a significant improvement over the pitch rate SAS of the first simulation, and greatly alleviated the pilot workload associated with pitch axis control.

4. At the current level of development the results did not show a reduction in tail thruster pitch control power usage for the geared flap configurations compared to the programmed flap configuration.

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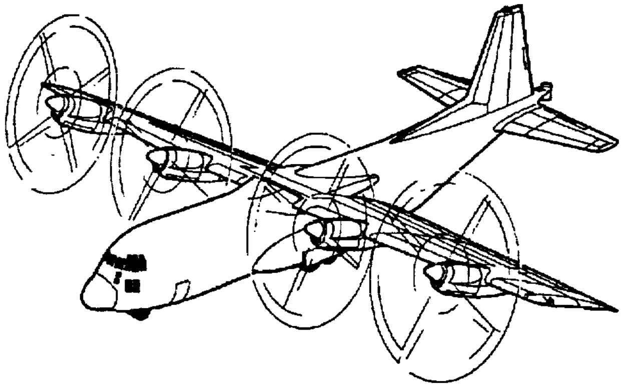

Figure 1. Simulate tilt-wing aircraft.

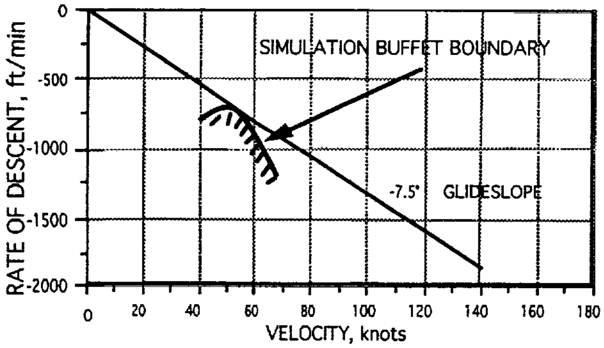

Figure 2. Simulation buffet boundary for –75% glideslope.

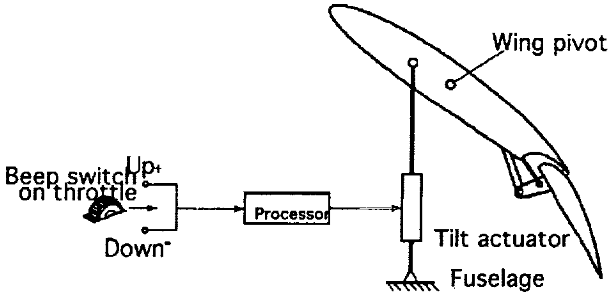

Figure 3. Programmed flap control concept.

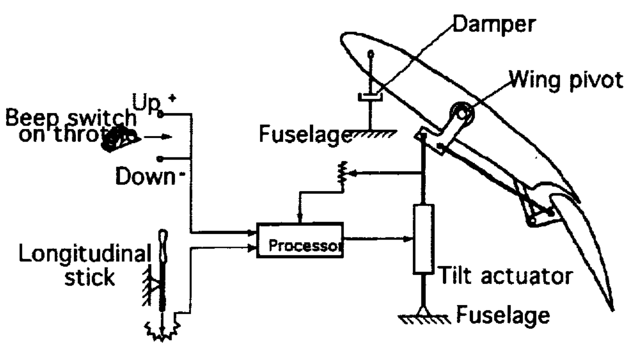

Figure 4. Geared flap control concept.

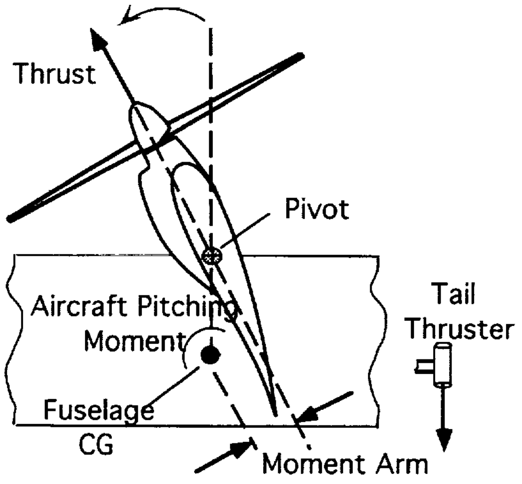

Figure 5. Tilt-wing pitching moments due to wing rotation.

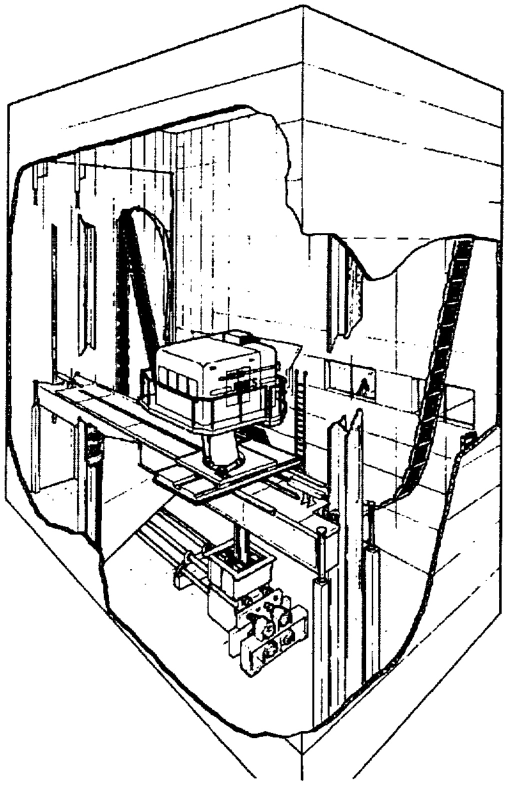

Figure 6. Vertical motion simulator.

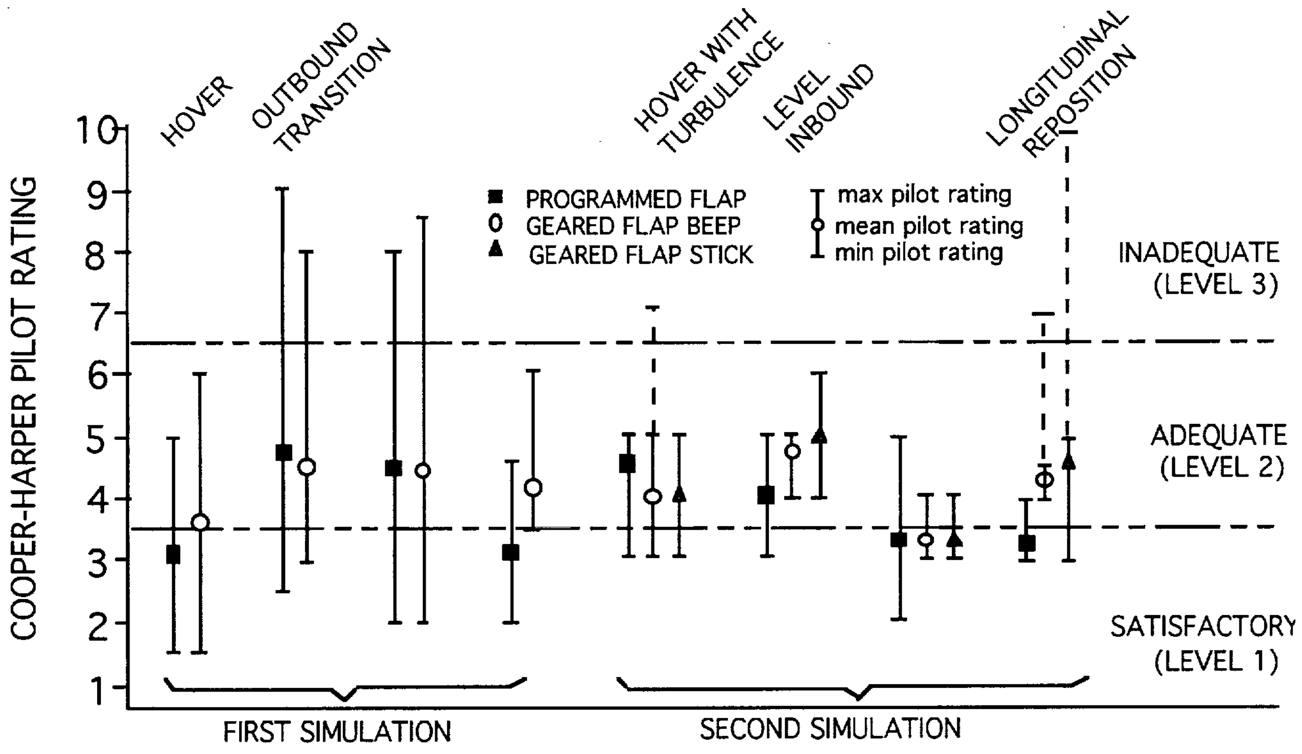

Figure 7. Flying qualities results.

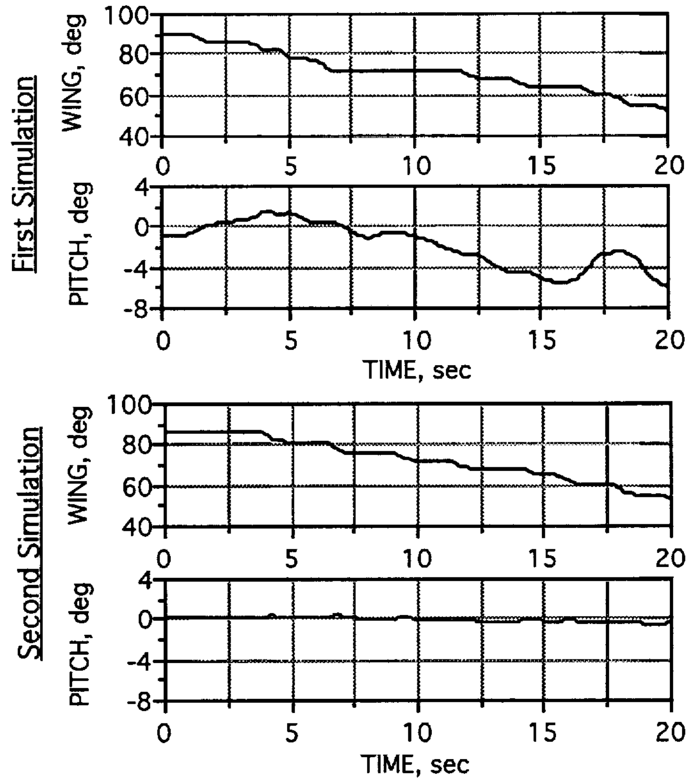

Figure 8. Time histories before and after pitch attitude stabilization.

Biography

Lourdes G. Birckelbaw has been working at NASA Ames Research Center since 1989. She is currently working in the STOVL/Powered-Lift Technology Branch where she was initially involved in the piloted simulation evaluation of ski jump and short takeoff performance of a supersonic STOVL aircraft. Most recently she has been a key researcher in the Ames piloted simulation study of wing/flap controls for tilt-wing V/STOL aircraft. She received a B. S. in Aerospace Engineering from Georgia Institute of Technology in 1983, after participating in the cooperative education program for two years with Lockheed Aeronautical Systems Company. She received her M.S. in Aerospace Engineering from Georgia Tech. in 1986. From 1983–1989, she worked at Lockheed Aeronautical Systems Company including two years in the Flight Simulations Group and four years in the Flight Controls Group.

Lloyd D. Corliss is presently in charge of flight controls for the NASA Ames Military Technology Office. He earned a B.S (1963) and an M.S. (1966) in Electrical Engineering from Michigan State University, and has completed post-graduate studies in Aeronautics at Stanford University. He was formerly with the US Army Research Technology Lab at Moffett Field, CA, where he served as flight controls project engineer for the development of several digital flight control systems on both VTOL and helicopter experimental test bed aircraft.
Mr. Corliss has conducted numerous simulation and flight test studies in the area of controls and flying qualities, and he has authored over 25 technical publications.
Mr. Corliss was the recipient in 1983 of the Department of the Army R&D Achievement Award and is a Professional Engineer.

Ms. Birckelbaw and Mr. Corliss are recipients of the 1991 Wright Brothers Medal awarded by SAE to the authors of the best paper relating to the invention, development, design, or operation of an aircraft or spacecraft. The award winning paper was titled "Handling Qualities Results of an Initial Geared Flap Tilt Wing Piloted Simulation" (SAE 911201).

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ENGINE EXHAUST CHARACTERISTICS EVALUATION IN SUPPORT OF AIRCRAFT ACOUSTIC TESTING

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Summary

NASA Dryden Flight Research Facility and NASA Langley Research Center completed a joint acoustic flight test program. Test objectives were (1) to quantify and evaluate subsonic climb-to-cruise noise and (2) to obtain a quality noise database for use in validating the Aircraft Noise Prediction Program. These tests were conducted using aircraft with engines that represent the high nozzle pressure ratio of future transport designs. Test flights were completed at subsonic speeds that exceeded Mach 0.3 using F-18 and F-16XL aircraft. This paper describes the efforts of NASA Dryden Flight Research Facility in this flight test program. Topics discussed include the test aircraft, setup, and matrix. In addition, the engine modeling codes and nozzle exhaust characteristics are described.

Introduction

Environmental issues are a continuing concern for designers of new transport aircraft. To meet the strict noise requirements of Federal Aviation Regulation, pt. 36, stage III—Community Noise Standards (ref. 1), such designers need to improve the understanding of engine noise levels and sources. Because of these needs, flight test techniques were developed, and a series of flight tests were conducted at NASA Dryden Flight Research Facility (DFRF), Edwards, California, in conjunction with NASA Langley Research Center (LaRC), Hampton, Virginia. The DFRF role in the study was to set up the flight test, provide the test aircraft, and reduce the flight data into exhaust characteristics that have a major impact on jet noise. The LaRC incorporated the exhaust characteristics into the Aircraft Noise Prediction Program (ANOPP) for validation of theoretical acoustic data.

To understand the acoustical characteristics of engines representative of future transport airplanes, designers must study current aircraft and update the noise prediction codes. The aeronautics industry generally uses the ANOPP for subsonic transport noise prediction. This computer program has a wide range of noise-prediction modules that can be upgraded to assess advanced engine and aerodynamic concepts for reducing noise (ref. 2). However, ANOPP is semiempirical and does not include a large amount of flight data generated with engines operating at high nozzle pressure ratios (NPRs) or at speeds above Mach 0.3.

Future advanced transport design concepts will have engines designed for efficient flight at high speeds and will tend to have the thermodynamic cycle of a turbojet or a low-bypass turbofan. Such concepts will also have high NPR and jet velocities similar to current military fighter engines. High NPR and jet velocity raises concerns about takeoff, climb, and landing noise. Noise-suppression requirements are already in place for up to a radius of 5 n. mi. around airports for conventional airplanes. For future transports, new noise-suppression requirements may need to be determined for a radius of up to 50 n. mi.

To obtain a high-quality database, DFRF and LaRC conducted a joint study of the subsonic climb-to-cruise noise acoustics using aircraft with engines operating at high NPR and flight speeds above Mach 0.3. The flight study consisted of a series of flights over microphone arrays. The test vehicles were an F-18 and an F-16XL, ship 2, aircraft. In the subsonic climb portion of the study, the flight matrix consisted of flyovers at various altitudes and Mach numbers. For the ANOPP evaluation flyovers, the test points were conducted at a constant altitude, while the Mach number varied. Ground tests were conducted on both aircraft to establish baseline acoustic levels under static conditions. For these tests, the measured engine data were collected and later analyzed by an F404-GE-400 in-flight thrust code. The code predicted the engine exhaust characteristics of exhaust velocity and Mach number, which cannot be directly obtained from the measured engine data.

This paper describes the role of DFRF in this flight test program. Topics discussed include the test aircraft, setup, and matrix as well as the engine modeling codes and nozzle exhaust characteristics.

Aircraft Description

The flight tests were conducted using F-18 and F-16XL, ship 2, because the engines of these aircraft can simulate exhaust characteristics of future transports. Figure 1 shows an F-18 aircraft. This supersonic, high-performance fighter has excellent transonic maneuverability and is powered by two F404-GE-400 (General Electric Company, Lynn, Mass.) afterburning turbofan engines. Both engines are mounted close together in the aft fuselage. The F404-GE-400 engine is in the 16,000-lb thrust class (ref. 3). The standard F-18 maintenance data recorder was used to record a limited number of airplane and engine parameters on board the aircraft.

Figure 2 shows the F-16XL, ship 2. This two-seat, supersonic, fighter aircraft is modified with a cranked arrow delta wing and is powered by a single F110-GE-129 (General Electric Company, Lynn, Mass.) afterburning turbofan engine. The F110-GE-129 is in the 29,000-lb thrust class. This aircraft and engine were fully instrumented for flight research (ref. 4). Data were telemetered from the aircraft and recorded at DFRF.

Setup and Flight Test Matrices

The flight tests were flown over Rogers Lake (dry) adjacent to DFRF. At an elevation of 2300 ft, this dry lakebed provides a flat, interference-free area for acoustic testing. The LaRc personnel set up analog and digital microphone arrays on the lakebed. Figure 3 shows the array which consisted of 28 microphones placed along the "fly-by" line on the northeast side of the lakebed. This area was ideal for tracking because of its close proximity to the DFRF radar site. For the static acoustic tests, both aircraft were tied down on the thrust stand pad at the Air Force Flight Test Center, Edwards, California. Microphones were placed in an arc 70 ft from the tailpipes of these aircraft (fig. 4).

These flight tests were conducted in two segments: subsonic climb-to-cruise and ANOPP validation. The flight matrix for the climb-to-cruise segment consisted of level flight acceleration at various Mach numbers to simulate points along an optimum climb profile. Altitudes varied from 3,500 to 32,500 ft with speeds from Mach 0.3 to 0.95. To maximize NPR, a power setting of intermediate (maximum nonafterburning) was used. The ANOPP evaluation segment was flown at a constant altitude of 3,500 ft (1,200 ft above the ground) with speeds from Mach 0.3 to 0.95. Power settings varied depending on what was required to maintain steady flight at any given speed. To establish baseline acoustic levels under static Mach number and altitude conditions, additional tests were conducted for both aircraft on the thrust stand pad at the Air Force Flight Test Center, Edwards, California. The test matrices varied power lever angle (PLA) between part and intermediate power. Table 1 shows the flight test matrices for the climb-to-cruise and ANOPP validation segments:

Table 1. Flight test matrices

Climb-to-cruise matrix		ANOPP matrix
Altitude, ft MSL	Mach number	Mach number
3,800	0.3	0.0
7,300	0.6	0.3
12,300	0.65	0.6
22,300	0.75	0.8
32,300	0.9	0.95

Procedure

The DFRF pilots flew both aircraft over the acoustic array at desired conditions for ANOPP validation and subsonic climb-to-cruise noise generation. Using the ground track and distance displayed in the control room, the pilots were guided over the acoustic array (fig. 3). Such flight conditions as altitude or Mach number needed to be kept as constant as possible to get good quantitative runs. Speed brakes were used on some ANOPP flyovers for both aircraft to minimize the rate of acceleration. There were 120 recorded flyovers.

A single exhaust jet was desired, so the acoustics tests would have one distinct noise source. For the twin-engine F-18 aircraft, both engines were used before the beginning of the maneuver. Then the left engine was reduced to idle power, while the right test engine was operated at intermediate power or as required for ANOPP. This procedure simulated the effect of a single engine. Speed brakes were used on some ANOPP flyovers to minimize the rate of acceleration.

The F-16XL, ship 2, has a powerful engine, so holding the speed constant proved difficult. As a result, altitude was maintained, and the aircraft was allowed to accelerate.

These tests needed to be conducted with minimum wind, air traffic, and ground traffic noise to get acoustic data with little or no interference. Ground and air traffic, wind velocities, or both, were lightest in the morning; therefore, most of the tests were performed from 6:00 a.m. to

11:00 a.m. Testing was stopped if windspeeds exceeded 15 kts.

Ground acoustic tests were conducted on both aircraft at thrusts from idle to intermediate power. Approximately 2 min of data were recorded at each power setting. Temperature, windspeed, and wind direction were also recorded. Engine noise was recorded on tape in the DFRF acoustics van. These tests were conducted if the windspeeds were below 5 kts.

Results And Discussion

Jet-mixing and shock cell noises are the two primary sources of noise for takeoffs and subsonic climbs (ref. 5). These noise sources are affected by the aircraft velocity, the jet exit Mach number and velocity, and the NPR. For acoustic analysis, exhaust characteristics are normally defined at the nozzle exit and exhaust plume. Jet-mixing noise is a function of the difference between the fully expanded jet velocity (V_{jet}) and the free-stream velocity. Shock cell noise is a function of the difference between the fully expanded jet Mach number (M_{jet}) and the nozzle exit Mach number (M_9). Nozzle exit velocity (V_9) and M_9 are based on the aerothermodynamic characteristics of the flow at the nozzle exit plane. The V_{jet} and M_{jet} are based on the jet flow after it leaves the nozzle and goes through a series of shocks and expansion waves in the exhaust (fig. 5).

The LaRC operates the ANOPP code, and DFRF operates the engine performance codes. The DFRF was responsible for reducing the engine data to provide the jet characteristic values that LaRC needed to use to validate the ANOPP. Data obtained from the engine during the flight and ground tests included compressor speed and discharge pressure, fan speed, fuel flow, inlet and gas temperatures, and turbine discharge pressure. Measured engine data obtained from the flight tests do not directly give the values of M_9, V_9, M_{jet}, and V_{jet} needed for ANOPP. As a result, the measured engine data must be input into the engine performance codes. The resulting output provides the calculated values for M_9, V_9, M_{jet}, and V_{jet}.

Two engine performance codes were used for this test. The F404-GE-400 in-flight-thrust performance code (ref. 6) was used for the F404-GE-400 engines in the F-18 aircraft. The F110-GE-129 steady-state code (ref. 7) was used for the F-16XL, ship 2, engine. Developed by the General Electric Company for the U.S. Navy, the in-flight-thrust performance code provides an accurate calculation of F404-GE-400 engine airflow, thrust, and V_9 throughout the flight envelope. This code models the engine as a gas generator to calculate mass flow, pressure, and temperature of the nozzle exhaust and uses several engine measurements as input. With the exhaust nozzle performance characteristics known, the gross thrust, V_9, and M_9 may be calculated. The F404-GE-400 code calculates V_9, M_9, V_{jet}, and M_{jet}. The F110-GE-129 is a steady-code which predicts performance consistent with average F110-GE-129 engine levels. Input conditions at the engine inlet are obtained from the engine flight data. Only V_{jet} and M_{jet} were calculated by the F110-GE-129 steady-state code. The V_9 and M_9 were determined in a follow-on calculation.

Figure 6 shows the effect of Mach number on F404-GE-400 exhaust characteristics for climb-to-cruise tests at intermediate power. Each point on the curve represents a different altitude in the climb-to-cruise matrix. The nozzle is overexpanded at the beginning of the climb profile when M_∞ is approximately 0.3, and altitude is approximately 3800 ft (The V_9 is greater than V_{jet}.) The point where these data cross, M_∞ equals approximately 0.85, and V_{jet} equals V_9, indicates that the nozzle is fully expanded. The nozzle is underexpanded when the climb-to-cruise profile reaches an altitude of approximately 32,300 ft, and M_∞ equals approximately 0.9. (The V_9 is less than V_{jet}.) Overall, V_9 varies from a minimum of approximately 2750 ft/sec to a maximum of approximately 2800 ft/sec. Then V_9 drops to approximately 2750 ft/sec, while V_{jet} varies from 2300 to 2900 ft/sec.

Figure 7 show M_{jet} and M_9 as a function of M_∞. The values for M_{jet} and M_9 follow the same Mach number and altitude trends as those for V_{jet} and V_9. The values for M_9 vary between 1.69 and 1.8 then drop to 1.7. The values of M_{jet} vary between approximately 1.35 and 1.76. Above a free-stream Mach number of 0.85, the difference between these two values reduces significantly.

Figure 8 shows the effect that aircraft Mach number has on the exit velocity for the ANOPP with the F-16XL, ship 2. The changing PLA for the different test points is also shown. Power settings varied from part power at Mach 0.3 to intermediate power at Mach 0.95. The V_9 varied from 1400 to 2200 ft/sec and increased with Mach number and PLA. Exit velocity trends for the F404-GE-400 code are similar to those of the F110-GE-129 engine.

Figure 9 shows the V_9 for the ground tests made with F-16XL, ship 2. These ground tests were completed with constant speeds of Mach 0.0 and altitudes of 2300 ft; throttle setting was permitted to vary. The V_9 varied from 1400 to 2000 ft/sec and increased with PLA. The velocity trends for the F404-GE-400 code are similar to the F110-GE-129 steady-state code. By determining V_{jet} and V_9, LaRC can validate the ANOPP prediction code. With real quantitative flight data available, the upgrades will result in high-fidelity predictive codes for use on future transport design studies.

Concluding Remarks

Flight tests were conducted at NASA Dryden Flight Research Facility in support of an acoustic study for future transport aircraft. One objective was to determine climb-to-cruise noise, while another was to expand the database to validate the Aircraft Noise Prediction Program. Dryden Flight Research Facility supplied the aircraft, set up the flight and ground tests, and reduced the data to the values of nozzle exit velocity and exit Mach number as well as the fully expanded velocity and Mach number. These values were used by Langley Research Center to validate the Aircraft Noise Prediction Program.

An F-18 aircraft with the F404-GE-400 engine and an F-16XL, ship 2, with the F110-GE-129 engine were used for these tests. One hundred and twenty passes were made over microphone arrays that were placed on Roger's Lake (dry), Edwards, California. To further validate the Aircraft Noise Prediction Program code, a ground test was performed on both aircraft. Data taken from these aircraft were then entered into engine performance prediction codes that modeled the F110-GE-129 and F404-GE-400 engines. The values of exit velocity and Mach number produced by these codes were forwarded to Langley Research Center for use in the Aircraft Noise Prediction Program. These flight tests demonstrated the ability to create a quality noise database and made it possible to validate Aircraft Noise Prediction Program predictive codes. With this new database, these codes will be upgraded to predict noise generated by future transport aircraft.

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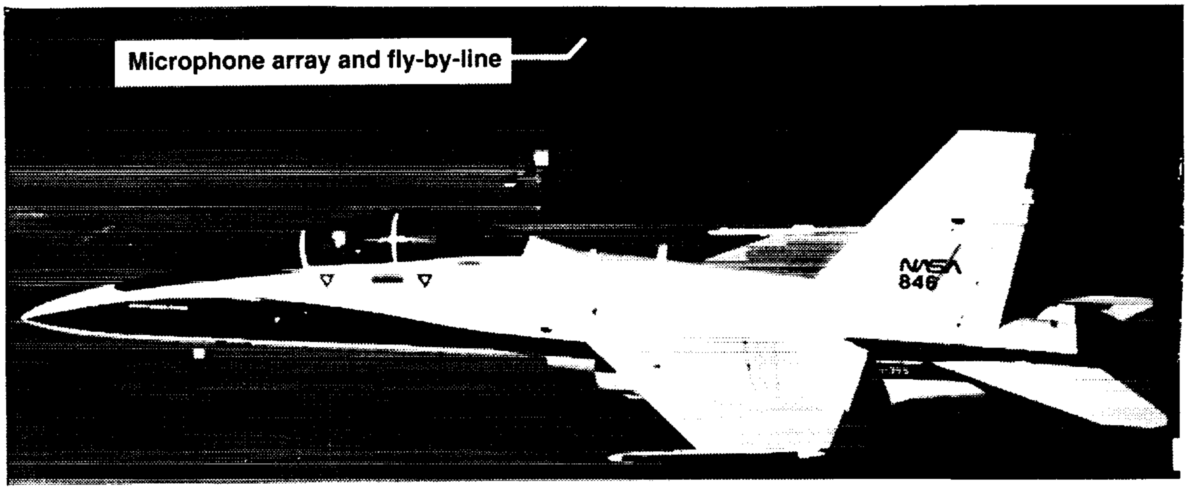

Figure 1. The F-18 aircraft.

Figure 2. The F-16XL, ship 2, aircraft.

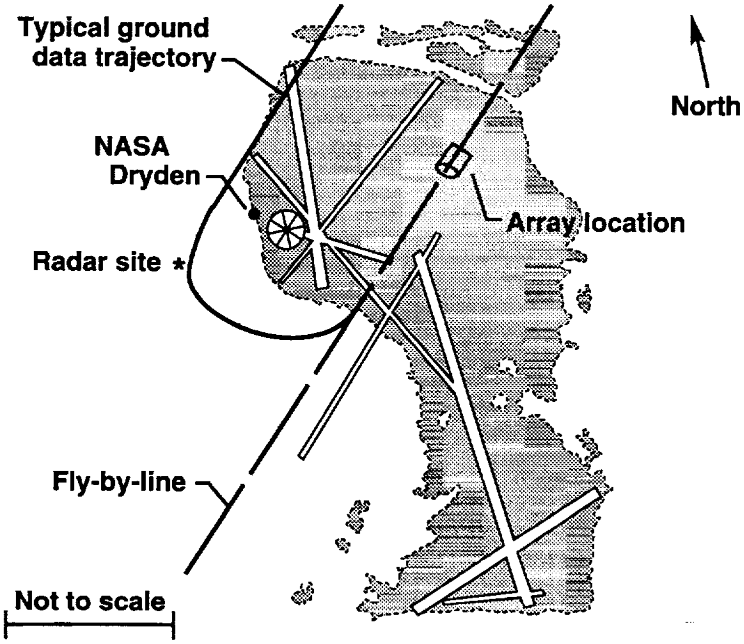

Figure 3. Ground-tracking and array layout at Rogers Lake (dry), Edwards, California.

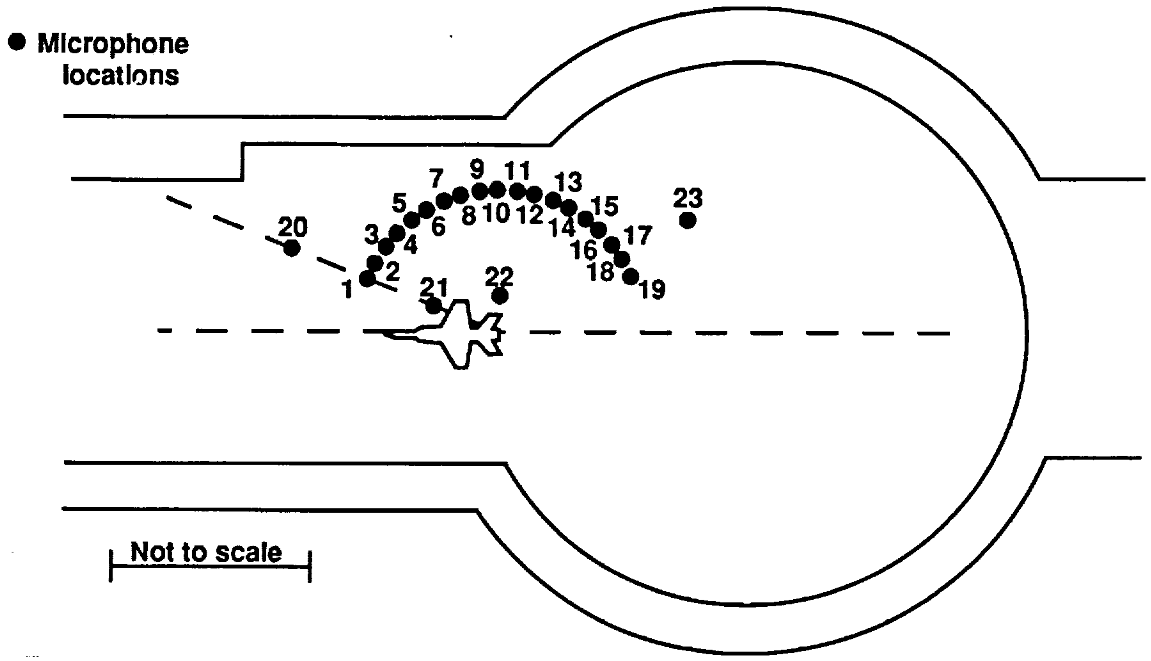

Figure 4. Test setup using the thrust stand at the Air Force Flight Test Center, Edwards, California. Microphones were placed in a 70-ft arc.

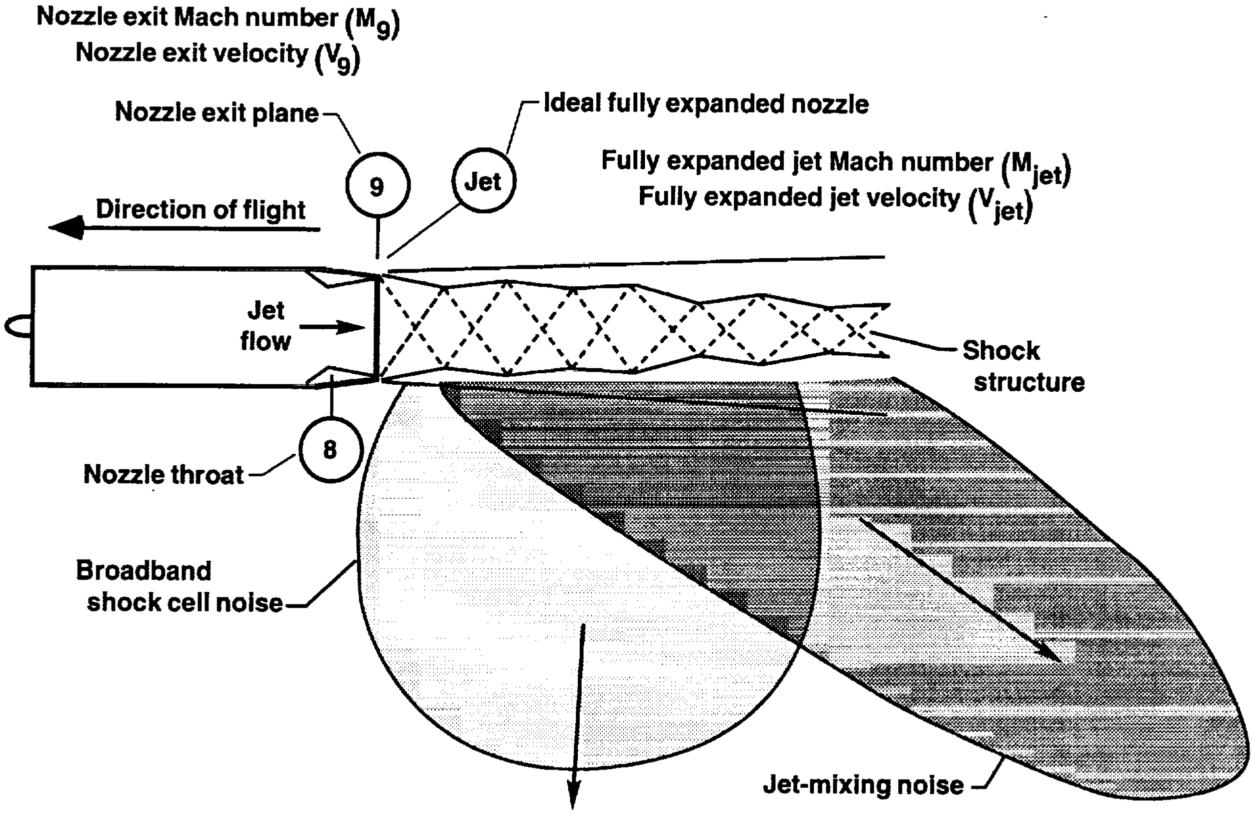

Figure 5. Noise sources for F-18 and F-16XL, ship 2, aircraft operating at high-nozzle-pressure ratios.

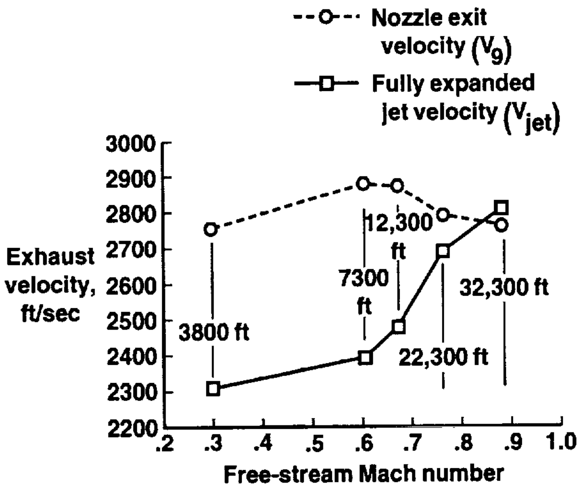

Figure 6. Climb-to-cruise exhaust Mach number test points for an F-18 aircraft at intermediate power.

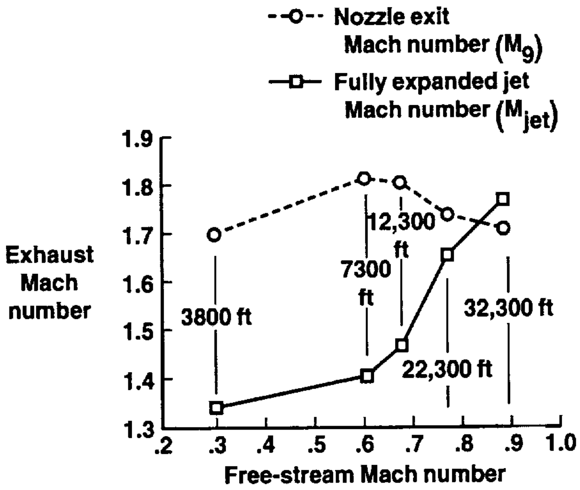

Figure 7. Aircraft Noise Prediction Program validation exhaust velocity test points for an F=16XL, ship 2, aircraft.

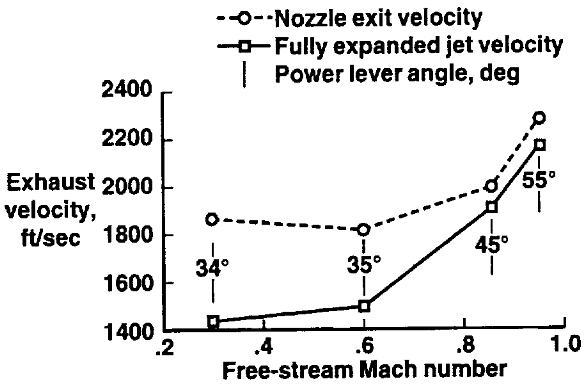

Figure 8. Fully expanded jet velocity for ground test points of an F-16XL, ship 2, aircraft at an altitude of 2300 ft amd at Mach 0.

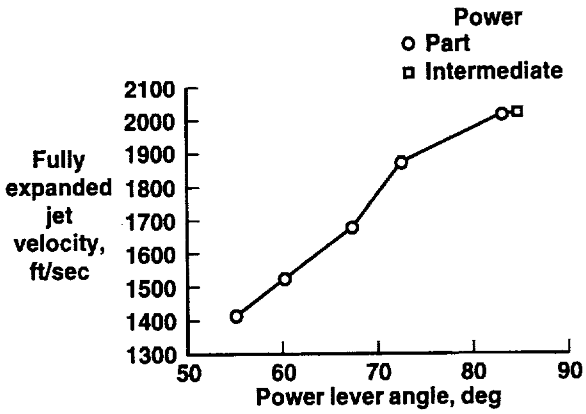

Figure 9. Fully expanded jet velocity for ground test points of an F-16XL, ship 2, aircraft at an altitude of 2300 ft and at Mach 0.

Biography

Kimberly Ennix has worked at NASA Dryden Flight Research Facility (DFRF) at Edwards, California, for two years as a propulsion analyst. During this time, she developed and conducted test plans for the acoustic research program. These tests involved the creation of flight plans for multiple passes over acoustic microphone arrays at varying altitudes and speeds. The research called for the reduction of the engine and radar data. She also developed the analytical support plan for the combustor tests conducted at NASA Ames Research Center, Moffett Field, California. The combustor tests were in support of the High Speed Civil Transport (HSCT) Program. Ms. Ennix volunteers her time to speak to elementary and high school children about engineering and the aerospace industry. Before coming to DFRF, Ms. Ennix worked in rocket propulsion analysis at the Rocket Propulsion Laboratory at Edwards Air Force Base, California.

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MENTORING FOR 2000 AND BEYOND

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Summary

Today, more than 40% of the United States workforce are women. However, only a small percentage of working women are employed in science or engineering fields. The numbers of women in engineering and math professions have actually decreased since 1984. Last year, a mentoring program was created at NASA Ames Research Center aimed at encouraging young girls to stay in school, increasing their self confidence and helping them perform better academically. Teachers at the Ronald McNair Intermediate School matched fifth through eighth grade students with women engineers at NASA Ames. Results from a year-end survey submitted by the mentees indicated that the program was successful in achieving its first-year goals; more than one student reported that she felt "really special" because of her mentor's efforts. The NASA Ames Mentor program has continued into the 1992–93 academic year with both returning mentor/mentee pairs and new participants.

Introduction

In 1991, NASA Ames Research Center in Mountain View, California, began the NASA Ames Mentor Program as a cooperative effort between the Ames Advisory Committee for Women (ACW) in conjunction with the Educational Programs Office "Adopt-a-School" program, and Ronald McNair Intermediate School. The ACW at Ames recognized the need to retain women and to expose girls to careers in Science and Engineering. The Ames Mentor Program was set up to encourage young girls to pursue academic interests and increase their self-confidence, by providing them the opportunity to develop a personal relationship with a consistent, reliable adult committed to working with them for at least a year.

"Mentoring" provides a one-to-one relationship between an adult and a student. In the Ames Mentor Program, government civil service and support service contract employees provided guidance, opportunities for learning, and friendship to fifth, sixth, seventh, and eighth graders at Ronald McNair School in East Palo Alto, California. In 1991, the student ethnic profile at McNair was 50% Black, 47% Hispanic, Asian 2%, and White 1% (ref. 1). Many of the students in the area are considered to be "at risk" for dropping out of school or not electing to attend college for socioeconomic and cultural reasons. Through a variety of activities described in this paper, Ames Mentors helped expand students' horizons with exposure to experiences and opportunities to which they might otherwise not have had access.

Ames Mentor Program

The Ames Mentor Program was patterned after the Norwalk Mentor Program in Norwalk, Connecticut. The Norwalk model offers a six step process to establish a mentor program (ref. 2). Those six steps are:

1. Recruit mentors
2. Orient and train mentors
3. Match mentors with students (mentees)
4. Have mentor/student meetings
5. Evaluate progress
6. Celebrate at year's end and renew mentors' commitments

At Ames, those six steps were implemented by Aga Goodsell, Mentor Program Coordinator for the pilot program during the 1991–92 academic year. After receiving approval and support for the program by McNair, Goodsell obtained a mailing list of the female civil servants employed at the center, and distributed flyers soliciting mentor interest in the program. A small advertisement was then placed in the *Astrogram*, the NASA Ames news bulletin, to generate interest in the program. Mentors were also recruited by word of mouth. Fourteen women expressed interest in becoming a mentor and attended an informal information meeting at which the Program Coordinator presented the purpose of the program, ground rules, and expectations of the amount of time spent with each mentee. At this meeting the mentors filled out information sheets on their background and interests. The mentors also discussed the types of individual activities, field trips, and support from the school and the Center that would be provided throughout the 1991–92 school year.

The teachers at McNair School chose the potential mentees they thought would benefit and showed interest in the program. Subsequently, the identified mentees completed an information sheet of interests so that the school could "match" the mentors and mentees. Each mentee was given a permission slip that was signed by a parent or guardian giving permission for the student to participate in the program. Once the matches were made, an introductory meeting was held at the school with the mentors, the mentees, and their parents. The Program Coordinator and Director of the "Adopt-a-School" program, Laura Shawnee, introduced each mentee and her parent(s) to her mentor, at which time they became acquainted and set up regular meeting times. The Ames Mentor Program required that the mentors meet with the mentees a minimum of two hours per month. Usually, the mentors would meet their mentee at the mentee's last period classroom or in the school library. Some mentors preferred meeting in a classroom after school, rather than the library where other students were studying. Others opted to take the mentees off campus and do a special activity elsewhere such as the city library, a bookstore, or even a college campus. In the classrooms some of the mentors would do arts and crafts activities with their mentee such as painting T-shirts or beading necklaces.

During the first year of the program, the Program Coordinator organized two field trips. The first was a visit to NASA Ames Research Center, and the second was to the Technology Museum in San Jose. The Ames field trip consisted of a guided tour through various facilities where the mentors worked. The tour began in the largest wind tunnel in the world, the 80 ft × 120 ft, where the mentors/mentees entered through the computer control room and then stood inside the massive test area of the wind tunnel. The next stop was the flight line where a mentor showed the mentees the various NASA experimental aircraft currently studied. The highlight of the day for many of the students was the Vertical Motion Simulator laboratory. Two NASA astronauts training on the Space Shuttle simulator flew the Shuttle with each mentee taking a turn as copilot. The mentees were then awarded Space Shuttle certificates, a momento of their trip. Many of the mentees wrote to the pilot they had flown with, thanking him for the simulator experience. To their surprise, each mentee received an autographed picture of the astronaut along with his autobiography! The final field trip to the San Jose Museum of Technological Innovation proved to be a popular event as well. The girls tried all of the hands-on design and interaction the museum offered such as walking through a life size computer chip assembly line, designing a bicycle and designing buildings to withstand earthquakes. The earthquake simulator allowed them to test their building designs with customized earthquakes.

Throughout the year the mentors held occasional meetings at Ames to discuss mentor/mentee relationships, suggested activities, and plans for group field trips. At the end of the year, mentees were asked to fill out an evaluation about their participation in the program. The consensus was that the field trips were fun and interactive and that they would have liked more of them.

Eight of the 14 students in the Ames Mentor Program completed the Mentor Program Evaluation forms. Responses were anonymous, and are summarized below. The percentage of "yes" answers is given in the right column.

How often did you and your mentor usually meet this past school year?

Once a week	50%
Once every 2 weeks	50%

How much time did you and your mentor usually spend together at your meetings?

1 hour	37.5%
2 hours	62.5%

What do you think of the time you spent together?

Just right	100%

What did you think of the field trips?

Liked them	100%

What do you think the mentor program was supposed to do for you?

"It was supposed to give me new experiences and meet new people."

"It was supposed to teach us new things."

"They were supposed to help us on our homework and projects too or in something else we needed help on."

"Teach us how to become more aware of the things that we have in life and to seek new opportunities in life."

"Help me to understand the basic standards in this world today."

"I thought the Mentor program was supposed to help you with your class work."

"It was supposed to show us friendship, teach us a little bit about NASA and sisterhood."

"To help me with my schoolwork, to help me with my problems, to have fun."

What do you think the mentor program did for you?

"It made me feel good, as if I were really someone special not just any normal student."

"I learned many new things, and had great experiences."

"What I think about the mentor program helped me a lot. It helped me in my homework, projects too and other things too. That's all I can think of."

"It taught my to think about the things that I could do and what to seek for in life."

"It help me and encouraged me to become a astronaut or scientist when I grow older."

"I think the Mentor program really helped me a lot with my classwork."

"I was shown a lot of things and did a lot of things."

"With the help of my mentor, I finished my school work and received good grades. I'm glad I had a female mentor; this way I could share my personal feelings with her and she understands. I really had fun with her."

McNair School hosted an appreciation event for the mentors and all other programs associated with the school. School personnel held a school-wide assembly with entertainment and food, and finished by handing out certificates to each of the mentors. In addition, the mentors received the mentee evaluation feedback, and were invited to participate in the 1992–93 program. Of the 14 mentors participating in the 1991–92 program, nine returned as mentors for the 1992–93 school year. Four of the 14 mentees from the pilot program returned. Many of the mentees were 8th graders who went on to high school, taking their experiences with them.

The Ames Mentor Program has continued into the 1992–93 academic year. Theresa Rose is currently the Program Coordinator at Ames, and the pilot program has been expanded in both execution and scope. Because so many boys at McNair School and men at NASA Ames expressed an interest, the Mentor Program now includes male mentors and mentees. The program participants felt it appropriate to include both sexes this year, as the boys are also likely to benefit from the attention and experience they will get from a mentor. The Ames Mentor Program policy is to match mentors and mentees of the same sex, so the girls are not being shortchanged with the addition of boys to the program. To date, 42 mentors have been matched with McNair students: 21 girls, and 23 boys.

Both male and female mentors were recruited through a series of articles published in the *Astrogram* (NASA Ames in-house newsletter) as well as by last year's network of mentors. Potential mentors were required to complete a 1 hour orientation and training session, sign a Mentor Agreement Contract, and provide references for a background check. The training session was conducted by the 1992–93 Mentor Program Coordinator and the authors—all "graduates" of the 1991–92 pilot program. It covered the following topics:

1. Program Goals
2. Orientation to Ronald McNair School
3. What Makes a Mentor Relationship Successful
4. Qualities of a Good Mentor
5. Mentor Agreement Contract and Pledge
6. Stages of the Mentor Relationship
7. How to Get Communication Started
8. First Meeting Activities
9. Suggested Mentor - Student Activities
10. Activities That Worked for Last Year's Mentors
11. Mentors' Resources

A different approach to matching the mentors with the mentees was implemented this year. In September, all McNair students were presented with the opportunity to apply to the Ames Mentor Program by submitting applications. Teachers were then requested to recommend which of those students they felt might benefit most from a Mentor relationship. At the mentor orientation/training session, mentors reviewed the student's applications and each mentor selected the mentee they felt would, be a good match, as opposed to the McNair teachers making the match. After parents' permission was secured in writing, a "Meet the Parents Night" was held at McNair School.

A new feature in this year's program is the mentors' lunch time support group, held once a month where mentors share ongoing successes and problems, and to conduct further training. Another addition is the position of McNair School–Ames Mentor Program Liaison. This liaison, a teacher at the school, coordinates school activities such as a "Meet the Parents Night" and distribution and collection of permission slips for field trips.

As part of this year's evaluation data, the Ames Mentor Program is keeping records of the number of hours spent by the volunteers in the program. These hours include program coordination and training time as well as student contact time.

Summary

The authors feel that mentoring middle school students is a challenging but rewarding experience. Early in the program we felt that the students were testing us by missing appointments and not expressing their true desires or interests. However, one of our greatest challenges was to manage the amount of time the student wanted to spend with us, which was greater than we had expected. Another challenge we encountered was the cross-cultural experience due to differences in our backgrounds. As with most students, the mentees were sometimes not interested in doing school work, so we found it especially challenging to encourage them in their studies. Both authors believe that we have influenced our mentees lives in a special way. Through the school year we observed the shyness of our mentees disappear with willingness to open up about personal matters. We also found it rewarding to see the students' interest in science and engineering develop over time. We found it particularly rewarding to have the opportunity to provide guidance to one of our mentees in choosing high school "college prep" classes she originally did not intend to take, and with another mentee to help in the completion of a Science Fair project that was awarded first place. We hope that the encouragement and positive feedback we provided to our mentees will be taken with them in their future successful careers.

References

1. School Report/Rorte Escolar, 1990-1991, Ronald McNair School, E. Palo Alto, Calif., 1991.
2. Weinberger, Susan: The Mentor Handbook. Educational Resources Network, Norwalk, 1990.

Figure 1. 1991–1992 Ames Mentor Program participants.

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Figure 2. 1992 field trip at NASA Ames Research Center.

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WIND TUNNEL MEASUREMENTS ON A FULL-SCALE F/A-18 WITH A TANGENTIALLY BLOWING SLOT

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Summary

A full-scale F/A-18 was tested in the 80- by 120-Foot Wind Tunnel at NASA Ames Research Center to measure the effectiveness of a tangentially blowing slot in generating significant yawing moments while minimizing coupling in the pitch and roll axes. Various slot configurations were tested to determine the optimum configuration. The test was conducted for angles of attack from 25° to 50°, angles of sideslip from −15° to +15°, and free-stream velocities from 67 ft/sec to 168 ft/sec. By altering the forebody vortex flow, yaw control was maintained for angles of attack up to 50°. Of particular interest was the result that blowing very close to the radome apex was not as effective as blowing slightly farther aft on the radome, that a 16-inch slot was most efficient, and that yawing moments were generated without inducing significant rolling or pitching moments.

Nomenclature

As	area of the slot = W_{sls}, ft^2
b	reference wing span, 37.42 ft
C_L	lift coefficient in body axes, lift/$q_\infty S$
C_m	body-axis pitching moment coefficient, pitching moment/$q_\infty Sc$
C_n	body-axis yawing moment coefficient, yawing moment/$q_\infty Sb$
C_p	pressure coefficient, $(p - p_\infty)/q_\infty$
C_{roll}	body-axis rolling moment coefficient,
C_Y	body-axis side force coefficient, side force/$q_\infty S$
c	reference mean aerodynamic chord, 11.52 ft
FS	fuselage station, inches (radome apex at FS 60.5)
h_s	height of blowing slot = 0.01 inches
l_s	slot length, inches
$\dot{m}_s$	mass flow rate of slot, $\rho_s V_s A_s$
$\dot{m}_{ref}$	reference mass flow rate, $\rho_\infty U_\infty S$, lb_m/sec
MFR	mass flow ratio, $\dot{m}_s/\dot{m}_{ref}$
mdot	mass flow rate through the slot, lb_m/sec^2
p	static pressure, lb/in.^{2}
p_∞	free-stream static pressure, lb/in.^{2}
q_∞	free-stream dynamic pressure, $1/2\rho_\infty U_\infty^2$, lb/ft^2
S	reference wing area, 400 ft^2
U	free-stream velocity, ft/sec
V_s	velocity at the slot exit, ft/sec
x	distance from nose apex along longitudinal axis
α	angle-of-attack, degrees
β	angle of side slip, degrees
Δ	change due to forebody flow control mechanism
δ_h	horizontal stabilator deflection, degrees
ρ_∞	free-stream air density, slugs/ft^3
ρ_s	air density at the slot exit, slugs/ft^3

Introduction

Current fighter aircraft configurations, designed for high-speed flight, consist of long slender forebodies that have experimentally been shown to encounter strong asymmetric flow separation on the forebody at high angles of attack. The airflow over the upper surfaces of the aircraft at these angles of attack is separated and largely unsteady while the rudder effectiveness of the aircraft decreases as the vertical tails become engulfed in the wake of the forebody and the wings. This separated flow introduces significant side forces on the forebody even when little or

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no sideslip is present: the induced side force results in large yawing moments.

Future fighter-aircraft configurations will be subject to maneuvers at these high angles of attack that include the post stall region. More specifically, maneuvers will include the ability to rapidly pitch the nose down so that high-speed, low-angle of attack flight can be resumed, and the ability to rapidly roll the aircraft about the velocity vector in order to achieve a tighter turn radius (ref. 1). At these angles, the roll about the velocity vector is accomplished by controls that generate yawing moments along the body axes of the aircraft preferably without producing rolling or pitching moments.

A great deal of research has used the asymmetric flow separation on the slender forebody of the aircraft in order to improve yaw control at these high angles of attack. A yaw control device on the forebody has a significant mechanical advantage over a yaw control device on the vertical tail because the distance from the forebody to the aircraft center of gravity (cg) is greater than the distance from the vertical tail to the cg, and thus provides a greater moment arm. Additionally, the forebody with yaw control is unaffected by unsteady separated flow from the fuselage and wings. Yaw control devices tried in the past include forebody strakes, forward and aft blowing on the forebody through jet nozzles, jet blowing in combination with forebody strakes, tangential slot blowing on the forebody, and forebody jet nozzle blowing with the nozzles canted both windward and leeward (refs. 2–13). All of these devices were tested on small-scale models in water tunnels or wind tunnels.

As part of the NASA High Alpha Technology Program at NASA Ames Research Center, a full-scale F/A-18 was tested in the 80- by 120-Foot Wind Tunnel of the National Full-Scale Aerodynamic Complex (ref. 14). In these tests, several different methods of forebody flow control were examined to improve the lateral-directional control of the aircraft at high angles of attack. These methods included an aft-blowing circular-jet, a tangentially blowing slot, and deployable strakes. All of the techniques provided lateral control by manipulating the structure of the vortices shed from the forebody at high angles of attack. The effectiveness of these forebody flow control devices in generating lateral force and yawing moments are reported in references 9 and 10. This paper will present the effectiveness of various tangentially blowing slot configurations in generating yawing moment while minimizing the coupling between the aerodynamic forces and moments induced by the slot blowing.

Description of Model

The full-scale F/A-18A aircraft tested in the 80- by 120-Foot Wind Tunnel and shown in figure 1 is a single-seat aircraft built by the McDonnell Douglas Aircraft and Northrop corporations. The F/A-18A fighter aircraft has two vertical stabilizers canted 20° outboard from the vertical position and has leading edge extensions (LEXs) on each side of the fuselage just forward of the wing. The LEXs used for this experiment were the same instrumented ones that were flown on the High Alpha Research Vehicle at the Dryden Flight Research Facility in 1990 (ref. 15). During the wind tunnel test, the aircraft had both aircraft engines removed but air was free to flow through the inlets. The wingtip missile launch racks were mounted. The flaps were configured for high angle of attack flight with the leading-edge flaps at 33° down and the trailing-edge flaps at 0°. The horizontal tails were operated on a flight control schedule that was a function of the angle of attack to maintain trimmed flight conditions. The rudders were fixed at 0° for the majority of the test, however some data were also collected with both rudders positioned 30° trailing-edge left.

The radome designed for this experiment was built from a composite laminate of fiberglass/foam/fiberglass and fabricated from a mold formed of the production-aircraft radome. Figure 2 shows the slot and the discrete jet arrangement on this radome. Only the port slot and jet were active. Care was taken to assure symmetry; the starboard geometry was made identical by using a dummy slot and jet. The blowing slot had a total length of 48 inches and began 3 inches aft of the radome apex. The slots were positioned at 90° and 270° from the windward side (bottom) of the radome. The active slot was at the 270° position (port-side) and was designed to blow tangential to the surface toward the leeward side of the radome. The 48-inch slot was divided into 24 separately controlled segments with each segment measuring 2 inches long. The slot height was 0.10 inches. The aft blowing jet experiment will not be discussed in this paper, however more detailed information on this configuration can be found in reference 10. Air for the slot was supplied by 125 psi compressors. The air passed through a plenum located in the cockpit of the aircraft, which functioned as a settling chamber before traveling to the slot. The hardware from the plenum to each of the 2-inch slot segments was nearly identical in order to maintain a constant total pressure across the length of the slot. The mass flow rate of the blowing air was measured using a turbine flow meter.

A three-strut configuration was used to mount the F/A-18 aircraft in the 80-by 120-Foot Wind Tunnel test section on a rotatable balance frame. The aircraft was attached to a circular cross beam at the two main landing gear positions, which, in turn was attached to the wind-tunnel main struts. A tail boom assembly connected the aircraft at each engine mounting pin, and the arresting tail hook was used to attach the aircraft to the third wind-tunnel tail strut. The angle of attack was varied by changing the length of the tail strut while sideslip angle was changed by rotating the entire balance frame. This mounting arrangement placed the cross beam 33 feet above the test section floor, as shown in figure 1.

Description of Experiment

This experiment measured the effect of a tangentially blowing slot on the aircraft forces and moments. The results presented show the yawing moment generated by the slot blowing and the induced coupling between the aerodynamic forces and moments. To evaluate the effect of the tangential slot blowing, the differences in forces and moments were measured between the blowing-off and blowing-on conditions.

Test conditions included angle of attack variation from 25° to 50°, angles of sideslip from −15° to +15°, and freestream velocity from 67 ft/sec to 168 ft/sec. The Reynolds number based on wing mean aerodynamic chord ranged from 4.5×10^6 to 12.0×10^6. The mass flow rate of air blown through the slot configurations presented in this paper varied from 0 to 1.3 lb_m/sec. Force and moment data for different slot configurations, blowing rates, freestream velocities, Reynolds numbers, angle of attack, and angle of sideslip are presented. The test conditions match flight speeds and Reynolds number for 1 g flight, a fact of particular importance in forebody flow control experiments because the boundary layer in the forebody region developed and transitioned from laminar to turbulent as it would in flight.

The various slot configurations were studied to determine the optimum configuration, that is the configuration which produced the largest change in yawing moment for the minimum required blowing. The parameters that were varied in order to determine the optimum configuration were the slot length, the slot position relative to the radome apex, and the mass flow rate through the slot. The aircraft forces and moments used to evaluate the blown slot performance were measured using the wind-tunnel scale system and, are shown in the body axes coordinate system. The rudders were positioned at 0° deflection unless noted otherwise.

Results

Tangential Slot Blowing Optimization

The yawing moments generated by four different slots are shown in figure 3. The slots were 8, 16, 32, and 48 inches long and each began 3 inches from the radome apex. For each of the slot configurations, yawing moment increased as angle of attack increased. The mass flow ratio (MFR) through each of the slots varied with slot length. Comparing the results at these conditions, the 32-inch and the 48-inch long slots had the largest effect on the yawing moment throughout the entire angle-of-attack range.

The position of the slot relative to the radome apex also had an effect on the amount of side force generated by the device. The various slot positions relative to the radome apex are shown in figure 4. Figure 5(a) shows that for a MFR of 0.00026, the 16-inch slot positioned at 3 inches was not as effective as when positioned 11 or 19 inches aft of the radome apex. It is important to note that the 16-inch slot positioned at 11 or 19 inches produced nearly the same moments as the 32 or the 48-inch-long slots positioned at 3 inches (fig. 3) for a lower mass flow rate. This makes the 16-inch slot positioned 11 or 19 inches aft a more efficient configuration. Efficiency is important because if this concept was used in flight, the air supplied to the slot would come from the same source that supplies the pilot with the cockpit environment controls. This supply of air is limited. Figure 5(b), shows data for the same slot mass flow rate as in figure 5(a), however, the freestream velocity was increased yielding a lower MFR. For the lower MFR, the 16-inch slot positioned 11 and 19 inches aft of the radome apex again proved to be more effective than when positioned 3 inches aft of the radome apex. For comparison, the yawing moments produced by maximum rudder deflection are shown in figure 5(b). It is clear that slot blowing produced much larger moments than the maximum rudder deflection at these angles of attack.

The tangential slot blowing produced a side force in the direction of the blowing side of the radome. This result indicates that the tangential slot blowing keeps the flow attached along the blowing side of the radome. This flow phenomenon, called the coanda effect, creates a low-pressure on the blowing side of the radome resulting in a suction force. Thus, blowing from the left-side of the radome will produce a nose-left yawing moment. It was also noticed that blowing 11 or 19 inches aft of the apex allows this low pressure to affect more surface area, resulting in a greater yawing moment than for 3 inches aft of the apex. Additionally, the tighter radius very near the nose of the radome could defeat the coanda effect.

Based on the results presented above, the 16-inch and 32-inch slots beginning 11 inches aft of the radome apex were determined to be the most effective; consequently they were tested over an expanded range of mass flow rates. For a given yawing moment, the 16-inch slot used between 8% and 30% less mass flow than the 32-inch slot (fig. 6). Thus, the 16-inch slot is more efficient than the 32-inch slot. Both the 16- and 32-inch-long slots produced a small moment reversal at very low mass flow ratios. This moment reversal also appeared in the water tunnel experiments of slot blowing on the forebody of a fighter aircraft (ref. 5). This result may be related to results presented by Ericsson which showed side force reversals for a rotating circular cylinder at low rotation speeds (ref. 16).

In the 80- by 120-Foot Wind Tunnel experiments, the exit velocities through the slots ranged from subsonic flow to sonic flow as the mass flow through the slots was increased. The data in figure 6 includes exit velocities in both the subsonic and sonic regions. For the 40° angle-of-attack case, choked flow occurs at a mass-flow ratio of 0.00013 and 0.00023 for the 16- and 32-inch-long slots respectively. These data confirm that even when the exit velocity reached sonic conditions, the yawing moments continued to increase with increasing mass flow.

Tangential slot blowing proved to be effective across the entire angle-of-attack range. In fact, its effectiveness increased as the angle of attack was increased (fig. 7). Again the results indicate a small moment reversal at very low mass flow rates for the 40° and 50° angle of attack cases. Data were not taken for small mass flows at 30°.

The effect of Reynolds number was examined in the tunnel by testing various velocities up to the maximum of 168 ft/sec. Figure 8 shows the variation of yawing moment with MFR for the 16-inch slot 11 inches aft of the apex and at $\alpha = 40°$. Results are shown for various wind-tunnel velocities, and there is very little difference between the curves. These results indicate that slot blowing was not sensitive to Reynolds number across this range of velocities.

Aerodynamic Coupling

The results generated by the 16-inch slot positioned 11 inches aft of the radome apex are used to illustrate the coupling between the aerodynamic forces and moments induced by the slot blowing. The effects of angle of attack on pitching moment due to the slot blowing are shown in figure 9(a). As a point of reference, the pitching moment due to the horizontal tail deflection, which is the conventional pitch control mechanism, is also shown in figure 9(a). The changes in pitching moment for the two different blowing rates are nearly the same with the greatest change measured as 0.03 seen at 50° angle of attack. The pitching moment due to the horizontal tail deflection over the same angle-of-attack range shows that the moments generated by slot blowing are easily correctable. Similar results are seen in the lift-coefficient data (fig. 9(b)) which demonstrates that there is no significant lift generated by the blowing slot. The lift due to 30° of rudder deflection is shown on figure 9(b) as a reference point.

As shown previously, the slot blowing generates large side forces and yawing moments (figs. 10(a) and 10(b)). Furthermore, the magnitude of the side force and yawing moment is controlled by the blowing rate as seen from the two blowing conditions, 0.5 and 1.1 lb_m/sec. These forces and moments were produced while maintaining relatively small changes in rolling moments (fig. 10(c)), which is a desirable condition because roll-yaw coupling or pitch-yaw coupling complicates control implementation. The greatest changes in rolling moment, 0.011 and –0.006, were seen at the 35° and 50° angles of attack, respectively. Measurements taken on a 16% scale F-18 model with an aileron deflection of 25° down on the left and 25° up on the right, showed a ΔC_{roll} of 0.024 and 0.015 for angles of attack of 35° and 50°, respectively (ref. 6). Although model scaling effects have not been determined, these values indicate that the rolling moments produced by the blowing are correctable with control surface deflections and are only lightly coupled with the yawing and pitching moments.

The tangentially blowing slot showed similar results at sideslip angles ranging from –15° to +15° (fig. 11). The results for the side forces and yawing moments (figs. 11(a) and (b)), show that blowing on one side of the aircraft produces significant forces and moments when the aircraft is yawed in either direction. For example, if the aircraft had a natural tendency to yaw to the right ($-\beta$), blowing on the left-hand side of the radome would generate a nose left ($+\beta$) yawing moment. These data also show a well-behaved trend, though not linear, in the yawing moment produced for various blowing rates. The rolling moment generated by the blowing is again relatively small across the range of sideslip (fig. 11(c)), with the largest incremental change, 0.012, occurring at –10° sideslip.

Figures 12(a)–(c) show the change in lateral-directional characteristics due to the blowing. For these comparisons, data acquired with the F-18 production radome were used for the baseline no-blowing condition; no-blowing data are not available for the modified radome. The data in figure 12(a) show similar behavior to the data taken at 40° angle of attack (fig. 11(a)). Figure 12(b) shows that blowing has a larger effect on yawing moment as angle of attack was increased from $\alpha = 40°$ to $\alpha = 50°$. These results also show an increase in effectiveness as the blowing rate was increased. The effect of blowing on the rolling moment was small and nearly linear across the sideslip range tested (fig. 12(c)). The rolling moment induced by the blowing was better behaved at $\alpha = 50°$ than it was at $\alpha = 40°$. This result may indicate the roll-yaw coupling induced by the tangential blown slot decreases as angle of attack increases.

Conclusions

The primary objective of the research reported in this paper was to measure the effectiveness of a tangentially blowing slot in generating lateral-directional control of the F/A-18 at high angles of attack. It was shown that the tangential slot blowing produced significant yawing moments at high angles of attack. It was also found that blowing 11 inches aft of the radome apex was more effective than blowing 3 inches aft. The 16- and 32-inch-long slots were more effective and efficient than either the 8- or 48-inch-long slots. Additionally, the full-scale results showed that the effect of the tangential slot blowing on the yawing moment increased with the angle of attack, the angle of sideslip, and the mass flow of air blowing through the slot.

It was shown that the effects of the tangentially blowing slot were weakly coupled in pitch and roll. The magnitude of the induced forces and moments will be correctable with control surfaces.

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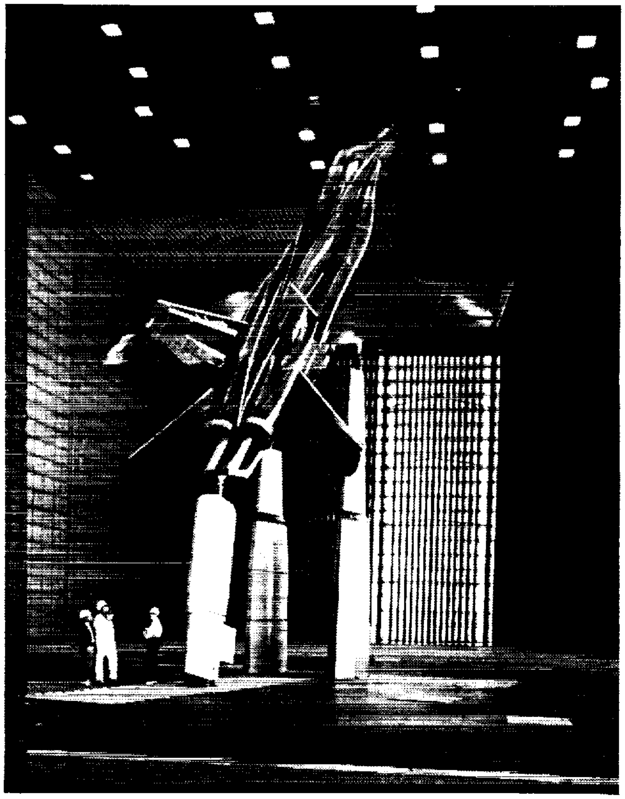


Fig. 1 Photograph of the F/A-18 mounted in the 80- by 120-Foot Wind Tunnel test section. A three-strut configuration with mounting hardware was used.

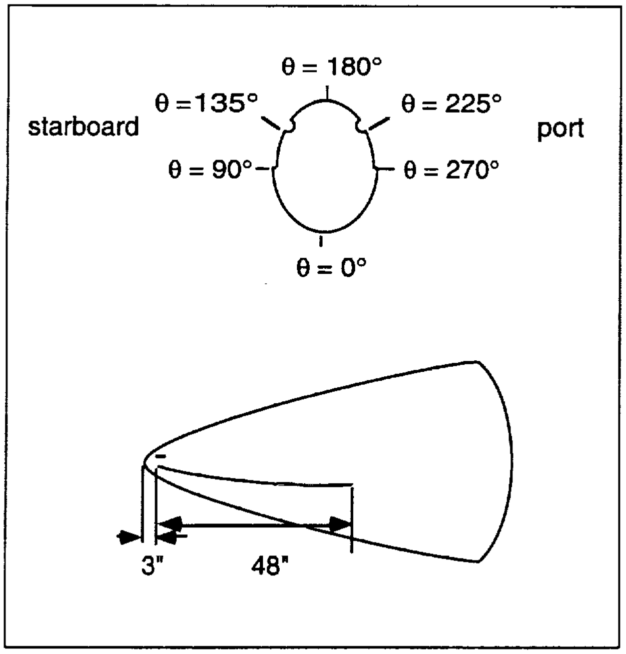


Fig. 2 The slot and discrete jet arrangement on the radome. The active slot and jet were located on the port side with the dummy slot and jet on the starboard side.

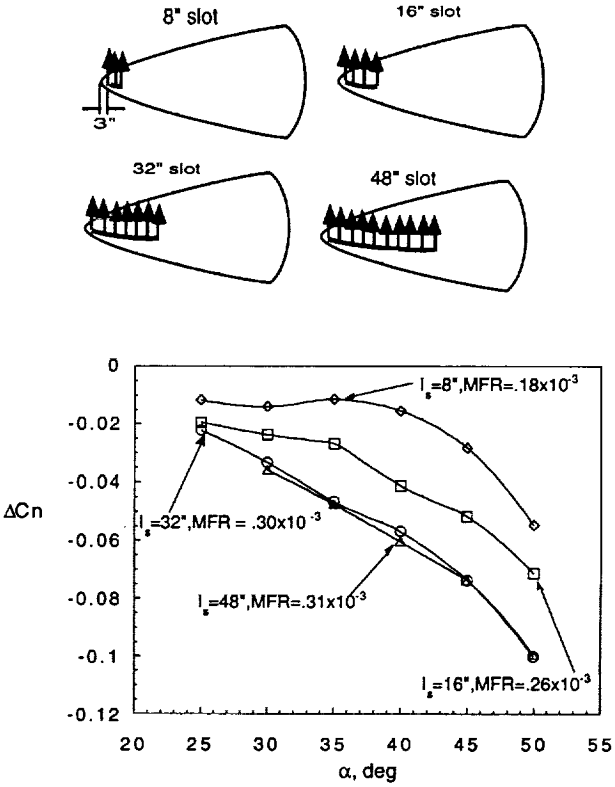


Fig. 3 The effect of angle of attack on yawing-moment coefficient in body axes for 4 different slot lengths; each slot began 3 inches aft of the radome apex: β = 0°, U_∞ = 132 ft/sec.

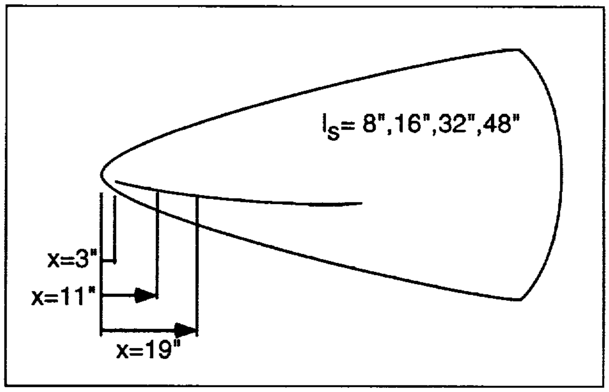
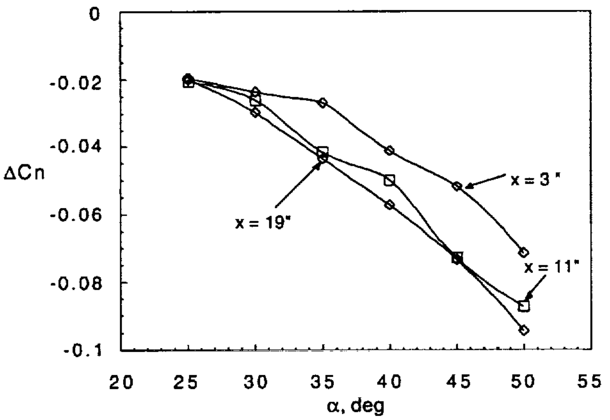
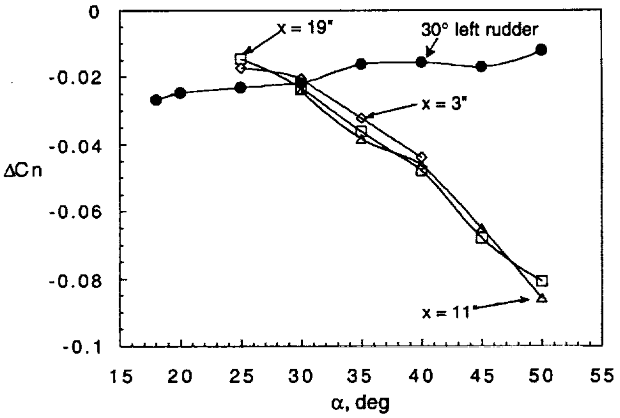


Fig. 4 Schematic of the various slot positions relative to the radome apex.



(a) U_∞ = 132 ft/sec, MFR = 0.26 x 10^{-3}



(b) U_∞=167 ft/sec, MFR = 0.22 × 10^{-3}

Fig. 5 Effect of angle of attack on yawing-moment coefficient in body axes for various U_∞ and slot positions on the radome: l_S = 16 inches, β = 0°.

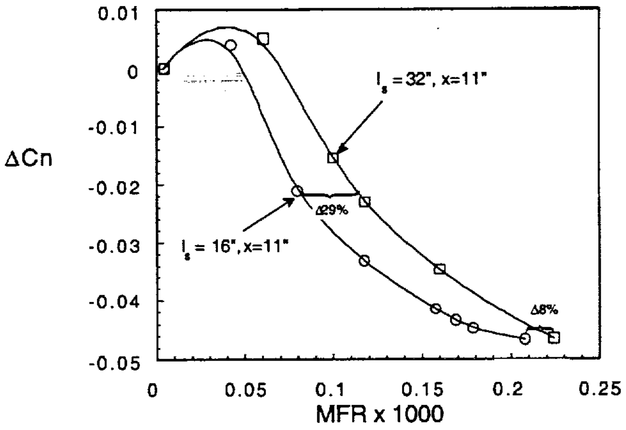


Fig. 6 Effect of the mass flow ratio on the yawing-moment coefficient in body axes: α = 40°, β = 0°, U_∞ = 168 ft/sec.

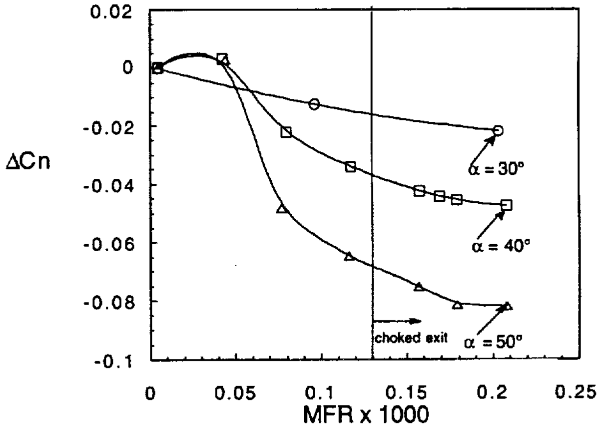


Fig. 7 Effect of mass flow ratio on yawing-moment coefficient in body axes for various angles of attack: l_S = 16 inches, β = 0°, U_∞ = 167 ft/sec.

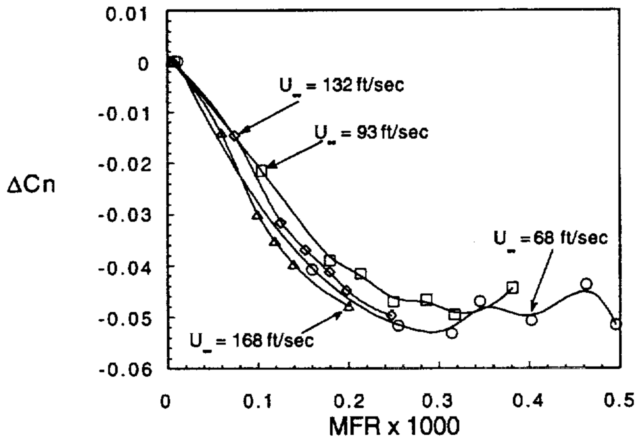
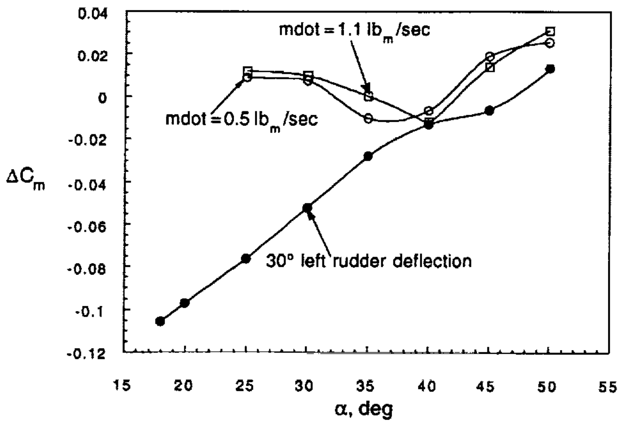
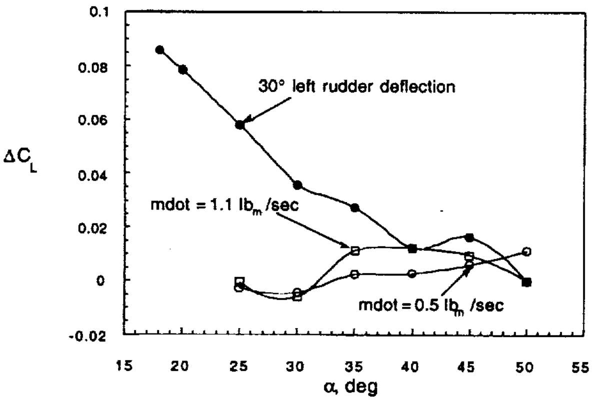


Fig. 8 Effect of mass flow ratio on the yawing-moment coefficient in body axes for various free-stream velocities: α = 40°, β = 0°, l_S = 16 inches, x = 11 inches.

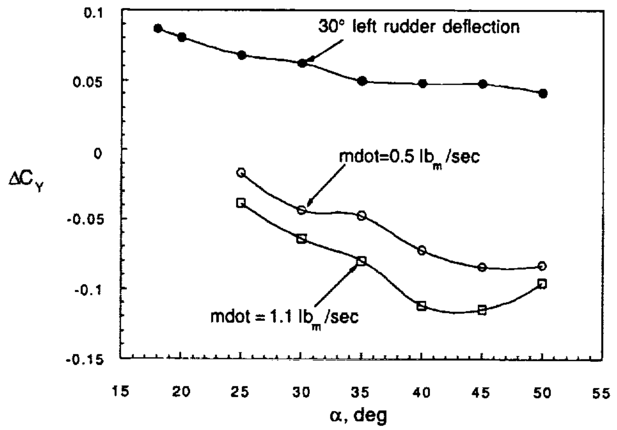


(a) Effect of angle of attack on pitching-moment coefficient in body axes.

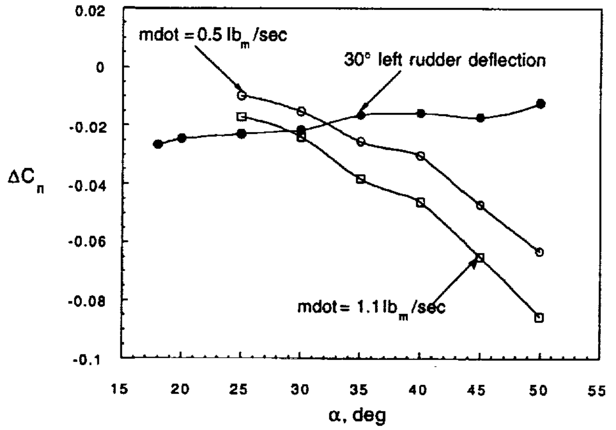


(b) Effect of angle of attack on lift coefficient in body axes.

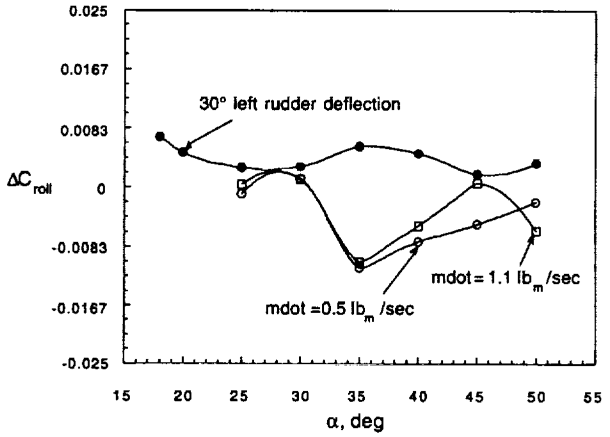
Fig. 9 Effect of angle of attack on the longitudinal characteristics due to port-side slot blowing for two blowing rates: $U_\infty = 168$ ft/sec, $\beta = 0°$, $\delta_h = f(\alpha)$.



(a) The effect of angle of attack on side force coefficient in body axes.

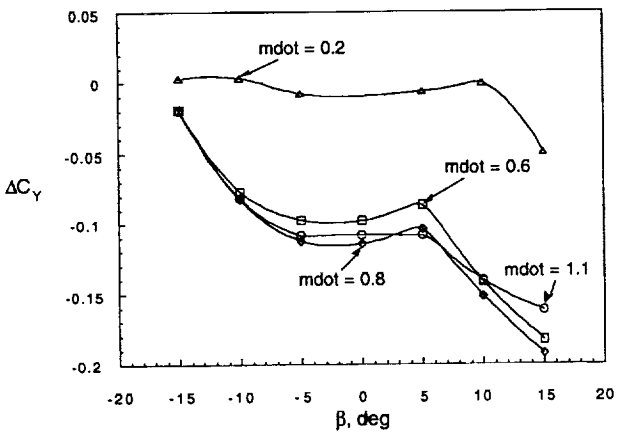


(b) Effect of angle of attack on yawing-moment coefficient in body axes.

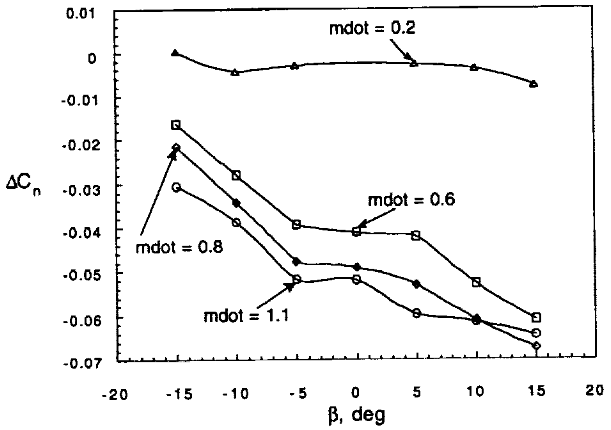


(c) Effect of angle of attack on rolling-moment coefficient in body axes.

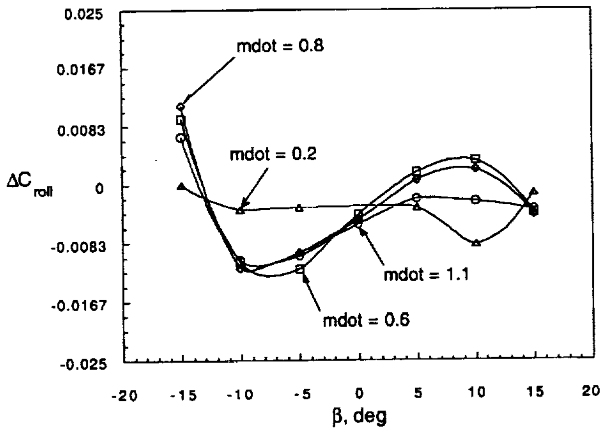
Fig. 10 Effect of angle of attack on the lateral-directional characteristics due to port-side slot blowing for two blowing rates: $U_\infty = 168$ ft/sec, $\beta = 0°$, $\delta_h = f(\alpha)$.



(a) Effect of sideslip angle on side-force coefficient in body axes.

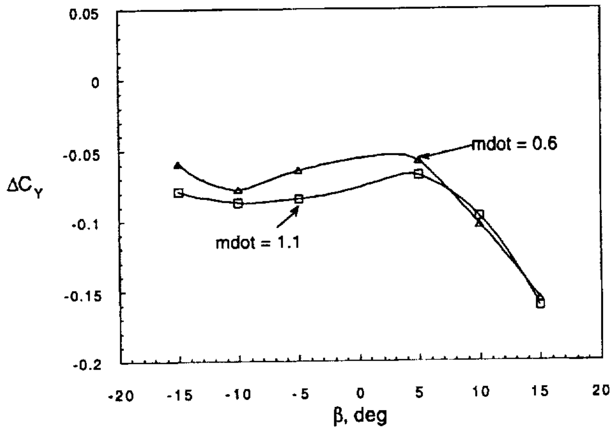


(b) Effect of sideslip angle on yawing-moment coefficient in body axes.

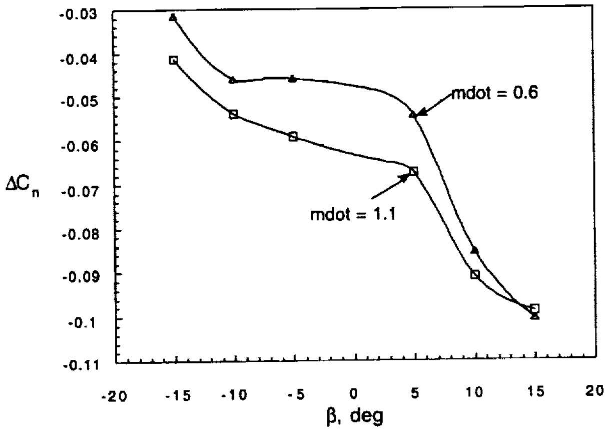


(c) Effect of sideslip angle on rolling-moment coefficient in body axes.

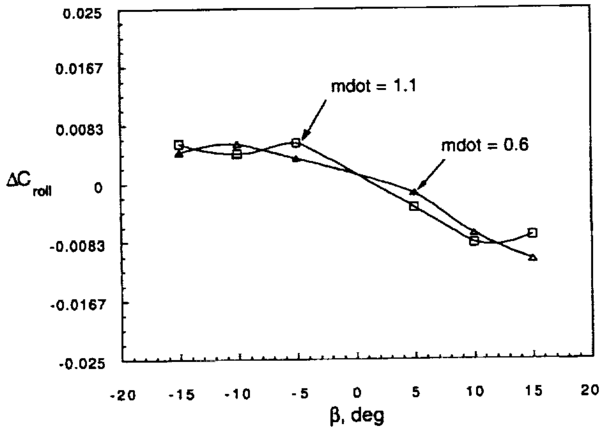
Fig. 11 Effect of sideslip angle on the lateral-directional characteristics due to port-side blowing for various blowing rates in lb_m/sec: $U_\infty = 132$ ft/sec, $\alpha = 40°$, $\delta_h = f(\alpha)$.



(a) Effect of sideslip angle on side-force coefficient in body axes.



(b) Effect of sideslip angle on yawing-moment coefficient in body axes.



(c) Effect of sideslip angle on rolling-moment coefficient in body axes.

Fig. 12 Effect of sideslip angle on the lateral-directional characteristics when port-side blowing is active at several blowing rates in lb_m/sec: $U_\infty = 132$ ft/sec, $\alpha = 50°$, $\delta_h = f(\alpha)$.

Biography

Wendy Lanser began her career with NASA Ames as a co-op student at Dryden in 1985. As a co-op student she worked on the Oblique Wing and X-29 programs at Dryden and later at the Unitary Wind Tunnels. In 1988 she graduated from California Polytechnic State University in San Luis Obispo with a degree in Aeronautical Engineering. Upon graduation she began work in the Full-Scale Aerodynamics Division at Ames-Moffett. Currently she is working in the Fixed Wind Aerodynamics Branch, FFF, at the 80-by 120 Wind Tunnel. For the past three years Ms. Lanser has worked on the High Alpha Technology Program. Her role in the program has been a research engineer on the Full-Scale Wind Tunnel tests of an F-18 aircraft.

She also participates in the College Recruitment Program at Ames. Ms. Lanser can be reached at 604-3543 or M/S 247-2.

N94- 35966

WOMEN AS A RESOURCE FOR THE FLEXIBILITY REQUIRED FOR HIGH TECHNOLOGY INNOVATION

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Summary

What do women scientists need to know for career advancement into senior level positions? Our declining economic conditions have been the cause for major political and technological changes. The U.S. Congress is turning toward technology to increase our competitive edge in the world. Allowing women scientists, and women engineers in particular, more voice in the decision making process may be an innovative alternative for the diversity and flexibility needed for the unknown technological problems of the future. But first women scientists need to know how the system measures scientific achievement and how to identify the processes needed to increase our technological capability in order for them to formidably compete and win higher ranking positions.

Introduction

The United States is in the midst of an economic change that most would agree is comparable to the Industrial Revolution. It is the threat of losing our dominant position in the world market that has caused deep concern and action by legislators and businesses. Foreign competition and the decay and dislocation of our manufacturing industries has caused a nation to look toward high technology for new economic growth. When the economy was growing rapidly, it was a concomitant belief, albeit an unchallenged belief that research fueled this expansion. The country is undergoing major transformations in order to reclaim its hegemonous position in the world economy. While we are still at a formative stage in this process, serious issues need to be addressed. Some of the key questions to be asked are: Can science and technology research assure us a dominant position as a world leader? How much money should be spent on science and technology research, and what should it be spent on? Who are the true beneficiaries, and will this change only perpetuate women's subordinate place in society or provide new possibilities for them? It is the purpose of this paper to investigate the revolutionary changes being made in our society and their impact on women in general, and women engineers in particular, as well as their work.

A nation's share in world trade in high-technology manufactured products is often used as a measure of its technological capacity (ref. 1). When considering the cause of our current economic crisis, the finger of blame points to our past technological performance. Since the 1980s, one of the most obvious and significant changes that has occurred is a trade imbalance between the number of manufactured products we exported and imported, particularly in the high-tech areas. Upon further examination, it becomes apparent that it was less of a deficiency in our own capabilities than it was a coordinated effort by our competitors at developing capabilities that manufacture goods of higher performance, a better quality, or a better price. When other nations, led by Japan, began to develop capabilities for synthetic innovation focusing on commercial products the U.S. started to lose its dominant position in the world market.

The U.S. economy has arrived at a point where other war ravaged foreign industries are now in a position to formidably compete with the U.S. for a larger portion of the world market. Between 1985 and 1987, the United States showed an increase in total national assets from \$30.6 trillion to \$36.2 trillion, while Japan's total national assets rose from \$19.6 trillion in 1985, to an unimaginable \$43.7 trillion in 1987 (ref. 2). The importance of this time frame is that it shows Japan, a small island with few natural resources, surpassing the U.S. in national wealth. This has resulted in shrunken profits and thus fewer resources to be allocated. The remedy became a short-term fix that borrowed heavily from foreign countries. By 1989, America's loss of economic power was reflected by a major decline in comparative world assets and purchasing power. This enormous transfer of wealth resulted in the U.S. being transformed from the world's largest creditor nation into the world's largest debtor nation. This economic decline has created doubts about not only the nation's ability to retain its influence and standing in the world, but its ability to retain its political and military power that ultimately depend on our economic strength and vitality.

What Can We Reasonably Expect from Science and Technology Research?

In 1983, Congress proposed over two hundred pieces of legislation to make science education and high technology a national priority. This consensus affirms the general belief that by strengthening our scientific and technological enterprises, we will revitalize our competitiveness in the global market which is now seen as crucial to both our country's well-being and military security. It is this understanding of technological innovation that suggests innovations are solely the product of research development. Although the evidence suggests otherwise, the U.S. has established a mechanism for systematically funding science while neglecting to establish a comparable system that promotes a technological process of innovation. The development of a science policy was assumed to carry within it an adequate technology policy.

It is difficult to demonstrate any clear correlation between research spending and the state of the economy. However, a frequently used indicator of a country's relative strength in science and technological capabilities is the number of Nobel Prizes awarded to its scientists. It is believed that the awarded Nobel Prize reflects the quality of an individual's contribution to science and if there are a number of Nobel Prizes awarded to individuals from a particular country, then that country would have greater potential or likelihood at being the world's leader in technological innovation and capability. Such a study was conducted to test the correlation between science achievement and industrial leadership. The national patterns of Nobel Prize winning were plotted against the rate of growth of either gross domestic product or manufacturing labor productivity. The results showed that among the countries that have hosted Nobel Prize winning science in chemistry and physics since 1945, the nations that have hosted fewer Prizes per capita have better economic performance, thus a negative correlation was identified (ref. 1).

The cash squeeze caused by our economic decline led to the development of "performance indicators" that not only assesses our national strength in science, but also its estimated relevance, effectiveness, productivity and investment return. What has become one of the most frequently-used indicators for estimating the quality of research is a statistical tool called bibliometrics. This approach uses the number of scientific publications and patents in a field that are authored by a nation's scientists as a measure of the quantity of that nation's contributions to that field. Some of the explicit assumptions of bibliometrics are that scientific research publications and U.S. patent records are legitimate measures of research output and that their citations and influence weights can be used to assess the relative importance of quality research or its scientific impact. It would seem that high-quality scientific publications are cited more frequently by other scientists than other work. Bibliometric indicators are being used to charter a comparative analysis of international research productivity; investigate specific topics for key patents and their leading researchers in the field; monitor the research activity of key scientists; spot technological trends; and provide hard data for business firms for planning, acquisitions, partnerships, and overall strategic direction.

Research and development (R&D) programs reflect our government's role in determining the theoretically possible activities in selected areas, sectors, or product types. Creating an R&D institution for systemic innovation is quite new. It is now generally accepted that basic research is only one of the things a country needs in order to be successful in commercializing new technology.

If our national goal is to increase our ability to compete commercially in the world market, then we must develop our strategies more carefully. To be successful innovators, we must ask the question: How can we develop a better product in order to make it commercially more competitive? This information is not found in doing science, but by talking to our customers. Surveying customers' needs and listening to their desires is the first step. It should be noted that upon listening to the concerns and information being provided by the customer, it is the practical problems that have been the source for identifying fundamental questions and important innovations. If we ask how to make a product less expensive, of higher reliability, or a better match to our customer needs we are improving the quality of the design, production, or processing (ref. 3). By developing "total flexibility" within production systems, we are combining the custom-tailoring of products to the customers' needs and desires with the power, precision, and economy of modern production technology. The strategic goal will be to deliver high-quality products tailored to each customer at mass-production prices (ref. 4).

Stephen J. Kline, Professor of Mechanical Engineering at Stanford University, suggests that engineers need to be taught not only the basics of manufacturing and how to apply its principles, but also which forms of innovation are important in commercial competition." We need to teach some of our brightest engineers the basics of manufacturing and encourage them to continue career paths in this area. We also need to teach our engineers about which forms of innovation are more or less important in commercial competition, a topic we seldom address in our schools. There is a category of information called technological knowledge, which, although considered inferior to scientific knowledge, on balance is more relevant for success in commercial markets."

When examining the individual's role in innovation, we realize that this includes a broader use of the concept of technical knowledge. Technical knowledge includes not only what we call the principles of science but also an engineering analyses of problem solving not specifically addressed by science. This includes codes, practices, knowledge about controlling and trouble-shooting specific processes and systems, and many forms of specialized skills using trained coordinated muscle responses. For instance, operating machinery and instruments may require eye-hand coordination or similar time-response coordinated movements. This type of individual technical knowledge does not appear in published materials as much as in the coordinated reflexes of many working technologists. Problems that arise in the technological workplace exercise a major role in shaping the research agenda of science. The workplace can be used as a platform to observe the problems that arise in industry and may be our best source for innovative improvements. Workers' technical skills and experience are now an integral part of the innovative process. No longer is it to the advantage of management to treat their workers as a cost to be controlled but should be seen as an asset to be cultivated. The skills and experience developed by the worker are important sources for identifying significant innovative processes for greater productivity and future commercial products.

Women's Role in High Technology Innovation

The various skills and experiences the employee brings to the job may be an important source for identifying alternative solutions for the unknown technological problems of the future. The commercial market operates within an international market that by its very nature is diversified. When developing an innovative process that focuses on our competitiveness in the world market, diversifying our options, giving ourselves permission to view things differently, may be our greatest strength. Women as a group show this type of diversity in their skills, experiences, and perspectives. No single person can be expected to have the definitive answer for our future problems. However, listening to a variety of suggestions may provide the pieces needed to arrive at the best possible solution. The greater the diversity in employee participation, the greater the potential for more alternatives. Diversified alternatives will increase our options for the unknown problems of the future.

The more significant changes that have occurred over the past decade are the enormous increase in women's labor participation and the unprecedented rate at which change is occurring. The wage-earning American and working women in particular are experiencing the greatest impact of these changes. Over the past decade, almost 7 out of 10 new entrants to the American work force have been women. Between 1975 and 1985 alone, more than 13 million women entered the workforce. By 1986, 55% of all women over the age of 16 were working outside the home (ref. 5). When many of the manufacturing jobs were lost or relocated, American males lost their means to earning a subsistence wage for their families. This resulted in women leaving the home and moving into the labor force in order to make up the differences in lost wages.

Today, in an economy where there is a "revolution" in women's labor-force participation there has been very little change in the conventional role structure of family life. On the average men perform an estimated 15 hours of household work per week while women perform 34. As many as a 25% of American husbands do no housework other than some basic child care (ref. 5). American motherhood has been transformed in less than a generation as well. In 1960, 20 percent of mothers with children under 6 years old were in the labor force, that has expanded to 58%, with most of them working full-time (ref. 6). Women's life duties show her constantly tailoring her work and abilities to fit the needs and demands of those who are her responsibility. Restructuring job duties on demand, broadening responsibilities, taking on new tasks in regular job rotations both in and outside the home produce a female work force with the potential for responding more rapidly and creatively to new problems. Skill and flexibility are the result of work experiences in a variety of assignments.

According to the MIT Commission on Industrial Productivity, innovative bench-marking includes a team approach to product and process development, closer relations with suppliers and customers, and a more democratic workplace that includes flatter organizations, increased sharing of information, employee participation in decision-making, profit sharing, increased job security, a commitment to training, and continuous improvement. Innovative factors such as these can only work to the advantage of women who often get shut out of the scientific and technological enterprises. Like the timeline of any research program, there are only a few strategic points at which input into the decision-making process is feasible or effective. For instance, technological design is at its most flexible during the initial stages of the process. Other opportunities present themselves at the beginning of each phase or subphase of production. The further along in the process, the less of an impact later decisions will have on the final product. Once in motion, the possibility of changing or halting its implementation is unlikely (ref. 7). The same timeline exists for any process; the window of opportunity occurs at the formative stage. It would seem more equitable and innovative to have women better represented in the decision-making process where change is most likely to occur whether on committees or throughout the production process. Women as a group show a unique diversity in their skills, experiences, and perspectives. If we consider our place in time and the diversity of our challenges in front of us, it is clearly the moment to more seriously consider a woman's point of view. A traditional, one-dimensional approach to innovation is self-defeating to the whole process. The greater the diversity in employee participation the greater the potential for more alternatives. A multi-dimensional approach to problem-solving increases our options for the unknown problems of the future.

Conclusions

The rapid rate of technological change is expected to continue. The U.S. is an integral part of the world market and our economy will continue to reflect our relative success at international commercial competition. The long term solution to our economic problems is continuous innovation which includes a better combination of market forces, consumer preferences, and technological opportunities. An era of "total flexibility" by production systems will combine the custom-tailoring of products to the customer needs and desires with the power, precision, and economy of modern production technology. The strategic goal will be to deliver high-quality products tailored to each customer at mass-production prices.

Regardless of how much a company invests in capital equipment, automation cannot replace human mastery of modern technology and experiences. Innovative human-resource policies promote participation, trust, flexibility, employment security, and teamwork. The enormous increase in women's labor force participation, an unfair share of domestic duties, a subsequent newly structured motherhood, and a lack of support by business and government show women as having an enormous capacity for flexibility and strength. Workers, managers, and engineers will be continually and broadly trained in the continuous innovation needed for a diverse international market of which women are already showing an enormous capacity.

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Biography

The author has a B.A. in Biological Sciences and Chemistry and an M.A. in Sociology. Her past work experiences have been as a librarian in a major university research library and at the Library of Congress. Today, she is a librarian at the VMS Laboratory, NASA Ames Research Center.

N94- 35967

A BIASED HISTORICAL PERSPECTIVE OF WOMEN IN THE ENGINEERING FIELD AT DRYDEN FROM 1946 TO NOVEMBER 1992

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Summary

Being a woman in engineering, and in particular, being the woman with the dubious distinction of having the most years at Dryden, gives the author a long-term perspective on the women who worked in the engineering field and their working environment. The working environment for the women was influenced by two main factors. One factor was the Dryden's growth of 14 persons (2 of them women) at the end of 1946 to the present size. The other factor was the need for programming knowledge when the digital computers came into use. Women have been involved with flight research at Dryden since the days of the first transonic and supersonic airplanes. This paper uses available records, along with memory, to document the number of women in engineering at Dryden, to comment about observed trends, and to make personal observations.

Establishment of NACA Flight Test Unit

In the early to mid-1940s, the National Advisory Committee for Aeronautics (NACA), Army Air Forces, and Navy decided to build and flight test aircraft that could fly in the transonic Mach number region (Mach 0.7 to 1.3). This decision was made because the wind tunnels at that time could not test at transonic and supersonic speeds. Also, the interim "short-cut" flight programs of that time which included air drops of weighted models, launches of models from rockets, and test models mounted on aircraft wings could not provide all the needed information. Certain requirements for the flight test area had to be met. The area had to be remote for safety reasons and to reduce unwanted observation. Another requirement was that the test area have good flying conditions of few cloudy days and long runways. Previous NACA Langley flight tests had demonstrated the difficulty in tracking aircraft in cloudy skies and the new test aircraft needed long runways for takeoffs and landings.

NACA selected Muroc Army Air Field, which became Muroc Air Force Base in February of 1948 and was renamed Edwards Air Force Base in December of 1949, as the site for the flight tests. Muroc, in the Mojave desert, met the remote location and good flying conditions requirements. Muroc had two other advantages. One was that the Army Air Forces, with whom NACA was working, had established Muroc as a wartime center for advanced aircraft testing. Another was the proximity of Muroc (fig. 1) to the leading aircraft industry in the Los Angeles area. The employees at the Muroc test site were to conduct flight tests and analyze the data for the X-1 (rocket powered) and the D-558 (jet powered and rocket powered) series of aircraft.

In the fall of 1946, NACA Langley began sending people to Muroc. The first contingent (five men) arrived on September 30, 1946. Six more men arrived two days before the first glide flight at Muroc of the XS-1 aircraft on October 11, 1946. The first two women, Roxanah B. Yancey and Isabell K. Martin, arrived in December 1946. The team now consisted primarily of engineers, computers (people who computed), and instrument and telemetry technicians. The computers, following the standard practice of the day, were the two women. In the Federal government's scientific community, almost without exception, the computers were women. In early September of 1947, NACA decided that the unit at Muroc (now 27 persons) would function as a permanent facility (NACA Muroc Flight Test Unit), managed by Langley. On November 25, 1947 the first NACA flight of the D-558-1 aircraft occurred. This meant that the X-1 and the D-558 series aircraft were now being flight tested at the NACA Muroc site.

The history of the establishment of the NACA Muroc site from its beginning to 1981 (then NASA Ames-Dryden Flight Research Facility) is told in reference 1. The purpose of this paper is to discuss the changes in the working environment for the women in the engineering field at Muroc/Dryden. Only the NACA/NASA civil service women are discussed; records were not available for women who worked for contractors.

Women's Involvement from 1946 to the Early 1950s

The women and probably many of the men sent from Langley had volunteered for one-year assignments at the Muroc site. The first two women (the computers) assigned to the Muroc site can be seen in the group photograph taken in late 1946 (fig. 2). The policy at Langley at that time was to hire women with math degrees to be computers. Roxanah Yancey, who had a math degree, retired in 1973 from the Muroc site, then called the NASA Flight Research Center. Isabell Martin, assumed to have had a math degree, left the Muroc site early in 1947.

By October of 1947, 27 persons were working at the Muroc site. The group photograph (fig. 3) shows 22 persons, 4 of them women. The number of people at the Muroc site almost doubled in size each year from 1947 to 1950. There were 40 persons in May of 1948, 60 in January of 1949, and 132 in January of 1950. (In late 1949, the name was changed to NACA High-Speed Flight Research Station.) The group photograph taken in 1950 (fig. 4) shows that the number of women had increased significantly from the four of 1947.

Until 1957, the single women and men could live in dormitories on the base. The women's dormitory at the south base (location shown in fig. 5) was near the base chapel and the base theater. The men's dormitories were on the north base approximately 8 miles away. The dormitories were inexpensive and close to the work site. Figure 6 is an aerial photograph of the Muroc site in the late 1940s. The last two photographs show the desert vegetation and indicates how different the climate was for the people from the east coast. Not everyone wanted to stay. One reason some stayed is related to the noseboom pressure traces, shown in figure 7, from the XS-1 airplane flight on October 14, 1947. These pressure traces are a record of the Mach jump from the first manned airplane to exceed the speed of sound. For some, being able to work on advanced aircraft such as the X-1 and the D-558 was reason enough to stay at the Muroc site.

Translating the traces on the oscillograph film into usable data required considerable effort. Figure 8 shows a roll of oscillograph film and two of the tools used, a film scale and a slide rule. The horizontal traces on the oscillograph film were either reference traces or data traces. The vertical lines were the time scale. A film scale was used to read the difference (delta) between a data trace and its reference trace at the desired time. The engineering value for each delta was then read from the corresponding calibration plot. After the engineering values were obtained, the desired parameters were calculated using the appropriate tools (slide rule, mechanical calculator, standard atmosphere tables, sine and cosine tables, etc.). The engineers did some of this but most of the film reading and calculations were done by the computers. This was tedious and time-consuming work, and required a great deal of patience. Men were not thought to have the patience to do this work. For this reason, almost all computers were women. Figure 9 is a photograph of the computers at work.

The working environment during the early days at the Muroc site was directly influenced by the small number of people working there and by the remote location. The small numbers meant that everyone was known by all in the group. This fostered a strong team spirit that resulted in people helping wherever they were needed. The computers worked closely with the engineers and were often co-authors on technical reports. This small-group working environment existed into the early 1950s.

Working Environment Change in the Early 1950s

The increase in the number of people at the Muroc site and in the number of aircraft being tested (fig. 10) changed the small group working environment. Another change, which was to have a significant effect on the working environment for the women in the engineering field, was that in March 1954, the NACA High-Speed Flight Research Station became the NACA High-Speed Flight Station (HSFS). The HSFS was now autonomous, which meant that Langley was no longer responsible for management or staffing. Also in 1954, the HSFS people (now 250 persons) and airplanes moved into a new, larger building on the main base. This building (4800) has been added to over the years and is still in use. Figure 11 is a group photograph taken in 1954 in front of the new building.

Two name changes were made in the late 1950s. In 1958, NACA became NASA, and in September of 1959, the HSFS became the Flight Research Center (FRC). The number of people at the HSFS continued to increase and by December of 1959 the complement at FRC was 332. One effect of the increase in complement was that people were placed in defined positions. In the early to mid-1950s, the women computers began working in a computer group, which was supervised by one of the senior women computers. Another change was in the technical background of the women in the computer group. Most of the women assigned from Langley had math degrees. The computers hired by the HSFS were usually from the local area and most of them did not have college degrees. This resulted in the working assignments becoming more routine and meant that there were fewer opportunities for women, even with degrees, to work in the technical engineering areas. The resulting decrease in interaction with the engineers also meant that the women were no longer co-authors on technical reports.

Women Authors from 1949 to 1960

From 1950 to 1960, three women engineers worked at the HSFS. Two of them were authors of NACA reports. The third woman engineer worked only a short time at the HSFS and was not an author on a report. Joan Childs was the first woman to write a technical report at the Muroc site. The year was 1953 and the report was on the Bell X-5 airplane, NACA RM L52K13b (ref. 2). Ms. Childs started as a computer and was reassigned to the engineering group because of her engineering degree. She was at the Muroc site approximately 2 to 3 years. The other woman engineer during that time worked at the Muroc site as a math aide during the summer. After graduation from college, she began working as an engineer and worked in the engineering field until 1983 when she transferred to a congressional staff position.

From 1949 to 1957, 12 computers were co-authors on reports about the X-1, X-3, X-5, D-558, and B-52 airplanes. The number of computers as co-authors was determined by looking through a card file of reports by Muroc/HSFS/FRC authors. The computers were always the last author listed on multiple author reports (usually two or three authors). During that time there were at least 23 computers who worked at Muroc/HSFS.

Later Work Environment Changes

The next change in the hiring and job requirements for women occurred during the early to mid-1960s. This change was caused by the development of digital computers and the need for people with college degrees to program them. One of the new people hired to work with the digital computers (at that time an IBM 3650) was a woman. Her primary duties appear to have been computer programming, which initially required a degree. The digital computers with their capacity for rapid data reduction began to replace the hand calculations. During the early years of the digital computers, most engineers relied on computer programmers to write the data reduction programs required to calculate the desired parameters. Two women programmers were hired during this time.

The oscillograph film recording systems were soon replaced by onboard magnetic tape recording systems. The work done by the women computers was no longer needed and their jobs eventually changed to running the computer programs written by other people. Three of the former women computers moved to engineering positions at this time. One woman had a math degree, one a degree in education, and one did not have a degree. Two of these women had a relatively easy transition to the engineering field; the other did not. Another of the women computers (she had a math degree) became chief of the programming and data processing branch. The remaining women computers eventually quit, retired, or were reassigned to other jobs.

The last change in the hiring and job requirements for women is also related to digital computers. As the digital computers became more powerful, they were used to run the airplane simulators. The early simulators were based on analog systems and the programs used to drive them were maintained and run by men. When digital computers began to replace the analog systems, women were also hired to run and maintain simulation programs. Hybrid analog–digital simulations were used for a few years (for example, X-15-2 simulation). The first all-digital simulation was for the 3/8-scale F-15 Remotely Piloted Research Vehicle (RPRV). Computer simulation programs require much attention to detail and women are well known for their attention to detail.

Number of Women in Technical Areas from 1960s to Present

The women computers of the late 1940s and early 1950s worked closely with the engineers, almost in the capacity of junior engineers. By the early 1960s, this working relationship, with four exceptions, no longer existed. These 4 woman (3 retired in 1973, 1 in 1979) are included in the numbers of women from 1960 to the present, shown in the following table. Also included in the table are the major airplane projects.

Some of the airplanes mentioned in the table are seen in the group airplane photographs of figures 12 to 14. Figure 12 shows the airplanes being worked on in the hangar in late 1966. There are no women working on the planes in this photograph.

In the 1970s, women began working on the flight crews (usually only one or two women) and presently three women (two are mechanics, one works in avionics) work on the flight crews. In general, the women had great difficulty fitting in and until the mid to late 1980s, all changed jobs (one for a better job, one to get a college degree, but most because of a difficult working environment). One obvious difficulty for these women is that of a woman working in a traditional male job. Another is that while most men develop their mechanical skills at an early age, most women do not. This means that using even simple

Number of Women In Technical Fields and Airplane Project from 1960s to the Present Time

Time period	Number	Major airplane projects
Early 1960s	7	X-15
Mid to late 1960s	12	X-15, XB-70, Lifting bodies (M2-F2, HL-10), Lunar Landing Research Vehicle (LLRV)
Early to mid 1970s	13	YF-12, Lifting bodies (M2-F3, HL-10, X-24A, X-24B), F-8 Supercritical wing, F-8 Digital Fly-by-Wire (DFBW), F-111 Transonic AirCraft Technology (TACT), 3/8-scale F-15 Remotely Piloted Research Vehicle (RPRV)
Late 1970s	11	YF-12, F-8 DFBW, KC-135 Winglets, Shuttle Orbiter approach and landing tests, F-111 TACT, Highly Maneuverable Aircraft Technology RPRV (HiMat)
Mid to late 1980s	17	B-720 Controlled Impact Demonstration (CID), X-29, F-111 Mission Adaptive Wing (MAW), F-16 XL Supersonic Laminar Flow Control (SLFC), F-18 High Alpha Research Vehicle (HARV), F-15 Highly Integrated Digital Electronic Controls (HIDEC)
Early 1990s	25	X-29, F-15 HIDEC, F-16 XL SLFC, F-18 HARV
November 1992	23	F-15 HIDEC, F-16 XL SLFC, F-18 HARV, X-31, SR-71

tools, such as pliers or a screwdriver, is not second nature to most women. Many women began working on the flight crews because the upward mobility programs of the late 1970s gave them an opportunity to move from the lower paying clerical jobs to the higher paying flight crew jobs. Those women with limited mechanical skills had an especially difficult time.

Two more name changes occurred from 1960 to the present. In 1976, the Flight Research Center became the Dryden Flight Research Center (DFRC). In 1981, the DFRC was combined with Ames Research Center and DFRC became the Ames-Dryden Flight Research Facility.

The type of work and the number of women who retired, quit, or transferred to another government facility are given in the Appendix for the time periods of the previous table. Of the 23 women presently working in the technical field, 12 are in the engineering disciplines, 3 are in airplane simulation, 4 are in program management (1 is also a flight test engineer on the SR-71 crew), 3 are in nondisciplinary management, and 1 is chief of the branch responsible for computer systems, flight control rooms, and information networks. As a point of interest, 6 of the women presently working at Dryden in the technical field were in its "co-op" program. The co-op program is a cooperative work-study between NASA and different universities. Engineering students alternate between work periods at a NASA site and their course work at the university.

Observations

The initial plan for this paper was to discuss the women with engineering degrees who worked at Dryden throughout its history. Until recently, however, there haven't been many women with engineering degrees who worked at Dryden. In addition, the women (and men) who work in the engineering, or technical, field have degrees in both engineering and the sciences (math, physics, etc.). Another reason the paper topic changed was because during the early years at Dryden, the women with non-engineering degrees (in some cases, no degree) performed the same work as a junior engineer.

The first woman in a technical management position at Dryden supervised the women computers. In the 1960s, this management position included computer programming and data processing. Women are still in management positions in these and related areas. Women began moving into program management in the 1970s and into nondisciplinary management positions in the 1980s. Women have yet to move into engineering discipline management positions.

One difference between the women who worked at Muroc during the early years and those who came later was the attitude toward working after marriage. Unlike now, most of the women who married when they were working appear to have quit their jobs soon after. The women who quit and transferred during the later years did so for a variety of reasons. Two transferred to jobs near where their husbands had moved, one transferred to improve her chances for promotion, one transferred to a nonengineering job (in this case, her husband transferred to be with her), one quit to get a better job, and two quit for other reasons, one being to spend more time with their children.

The number of women in technical fields from the early days to 1963 was based on the women authors and co-authors of technical reports, available organizational charts, photographs, the information in reference 1, and the memories of people who worked here during that time. The additional information resources from 1963 to the present, included my memories, the memories of those still working at Dryden, and the equal employee opportunity records from 1990 through 1992. I apologize to any of the women I may have missed.

Acknowledgments

I would like to thank all the people who helped me with special thanks to Mary V. Little Kuhl, Mary (Tut) Hedgepeth, Edwin J. Saltzman, Terry J. Larson, Lannie Dean Webb, Erma Cox, and Elizabeth Davis.

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2. Childs, Joan M.: Flight Measurements of the Stability Characteristics of the Bell X-5 Research Airplane in Sideslips at 59°Sweepback. NACA RM L52K13b, 1953.

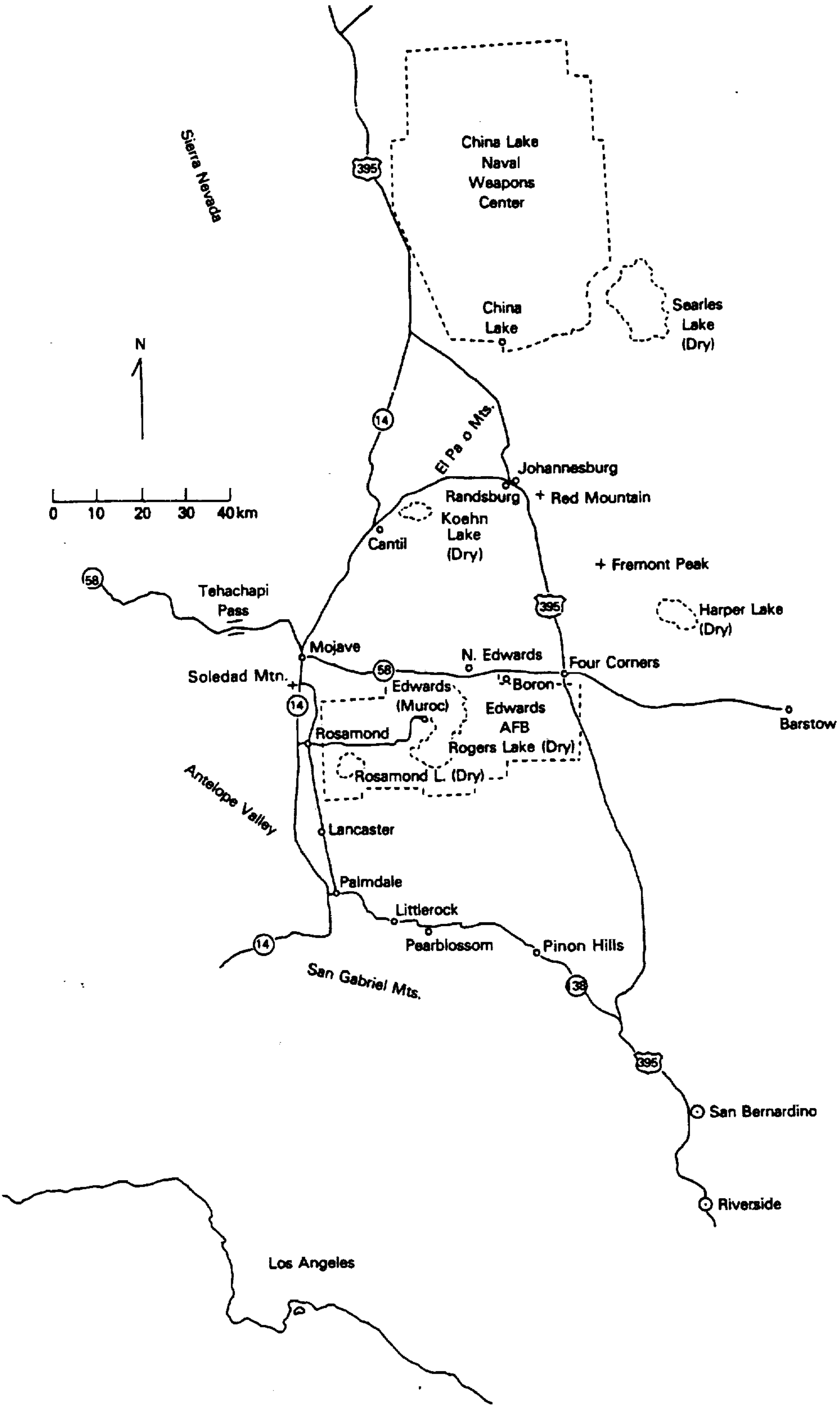
Appendix

Number of Women by Job Category from 1960 to Present

Engineering disciplines	Computer programming	Airplane simulation	Management
Early 1960s 6 (2 engineers, 4 former woman computers) [1 engineer transferred]*	1		
Mid to late 1960s 8 [1 transferred, 2 quit]	3		1 Chief of Programming and Data Processing Branch
Early to mid 1970s 7 [2 former woman computers retired 1973; 1 died in glider accident in 1976]	4 [1 quit]	1	1 Chief of Programming and Data Processing Branch [Retired 1973, former woman computer]
Late 1970s 6 [1 retired (last of former women computers); 1 quit]	3	1	1 in program management [transferred to congressional staff position]
Mid to late 1980s 11 (1 an instrumentation engineer responsible for research instrumentation airplane; 1 an operations engineer responsible for flight readiness of airplane) [Medical retirement for instrumentation engineer; 1 quit]		1	2 in program management 1 assistant chief of branch responsible for computer systems, flight control rooms, and information networks, 2 in non-disciplinary management positions
Early 1990s 13 [1 transferred]		4 [1 quit]	4 in program management 1 branch chief (former assistant branch chief), 3 nondisciplinary management
November 1992 12		3	4 in program management (1 also serves as a flight test engineer on the SR-71 crew), 1 branch chief (former assistant branch chief), 3 nondisciplinary management

*[Change by next time period]

Notes: "Transferred" means the woman went to another government facility. "Engineering discipline" refers to any of the airplane discipline studies, for example, propulsion, aerodynamics, stability and control, structures, etc. and "Program management" refers to general oversight of an airplane program such as coordinating, scheduling, funding, working with any outside partners involvedwith the program, etc.



The western Mojave Desert

Figure 1. Location of Muroc (Edwards Air Force Base since December 1949) with respect to Los Angeles. The names and road numbers are for the present time.

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Figure 2. Group photograph taken in late 1946 in front of the XS-1 and the B-29 (carrier airplane for the XS-1). Roxanah Yancey is in the second row, fourth from the right.

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Figure 3. Group photograph taken in October 1947 in front of the B-29. Roxanah Yancey is in the second row, fifth from the left.

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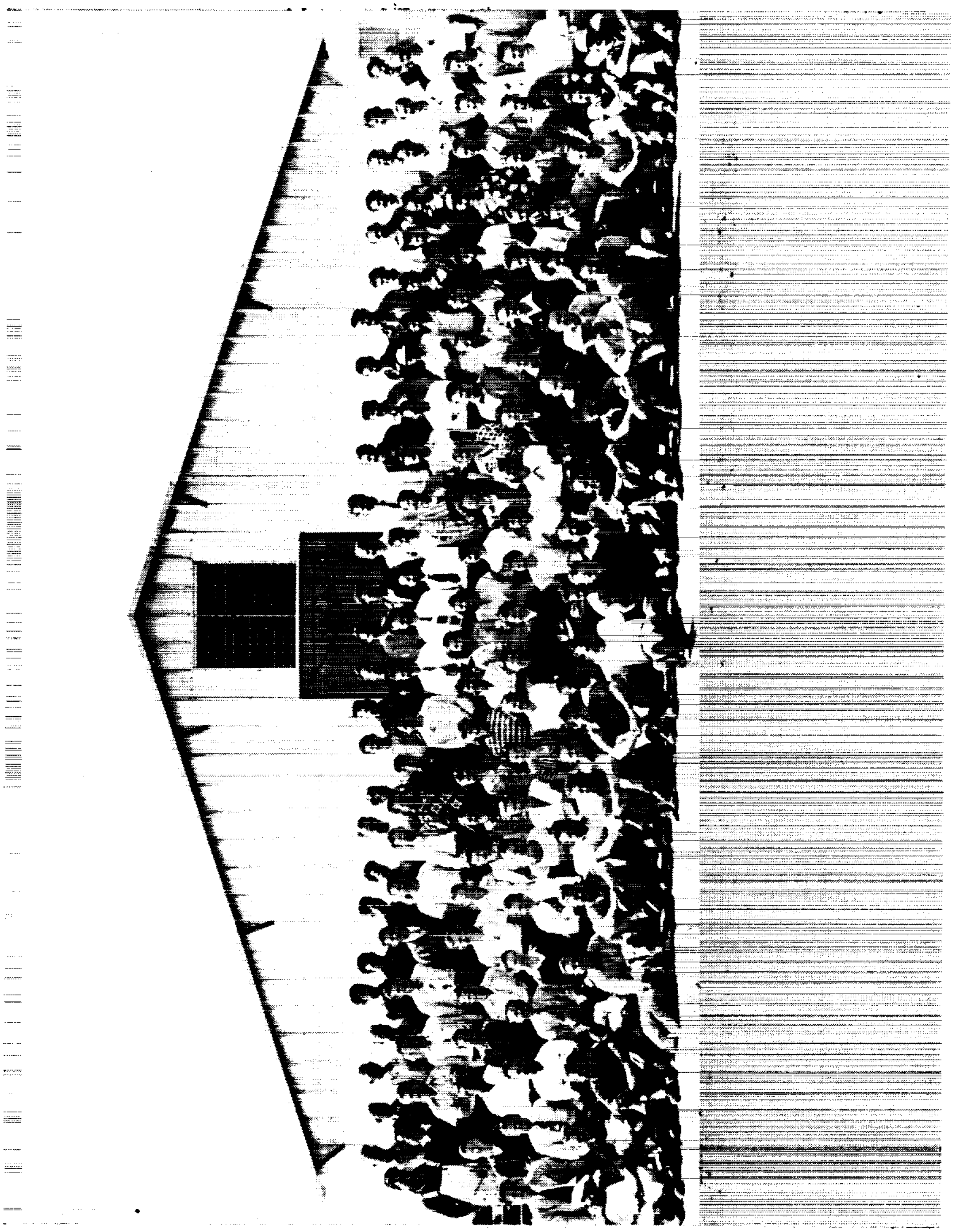

Figure 4. Group photograph taken in 1950 in front of the NACA building. Roxanah Yancey is in the first row of women, third from the right.

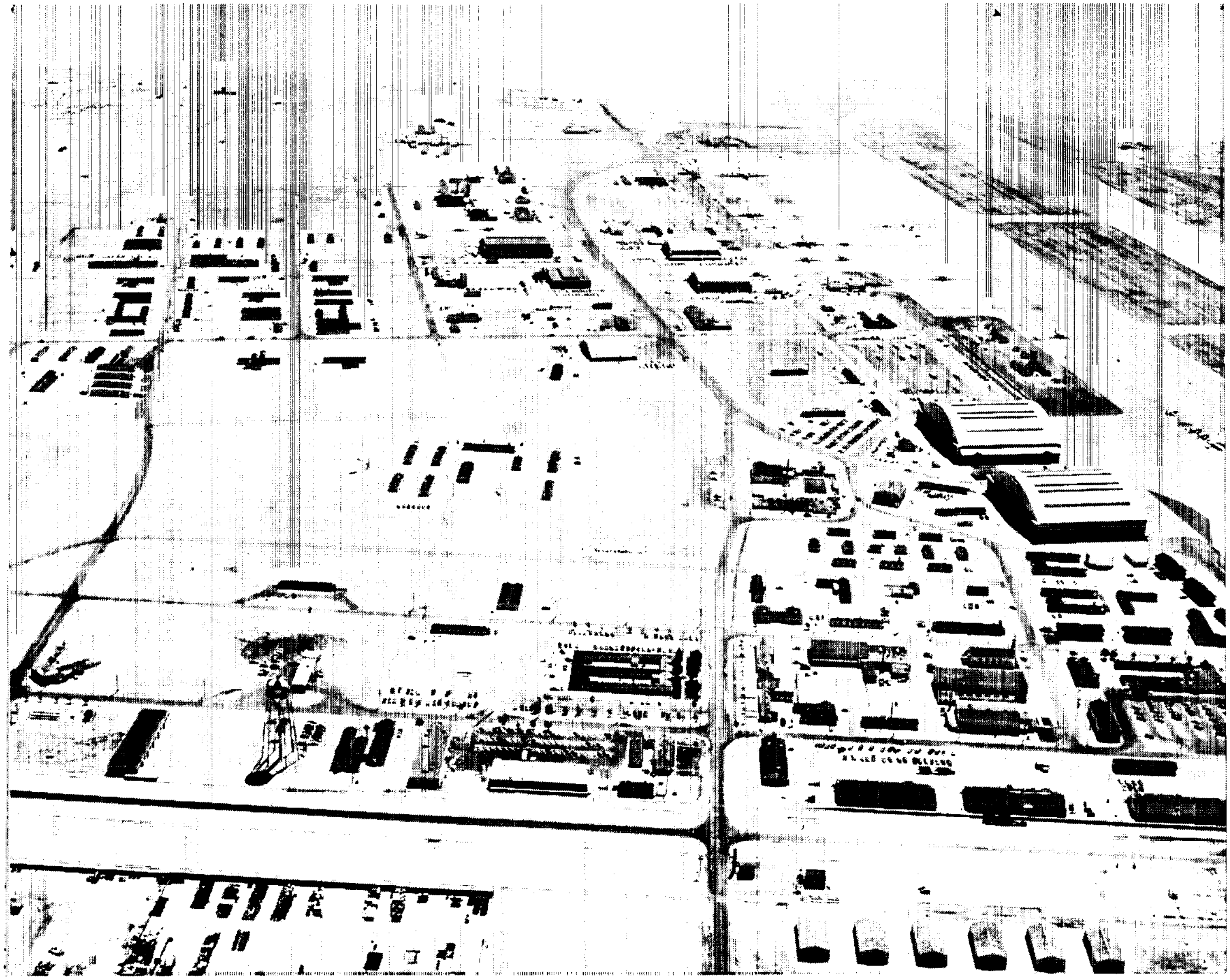

Figure 5. Aerial view of the south base taken July 1951; the women's dormitory, NACA site, and other buildings are indicated.

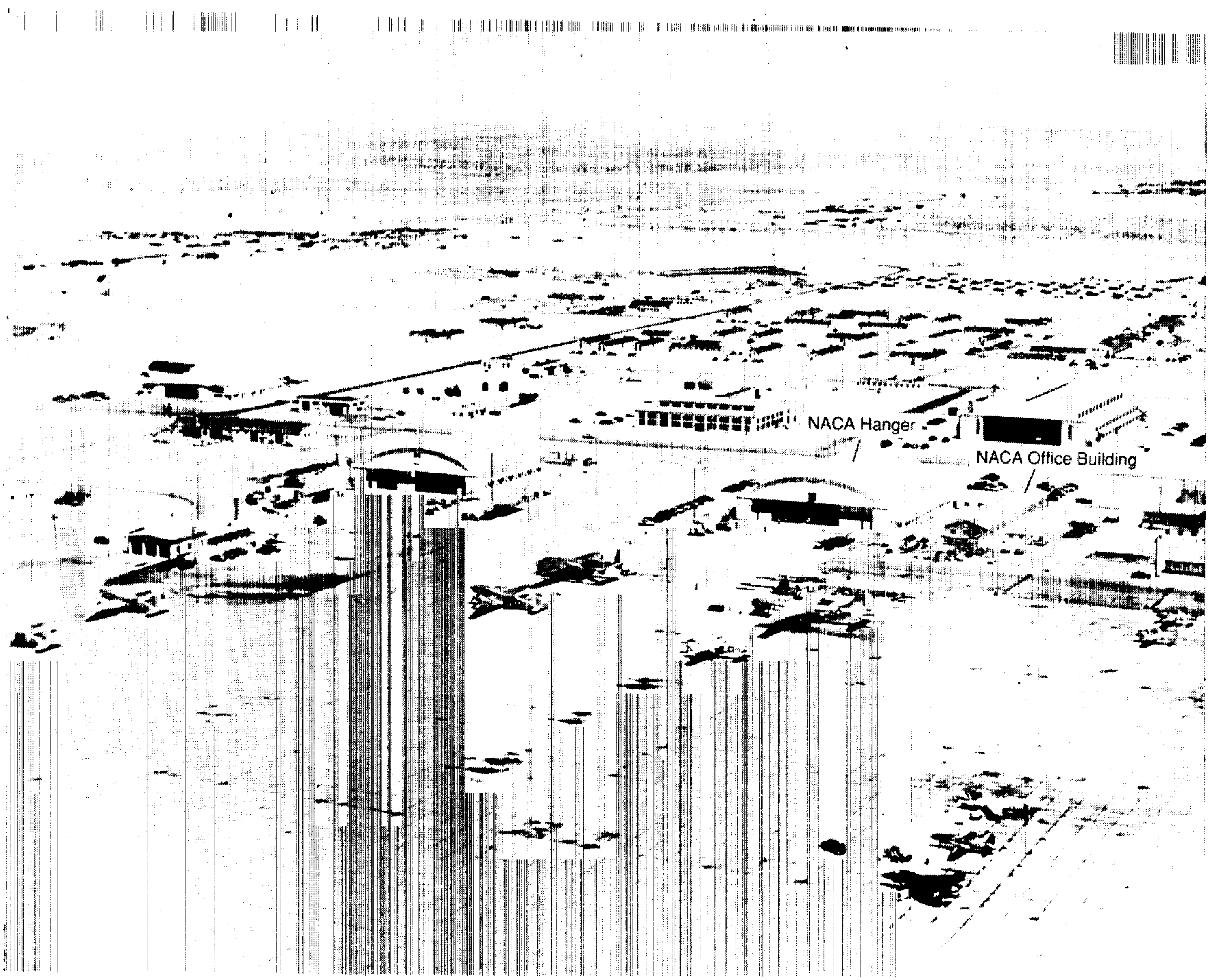

Figure 6. Aerial view of NACA site at the south base late 1940s.

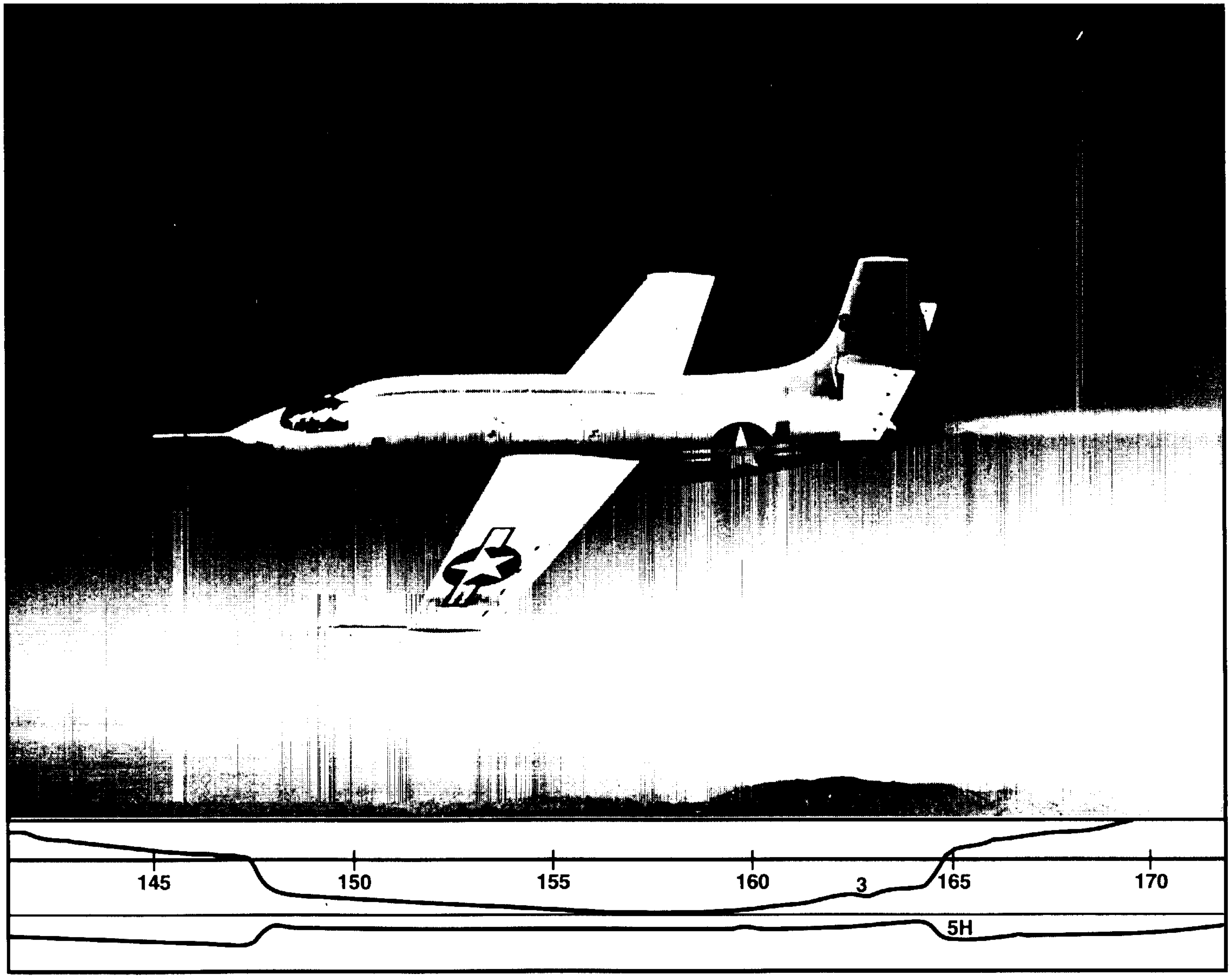

Figure 7. XS-1 and film pressure traces from first airplane flight to exceed the speed of sound. Flown by Charles Yeager on October 14, 1947.

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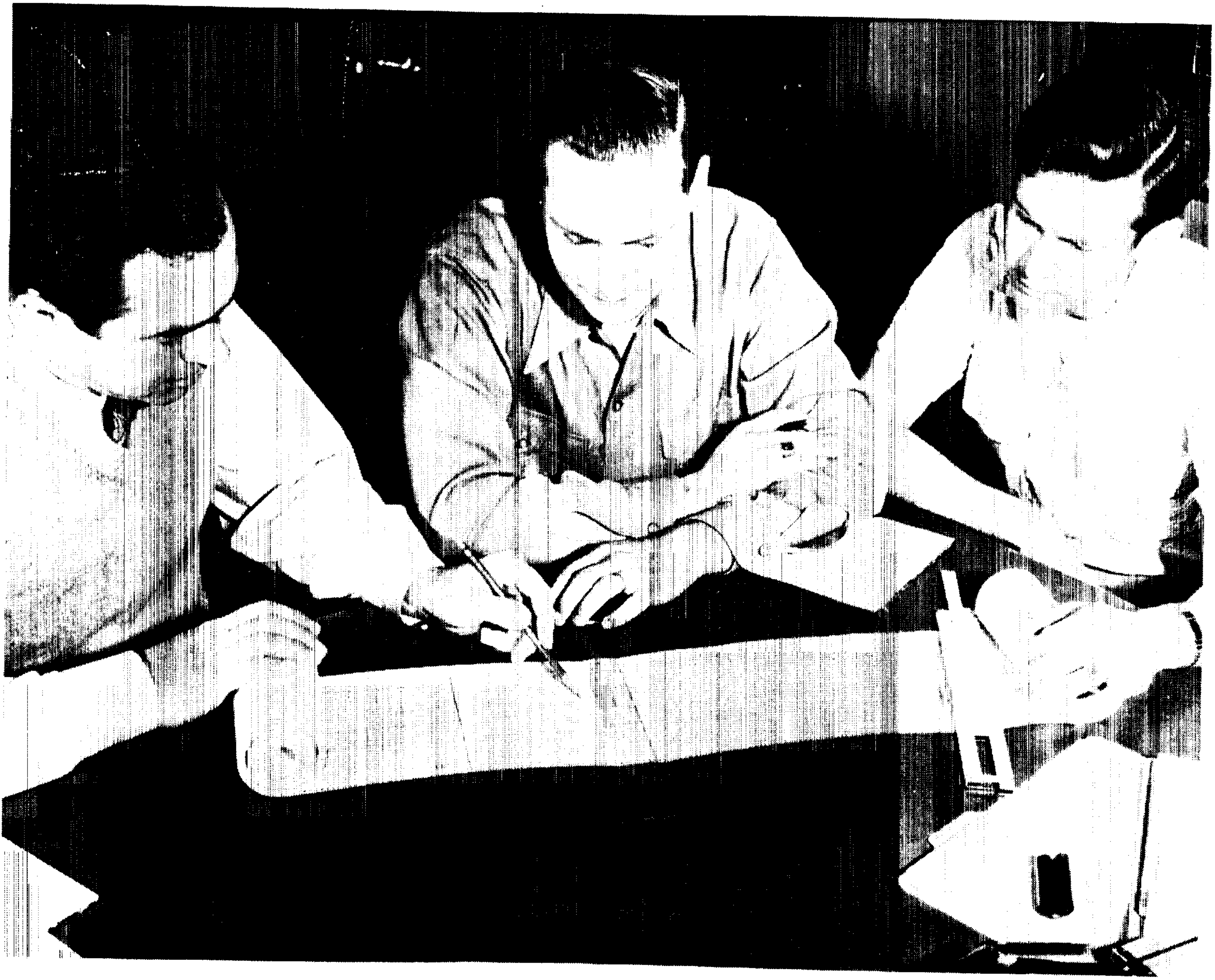

Figure 8. Engineers with oscillograph film, film scale, and slide rule, late 1940s or early 1950s.

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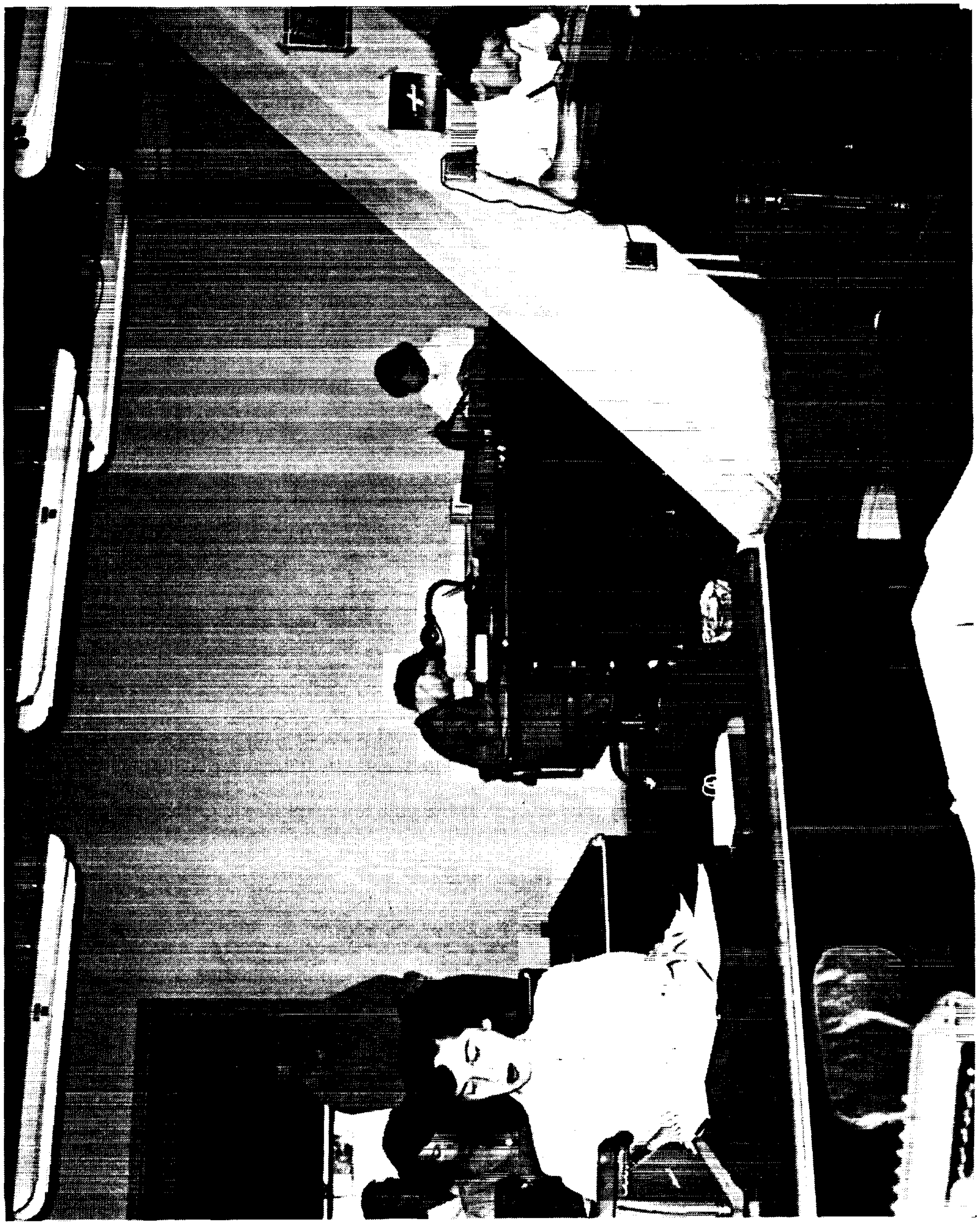

Figure 9. Women computers at work, late summer 1949. Mechanical calculators, Fridens, are seen on desks on the left side. Woman at center desk with lamp is reading film traces.

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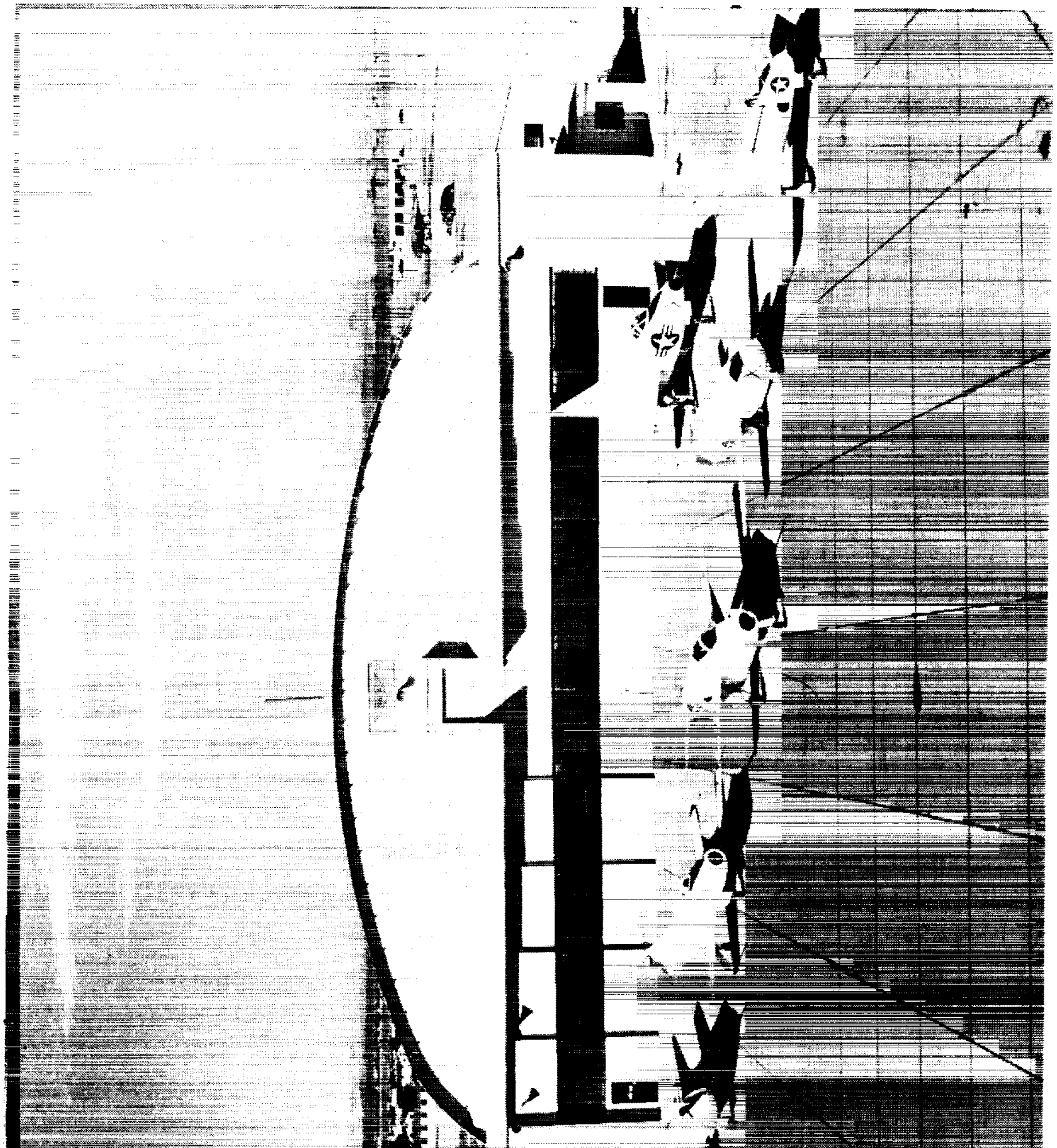

Figure 10. NACA's X-series in the early 1950s.

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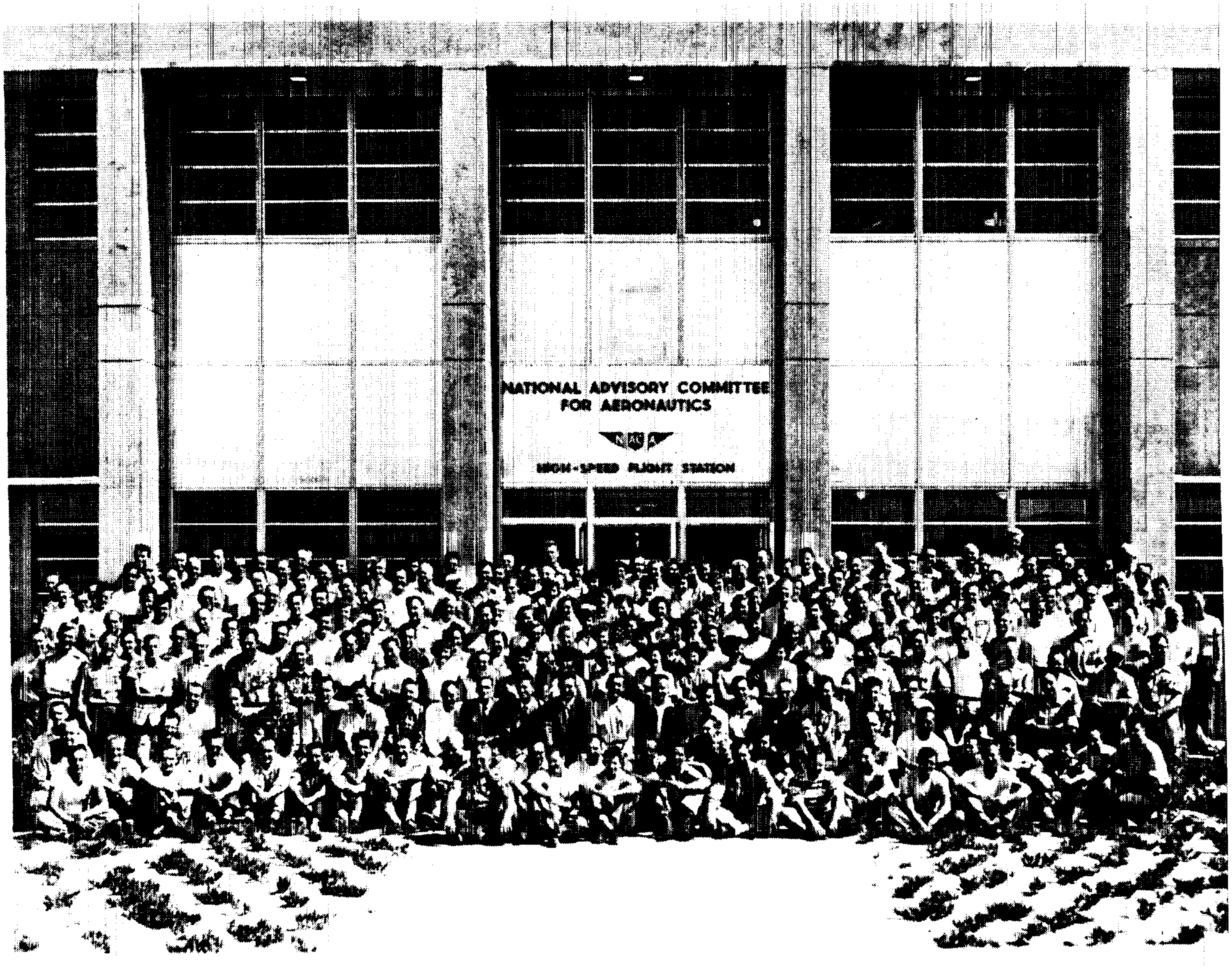

Figure 11. Group photograph taken in 1954 in front of the new building, main base.

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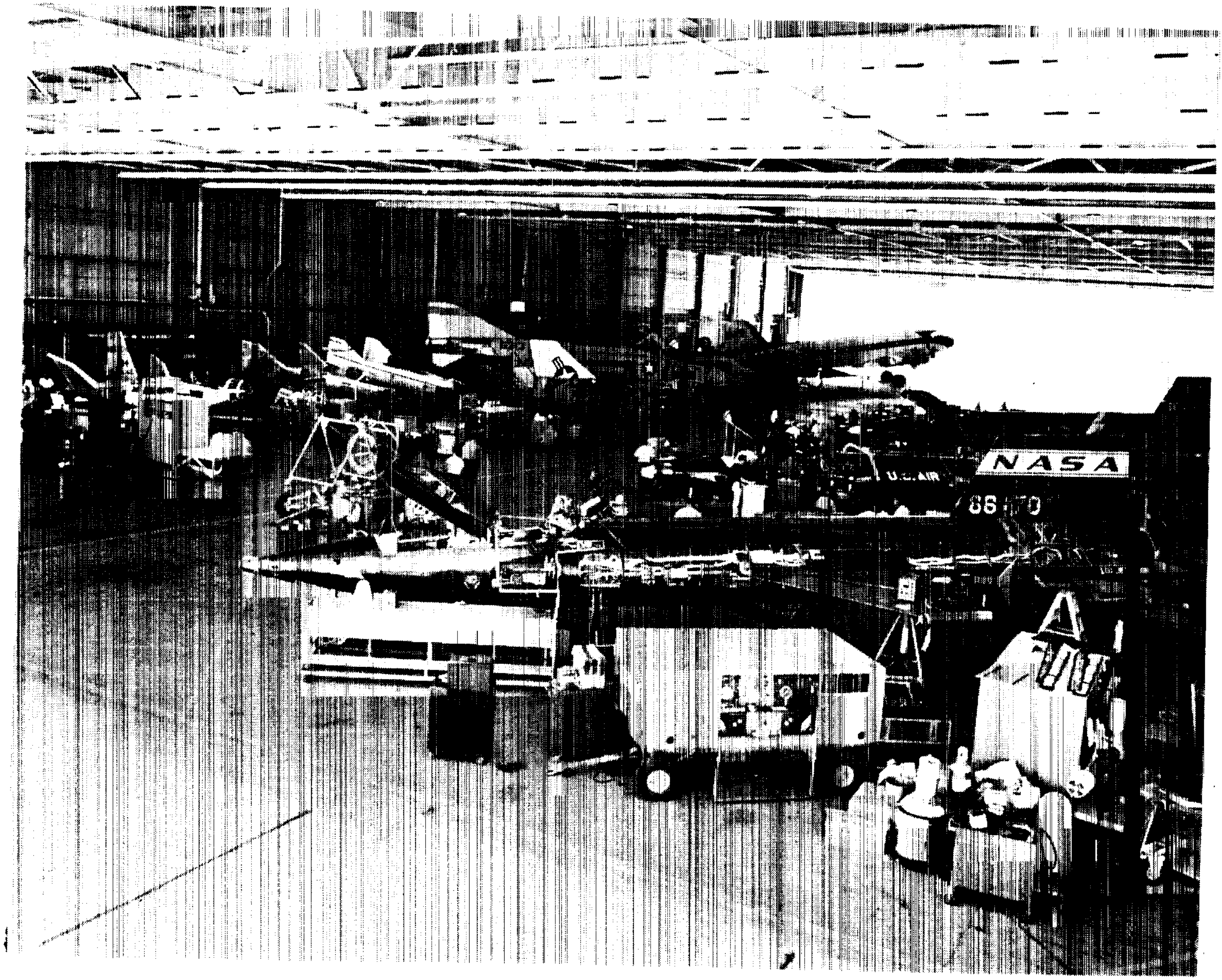

Figure 12. Airplanes in hangar in late 1966. From front to rear: left side, lifting bodies HL-10, M2-F2, M2-F1, F-4, F-5D, F 104, and DC-3; right side, X-15-1, X-15-3, and X-15-2.

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Figure 13. Airplanes on ramp, 1988. From front to back and left to right: X-29, AD-1, PA-30, HiMAT, F-104, F-8 DFBW, F-16 AFTI, T-38, F-18, F-18, F-111 MAW, F-15, RSRA, B-52, Jetstar, and 747 shuttle carrier aircraft.

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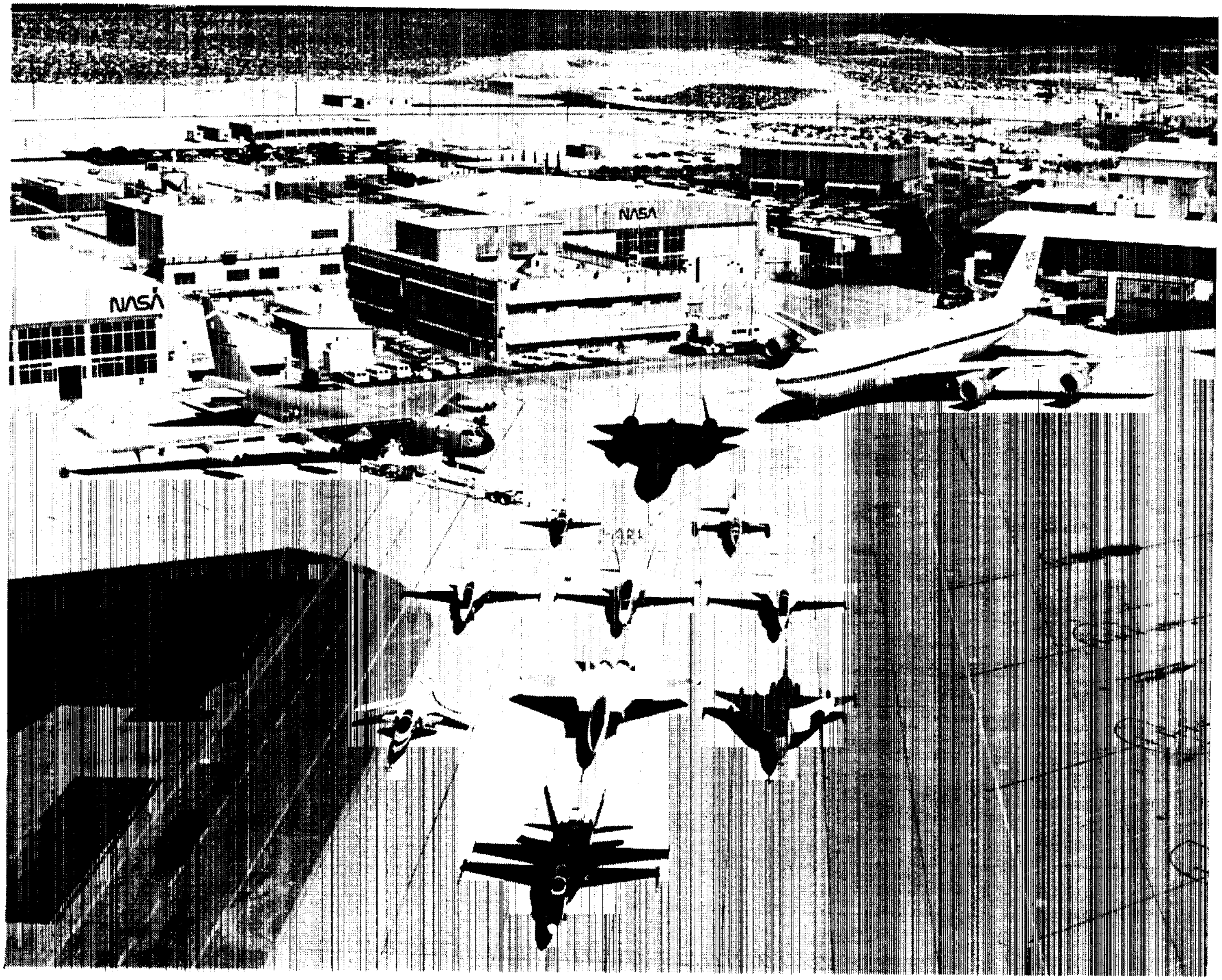

Figure 14. Airplanes on ramp, 1990. From front to back, left to right: F-18 HARV, X-29, F-15, F-16 XL SLFC, 3 F-18 support aircraft, T-38, F-104, B-52, Pegasus, SR-71, and 747 shuttle carrier aircraft.

Biography

Sheryll Goecke Powers first began working for NASA in the cooperative work study plan between Iowa State University and the NASA Flight Research Center (presently the Dryden Flight Research Facility of the NASA Flight Ames Research Center) at Edwards, Calif. She began working full time for NASA at Edwards, Calif. after obtaining her B.S. degree in Aerospace Engineering from Iowa State University. While working, she obtained a M.S. degree and an E.D. degree, both in Aerospace Engineering, from the University of Southern California.

Her first project at NASA concerned the base drag for the sharp leading edge upper ventral fin on the X-15.

Subsequent projects included: determining the base drag for the XB-70; determining the drag caused by surface discontinuities, such included aircraft component base drag reduction and boundary layer measurements, on the F-111 TACT, F-111 MAW and JetStar; lift and drag studies on the space shuttle; lift and drag sensitivity studies on the X-29; and serving as technical director for the F-111 MAW symposium. She presently is a group leader in the Propulsion and Performance Branch.

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EXPERIENCE WITH ADA ON THE F-18 HIGH ALPHA RESEARCH VEHICLE FLIGHT TEST PROGRAM

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Summary

Considerable experience has been acquired with Ada at the NASA Dryden Flight Research Facility during the on-going High Alpha Technology Program. In this program, an F-18 aircraft has been highly modified by the addition of thrust-vectoring vanes to the airframe. In addition, substantial alteration was made in the original quadruplex flight control system. The result is the High Alpha Research Vehicle. An additional research flight control computer was incorporated in each of the four channels. Software for the research flight control computer was written in Ada. To date, six releases of this software have been flown. This paper provides a detailed description of the modifications to the research flight control system. Efficient ground-testing of the software was accomplished by using simulations that used the Ada for portions of their software. These simulations are also described. Modifying and transferring the Ada flight software to the software simulation configuration has allowed evaluation of this language. This paper also discusses such significant issues in using Ada as portability, modifiability, and testability as well as documentation requirements.

Nomenclature

A/D	analog-to-digital
D/A	digital-to-analog
DDI	digital display indicator
DPRAM	dual port random-access memory
EEPROM	electrically erasable programmable read-only memory
FAST	F-18 FCS automated software testing
FCS	flight control system
FORTRAN	FORmula TRANslation
GE	General Electric, Lynn, Massachusetts
HARV	High Alpha Research Vehicle
HUD	head-up display
JOVIAL	Jules' Own Version of the International Algorithmetic Language
LEF	leading-edge flaps
McAir	McDonnell Aircraft Division, McDonnell Douglas Corporation, St. Louis, Missouri
MDTOT	parameter identifier
MIL-STD	military standard
OBES	on-board excitation system
PASCAL	Philips Automatic Sequence CALculator
RAM	random-access memory
RFCS	research flight control system
ROM	read-only memory
TEF	trailing-edge flaps
UART	universal asynchronous receiver-transmitter
UMN	universal memory network
UVPROM	ultraviolet programmable read-only memory

Introduction

Higher order languages have not been extensively used to develop flight control systems because of the lack of speed and capacity in the flight control computers. With the large improvements in computer speed, or throughput, and in memory, use of higher order languages is now practical. Examples of higher order languages used for aircraft include PASCAL (Philips Automatic Sequence CALculator), JOVIAL (Jules' Own Version of the International Algorithmetic Language), and Ada.

Because the United States military selected Ada for use as the common language, more aircraft will be flown using this software. Thus, NASA Dryden Flight Research Facility (DFRF) personnel must become familiar with the language and its capabilities.

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An F-18 testbed aircraft, the High Alpha Research Vehicle (HARV), offered an opportunity to acquire experience with the use of Ada for flight control applications.[1] The aircraft was built by the McDonnell Aircraft Division (McAir), McDonnell Douglas Corporation, St. Louis, Missouri, and the Northrop Corporation, Newbury Park, California.

This paper describes the DFRF experience with Ada and details the observed advantages and disadvantages to using this language. The conclusions reached here through the use of Ada in the real-time control environment are applicable to other control areas as well. Many real-time control systems using Ada to control complex systems would be expected to have similar experiences.

Research Flight Control System Description

The following subsections describe the hardware, control laws, and software of the system in which Ada was used:

Hardware

The HARV is a modified preproduction F-18 aircraft equipped with spin chute and emergency hydraulic and electrical systems. These modifications include a simple, low cost, thrust-vectoring system. This installation required modifications to the flight control system and mission computer.[2]

The basic F-18 flight control system consists of quadruplex redundant GE 701E (General Electric, Lynn, Massachusetts) computers and was modified for HARV by adding an analog interface to the thrust-vectoring vane actuators and a research flight control system (RFCS). Figure 1 shows the F-18 HARV computer architecture. The analog input card and RFCS were added to spare card slots in the basic flight control computer. This basic flight control computer maintains control of the aircraft; controls input, output, or both processing functions; communicates with the F-18 mission computer for outer loop control; and displays information through a military standard (MIL-STD) 1553 data bus. The RFCS was added to provide a flexible system for control law research. Ada was chosen as the programming language for the RFCS.

The RFCS central processing unit is a MIL-STD-1750A processor with a 20-MHz clock slaved to the GE 701E computer (Fig. 1). The RFCS contains 32,000 words of electrically erasable programmable read-only memory (EEPROM), 16,000 words of ultraviolet programmable read-only memory (UVPROM), 2,000 words of random-access memory (RAM), and 2,000 words of dual port RAM (DPRAM). The RFCS communicates to the basic flight control computer through the DPRAM. Hence, RFCS may be called an embedded control system. It, however, has no direct control of the aircraft. The aircraft is under RFCS control only during the research phases of a HARV flight. First, the RFCS is armed or enabled by a cockpit switch. Then, it is engaged or activated through use of a switch on the control stick. The RFCS is manually disengaged via the arm switch or a control-stick-mounted paddle switch. Autodisengagement occurs as a result of internally defined limits on rates, accelerations, engine sensors, and airdata sensors.

Control Laws

The longitudinal control laws contain an angle-of-attack command system that uses angle-of-attack, pitch rate, and inertial coupling feedbacks (Fig. 2).[3] The lateral–directional control laws contain a feet-on-the-floor stability axis roll rate command system (Fig. 3). This system provides the control for the roll and yaw axes.[3] The lateral–directional system uses roll, yaw, and sideslip rates as well as lateral acceleration and inertial coupling as feedback signals.

Figure 4 shows a simplified diagram of the thrust vane mixer section. This section converts the command pitch and yaw-vectoring moments computed in the longitudinal and lateral–directional control laws into vane commands. The mixer also uses estimated thrust and current vane positions to calculate new vane commands. The RFCS gross thrust estimator uses nozzle pressure ratio, nozzle exit radius, power level angle, and static pressure to calculate gross thrust.

Software

The RFCS software is programmed in Ada and was developed on a separate minicomputer system and cross-compiled to the MIL-STD-1750A processor. The software is loaded into the flight control computers through an RS232 serial port using a personal computer.

The original RFCS software was designed and tested by McDonnell Douglas Corporation under a NASA contract. None of the real-time kernel capabilities or elements available with Ada, such as taskings, priorities, terminations, and exceptions, were used for this system because of concerns about timing.[4–6] The RFCS software consists mainly of the control laws with a few redundancy management functions. Because it can always downmode safely to the F-18 basic flight control system, the RFCS is not considered flight critical. Choice of a language impacts neither the number of redundancy management functions nor their complexity. Redundancy management functions of the RFCS include such elements as reasonability checks and engage logic.

The RFCS software consists of approximately 78 Ada specifications, which define the interface to the outside world, and 13 Ada bodies, which give the details of the program. These specifications and bodies consist of approximately 130 modules, 175 procedures, 5 functions, and 4,600 lines of code (16,302 sixteen-bit words of EEPROM and 1,699 words of RAM). The RFCS software can be divided into six functional areas. These areas include input-output functions, disarm-disengage logic, longitudinal control laws, lateral–directional control laws, thrust vane mixer, and gross thrust estimator. Figure 5 shows these functional areas. Timing estimates for the current RFCS software indicate less than 85 percent worst case throughput and 50 percent memory use.

The input-output functional area transfers data through DPRAM, converts these data to and from a fixed point machine (the basic flight control system) to the RFCS floating point format, and checks for data validity. The disarm-disengage logic functional area determines whether the RFCS should arm or engage. This functional area includes such elements as envelope limits and reasonability checks on control law feedbacks and RFCS outputs.

Simulations

Three configurations of the real-time HARV simulation are used: an all-software, a hardware-in-the-loop, and an ironbird. Figures 6, 7, and 8 show that these configurations use many of the same elements. Detailed descriptions of these configurations are provided next.

All-Software Simulation

Written in FORmula TRANslation (FORTRAN) and Ada, the all-software simulation is used for engineering development of control laws, for pilot training, and for flight test planning. Figure 6 shows the elements of the all-software simulation. The aircraft model is performed in the simulation computer and includes the basic flight control laws as well as the aerodynamic, propulsion, thrust-vectoring, sensor, and actuator models. The only element of the all-software simulation coded in Ada is the RFCS control laws. These control laws are in the RFCS control law computer, a Unix-based workstation. Both the simulation computer and RFCS control law computer cycle at 80 Hz. The simulation cockpit includes the flight digital display indicators (DDI) and a head-up display (HUD) along with the simulated instrumentation and the pilot controls. Other flight hardware include mission computers and communication system control. An interface between the research flight control laws and the basic flight control laws in the simulation emulates the actual flight system interface as closely as possible. Four MIL-STD-1553 multiplex buses are included in the simulation. Three are for communication between the simulated and flight avionics. One is for an aircraft model display communication path. In addition, the three MIL-STD-1553 buses model the three HARV MIL-STD-1553 buses.

Hardware-in-the-Loop Simulation

Hardware-in-the-loop, the most frequently used simulation configuration, is the primary tool for developing and testing software. This configuration is also used for pilot training, flight test planning, and, to a lesser degree, engineering development. In addition, this configuration is extensively used for failure modes and effects testing and for control law validation. Actual flight control computers replace the control laws modeled in the simulation computer and the workstation. Figure 7 shows the hardware-in-the-loop simulation. Actuator models are also moved from the simulation computer and modeled using analog models. All other elements of the all-software simulation remain the same.

Ironbird Simulation

Figure 8 shows the ironbird simulation. As a final check for the system configuration, this simulation configuration is used to measure the closed-loop response of the control laws and to verify actuator models. A decommissioned F-18 airplane with hydraulic lines is used. With the exception of the leading- and trailing-edge flaps (LEF and TEF), the ironbird simulation replaces the analog actuator models with the actual flight actuators.

Compilers

Two Ada compilers were used: one for the RFCS software and the other for the simulation software. The cross-compiler used for the RFCS is a TLD Systems, Limited, Torrance, California, compiler hosted on a minicomputer. This compiler conforms with MIL-STD-1815A-1983 requirements. For the simulation software, a SunPro (Sun Microsystems, Incorporated, Mountainview, California) Ada language compiler is used. This compiler also conforms to MIL-STD-1815A-1983 requirements. No evaluation was done on the different compilers, and only obvious differences, such as one compiler flagging errors that the other compiler missed, were noted.

Software Modifications

Two major areas of software modifications are discussed in this section. These areas include modifications to the flight software and adaptations of the flight software to the simulation. McAir developed the RFCS software in a simulation and then transferred it to the flight hardware. The DFRF tested the software in the hardware-in-the-loop simulation and later added the RFCS software to the all-software simulation.

Flight Software Modifications

The RFCS software delivered from McAir to DFRF was not tested in a closed-loop system but was verified by McAir in an open-loop environment on the flight hardware. The contract stated that NASA would complete the closed-loop validation testing. The compiler that McAir and DFRF used to develop the Ada software includes a profiling tool that allows timing estimates to be generated for the target computer. Results of the timing estimates made by McAir using this tool significantly underestimated the actual execution time in the MIL-STD-1750A computer. McAir modified the RFCS software during the open-loop tests to improve its throughput. When the RFCS was delivered, it was installed in the hardware-in-the-loop simulation for validation testing. During the hardware-in-the-loop validation testing, RFCS exceeded the allocated cycle time for one unusual set of conditions. The code required modification to allow some throughput margin.

The following list shows the changes made to the RFCS software to date. Several functions were changed from 80- to 40- and 20-Hz functions (items 1 and 2 in list). At the same time, the code was reviewed to find additional changes to increase the throughput margin (item 3 in list).

1. RFCS multirate tasking
2. Modify order of rate structure
3. RFCS Ada code cleanup
4. Code reconfiguration
5. Change mixer-predictor constant
6. Thrust estimation modification
7. Betadot sign change miscompare
8. On-board excitation system (OBES)
9. RFCS 701E fader gain
10. Fix OBES frequency sweeps by overlay*
11. Fix OBES frequency sweeps and cleanup syntax
12. Static pressure with weight on wheels
13. Fix RFCS flag word outside envelope indication
14. OBES requirements
15. Incorrect differential stabilator, TEF, and LEF computations
16. MDTOT sign change
17. OBES cleanup
18. Persistence on betadot and angle of attack
19. Engine parameters channel 1/3 miscompare
20. Change instrumentation scaling of error signal
21. Update configuration identification to version 24.0
22. Sideslip rate delta tolerance—overlay*
23. Sideslip rate delta tolerance—compile
24. Add test variables for FAST command limit tests
25. Replace message 8 RFCS parameters
26. Change scales of angles of attack and sideslip in RFCS
27. Change parameters for angle of attack and inertial navigation system angle of attack scaling to ±180°
28. OBES aileron rate limit
29. Add component of alphadot and betadot in mission computer
30. Parameter identification OBES
31. Move RFCS message 17 code
32. Thrust estimator
33. Enable RFCS go
34. Angle-of-attack filter coefficient
35. Message 17 parameter change
36. Message 8 RFCS modification
37. RFCS persistence counter for channel 1/3 miscompare
38. Change constants in pitch and roll trim processing
39. RFCS scaling for message 8 instrumentation
40. Static pressure with weight on wheels by overlay*
41. Downlink OBES signal
42. Change configuration identification to version 22.0 in RFCS software
43. Version 22.0—message 8
44. Change instrumentation error signal by overlay*
45. Pitch rate lead and gain changes

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*Indicates an overlay generated.

46. Update configuration identification to version 23.0
47. Message 8 word 20-bit toggle
48. RFCS thrust failures
49. Sideslip rate delta on instrumentation
50. Angle-of-attack rate gain fix
51. Update fade rate
52. Angle-of-attack scaling and inertial components—overlay*
53. Update configuration identification to version 25.0
54. Add test variables for FAST command limit tests
55. Parameter identification OBES modification
56. Update configuration identification to version 26.0
57. OBES command limiting
58. Collective trailing-edge flap test command

*Indicates an overlay generated.

The original RFCS control law software was developed as two parts: longitudinal and lateral–directional. While the delivered code was modularized, some functions were distributed through several modules. Airdata was the principal segment calculated in more than one module and was processed in the input-output and in the lateral–directional control law sections. To allow completion of updates to one functional group without affecting another functional group, the software was modified to include all airdata functions in input-output (item 4 in list). The update rate for airdata-dependent gain scheduling was at 80 Hz, but airdata was updated at 20 Hz. Consequently to increase the throughput margin, the code was modified to update the airdata-dependent gains at 20 Hz. Unless better profiling tools are developed, these problems in throughput margin will continue to be found in final hardware-in-the-loop testing.

During the flight program, modifications were made to correct problems or make improvements. The majority of these changes involved a simple constant or a couple of line changes. A few were more extensive and included new capabilities. An OBES was incorporated in RFCS to generate commands to the surfaces using a function generator for sine waves and doublets.

Simulation Software Modifications

The RFCS Ada code was ported to the software simulation. This code was developed on a minicomputer system and ported to a computer where it could be validated using the real-time, all-software simulation. Because the simulations were developed on the simulation computer, the Ada RFCS code was initially ported to this computer where it could interface with the residing simulation through shared memory. The simulation computer was incapable of supporting the Ada code in the time required. The code was then ported to a Unix-based workstation RFCS control law computer with a different Ada compiler. Here, the RFCS code communicated with the simulation computer through the universal memory network (UMN) instead of shared memory.[7] Real-time performance speed improved significantly on this computer. This performance improvement was the result of several factors. These factors included the limited time available on the simulation computer and the improved Ada compiler available on the RFCS control law computer.

Additional code was added to set-up a means of exchanging data between the Ada RFCS code and the real-time simulation. Because of timing restrictions, the calling order of the routines in the executive RFCS program was also changed. The hardware-in-the-loop code's executive operates at a 160-Hz frame rate overall. The individual routines are called at various rates. Originally, two 80-Hz tasks ran alternately on an even or an odd frame. One task handled the longitudinal control laws, while the other frame handled the lateral–directional control laws. The Ada on the RFCS control law computer was unable to support the 160-Hz schedule without time overruns. As a result, the even-odd-frame arrangement was replaced by a new calling sequence. This sequence first calls the longitudinal mode calculations and then calls the lateral–directional mode calculations. Otherwise, the source code developed on the minicomputer system is easily transferred to the RFCS control law computer.

Significant Issues

This section describes major issues relating to Ada and its use in real-time embedded control systems. These issues include porting, documenting, modifying, and testing the software. In addition, software development is discussed.

Portability

The RFCS Ada code was fairly portable. This code was transferred from the MIL-STD-1750A processor to the simulation computer to the control law computer. The majority of modifications needed for Ada to run in the simulation were changes to account for differences in the flight control and simulation systems. Because the hardware-in-the-loop RFCS source code resides on the minicomputer system and the all-software code is on the Unix-based workstation, two Ada compilers were used to achieve optimal performance on the individual machines. Use of two compilers can also result in differences if one compiler is more nearly accurate than the other. For example, the Unix-based compiler would flag errors that the minicomputer compiler would accept. The two compilers provided an extra test for errors in the Ada software.

Documentability

An often mentioned feature of Ada is the fact that it is a self-documenting code. Although very easy to read, Ada is self-documenting only on a detailed level; that is, Ada is more similar to self-commenting. The self-documenting feature of Ada does not remove the need for developing specifications and system documentation. Any system requires a specification for the software to be developed against; otherwise, errors propagate throughout the system. Use of a higher order language, such as Ada, makes it easier to design and code a system without developing specifications. As with any other programming language, such program specifications as specification block diagrams, program requirements, software design specifications, and program flowcharts are needed to give an overall picture of the entire system.

Modifiability

Use of Ada or any higher order language simplifies all but the most difficult software updates. The compiler can show the assembly-level code along with the Ada, which helps when trying to understand the operation of the software. An assembly-level listing is necessary when the software is not performing as expected, and debugging is required. The assembly-level listing and the memory map are used to examine the system memory and to assist in locating errors. This technique was used several times during the system integration stage. The Ada code proved fairly easy to modify, but assembly-level modifications were still used.

Updates to the RFCS software are done either by overlay or by recompiling. To change constants, an overlay is performed. For an overlay, no source code is changed. The majority of overlays are then added to later software versions by modifying the source code and recompiling. Load files, the machine code in hexadecimal that is loaded onto the flight control computers, are updated on the minicomputer system. Once completed, the newly overlaid code is downloaded to the flight control computers. Because a recompile is not performed, a bit-for-bit comparison can be done to verify any memory changes.

For all other changes, the program is recompiled. This process involves changing the source code to meet the new requirements. Once the changes have been added to the code, a compilation is performed. Then, the new software is downloaded to the flight control computers. Software changes made by recompiling require significantly more testing than those done by overlay. Because a bit-for-bit comparison cannot be performed, it cannot be assumed that the source code updates did not affect any other software functionality.

One disadvantage in using Ada is that changes in the calling sequence, addition of new routines to the code, or both require changes in the compilation order of the dependent routines. The proper order or sequence must be established to ensure that any routine which depends on another routine is compiled before the calling routine is compiled. This ordering process can become a difficult task when major changes in the calling sequence are required.

Another disadvantage of higher order languages versus assembly languages is that software overlays cannot be inserted on-line. With assembly language, a logic overlay can be inserted into the source code and reassembled. Overlays can be written to branch to a predetermined patch area in read-only memory (ROM), execute the new code, and return to the point of origin. This type of change requires less testing than a complete reassembly because a bit-for-bit comparison can be performed.

Testability

The language used to implement the software has no impact on the testing requirements. The level of testing required is determined by the criticality of the system. Obviously, flight-critical systems require more testing than those systems that are less essential. Regardless of the programming language used, verification and validation tests are required to flight qualify a new software release. Verification is the process of determining that the software performs as specified. This process is accomplished by devising individual tests for each specified software task, conducting the test, and observing that the task was completed according to the specification. Validation, the broader task, seeks to determine if the system of which the software is a part performs adequately to fulfill the flight requirements. Open- and closed-loop failure modes and effects tests are among the techniques used in software validation. In these tests, failures are artificially induced, and a correct system response to those failures is verified.

Verification. When a higher order language is used, the compiler and linker must provide outputs which give the tester the information required to understand and verify the code. This information includes a listing of the assembly language code generated by the compiler and a memory map showing the locations of all modules, constants, and variables. The ability to complete the testing without modifying in any way the code under test is highly desirable. If the required test interfaces exist, then the locations of the input and output variables provide the interfaces to the code under test. The tester may inject and monitor inputs and outputs to determine if the code performs as specified. If modification of the software is necessary to allow the tests to be performed, then a test patch is written.

Digital flight control systems seldom have the test interfaces required to perform complete verification testing without modification of the code under test. Of course in many instances, the change being verified involves inputs and outputs which are available during normal system operation. Test patches are not required in these cases. When test patches are required for higher order languages, these patches are coded in assembly language using areas of program and variable memory that are not used by the compiled software. The software under test is minimally impacted.

Validation. Software is validated in conjunction with the system of which it is a part. In the case of the RFCS, validation is accomplished on the HARV hardware-in-the-loop simulation. Time histories, failure modes, and effects tests are performed while the simulated aircraft is flying closed-loop. Depending on the interfaces available, occasionally test patches are needed to simulate system failures which cannot be induced in any other way.

Software Development

Development of real-time code requires an understanding of the requirements and limitations of memory and time. Real-time software generally requires more time than is readily available; therefore, care must be taken in developing the code. Use of a higher order language makes it more difficult to control the timing directly. The compiler generates the code and, even if optimized, may not produce the most time-efficient code. As discussed in the Compiler section and in the Portability subsection, one of the two compilers used by HARV detects more errors than the other. Although not required, use of two compilers provides a good check-and-balance scheme for any software development.

The use of two or more compilers is not required and was only used on this program to facilitate the transfer of the Ada software to the all-software simulation. The majority of the Ada software in the all-software simulation is identical to the flight software. Using the same software in the simulation and in the flight software saves time when transferring the software between systems. Software implementation differences between the hardware-in-the-loop and all-software simulations are also minimized.

The developer also needs to be aware of any microcode errors within the target processor. Many compiler developers work closely with processor manufacturers. Such cooperation allows the developers to correct microcode errors within the compiler, but not all errors will be necessarily corrected. Validated Ada compilers can also have errors. The assembly-code listing also gives the implementer the information required to deal with possible compiler errors and with known microcode errors in the target processor hardware. Knowledge of the system is still necessary for the development of software for real-time systems.

Concluding Remarks

The NASA Dryden Flight Research Facility experience with using Ada software for the F-18 High Alpha Research Vehicle has been positive. Although the Ada software developed was not for an extremely complex system, it is representative of most uses. Compiled Ada code can be used in a flight-critical system. The conclusions reached in this paper are not effected by the lack of a complex redundancy management or of a flight-critical system.

Positive conclusions reached concerning Ada are listed next. Ada is

- Portable—Ada was transferred among three computers using different compilers. The changes made to the transported code were to account for system changes.
- Documentable—For commenting purposes, this easy-to-read code is self-documenting. On the other hand, the self-documenting feature of Ada does not remove the requirement for system-level documentation or for a specification before coding.
- Modifiable—Ada is easy to modify, but it is still easier to make simple constant changes without recompiling. Individual changes in the code that are of major significance and numerous changes that are of less significance are easy to accomplish in Ada.
- Testable—Ada is no more difficult to test than any other language. The criticality of the system—not the language used to program the system—defines the testing requirements. Any system can be coded in Ada. For example, a system with complex redundancy management functions can easily be written in Ada, and the testing requirements would not change. A flight-critical system can easily use Ada, and the testing requirements would be the same as for other flight-critical systems.

Negative factors identified were not really Ada specific; that is, these factors are also found in other higher order languages. If a system does not follow standard software design practices, then problems will occur. Software and system specifications must be developed before the software implementations. Compilers, even validated Ada compilers, can have errors. As a result, compiled software must be tested before use.

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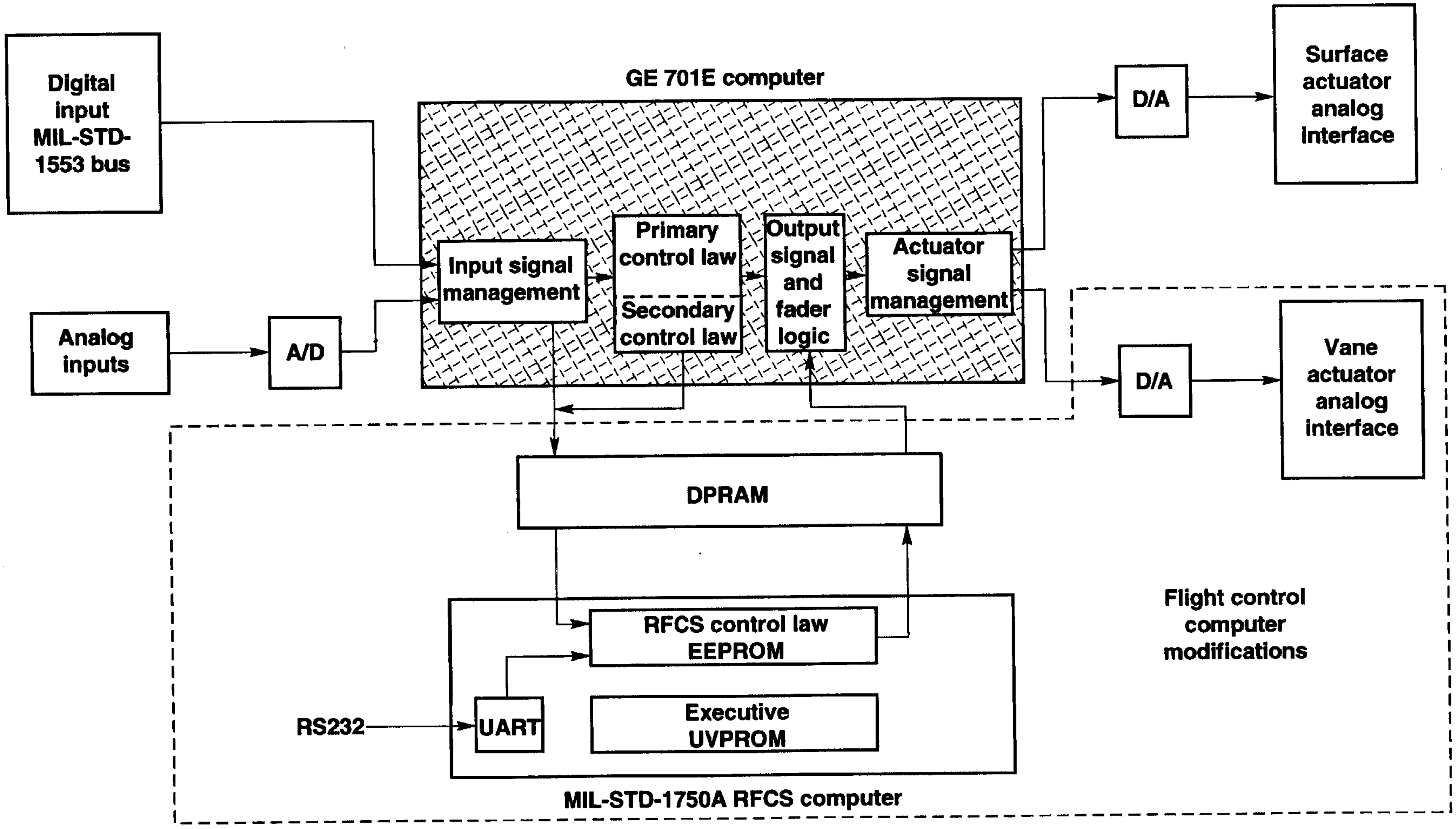

Fig. 1 The GE 701E and MIL-STD-1750A flight control computers.

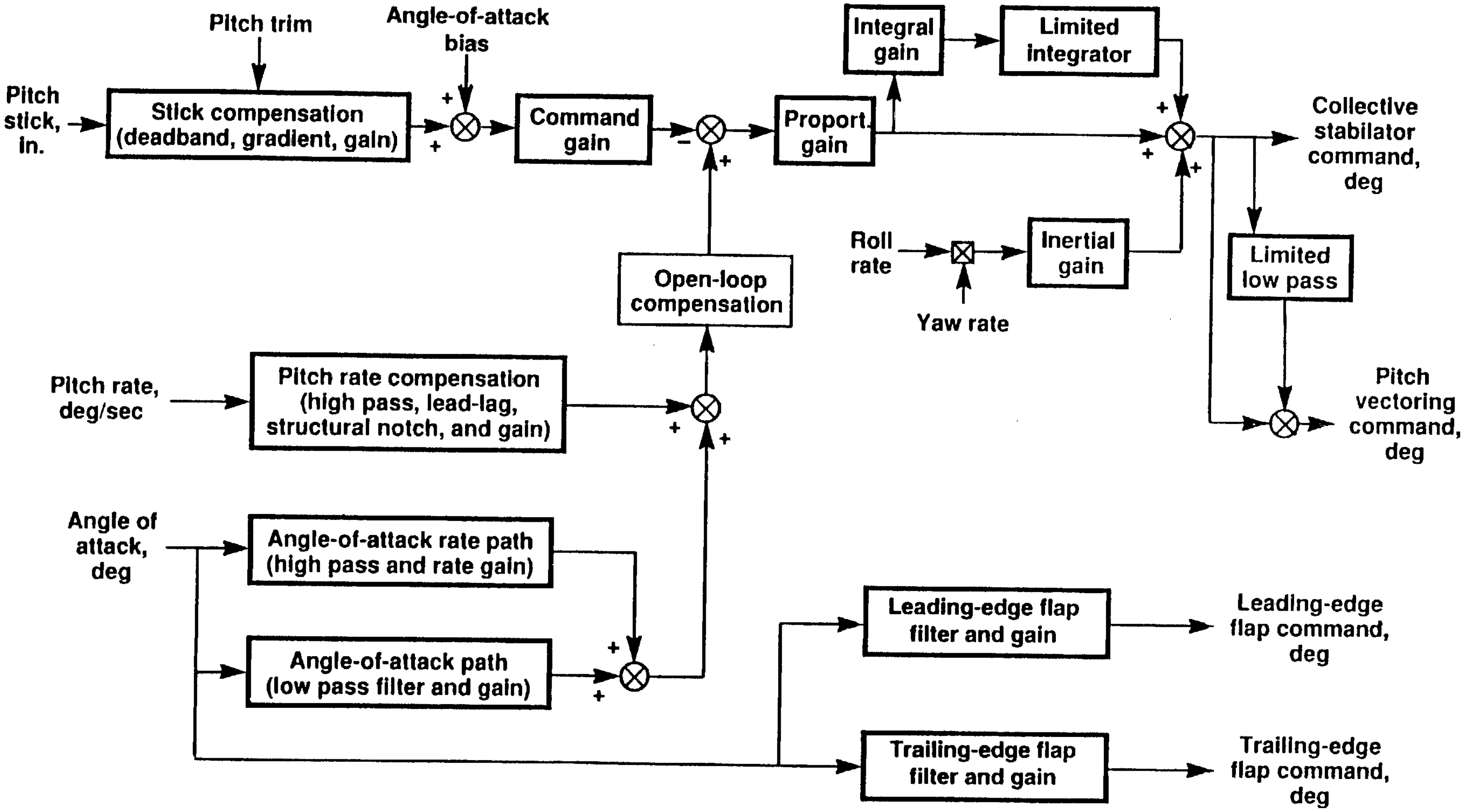

Fig. 2 Simplified research flight control system longitudinal control laws (angle-of-attack).

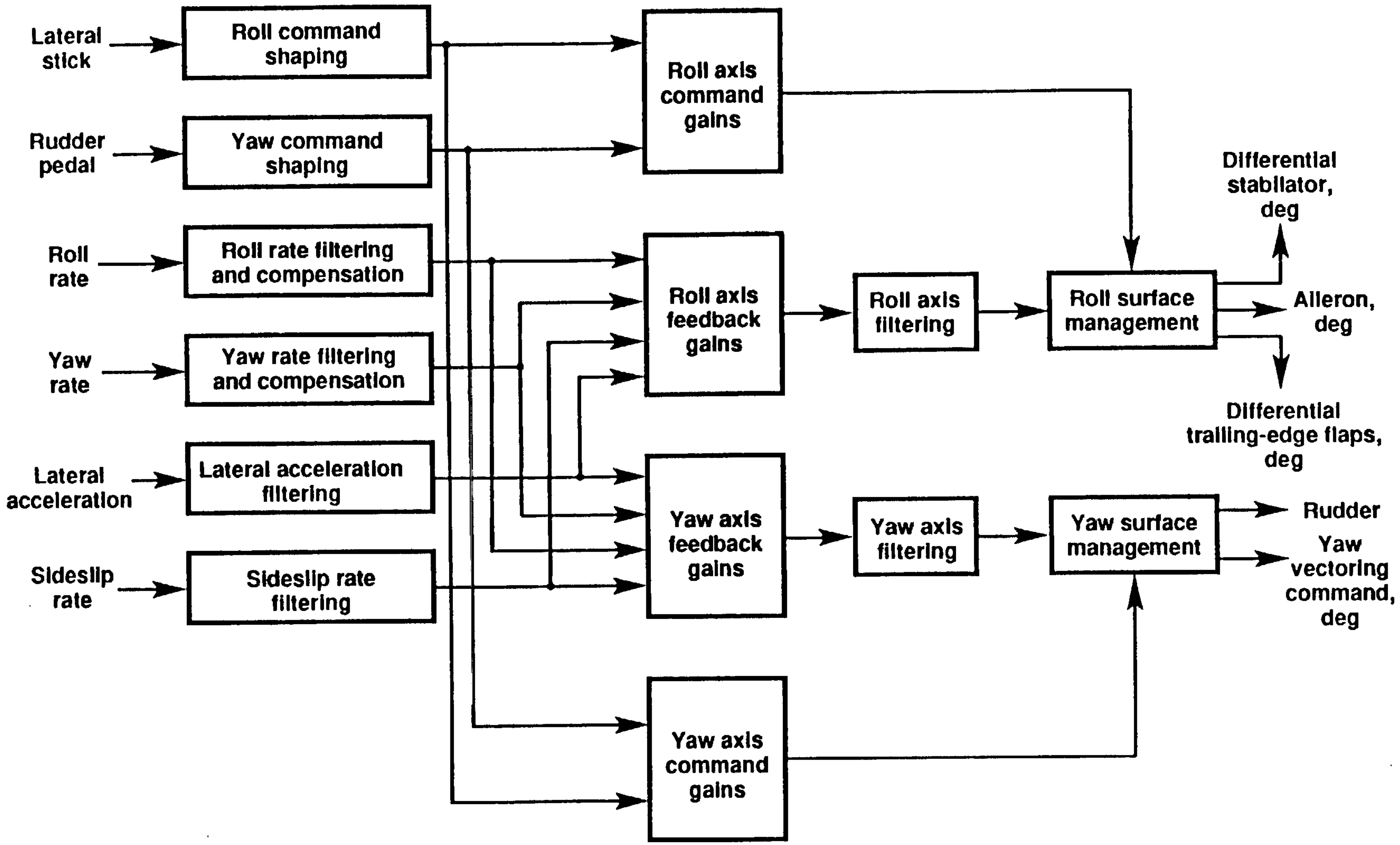

Fig. 3 Simplified research flight control system lateral—directional control laws.

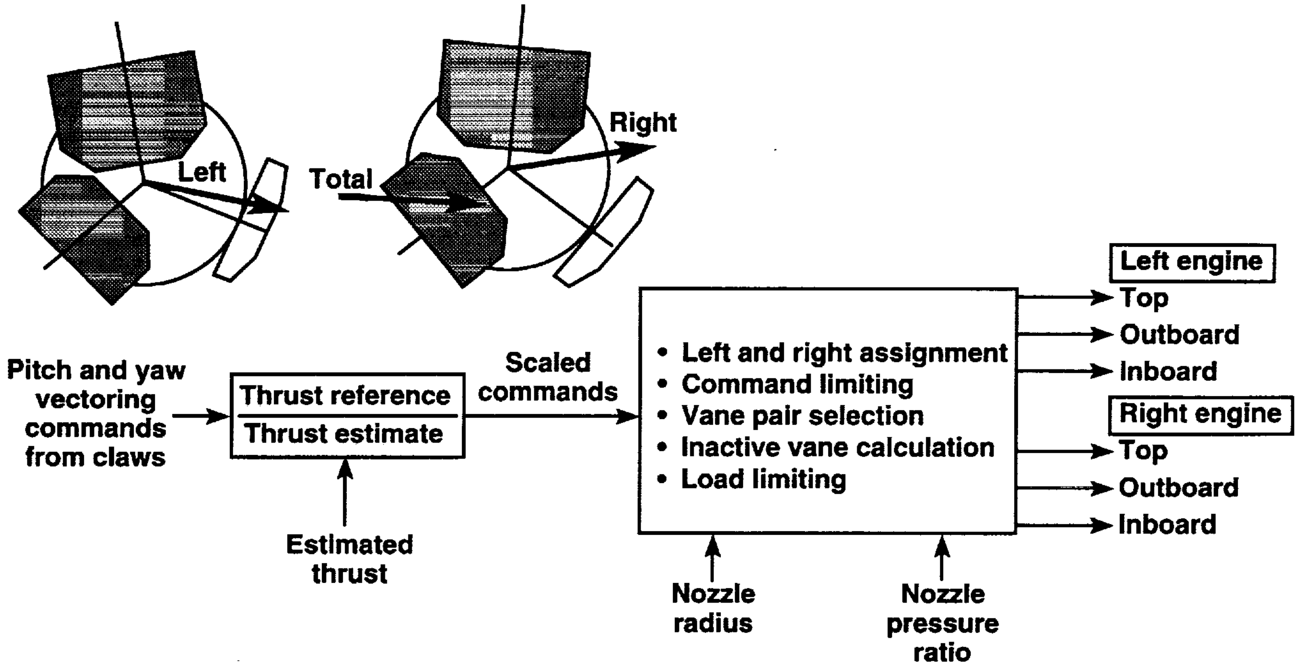

Fig. 4 Simplified thrust mixer.

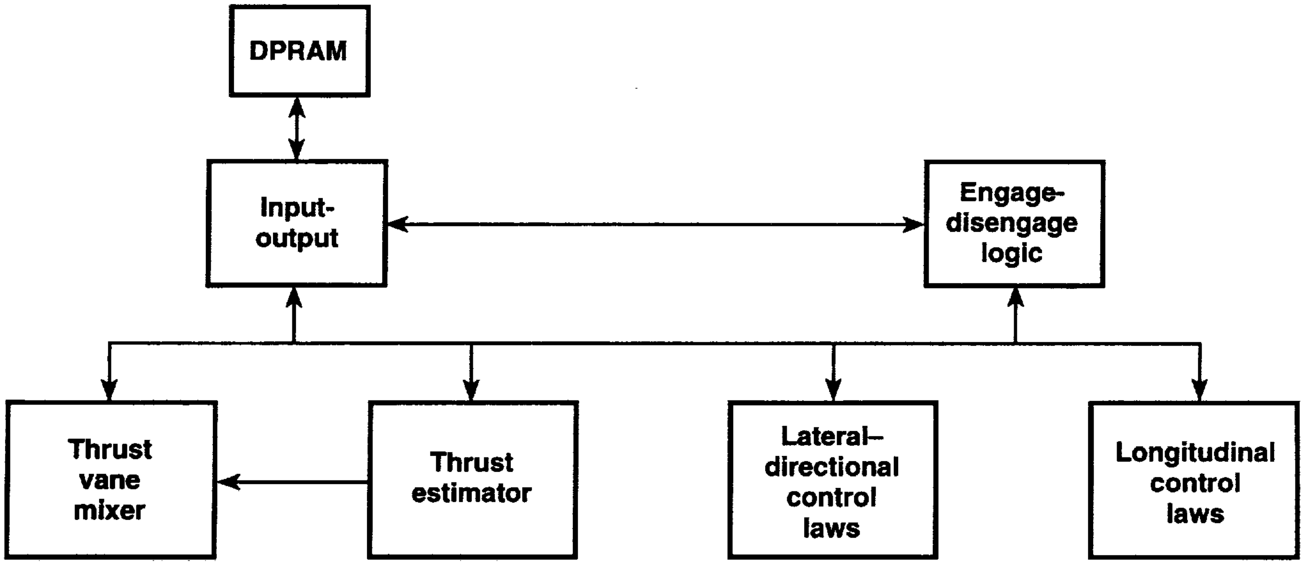

Fig. 5 The research flight control system software functional areas.

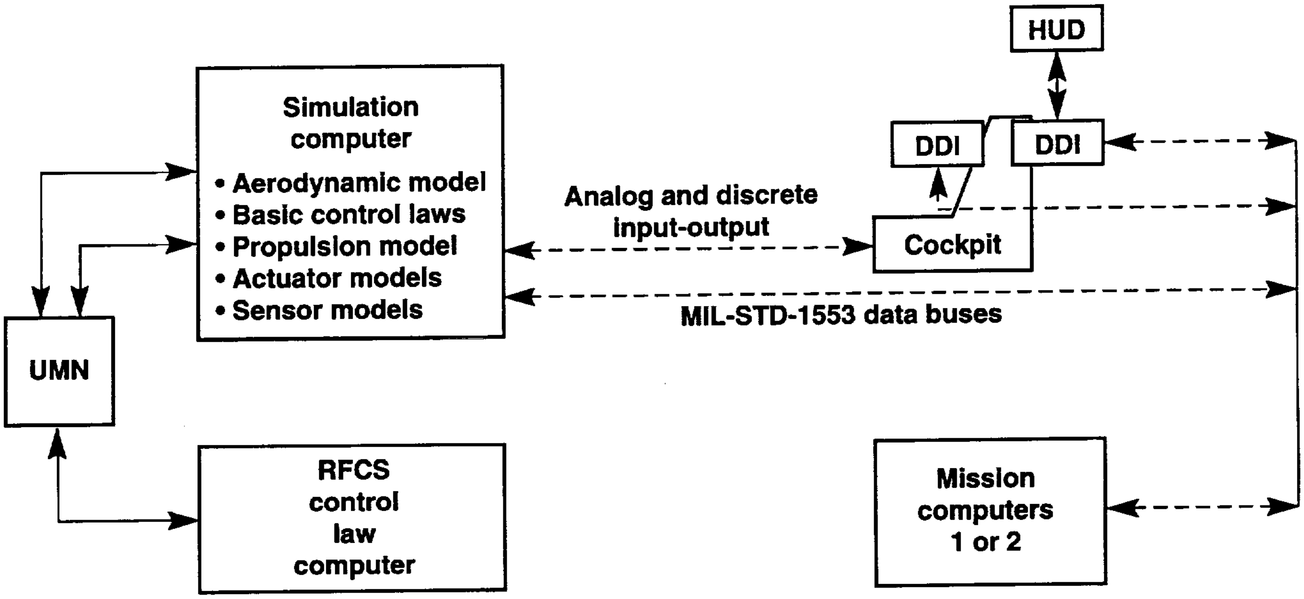

Fig. 6 The High Alpha Research Vehicle all-software simulation.

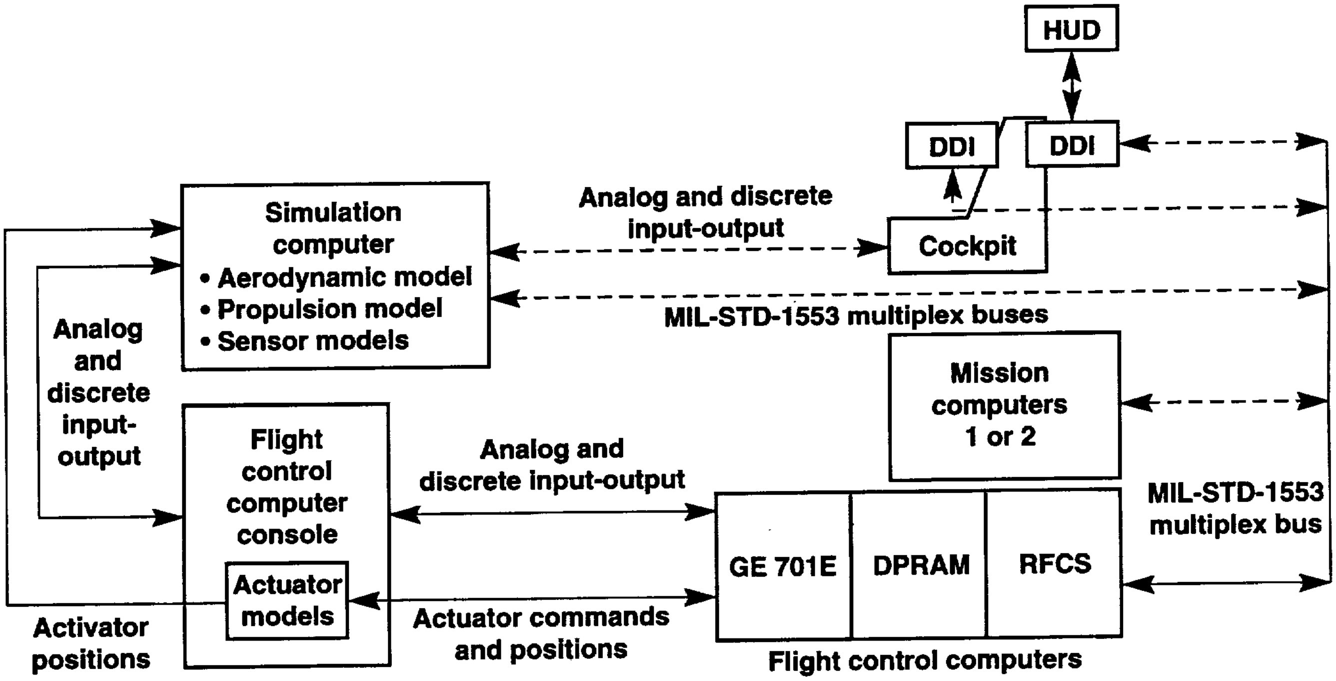

Fig. 7 The High Alpha Research Vehicle hardware-in-the-loop simulation.

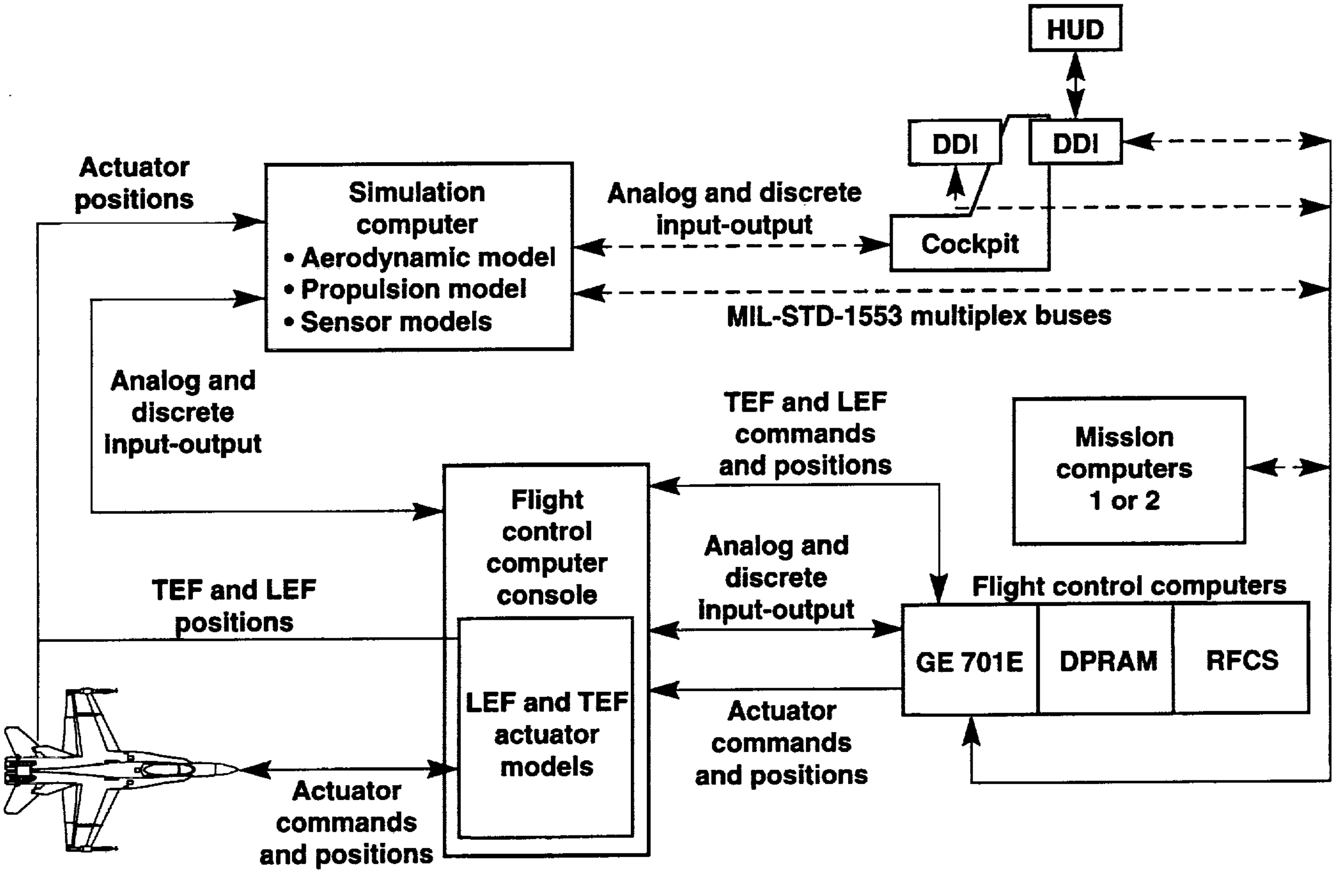

Fig. 8 The High Alpha Research Vehicle ironbird simulation.

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IN-FLIGHT SIMULATION STUDIES AT THE NASA DRYDEN FLIGHT RESEARCH FACILITY

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SUMMARY

Since the late 1950s the National Aeronautics and Space Administration's Dryden Flight Research Facility has found in-flight simulation to be an invaluable tool. In-flight simulation has been used to address a wide variety of flying qualities questions, including low-lift-to-drag ratio approach characteristics for vehicles like the X-15, the lifting bodies, and the Space Shuttle; the effects of time delays on controllability of aircraft with digital flight-control systems, the causes and cures of pilot-induced oscillation in a variety of aircraft, and flight-control systems for such diverse aircraft as the X-15 and the X-29. In-flight simulation has also been used to anticipate problems and to avoid them and to solve problems once they appear.

This paper presents an account of the in-flight simulation at the Dryden Flight Research Facility and some discussion. An extensive bibliography is included.

NOMENCLATURE

C^*	blended normal acceleration, pitch rate, and pitch acceleration
DFBW	digital fly-by-wire
DFRF	Dryden Flight Research Facility, Edwards, CA
FCS	flight-control system
GPAS	General Purpose Airborne Simulator
HUD	head-up display
L/D	lift-to-drag ratio
LLRV	Lunar Landing Research Vehicle
NASA	National Aeronautics and Space Administration
NASP	National AeroSpace Plane
PIO	pilot-induced oscillation
RAV	remotely augmented vehicle
RPRV	remotely piloted research vehicle
SST	Supersonic Transport
TIFS	Total In-Flight Simulator
USAF	United States Air Force
VSA	variable-stability aircraft
$1/\tau_{\theta_2}$	high-frequency pitch attitude zero
$\dot{\beta}$	sideslip rate, deg/sec
$\omega_{n_{sp}}$	undamped natural frequency of the short period mode, rad/sec

INTRODUCTION

Before flying an experimental aircraft it is always desirable to consider the flying qualities of the vehicle. If the new vehicle is similar to an existing aircraft, this may provide an idea of the flying qualities of the new vehicle. New aircraft of unusual configuration or flight envelope, however, require special handling.

Ground-based simulation is a good tool to use for an initial examination of the flying qualities, but ground-based simulators are deficient when reproducing visual or motion cues. They are suitable for many regions in the envelope, like cruise, but more demanding tasks, such as precision landings, frequently cannot be simulated well enough to provide complete confidence.

In-flight simulation does not have the same limitations as ground-based simulation. Visual cues are identical with those in the subject aircraft and motion cues, if the simulation is modeled correctly, also match those of the subject aircraft. In-flight simulation is also better at exposing deficiencies like proneness to pilot-induced oscillation (PIO). In fixed-base simulations, PIOs are not often seen, no matter how deficient the aircraft and its flight-control system (FCS), unless unusual, unrepresentative tasks are used. During in-flight simulation, these PIOs occur more readily.

There are two roles for in-flight simulation. The more difficult role is the examination of the dynamic response of an aircraft. Simulating the dynamic response (natural frequency and damping and the phasing between them, for example) of the subject aircraft requires modifying the dynamic response of the simulation aircraft. The variable stability aircraft used for dynamic simulation are the aircraft most often thought of when considering in-flight simulation.

The other role of in-flight simulation is performance simulation. This is the use of a similar aircraft to explore various performance characteristics which are not highly dynamic. An example of performance simulation is the use of an F-104 Starfighter in a low-lift-to-drag ratio (L/D) configuration to simulate the X-15 aircraft in approach and landing. No modification to the F-104 aircraft was required for this simulation, because the F-104 can easily be configured with low L/D.

In-flight simulation is more difficult, more time-consuming, and frequently more expensive than ground-based simulation and is reserved for those portions of the flight regime that cannot be adequately evaluated on the ground. It is not a cure all, as the simulation is only as good as the understanding of the characteristics of the simulated aircraft. The limitations of the simulator aircraft also limit the fidelity of the simulation.

The mission of the National Aeronautics and Space Administration's Dryden Flight Research Facility (NASA DFRF) is the study and flight test of a variety of unconventional and experimental fixed-wing aircraft. Dryden has used in-flight simulation to support this mission since the late 1950s. The first simulation was a generic study into the approach and landing of low-L/D aircraft using an F-104. The most recent was a 1990 inquiry into the visibility requirements in the approach and landing of a hypersonic vehicle using an F-104 aircraft.

Between these two simulations there have been a wide variety of simulation programs, using both dynamic and performance simulators to simulate such diverse subject aircraft as the X-15, the lifting bodies, the X-20 DynaSoar, and the X-29. Extensive inquiries into a variety of flying qualities topics have also been made. In keeping with the limitations of in-flight simulation, only pertinent portions of the flight regimes of the various aircraft have been studied.

This paper, a history of in-flight simulation at DFRF, describes the dynamic flight simulators and many of the performance simulators and presents a brief chronology of in-flight simulation here. The summary discusses a number of common threads in the history. An extensive bibliography is provided for further information.

DESCRIPTION OF SIMULATOR AIRCRAFT

There are two types of in-flight simulation, dynamic and performance, and, hence, two types of simulators. The dynamic simulator aircraft are extensively modified because control of the dynamic response is difficult. Computers control the actual response, completely overpowering the natural response of the aircraft. This complexity also means that these simulators provide the most information about flying qualities because they can be made to fly like different aircraft. In addition, the more recent of these variable-stability aircraft can be used to assess a variety of FCSs because the aircraft already have powerful and flexible flight-control computers.

The aircraft used for the in-flight simulation of the performance of the subject aircraft are much simpler. Typically, modifications are small changes to existing structures—a bigger speed brake, for example, to match the L/D of the subject aircraft better. These performance simulators are frequently used to provide information about the feasibility of a flight task, to provide qualitative information about a generic class of aircraft, or to establish piloting techniques. At the DFRF, the performance simulators were frequently support aircraft, pressed into duty when the need arose. This is particularly conspicuous in some of the visibility studies, where card or plastic was used to block the windows of standard support aircraft.

Performance simulation is less versatile than dynamic simulation because it is limited by the performance of the simulator aircraft. For example, the unmodified F-104 aircraft was not suitable for simulating the X-15 in any other flight regime, but it was an excellent simulator in the pattern.

Dynamic Simulators

Variable-Stability F-100C Super Sabre– The NASA F-100C Super Sabre (fig. 1), a single-engine swept-wing supersonic fighter, was modified by the Ames Research Center as a variable-stability research vehicle that provided variation of parameters around all three axes (refs. 1 and 2). An analog fly-by-wire

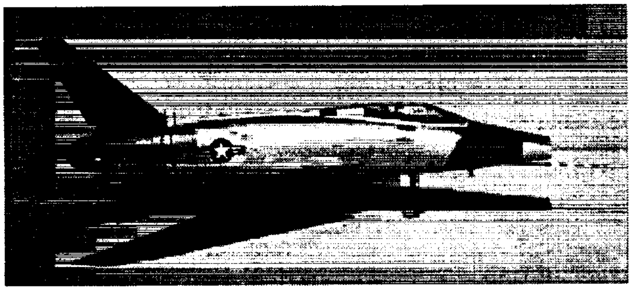


Figure 1. The NASA F-100 Super Sabre aircraft.

system was used in all three axes, although the pitch axis had safety trips installed because of the run-away potential of the all-moving horizontal tail.

NT-33A Variable Stability Aircraft– The United States Air Force NT-33A variable stability aircraft (VSA) (fig. 2) is an extensively modified T-33A Shooting Star jet trainer (ref. 3). The most conspicuous modification is the enlarged nose section that provides more room for electronics. The front seat, where the evaluation pilot sits, has a standard center stick or side stick and rudder pedal arrangement. The standard front seat control system has been replaced by a full-authority fly-by-wire FCS and a variable-response artificial feel system. The safety pilot sits in the rear seat to program the configuration characteristics.

The NT-33A aircraft has independent control of three-degrees-of-freedom for in-flight simulation. The simulation technique uses a response feedback methodology with three moment controllers of the vehicle (elevator, aileron, and rudder) as the simulation effectors. At one time the NT-33A had drag modulation, using drag petals at the wingtips, but this feature was removed following a structural failure.

The General Purpose Airborne Simulator– The NASA General Purpose Airborne Simulator (GPAS) (fig. 3) was a modified Jetstar, an executive transport airplane. The original modifications made the GPAS a four-axis simulator (pitch, roll, yaw, and thrust force along the longitudinal axis) with a model-following variable stability system (refs. 4 and 5). Direct lift control and direct side force were eventually added. The evaluation pilot sat in the left seat, which had a special set of transport-airplane-type controls and displays. This simulator exhibited extraordinarily good model following and had remarkable fidelity (ref. 6). Werner von Braun was taken for a demonstration flight early in the career of the GPAS. Impressed, he described it as a "dial-a-plane," the first known use of this phrase (ref. 6).

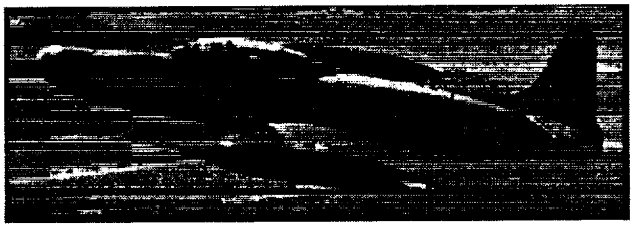


Figure 2. The USAF NT-33A variable stability aircraft.

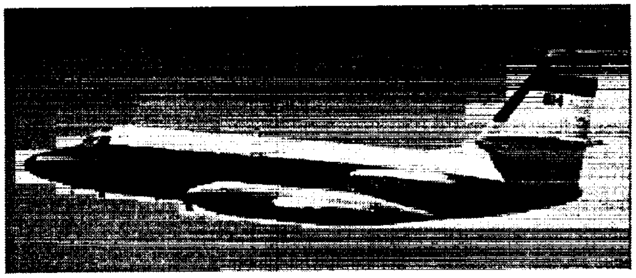


Figure 3. The NASA General Purpose Airborne Simulator aircraft.

The Total In-Flight Simulator– The USAF Total In-Flight Simulator (TIFS) is a highly modified C-131 aircraft configured as a six-degree-of-freedom simulator (fig. 4). It has a separate evaluation cockpit forward and below the normal C-131 cockpit. The six-degrees-of-freedom are independently controlled by use of the elevator, aileron, rudder, throttle, direct lift flap, and side force surfaces. This side force surface is a large vertical surface mounted at mid-span of the wing. Longitudinal and lateral–directional model-following systems provide the evaluation pilot with motion and visual cues representative of the simulated aircraft. The evaluation cockpit can be modified with appropriate controls and displays and can accommodate a co-pilot. The TIFS can simulate turbulence and crosswinds or cancel an actual crosswind.

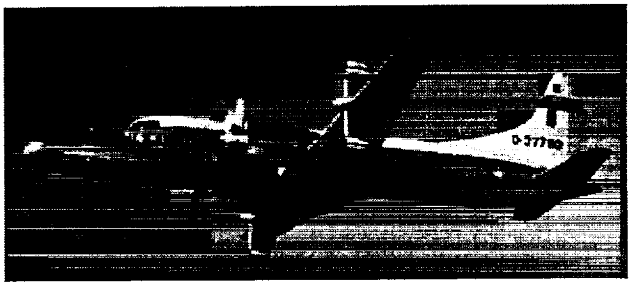


Figure 4. The USAF Total In-Flight Simulator aircraft.

The F-8 Digital Fly-By-Wire Aircraft– The NASA F-8 digital fly-by-wire (DFBW) was an F-8C Crusader, a single-engine, single-seat supersonic fighter (fig. 5), with a full-authority digital fly-by-wire FCS (ref. 7). The control system was designed so parameters such as time delays and control system gains could be entered from the cockpit in flight.

The aircraft was also capable of accepting control-surface commands from a ground-based computer when in the remotely augmented vehicle (RAV) mode (refs. 8–10). Using this feature, experimental control laws could be programmed in the ground-based computer, giving a special flexibility to simulation programs and keeping the evaluation pilot from knowing what configuration was being flown.

Calspan Variable-Stability Learjets– The Calspan variable-stability Learjets (figs. 6(a) and 6(b)) are executive transport aircraft, modified as three-axis simulators with a response feedback flight-control system (ref. 11). The evaluation pilot sits in the right seat, which is equipped with a center and a side stick which are, like the rudder pedals, driven by the variable feel system.

The first of these aircraft, a Lear 24D, was originally converted as a training tool for the Air Force and Navy test pilot schools, but has been used by DFRF for flying qualities research. It was converted to a variable-stability aircraft in 1981. The second, a Lear 25B, is used for flying qualities research. It was converted to a variable-stability aircraft in 1991. The two differ slightly; the second Learjet is larger and carries a bigger fuel load. It also has a programmable side stick, rather than the unmodifiable side stick in the first Learjet. A reprogrammable digital flight-control computer will be installed in the near future.

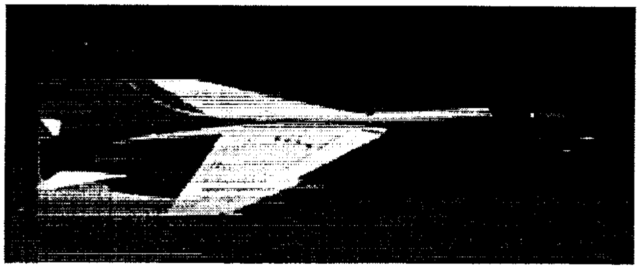
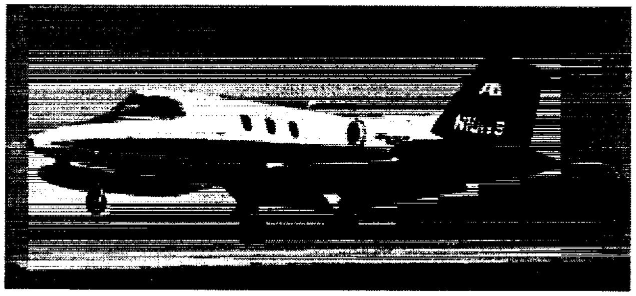
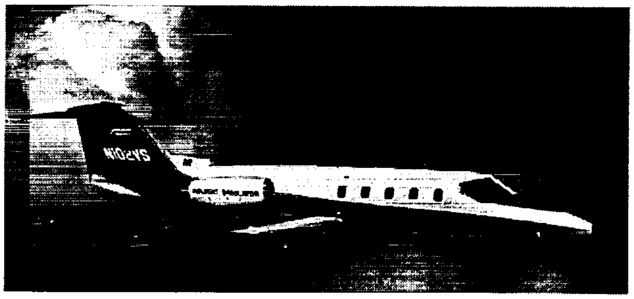


Figure 5. The NASA F-8 digital fly-by-wire aircraft.



(a) First Calspan variable-stability Learjet



(b) Second Calspan variable-stability Learjet.

Figure 6. Calspan variable-stability Learjets.

Performance Simulators

The aircraft used in performance simulators are not extensively modified. Most of these aircraft were used for support at DFRF.

The F-102A Delta Dagger– The NASA F-102A Delta Dagger was a single-engine supersonic delta-wing interceptor aircraft (fig. 7) that could be configured as a low-L/D aircraft in the power approach configuration (refs. 2 and 12). The F-102A Delta Dagger was used for pilot proficiency, chase, and research studies. It was modified with a larger speed brake for certain low-L/D aircraft studies.

The F-104 Starfighter– The NASA F-104 Starfighter is a single-engine, Mach 2 aircraft with a small, straight wing and a T-tail (ref. 2). The wing area is less than 200 ft^2 and the weight is approximately 24,000 lb, so it has a fairly high wingloading (ref. 13). These F-104 Starfighters were used for pilot proficiency, chase, and as testbeds for a variety of experiments. The F-104B and TF-104G (fig. 8), both

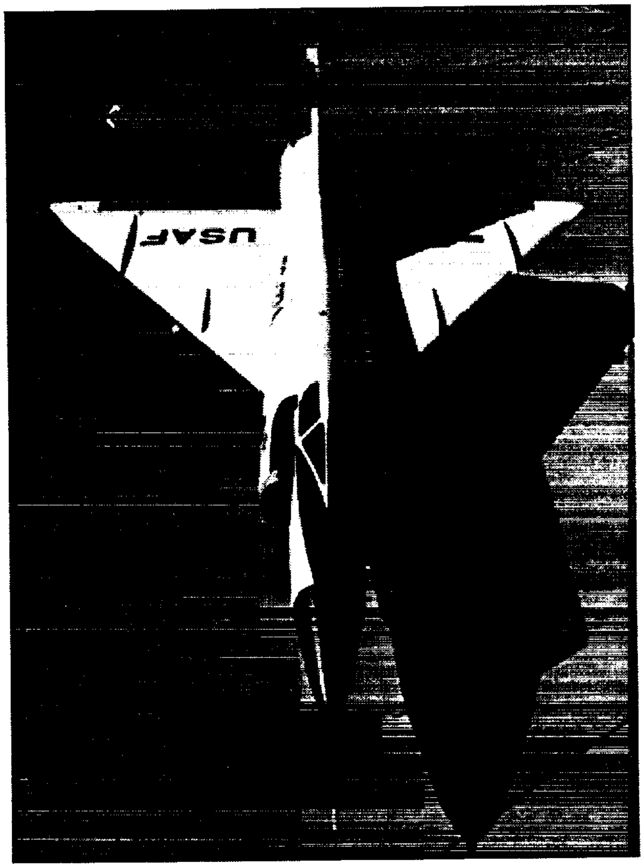


Figure 7. The NASA F-102A Delta Dagger aircraft.

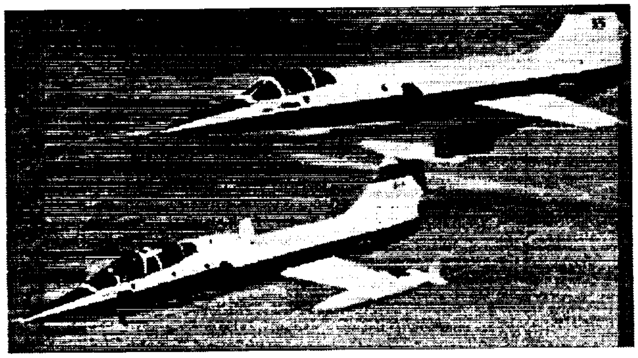


Figure 8. The NASA TF-104G Starfighter aircraft, lower left.

two-seat Starfighter aircraft, were used in restricted visibility studies. Another Starfighter, the YF-104A, was modified with a reaction control system.

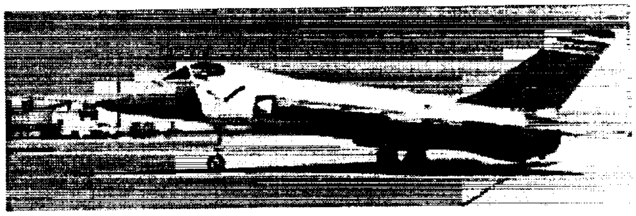


Figure 9. The NASA F5D Skylancer aircraft.

The F5D Skylancer– The NASA F5D Skylancer aircraft (fig. 9) was designed as a carrier-based short range interceptor fighter (ref. 14). It was a tailless single-engine aircraft with a swept back wing of extremely low aspect ratio; the planform resembling the proposed DynaSoar vehicle and some Supersonic Transport (SST) configurations. Enlarged speed brakes were used in a lifting body approach and landing study.

The A-5A Vigilante– The twin-engine supersonic strategic bomber A-5A Vigilante (fig. 10), operated by NASA, had a high wing, a rolling tail, and a slab fin (ref. 14). The low-aspect-ratio swept back wing had no ailerons; blown flaps were used for low speeds and spoilers and rolling tail for high speeds. The aircraft also had variable-geometry intakes. This aircraft was borrowed from the U. S. Navy for use in the SST approach control studies.

The NB-52B Stratofortress– The NASA NB-52B (fig. 11) is a modified B-52B Stratofortress, a strategic bomber with a high, swept wing and eight engines (ref. 2). This aircraft was modified to carry and

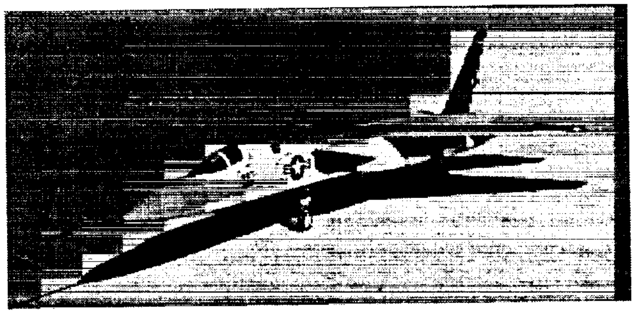


Figure 10. The NASA A-5A Vigilante aircraft.

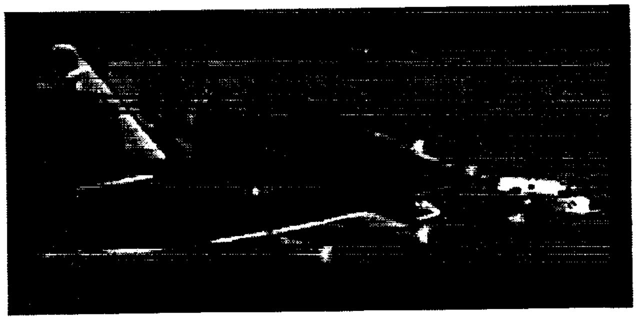


Figure 11. The NASA NB-52B Stratofortress aircraft.

launch the X-15. It has an inboard pylon on the right wing and a large notch in the inboard flap. Dryden acquired this airplane in 1959 and it is still in use.

The F-111A– The F-111A (fig. 12) is a supersonic sweep-wing, twin-engine tactical bomber. The aircraft belonged to the USAF and was flown by NASA and air force pilots in support of the shuttle program.

The CV-990– The NASA CV-990 (fig. 13) was a four-engine transport aircraft that was used in several transport flying qualities investigations in the 1960s. This aircraft was then converted to an airborne observatory by NASA.

The PA-30 Twin Comanche– The NASA PA-30 (fig. 14) is an extensively modified PA-30 Twin Comanche, a twin-engine, low-wing, four-seat general aviation airplane. The modifications include a complete flight-test instrumentation system and an uplink–downlink system for telemetering pilot commands and aircraft response, for the emulation of remotely piloted research vehicles (ref. 10). This airplane was acquired by DFRF in 1967 and is still in use.

Figure 12. An F-111A aircraft.

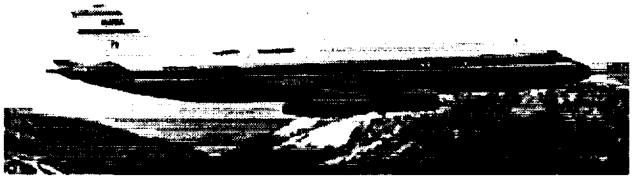


Figure 13. The NASA CV-990 aircraft.

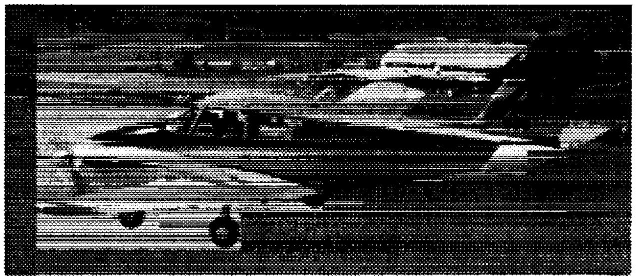


Figure 14. The NASA PA-30 Twin Comanche aircraft.

The YF-12 Blackbird– The NASA YF-12 Blackbird (fig. 15) was a twin-engine, Mach-3 interceptor aircraft. Two models, the YF-12A and the YF-12C (visibly differing mainly by the length of the chine), were used for supersonic research in propulsion, structures, and aerodynamic heating (ref. 15). These airplanes were operated at DFRF from 1969 to 1979.

The F-15 Eagle– The NASA F-15 Eagle (fig. 16) is a twin-engine, Mach-2 air superiority fighter. This aircraft, used in propulsion research, has an advanced digital engine control system.

CHRONOLOGY OF IN-FLIGHT SIMULATION AT DRYDEN FLIGHT RESEARCH FACILITY

Low Lift-to-Drag Ratio Approach and Landing

In the late 1950s, the F-104A Starfighter aircraft was used in a generic study to investigate low-L/D approach and landing techniques (refs. 12, 13, and 15).

Figure 15. A YF-12 aircraft.

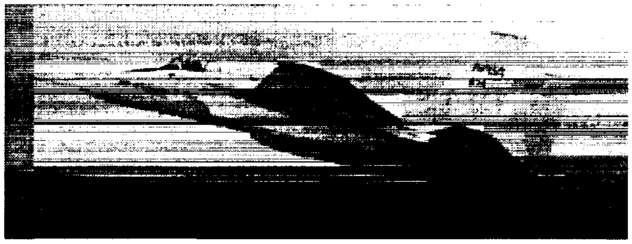


Figure 16. The NASA F-15 Eagle aircraft.

By suitably scheduling thrust- and drag-producing devices, a maximum L/D as low as 2.8 and a wing loading of about 75 lb/ft^2 was obtained.

A similar generic study was undertaken with the F-102A Delta Dagger, with maximum L/Ds of 3.8 at a wing loading of 35 lb/ft^2. Circular landing patterns were used by the pilots and a 270°-approach was preferred by the pilots in both studies, as this enabled them to establish a desired initial orientation before landing. An L/D of 3.5 presented no problem in the F-104A approach and landing. Lower L/Ds, down to 2.8, caused no problem arriving at the touchdown point. However in this latter case, it was difficult to judge the factors controlling the flare to achieve acceptable vertical velocity at touchdown. No such difficulty was noticed with the F-102A Delta Dagger because of its lower wing loading and the resulting increased float time.

X-15 Approach and Landing

Before the X-15 aircraft was flown, the F-104A Starfighter and F-102A Delta Dagger were used to simulate it in the landing and approach phase (refs. 15–18). The X-15 was a low-L/D vehicle (fig. 17) that could only be landed dead stick at fairly high speeds, so it was important to establish the landing pattern and to train the pilots in the proper procedure. This study was done to determine an optimal landing technique for the X-15 and to obtain information applicable to other reentry vehicles. Several F-104A Starfighters were used to evaluate circular and straight-in approach procedures under simulated X-15 mission conditions. The experienced test pilots who participated in this study preferred the flexibility of the circular pattern. One reason for this preference is that turn rate can be used as an energy management device, making precise landings easier (ref. 19). However, there was little difference between the two landing techniques in regard to final control of the touchdown conditions. Experience with the F-104 aircraft indicated that an L/D of approximately 2.5 in the flare represented a practical lower limit for piloted flared landings and that an aircraft with a lower maximum L/D could not be landed reliably. The F-104 simulation also indicated the desirability of extra airspeed during approach and landing, providing better control capability throughout and giving the pilot an extra g margin during the flare.

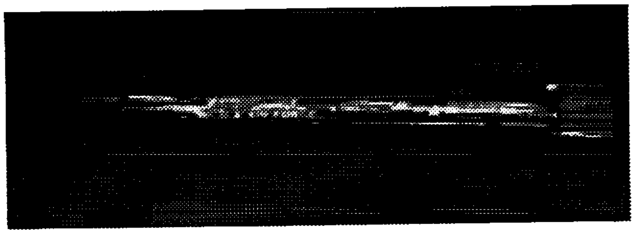


Figure 17. The X-15 experimental rocket vehicle.

The F-102A Delta Dagger, modified with large speed brakes, was also used at this time in a performance simulation of the X-15 in approach and landing. The F-104s were also used later for pilot training for the X-15 and the lifting bodies (refs. 18 and 20).

Investigation of X-15 Roll-Damper-Off Controllability and Motion Feedback

Early in the X-15 program, even before the first flight, it was determined that the aircraft was unstable with roll damper off (refs. 16, 17, and 21). An unconventional piloting technique known as the sideslip rate ($\dot{\beta}$) technique was developed and the instability investigated in the variable-stability F-100C and NT-33A aircraft. The $\dot{\beta}$ technique used small, discrete pulses to control the aircraft.

Another element in the problem was identified as motion feedback. The variable-stability F-100C and the NT-33A aircraft were also used to assess the X-15 motion feedback phenomenon in the late 1950s and early 1960s (refs. 16, 17, and 22). The aircraft motion was fed back into the stick through the pilot's arm. The pilot attempted to hold the stick fixed but the airplane motions caused the pilot to inadvertently apply small control inputs and increase the amplitude of the oscillation. When the pilot let go of the stick the oscillations damped out. When the pilot attempted to apply conventional corrective control the amplitude again increased. Although use of the X-15 side stick alleviated this problem somewhat, it was necessary to develop the unconventional $\dot{\beta}$ technique to enable the pilot to control and damp this motion effectively. A fixed-base simulation was initially used to examine the problem. However, the lack of motion and outside visual cues gave an overly optimistic indication of controllability compared to flight (ref. 18).

NT-33A Simulation of the X-15 Reentry

The NT-33A aircraft was used to simulate the reentry characteristics of the X-15 in 1960 (refs. 5, 23, and 24). The NT-33A was configured to match the dynamics of the X-15 and special instrument displays simulating those of the X-15 were also used, as was a side stick controller. The evaluation pilot took over control of the NT-33A aircraft in a zero g environment, accomplished the initial rotation of the airplane to the proper angle of attack, and subsequently made an instrument reentry, with the gradual build up of normal acceleration occurring just as it would in the X-15. This build up of normal acceleration was accomplished by rolling the plane. The technique worked because the evaluation pilot was flying "under the hood" using instruments only. Roll-damper on and roll-damper off configurations were evaluated, since ground simulation had indicated that the X-15 with roll-damper off was somewhat unstable. That instability and the pilot's ability to compensate for it were verified in this study.

F-104 Reaction Control System Program

An instrumented YF-104A aircraft had a reaction control system installed and tested in 1960 (refs. 16 and 25). This reaction control system program was done to obtain flight experience with jet reaction controls at low dynamic pressures prior to testing the X-15 aircraft in that region and to determine the handling qualities of the airplane at low dynamic pressures. This YF-104A is on display in the National Air and Space Museum in Washington, DC, near the X-15 that it simulated.

F5D Skylancer Assessment of Off-the-Pad Escape and Landing Maneuvers for a Hypersonic Glider

The F5D Skylancer was used in an early 1960s performance simulation to assess off-the-pad escape and landing maneuvers for the X-20 DynaSoar, a hypersonic glider (refs. 16 and 26). The F5D was used because of its low L/D and the resemblance of its planform to that of the X-20 DynaSoar. The proposed hypersonic glider would have been launched vertically from a large booster rocket and landed unpowered. Flight crew safety concerns in the event of a booster malfunction on the pad or shortly after launch led to the proposal of an auxiliary booster to pull the glider away from the danger area so that the pilot could assume control and land nearby. However, such hypersonic gliders had low L/D and were landed unpowered. In addition, thermal-structural consideration led, then as now, to minimally sized windows, limiting the pilot's field of view.

The simulated escape maneuvers were entered from a high-speed run approximately 1,000 ft above ground level. The pilot pulled up vertically and cut power, extending the speed brakes. This simulated the auxiliary-booster-rocket burnout. The approach and landing maneuvers examined were 360°-spiral and straight-in approaches. A blue–amber system was used to restrict the visibility, with two different window configuration being examined. (The blue–amber system uses a transparent blue visor with a transparent amber plastic lining of the canopy. The pilot can see the cockpit instruments through the blue visor but cannot see out of the canopy because amber is the complementary color.)

The simulated escape maneuvers were acceptable to the pilots, with good control. The circular pattern was again preferred and flare control was not affected by the restricted visibility. The visibility restriction did not interfere with navigation capability, although it did adversely affect portions of the escape maneuvers and landing approaches, particularly in the location of the high-key point.

F-102A Delta Dagger Simulation of Hypersonic Glider Landing-Approach

The F-102A Delta Dagger aircraft, like the F5D Skylancer, was used in landing-approach simulations of a hypersonic glider (X-20 DynaSoar) in the early 1960s (ref. 16). The same circular and straight-in approach and landing patterns were examined and the same conclusion reached. Pilots thought that circular patterns allowed more control in positioning the aircraft relative to the runway and in the flare.

A-5A Vigilante Assessment of Supersonic Aircraft in Traffic

An A-5A Vigilante was also used in 1963 to determine if there were problems inherent to operating an SST in a dense air traffic network (refs. 21 and 39). This was first explored at Edwards, with light traffic, and supersonic approaches were eventually flown into the terminal approach and departure control zones at Los Angeles International Airport. The only piloting problems associated with flying the supersonic transport profile appeared to be minor, limited primarily to speed and altitude fluctuation during the high-speed–high-altitude portion of the profile and overshoot tendencies during level-offs from steep portions of the climb. Integrating the test aircraft used to simulate a supersonic transport resulted in only minor compatibility problems with the air traffic control system.

T-33A Shooting Star Study of Restricted Fields of View For Approach and Landing

In the mid-1960s a T-33A Shooting Star aircraft was used to determine the relationship between the pilot's field of view and the performance of the landing task (ref. 27). The field of view was reduced from unrestricted to a minimum of 5.7° horizontal and 30° vertical, using a blue–amber system. The pilot's task was to fly a 180°-power-on pattern and final approach and to land the aircraft on a predetermined point on the runway. In addition, 360°-power-off overhead and straight-in approaches were performed by one pilot. Data taken included pilot comments and touchdown error.

Performance of the precision landing task, as measured by the touchdown error, was not affected by the reduced field of view. However, pilot comments indicated that the task became increasingly difficult with decreasing field of view (fig. 18).

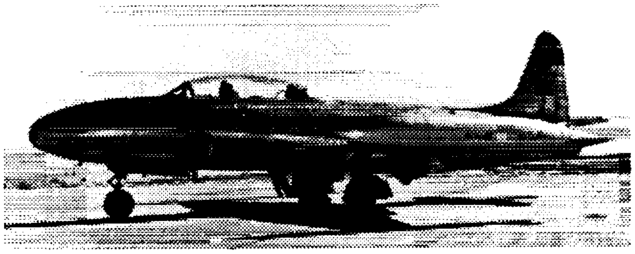


Figure 18. The NASA T-33A aircraft.

F-104 Investigations of Approach and Landing Visibility

The F-104 aircraft have been used for many investigations into visibility requirements for approach and landing for low-L/D aircraft (ref. 28). The first, in the early 1960s, used an F-104B aircraft with an indirect viewing system that had two wide-angle overlapping periscopes with stereoscopic vision, for conventional and low-L/D landings (ref. 29). The periscopes were mounted on the canopy bow between the front and rear cockpits (fig. 19) and the image was shown to the evaluation pilot in the rear seat. This system showed safe and acceptable performance in all phases of daylight flight. When the horizon was in the field of view, aircraft attitude sensing with the optics was satisfactory about all axes except pitch attitude in climbing flight. This degraded pitch-attitude sensing was caused by the poor resolution at the bottom of the field and the lack of view to the sides. However, this system had such large light loss and degraded resolution that it was not usable for night operations. It was also found that more view directly to the side was needed to perform circling approaches.

The second study, with the same setup, examined the use of the stereoscopic periscope system in lifting body approaches and landings (ref. 30). Three approach techniques (circling approach, straight-in approach, and a three-turn multiple-aim-point approach) had been proposed for lifting body approaches. The previous F-104B study had determined that the circling approach required side vision which the periscope system did not provide, so the two approach techniques requiring only forward vision were added to the assessment.

The previous F-104B program had left some doubt about the system's suitability for low-L/D approaches and landings because of the effects of exaggerated stereopsis at or near the ground. To solve this problem, a radar altimeter was also installed and pressure altitude, radar altitude, radar altitude rate, and indicated airspeed were inserted into the field of view of one of the periscopes. However, this early attempt at a head-up display (HUD) was unsuccessful, as the pilots found the information unreadable or unusable. Interestingly enough, pilots, with their excellent uncorrected

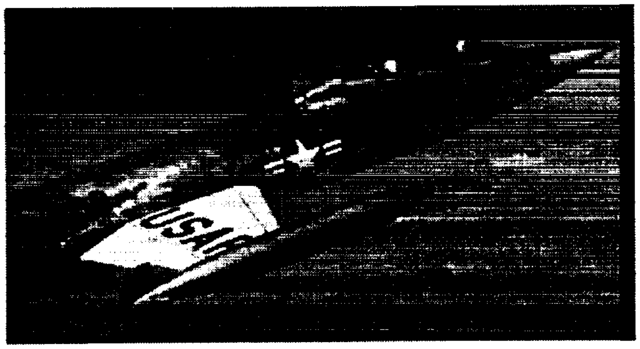


Figure 19. The NASA F-104B Starfighter aircraft with periscopes mounted on canopy bow.

vision, found this periscope system tiring and difficult to use while non-pilots who wore glasses did not have such problems. As in the study of conventional approaches and landings, the optical system provided adequate visual information for the flare and landing tasks and landing performance characteristics comparable to those obtained with normal vision. The exaggerated stereopsis played only a minimal roll in the high-speed landings, compared to the slower landings in the first study of this system.

The third F-104 limited visibility study, flown in the 1960s, involved masking the forward view, so the pilot had to rely on the field of view from side windows to land (ref. 31). An appreciable amount of the forward field of view could be obscured before the landing performance suffered markedly.

In 1990, the fourth study used stencil board to mask the front cockpit field of view of the TF-104G (ref. 28). This technique was also used in the third study. A number of windows, selected to match those proposed for the National AeroSpace Plane (NASP), were examined using straight-in approaches. In agreement with the earlier results, it was found that the pilot could land the plane with a fairly limited field of view. Unlike the earlier studies no circling approaches were examined, since it was assumed that some type of external guidance would deliver the airplane to the high-key position.

This TF-104G is currently being measured and instrumented for the installation of a folded-mirror optical viewing system which has been proposed for the NASP. This monoptic system for low-L/D approaches will be tested in the same manner as was the stereoptic system, with low-L/D approaches and precision landings.

NT-33A Simulation of M2-F2 Pilot Induced Oscillation

In 1965 the NT-33A aircraft was used to examine lateral–directional handling qualities of a variety of flight characteristics for the reentry mission (ref. 32). One set of configurations matched the M2-F2 lifting body (fig. 20) being tested at DFRF at the time. This simulation program found a coupled roll-spiral PIO (or lateral phugoid) which later manifested itself in the M2-F2 (refs. 21 and 33). The M2-F2 PIO was anticipated because it had been seen in the NT-33A simulation. This coupled roll-spiral PIO had been encountered in up-and-away flight twice and had posed no problem. When this PIO was encountered on final approach it was quite severe and led to a serious accident.

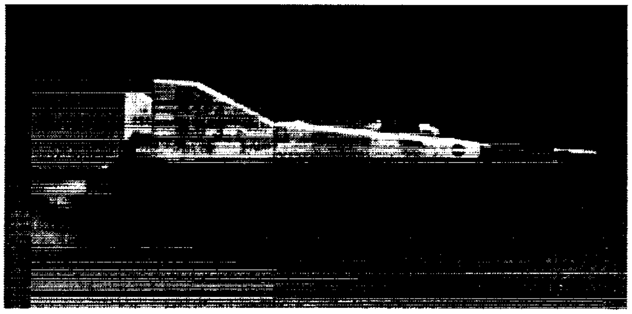


Figure 20. The NASA M2-F2 lifting body.

Lunar Lander Research Vehicle

The Lunar Lander Research Vehicles (LLRVs) (fig. 21), a program of the mid-1960s, were initially procured to examine the problems associated with lunar landing (refs. 21, 34, and 35). Lift and attitude control rockets were used during the landing simulations but the jet engine of the vehicle was used to lift and translate the craft to the simulation starting point. This led unavoidably to the examination of low dynamic pressure vertical take-off and landing flight. This jet engine was also used to counter 5/6 of the weight of the vehicle, simulating the lunar gravitational acceleration. The variable-stability control system permitted the examination of attitude command and of rate command with on–off control acceleration and proportional acceleration. Pilots discovered that attitude command was easier to fly than rate command and that satisfactory control was more easily achieved in rate command with on–off control acceleration than with proportional control.

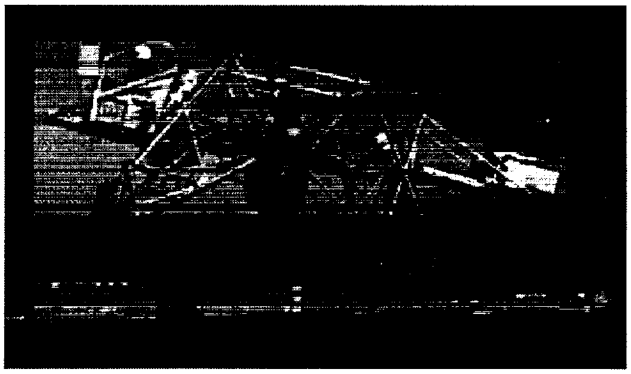


Figure 21. The NASA Lunar Lander Research Vehicle.

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The visual, motion, and audio cues made the simulation highly effective. The LLRVs were so successful at simulating lunar landings that they were transferred to the space program (ref. 21) and used for astronaut training, renamed Lunar Lander Training Vehicles, type A or LLTV-A. Three more derivative vehicles, the LLTV-Bs, were later acquired by the space program.

General Purpose Airborne Simulator Simulation of Supersonic Cruise

The Valkyrie GPAS was programmed to simulate the Mach-3 XB-70 aircraft (fig. 22) as part of the initial testing of the aircraft in the mid-1960s (refs. 36 and 37). After this testing, the simulation was used as a pilot training tool in the XB-70 program and was also proposed for evaluation of the cruise regime of proposed SSTs (ref. 38). The F100C aircraft was also used to study SST flying qualities (ref. 21). The F5D Skylancer was used to establish minimum speed criteria for the proposed SST (ref. 15).

General Purpose Airborne Simulator Investigation of Motion and Visual Cues

An interesting part of the mid-1960s initial testing of the GPAS system was a study of motion and visual cues (ref. 37). The effects of mismatched cues on observed handling qualities were studied by varying yaw rate and lateral acceleration at the pilot's location, while keeping constant the lateral–directional dynamics displayed on the pilot's instruments. This experiment showed pilot sensitivity to directional motion cues to be different for the simulation of two XB-70 flight conditions. Motion cue effects were determined using consecutive evaluation of moving-and fixed-base configurations in flight.

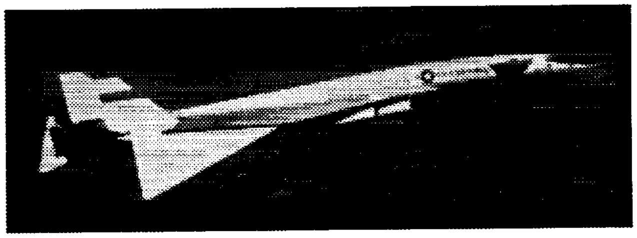

Figure 22. The XB-70 Valkyrie aircraft.

The second area investigated in this study was the measurement and description of simulation fidelity. In-flight frequency response measurements of the model-following system were taken to examine model-following fidelity for directly matched variables such as sideslip and roll rate as well as uncontrolled parameters such as lateral acceleration.

General Purpose Airborne Simulator Investigation of Roll Handling in Cruise and on Approach

The GPAS was used to evaluate roll handling for transport aircraft in both cruise and approach in the mid-1960s (refs. 40 and 41). In cruise, maximum roll-control angular acceleration, maximum available roll rate, roll time constant, and bank-angle change in a given time were all found to be effective roll-criteria parameters and the criteria developed in this program agreed well with previously proposed roll criteria. In approach, maximum roll rate, roll time constant, and wheel characteristics were varied.

General Purpose Airborne Simulator Simulation of the HL-10 Lifting Body

In 1967 the GPAS was used to investigate the longitudinal flying qualities of the HL-10 lifting body (ref. 42). Two flights were flown, but the simulation was not entirely satisfactory because of limitations in the closed-loop response of the GPAS (ref. 6).

General Purpose Airborne Simulator Investigation of Ride Qualities– In the early 1970s the GPAS was used to investigate ride qualities, particularly in turbulence. In the first study, subjects (naive non-pilots recruited from the DFRF support staff and junior engineers) evaluated the ride quality and any motion sickness symptoms that manifested themselves. This information was compared to the dynamic data collected during the various runs. From this data a number of ride quality rating models were proposed. The assessments were also compared to assessments made by a number of passengers on scheduled airliners.

In 1973-74 several ride smoothing flight-control systems (basic, command augmentation, and rate feedback) were evaluated in turbulence. These flight-control systems were designed to maintain good flying qualites while smoothing the ride, to the advantage of pilots and passengers (ref. 42). In the longitudinal axis command, augmentation systems reduced the normal acceleration response and the flightpath angle disturbances, compared to the basic and rate feedback systems, by greatly reducing the phugoid response. However, the calculated ride quality ratings showed only small improvements.

In the lateral–directional axes, significant reductions in roll rate, yaw rate, and lateral acceleration responses to turbulence were seen with a rate feedback system. The command augmentation systems were no better at reducing these responses; however, they did provide a significant reduction in bank angle and heading angle disturbances, which are of interest from a piloting standpoint. Some of the ride quality rating models indicated that these improvements modified the ride greatly while others showed no effects, depending on how greatly the lateral–directional variables were believed to affect the ride.

It was during a flight in support of this mission that the GPAS suffered an over-g condition and was retired. However, after new wings were installed, this aircraft was used as a testbed for a variety of experiments, including propulsion and boundary-layer control.

Shuttle Simulation Using Large, Low-L/D Vehicles

In support of the Space Shuttle Program, simulations of the shuttle using large, low-L/D vehicles, were undertaken in the late 1960s and 1970 using the NB-52B (fig. 11), an F-111A (fig. 12), and a CV-990 (fig. 13) (refs. 43 and 44). These large aircraft were configured for low L/D (the CV-990 had L/Ds of approximately 5 to 8, the NB-52B had L/Ds of about 3.3 to 8, and the F-111A had L/Ds from about 6.6 with the wings at 26° to about 3.7 with the wings at 72.5° and the gear down) and the engines shut down or throttled back sufficiently to produce power for necessary systems only.

The NB-52B and CV-990 aircraft were initially used to evaluate the feasibility of landing such vehicles. Once it was determined that large, low-L/D aircraft could be landed visually, the programs were expanded to examine instrument flight rules (IFR) approaches and landings with the NB-52B, instrument landing system (ILS) approaches and landings with the F-111A, and ground-controlled approaches (GCA) and landings with the F-104 aircraft. Again, a circling approach was found to provide the best energy management and control of the touchdown point. A YF-12 aircraft (fig. 15) was also used as part of this effort to develop baseline flying qualities data for large, low-L/D aircraft in the approach and landing.

PA-30 Emulation of Remotely Piloted Research Vehicles

The PA-30 aircraft (fig. 14) was used in the early 1970s in a remotely piloted mode (refs. 8 and 45) to practice piloting techniques for a variety of unmanned remotely piloted research vehicles (RPRV), including the 3/8-scale F-15 RPRV, an unpowered model used in spin testing; the Drone for AeroStructural Testing (DAST) aircraft, a modified Firebee drone used to examine aeroelasticity; and the Highly Maneuverable Aircraft Technology (HiMAT) aircraft, an aerodynamically advanced supersonic RPRV.

The PA-30, a low-wing, twin-engine general aviation airplane, provided training and currency for the exacting task of landing the RPRVs, and some currency in the ground cockpit. In addition, a variety of cameras and displays were tested to determine effective ways of presenting information to the pilot of a remotely piloted aircraft.

The PA-30 aircraft was equipped with a television camera and the picture was down-linked to the ground and shown to the pilot. The PA-30 was later used to research visual requirements for the remote piloting task, with various focal lengths and fields of view being examined. Stereoptic presentations were also examined.

Total In-Flight Simulator Investigation of Shuttle Pilot-Induced Oscillation

On October 26, 1977 the Space Shuttle Enterprise (fig. 23) exhibited a fully-developed PIO in both the roll and pitch axes during a landing on the paved runway during the approach and landing test program. As a result, in 1978 the Total In-Flight Simulator (TIFS) aircraft was used in a simulation program to discover and confirm the reasons for this PIO (ref. 46).

Analysis indicated that PIO was caused by several factors, among them time delay in the FCS and the position of the pilot relative to the center of rotation (ref. 46). The pilot's position masked the normal motion cues, since the pilot was somewhat behind

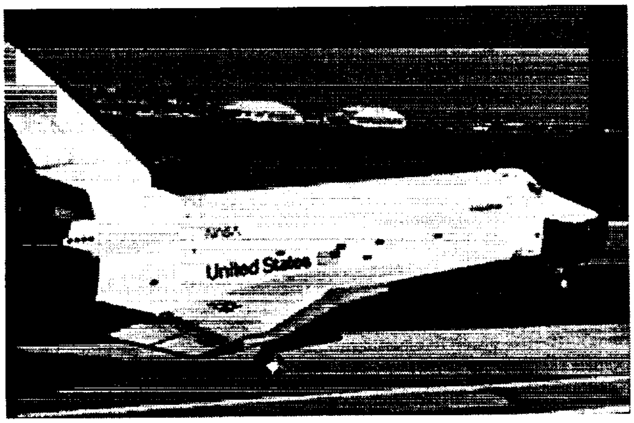

Figure 23. The Space Shuttle Enterprise about to touch down on the paved runway.

the center of rotation. Surface rate limiting also contributed to the apparent time delay. This simulation confirmed the effects of these factors.

F-8 Digital-Fly-By-Wire Evaluation of Effects of Time Delay on Handling Qualities

Immediately following the TIFS investigation of the shuttle PIO, the F-8 DFBW was used in a test program to study the effects of time delays in a digital control system like that of the shuttle and to provide more insight into the shuttle approach and landing experience (refs. 47 and 48). Transport delays were inserted into the roll and pitch axes and evaluated with formation flying and precision landing approaches (straight in and offset) at idle power, simulating the low-L/D approach typical of the Space Shuttle. In the pitch axis three different control modes were examined; stability augmentation, command augmentation, and no augmentation. The addition of time delay markedly affected the pilot's ability to control the airplane, to the point that the pilot scraped the tail of the plane on the runway during one go-around.

Formation flight was much less sensitive to the effects of time delay than was the approach task. Offset landing (where the pilot could not set up the approach but had to fly the plane more aggressively) was approximately twice as sensitive to time delay as was the straight-in approach. Furthermore, the ratings in pitch were most strongly affected by the task and were only slightly affected by changes in control system augmentation mode.

Total In-Flight Simulator Investigation of Shuttle Pilot-Induced Oscillation Suppressor Filters

Further investigation of the shuttle PIO led to the design of two candidate PIO suppression filters to control the problem. Flown in 1979, this TIFS investigation examined two PIO suppression filters that were proposed as an addition to the shuttle FCS (ref. 49). In addition, this program also examined some other modifications to the shuttle FCS, including feedforward of the pitch command and normal acceleration feedback. The effects of moving the pilot forward 100 ft were also investigated, although this was not proposed as a solution to the PIO problem. One of the two PIO suppressors evaluated in the TIFS program was implemented in the shuttle FCS prior to its first flight (ref. 50).

Pilot-Induced Oscillation Suppression Filter Assessment with the F-8 Digital Fly-By-Wire

The Space Shuttle PIO, caused in part by excessive time delay and the success of the PIO suppression filters devised to alleviate the problem, created an interest in the usefulness of PIO suppression filters in more conventional aircraft. In 1980 there was a program to evaluate the same types of filters in more conventional fighter-type aircraft using the F-8 DFBW (ref. 7). As previously described, the F-8 DFBW aircraft had already been used to evaluate the effects of time delay on digital FCSs so that the only addition required was the PIO suppression filters. The same two types of filters were examined, with a variety of breakpoints and filter slopes. The basic F-8 DFBW configuration was a good airplane with little time delay. Either a pure time delay or a first order lag was added to the FCS. The latter was used to simulate the cascading of filters in a poorly designed control system.

To provoke any possible PIO, two high-gain tasks were used. The first task, close-trail formation, involved flying just behind and below the F-104 chase plane. Pilots found that this task was somewhat artificial and not well defined. As a result of this assessment a more demanding task, probe-and-drogue refueling, was used in the second phase of the program. However, the results for the two tasks did not vary much.

The PIO suppression filters suppressed the PIOs in the configurations with added transport delay. They did not, however, help with the configurations with the first order lag.

NT-33A Pilot-Induced Oscillation Suppression Filters

In 1981 a simulation program was flown in the NT-33A aircraft to investigate PIO suppression filters in fighter-type aircraft (refs. 7, 51, and 52). A basically good configuration was selected as the baseline. To this baseline were added either time delay or lag pre-filtering in the longitudinal axis, similar to the F-8 DFBW PIO suppression filter study, and the same two PIO suppression filters were examined. In this study, the task was a precision offset landing.

The results of this and the F-8 DFBW experiments matched the shuttle program results, indicating that PIO suppression filters worked well for fighter-type aircraft as well. The PIO suppression filter greatly reduced PIOs, even with excessive time delay that led to serious PIOs in configurations without the filter. Already good flying qualities were not degraded by the filters. However, in the NT-33A study, as in the F-8 DFBW studies, the filters made configurations with lag pre-filtering worse, indicating that poor system design could not be compensated for with the PIO suppression filters.

F-8 Digital Fly-By-Wire Investigation of Nonlinear Control Algorithms

In the early 1980s the F-8 DFBW was used to investigate active, nonlinear flight-control techniques and handling qualities in a cooperative program with the Royal Aircraft Establishment (ref. 53). The evaluation was accomplished using the RAV mode.

The purpose of the study was two-fold, with the first goal being to establish whether a variable-gain controller could offer improved control performance over a linear baseline pitch-rate command system and whether any adverse handling problems would be introduced by the rapidly varying gain. The second goal was to investigate the effects of a nonlinear command pre-filter. The nonlinear pre-filter was designed to provide a small overshoot on the pitch rate and a relatively slow buildup of normal acceleration for small commands and to increase the pitch-rate overshoot and normal acceleration response for large commands. This was accomplished by varying the lead time constant of the pre-filter.

Distant tracking and close tracking were the two typical fighter tasks evaluated. The nonlinear pitch-rate command system worked well in the distant-tracking task; however, it was discovered that different responses are preferred for the two different tasks. Low-overshoot pitch-rate responses are preferred in the distant-tracking task and high-overshoot pitch-rate responses are preferred in the close-tracking task.

Nothing conclusive was learned about the variable adaptive, lead pre-filter time constant because the range of pre-filter time constants was not sufficiently related to the augmented dynamics. The F-8 DFBW aircraft, with its versatile FCS, was also used at this time in a brief, undocumented study of roll mode time constant and roll ratcheting.

Total In-Flight Simulator Investigation into Pitch Rate Command Systems in the Flared Landing Task

In 1983 an extensive TIFS investigation into pitch rate commands in the flared landing task was undertaken (refs. 56 and 57). This study evaluated pitch-rate feedback with proportional and integral forward paths, rate command design, lead–lag pre-filters, superaugmentation, superaugmentation with lead–lag pre-filters, neutral static stability, and angle of attack and pitch-rate feedback required for level 1 conventional aircraft response. The aircraft configurations evaluated were a matrix constructed from seven aerodynamic models (three stable aircraft with different values of $1/\tau_{\theta_2}$, two neutrally stable aircraft with different values of $1/\tau_{\theta_2}$, a shuttle-like vehicle, and a shuttle-like vehicle with canards) and eight pitch axis FCSs (two proportional plus integrated pitch-rate feedback systems with different undamped short-period frequencies ($\omega_{n_{sp}}$), superaugmented, conventionally augmented, three shuttle FCS variants, and one shuttle FCS variant with a time delay).

Results from this study included findings that current integral-proportional pitch-rate FCSs provided good attitude control, which is required for good performance in the flared landing task. In addition, the pilot needs cues to control flightpath precisely in the landing flare. These cues may come from pilot acceleration, stick deflections and forces, initial aircraft response, and longer term aircraft response. In addition, many techniques can be used to provide level 1 performance.

Interestingly, this study discovered that classical predictive criteria did not provide adequate prediction for the flared landing task, although a time-domain predictive criterion developed from this experiment did work well.

Total In-Flight Simulator Validation of the X-29 Control System

The TIFS was used in 1984 to examine the X-29 control system, with particular attention to power approach (ref. 58). The X-29, with its forward-swept wing (fig. 24), is a statically unstable fly-by-wire airplane with a digital primary FCS, a digital backup FCS, and an analog backup FCS. This vehicle has a canard and a strake flap in addition to the full-span flaperon and rudder. The canard, strake flap, and flaperon are used for pitch control; the flaperon alone for roll control. Ground simulation had raised questions about the flying qualities of the X-29 in power approach, with some indication that the lateral–directional gains and stick gearings might be unsatisfactory. A three-phase program was undertaken to examine these issues.

In the first phase, the originally proposed gains and stick gearing were examined in up-and-away and in power approach in the primary and both backup modes. Numerous PIOs led to reduction of the lateral–directional gains and the stick gearing in the primary mode and in the digital backup mode. The analog backup mode initially received only a limited evaluation because of a simulation anomaly, but the gains were modified and a corrected analog backup mode was evaluated. This corrected mode also demonstrated a number of PIOs, but because of the limited data, no changes were made in this mode. The primary and digital backup modes were, however, modified with reduced gains and stick gearing.

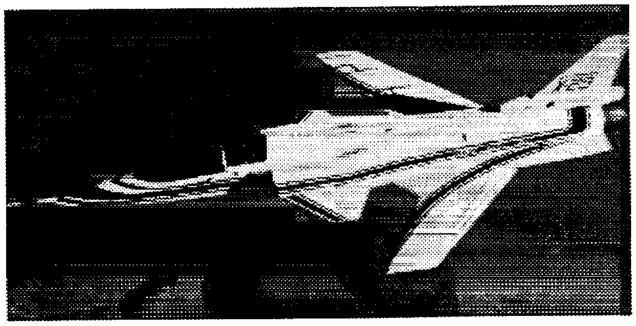

Figure 24. The forward-swept wing X-29 aircraft.

Phase two of this study was a quick-look program that examined the design changes that resulted from phase one. Phase three, flown shortly before the first flight of the X-29, provided one last evaluation of the control laws in power approach, familiarization with the first-flight profile for the pilot and the control room personnel, and evaluation of selected emergency landing modes. The primary concern in this phase was the lateral PIO in the analog backup mode, which raised a safety-of-flight question. In this phase, the flying qualities in all modes were found to be adequate for the first flight. The primary and digital backup modes, with their gains determined in previous testing, were found to exhibit level 1 and 2 handling qualities and the analog backup mode exhibited levels 1 to 3 handling qualities.

The X-29 aircraft was later flown at altitude in the analog backup mode to examine the lateral PIO seen in the TIFS study. Precision tasks, including bank angle captures and formation flight, were used to provoke any PIO. However, no lateral PIO tendencies were seen. This difference between the TIFS and the aircraft was attributed to errors in the predicted mathematical model of the X-29 and to the model-following techniques used to quicken the TIFS response, allowing this large airplane to fly like a fighter.

Total In-Flight Simulator Investigation of Proposed Shuttle Flight-Control System Modification

After the successful PIO suppressor study, another TIFS study was done in 1985 to examine further possible changes to the orbiter FCS (refs. 54 and 55). In particular, a shaped pitch-rate feedback system, a command pre-filter and pure pitch-rate feedback equivalent system, and a C^* feedback system were compared to the baseline shuttle system. Additionally, reducing time delay in the FCS by moving the body bending filters from the command path to the feedback path was examined.

Although the addition of canards to the orbiter was not seriously contemplated, the use of canards was evaluated with the baseline and modified FCSs. Canards would have given sufficient control of the center of rotation so that the problems caused by pilot location would have been greatly reduced.

Learjet Flying Qualities Research

In the mid-1980s the first variable-stability Learjet was used for a limited in-flight simulation program that examined the effects of feel system dynamics on aircraft lateral handling qualities in the approach and landing task (ref. 59). This study was sparked by the results of a brief study in the NT-33A aircraft (ref. 59). In this Learjet study, two feel systems, one fast and one slow, were examined. The flight-control configurations had two possible transport time delays, designed so that the equivalent time delay for the feel system and FCS combined were the same in each case. A baseline configuration with minimum overall time delay was also included. The tasks were bank angle captures and lateral-offset spot landings.

This study showed that the location of the time delay is important and that the feel system should be regarded as a separate dynamic element. Large overall time delay could be tolerated if a significant portion of the delay resided in the feel system. However, the same amount of overall time delay was unacceptable to the pilot if much of the delay was transport time delay downstream of the feel system. Additionally, this study indicated that the allowable time delay in the roll axis is a function of initial acceleration rate or "jerk."

The first variable-stability Learjet has been used as a training tool at DFRF since 1983. Engineers are exposed to a training syllabus based on that used by the Air Force and Navy Test Pilot Schools (ref. 11). All axes and modes are examined and stable, neutrally stable, and unstable configurations are flown. Time delays and feel system dynamics can also be varied. This aircraft has also been used by test pilots to review flying qualities areas.

NT-33A Investigation of Feel-System Characteristics on Roll Dynamics

In the late 1980s an investigation of the influence of lateral feel-system characteristics on fighter aircraft roll axis flying qualities was done with the NT-33A (ref. 3), partly in response to the Learjet study of feel-system dynamics. This extensive study examined power approach, visual landing, and up-and-away tasks including formation, gun tracking, and computer-generated compensatory attitude tracking tasks displayed on the HUD. Experimental variations included the feel system frequency, force-deflection gradient, control system command type (force or position input command), aircraft roll mode time constant, control system pre-filter frequency, and control system delay. The investigation was undertaken to determine how the feel system and the FCS interact and how the pilot assesses each.

The feel system is not equivalent to analogous control system elements in its influence on flying qualities. This led to the conclusion that flying qualities criteria should treat the feel system separately from the control system, since the feel system dynamics are apparent to the pilot and are not hidden in the total dynamics.

Investigations of Flightpath Control Using Throttles Only

In 1989 an airliner accident in which hydraulic power failed completely and differential thrust was used for flightpath control led to an investigation of the use of throttles for emergency flight control (ref. 60). In addition to fixed- and moving-base ground simulations, this investigation included a cursory flight simulation program using the first variable-stability Learjet, the F-15, and the PA-30 aircraft. In twenty minutes of flight using throttles only, the Learjet demonstrated some control capability, with heading and altitude maintained within 500 ft. It showed good roll controllability with differential thrust and poor pitch control, with the phugoid being difficult to damp with throttle inputs.

The PA-30, a low-wing, twin-engine four-seat general aviation airplane, was difficult to control in all axes with thrust only. Gross control of the PA-30 was possible but landing on a runway would have been difficult.

The F-15, a twin-engine air superiority fighter, demonstrated good roll response and pitch response to throttle control. The F-15 rolled and banked well with throttle control only and a heading could also be held well. Altitude could be held within 100 ft at airspeeds below 200 kn, though phugoid damping was difficult.

These three experiments indicated that it is feasible to develop a control system for a large transport that would allow a safe return if hydraulic power were completely lost.

A more extensive investigation into the feasibility of thrust-only flightpath control used the second variable-stability Learjet in a six-flight program in the fall of 1991. Two different basic configurations, an

F-15-like fighter and a large transport, were examined. Apparent engine location was varied for the two configurations, although the actual engine characteristics (spool-up time, for example) could not be varied. This limited study determined that thrust-only flight-path control was extremely vunerable to turbulence and confirmed the necessity of special piloting techniques.

CONCLUDING REMARKS

There are two areas of major interest at the Dryden Flight Research Facility that simulation has addressed, which are landing fast, low-lift-to-drag ratio aircraft that cannot do go-rounds and pilot-induced oscillations in digital flight-control systems.

The first in-flight simulation program at the Dryden Flight Research Facility was an investigation of low-lift-to-drag ratio approach and landing characteristics, using the F-104 and the F-102A Delta Dagger aircraft. The most recent inflight simulation program here is an F-104 investigation into field of view requirements for the National AeroSpace Plane, a low-lift-to-drag ratio vehicle with limited visibility.

The X-15, the lifting bodies, X-20 Dynasoar, the shuttle, the National AeroSpace Plane–these low-lift-to-drag ratio airplanes land at high speeds and go-arounds are impossible. It has always been critical to get the landing pattern right before the flights. In-flight simulation has aided in the design of the pattern, the designation of high keys, approach angles, flare speeds, roundout altitudes, and touchdown speeds.

Structural and aerodynamic heating dictate small windows or remote viewing systems in hypersonic aircraft. The use of in-flight simulation answered questions on how small the windows could be, whether the remote viewing system needs to be stereoptic or monoptic, what resolution is required, what supplementary instrumentation is necessary and how to present this to the pilot, and a number of other display questions.

The interest of Dryden Flight Research Facility in aircraft with digital flight-control systems started around 1970 when the F-8 digital fly-by-wire program began. This aircraft, the first ever to be all-digital fly-by-wire, was used first as a demonstrator of the technology but it soon turned into a research tool examining digital flight-control system problems like roll ratcheting. Interest in pilot-induced oscillations has always been high in the fast, high-performance research aircraft like the X-15 and the lifting bodies, as evidenced in part by the studies previously mentioned.

These two threads came together dramatically on October 26, 1977, when the Space Shuttle Enterprise, making a precision landing on the main runway at Edwards Air Force Base, experienced a fully-developed multiple-axis pilot-induced oscillation. As soon as the dust settled, Dryden Flight Research Facility began to use its experience in the investigation of flight-test problems.

The data were analyzed and the first Total In-Flight Simulator program confirmed that the causes were known. The effects of time delays in digital flight-control systems were examined in the F-8 aircraft. The pilot-induced oscillation suppressor filters were developed and tested in a second Total In-Flight Simulator program. While these filters were proven to work well, Dryden Flight Research Facility continued to examine improvements to the flight-control system for approach and landing and these proposed changes were examined in another Total In-Flight Simulator program.

Dryden Flight Research Facility then moved on from the practical, fix the problem and get the aircraft flying again approach, to research into more general issues, examining pilot-induced oscillation filters in fighter-type aircraft with the F-8 digital fly-by-wire and the NT-33A.

The location of the time delay, either in the feel system or in the flight-control system, was examined quickly in the NT-33A aircraft, more thoroughly in the Learjet, and exhaustively in a major NT-33A study. Thus a seemingly isolated incident led first to a solution to the incident and then to a body of research into the root problems.

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N94-35970

IMPLEMENTATION OF A COMPUTERIZED MAINTENANCE MANAGEMENT SYSTEM

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Summary

A primer Computerized Maintenance Management System (CMMS) has been established for NASA Ames pressure component certification program. The CMMS takes full advantage of the latest computer technology and SQL relational database to perform periodic services for vital pressure components. The Ames certification program is briefly described and the aspects of the CMMS implementation are discussed as they are related to the certification objectives.

Introduction

The Computerized Maintenance Management System (CMMS) is a response to calls for high performance and quality in areas of asset management and employee productivity. At NASA Ames Research Center (ARC), there is an urgent need for monitoring a large number of special equipment which is part of the high-pressure gas or liquid lines throughout the Ames property. Due to the nature of the working fluids and operating conditions, high pressure systems create a potential hazard to the surrounding environment. The safety of the personnel and facilities on-site would be jeopardized if this equipment fails to perform designated functions. Motivated by this need and the demand for more prompt services on this equipment, a computerized maintenance management system was implemented for the monitoring process. Documented here is the first phase of the pressure system monitoring project.

Pressurized Systems and Safety Inspection

There are more than a hundred research and development facilities used at ARC for various scientific experiments and studies. Approximately 80% of these facilities use pressurized vessels and systems (PV/S). Many of Ames' PV/S were built without being certified for conformance to applicable codes and standards. To ensure both the structural integrity of ARC's unique research facilities and the on-site personnel's safety, these PV/S must comply with current applicable safety codes and standards. To accomplish this, ARC established a certification/recertification program in the early 80's to determine the system's status (i.e., certification, repair, or replacement). After initial certification, recertification is periodically conducted using a schedule of inspection and tests to verify that a previously certified pressure system continues to be safe to operate. Ames certification and recertification may be accomplished on a whole system basis or on an all-individual component basis.

The process starts with collecting information by field visual inspection, size measurements of the pressure components, retrieving manufacturers's nameplate data, and historic records. Each component of every system is assigned a unique three-digit number called the component number, and is shown on a piping isometric drawing. The field data is then processed by a FORTRAN computer program on a VAX 11/785 in building N-213. The computer program produces comprehensive status sheets (SS) for the PV/S. The SS include field measurements, physical properties, the maximum allowable working pressure and temperature, certification status, future inspection intervals, and recommendations for recertifying, derating, repairing, or replacing each component. The SS, however, do not provide an easy way of tracing the changes and modifications made to the system after recertification. They also lack the capability to monitor the components continuously.

Objective of the Monitoring Project

Past recertification documents show that a large number of special components in ARC's pressure systems, such as pressure gauges and relief valves, are overdue for servicing. These special components need to be more closely monitored to safeguard the entire system. It is therefore necessary to establish an automatic tracking system in order to keep a timely record of each component and generate servicing notices. The Pressure System Safety Committee of ARC recognized this necessity, and consequently, a pressure system monitoring project for the recertification group was proposed in March 1992. The first phase of the project includes monitoring five types of components, namely pressure gauges, relief valves, hoses, rupture disks, and temperature gauges. These five special components were chosen because of their importance to the safety of the PV/S, and because

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the code requirements for them are more restrictive than other pressure components.

Pressure Gauges

A pressure gauge should give accurate readings for the pressure in a piping system. To ensure its function, Ames Health and Safety Manual (AHB 1700-1) requires that all pressure gauges be calibrated every two years and be of safety type. "Safety type" means that, in case of failure, the broken pieces of the gauge will blow out the back of the gauge, to prevent injuries to the gauge reader. Several manufacturers have established trademarks that represent the safe case. Typical gauges used in ARC facilities are made by US Gage and Ashcroft, trademarked by "SOLFRUNT," "MAXISAFE," or "DURAGAGE," respectively. The dial range of a gauge is recommended to be twice the intended operating pressure, and not less than 1-1/3 of the maximum operating pressure.

Recertification documents show that many gauges used in ARC have expired calibration dates, and that unsafe gauges are used occasionally. Some gauges do not have the recommended dial range. Some even have broken dial cover glass.

Relief Valves

These valves control the fluctuation of pressure in PV/S and protect the system from being suddenly over-pressurized by fire, among other causes. Generally, relief valves are required to open at 10% over the maximum allowable operating pressure and to be spring-loaded. NASA standards specify that the valves must be reset every two years while in more corrosive PV/S, such as water and liquid carbon dioxide, the valves must be reset annually.

The relief valves used in ARC's facilities often do not meet the above safety standards. A large number of valves were tested and reset in intervals greater than the required two years.

Hoses

When used in high pressure systems, hoses must pass hydrostatic pressure test every two years to ensure there are no leaks or other damages done to the hoses. Many hoses used in the field do not comply with the requirement.

Rupture Disks

These are commonly used in parallel with relief valves. The disks are made to burst at certain pressure levels therefore to protect the system from being over pressurized. To avoid premature rupture, they should be replaced per manufacturer's specification. Many rupture disks used in the high pressure systems at ARC are not properly tagged to show the installation date.

Temperature Gauges

The temperate gauges installed on PV/S have the same requirements as for pressure gauges. There are not many pressurized temperature gauges used in ARC's facilities, however, some of them are found to be outdated.

All these five types of pressure components have to be recertified every ten years in addition to the above-mentioned regular maintenance. Any problems, such as the ones mentioned above, should be brought to the user's attention, along with suggestions for appropriate action.

Implementation of CMMS

To prepare the database of the monitoring project, all the special components inventoried in the previous status sheets were assembled. The data collected in the status sheets were updated by field-checking. Errors were corrected and missed information was added. Original drawings showing the location of each component were retrieved and attached to the complied SS for five types of special components. When substantial modifications had been made since the last recertification, new drawings were sketched and new set of numbers were assigned to the components. There are approximately 700 special components in 60 facilities or systems that were selected for the first phase of monitoring project. Each facility and/or system was assigned a three-digit number. The previous component number used in the drawings was prefixed with its facility/system number, making a unique identification for the component. Examples of the new component number are 100-038, 230-199, etc.

Research was conducted to find a suitable database to accomplish monitoring goals. Several sources were accessed including the one used by NASA Ames Maintenance Management Office. They surveyed about 20 different CMMS products for their routine maintenance work and decided on MAXIMO Maintenance System by Project Software & Development, Inc. (PSDI). The software was installed on a file server (PC) and has been used since 1990. Our main concerns were cost-effectiveness, customization, training, graphics and multi-task capability and other aspects of the prospective

CMMS. It was concluded that MAXIMO was best suited too. The heart of MAXIMO is its work-order system, which tracks maintenance activities through a standardized database that automatically generates a work order using user-defined criteria. However, due to the limitations of the version (Version 2.6) used by EM, some requirements of the monitoring project, such as data entry validation, are not satisfied. During the period of July to August of 1992, a new version of Windows-based MAXIMO (Series 3, Version 1.1c) was installed for the Pressure System Recertification Group. Series 3 has an on-screen menu with a wide range for customization in areas such as screen layout, extra tables, etc. The most useful feature for the monitoring project is the capability to attach a user-defined value list to any data field that requires operator entry. This feature validates all the crucial data entered by accepting only those values as defined in the value list. The pull-down menu of the value list provides additional convenience for the operator and reduces the possibility of human error. Another advantage of Series 3 is the accessibility of the information stored in the database. Since MAXIMO utilizes the SQL relational database and is Windows compatible, queries about the data can be made right from the data screen, including the use of wild cards and operators. The need for extracting information easily from the database was recognized before but was not achieved until the implementation of MAXIMO series 3. The third feature that is rather attractive to the monitoring project is the ability to add new screens or modules within MAXIMO. The added screens are not necessarily related to the maintenance activities but are required by the pressure system inspection and recertification. This flexibility enables MAXIMO to be "made" exactly for the monitoring project.

Because MAXIMO was designed for maintenance function not specifically for pressure safety inspection, however, substantial modifications are necessary to match the needs of monitoring a pressure system. Four modules or applications of the MAXIMO have been modified. The Equipment module, which contains all the information for a piece of equipment to be maintained, has been changed to match the SS. It includes information that is common to all types of pressure components. The Preventive Maintenance Master (PM) module, which sets up the maintenance schedule for periodic services, and the Work Order Tracking module, which processes the work orders, have been altered also to meet monitoring requirements. The Job Plan module, which details the work procedures, has been changed into a code reference library with an identification (ID) number assigned to each applicable reference.

Five additional screens (modules) were created to accommodate the data for pressure gauges, relief valves, hoses, rupture disks and temperature gauges. These screens contain the data pertaining only to each type of components. Value lists are attached to several data fields in these screens. Data fields "Inlet type" and "outlet type" describe how the component is engaged to the piping system. Typical types, such as male-pipe threaded (MPT), female-pipe threaded (FPT) or flanged (FLGD) are included in value list INTYPE. In the pressure gauge screen, value list CASETYPE is attached to the case type field which specifies the trade marks of the gauge (e.g., SOLFRUNT, MAXISAFE, DURAGAGE and other brands). Numerical fields (such as inlet size) are defined to accept only numbers. These five screens separate the special components from others and allow easy querying of one group of special components at a time. The value lists provide a certain degree of protection from data entry errors and reduce the chance of mixing different type of data with different components.

The implementation of the CMMS was finished in early September 1992, and the data entry started in the middle of the September. Information from updated SS and additional data from field inspection were input to the database via the Equipment screen and corresponding component screens. A maintenance scheduler (PM) for each component was established. Based on component type, a pertaining code reference ID number was assigned on the PM of a component. When corrective maintenance is required, a work order is generated separately. Service requests are based on the last completion date of the service, plus the frequency of service defined by the relevant code. The due dates printed on the work order reflect the actual date when the service should be completed plus 30 extra days allowance. It is expected that when all the components are brought up to schedule, a more restrictive due date will be imposed. The first set of work orders, renamed as "Periodic Maintenance Notice" (refer to fig. 1 for a sample output), were sent out on Oct. 6, 1992, to appropriate facility representatives. The response from the users who received the notice was prompt and supportive. On one occasion, the user finished the required service within 24 hours. All the notices have been responded to before the due date. Users have expressed their appreciation of the notice. As of January 1993, the modified CMMS is fully functional and the first phase of the monitoring project is progressing satisfactorily.

Summary

Safety is the paramount concern when dealing with pressure vessels and systems, and good maintenance is the only way to ensure it. A systematic approach and well-organized maintenance scheme is necessary for any facility or plant. The Computerized Maintenance

Management System (CMM) alone will not improve maintenance performance without proper implementation and a feasible plan. To produce positive results and justify their cost, CMMS's must be incorporated with careful maintenance planning and goal setting. The implementation of MAXIMO in the monitoring project is successful because these guidelines have been followed.

While improvement of the current version of the CMMS continues, the second phase of the monitoring project is expected to include all pressure components which require regular services. More advanced features of updated CMMS will be explored. Graphics packages will be attached to the database so that engineering drawings can be reviewed on the same data screen of the component. The physical appearance of the component and disassembly charts can also be scanned into the CMMS, making a complete database for a particular component or equipment. The prospect of future application to other aspects of maintaining PV/S, such as nondestructive examination, is promising as the project progresses.

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Biography

Yonghong Shen was born in China in 1958. In 1982 Shen completed her undergraduate education and continued graduate study at Stanford University. She obtained her Master's Degree in Mechanical Engineering in 1983. She then worked in various research institutes in Arizona and Illinois. She joined Bentley Engineering Company in February 1992.

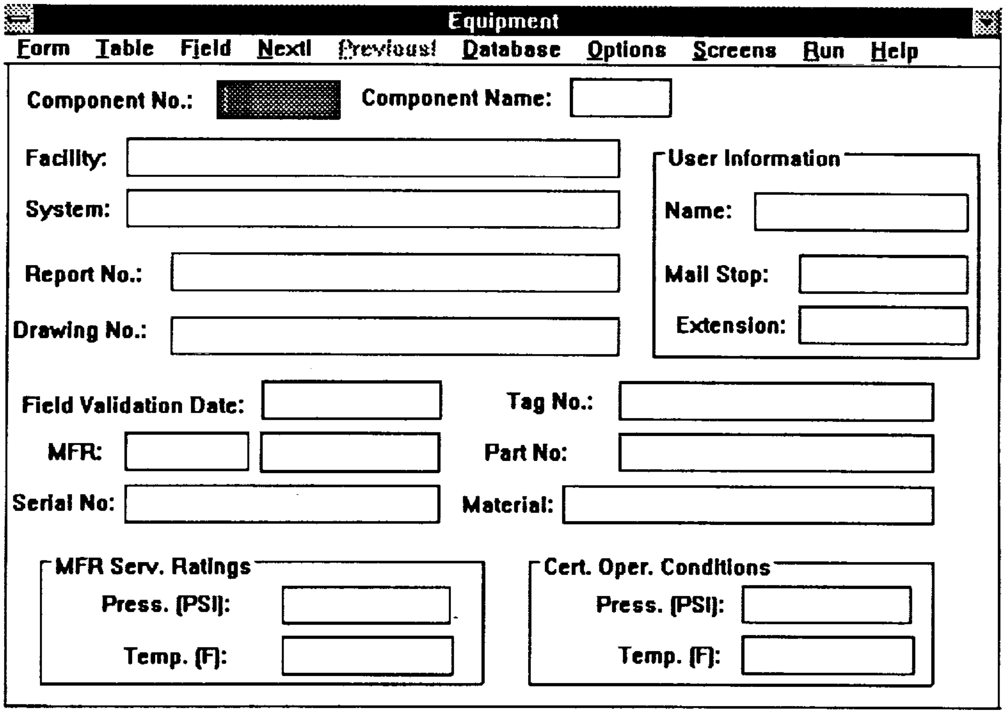


Figure 1. Equipment Screen

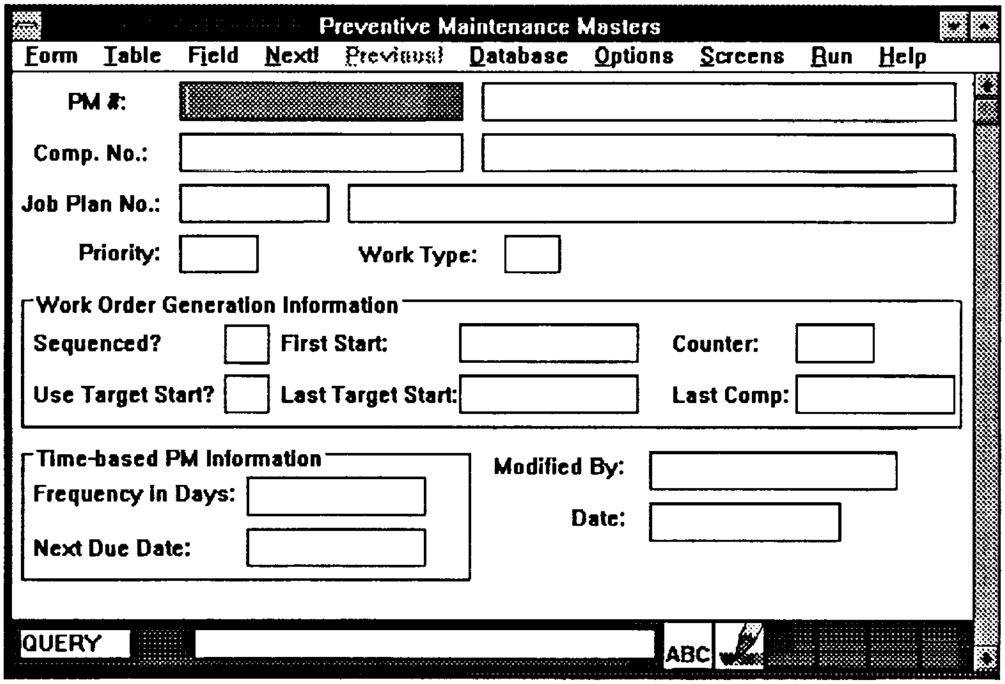


Figure 2. Preventative Maintenance Master Screen

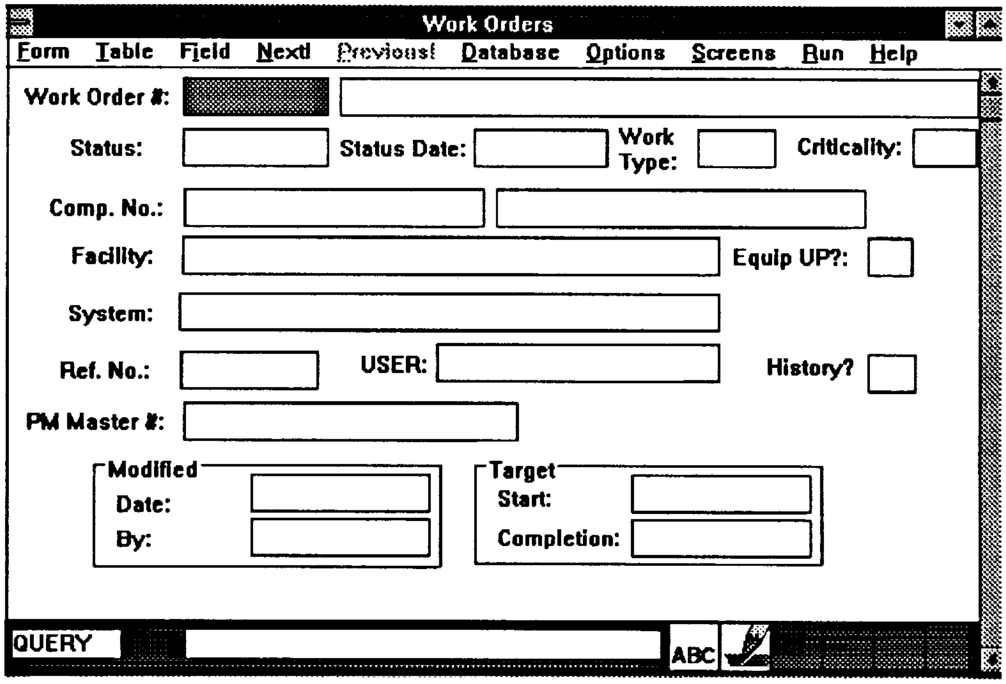
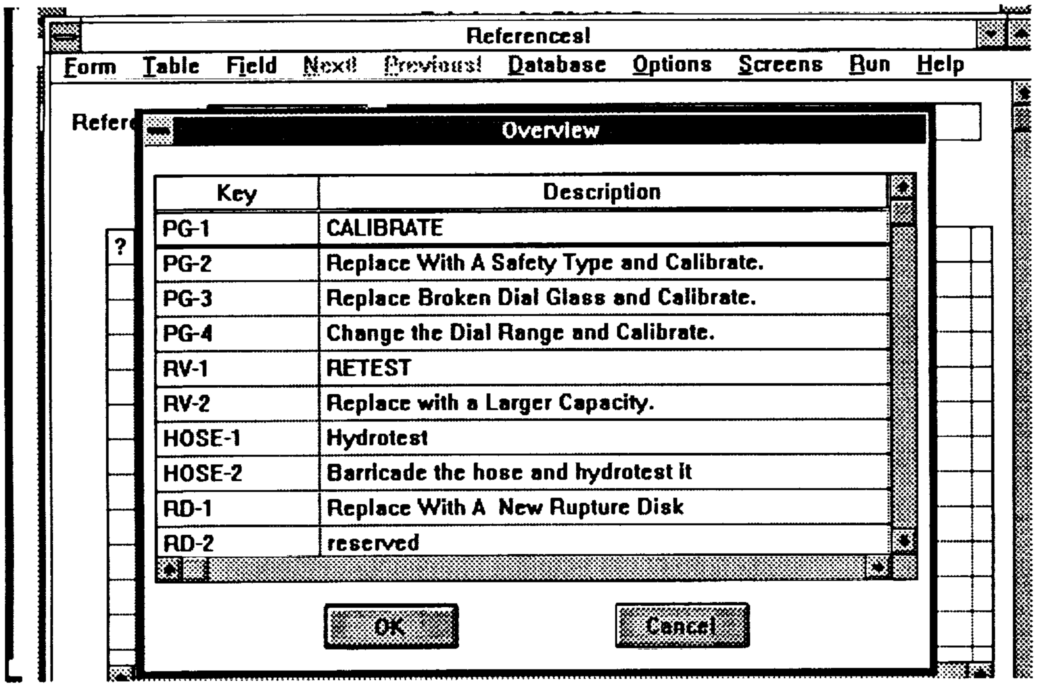


Figure 3. Work Order Tracking Screen



Key	Description
PG-1	CALIBRATE
PG-2	Replace With A Safety Type and Calibrate.
PG-3	Replace Broken Dial Glass and Calibrate.
PG-4	Change the Dial Range and Calibrate.
RV-1	RETEST
RV-2	Replace with a Larger Capacity.
HOSE-1	Hydrotest
HOSE-2	Barricade the hose and hydrotest it
RD-1	Replace With A New Rupture Disk
RD-2	reserved

Figure 4. Reference (Job Plan) Screen

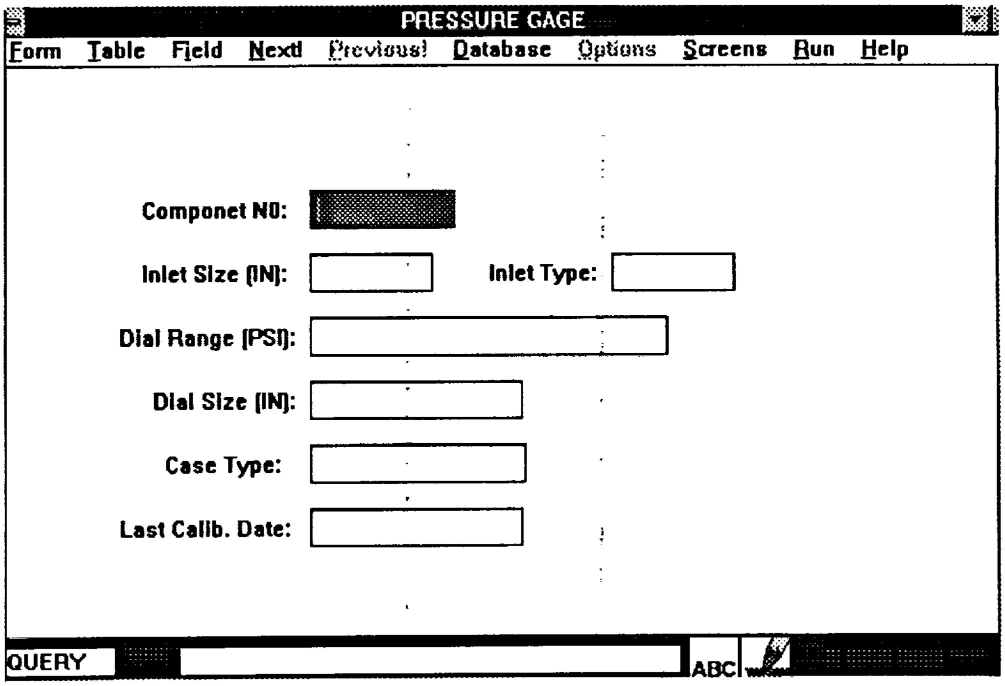


Figure 5. Pressure Gauge Screen

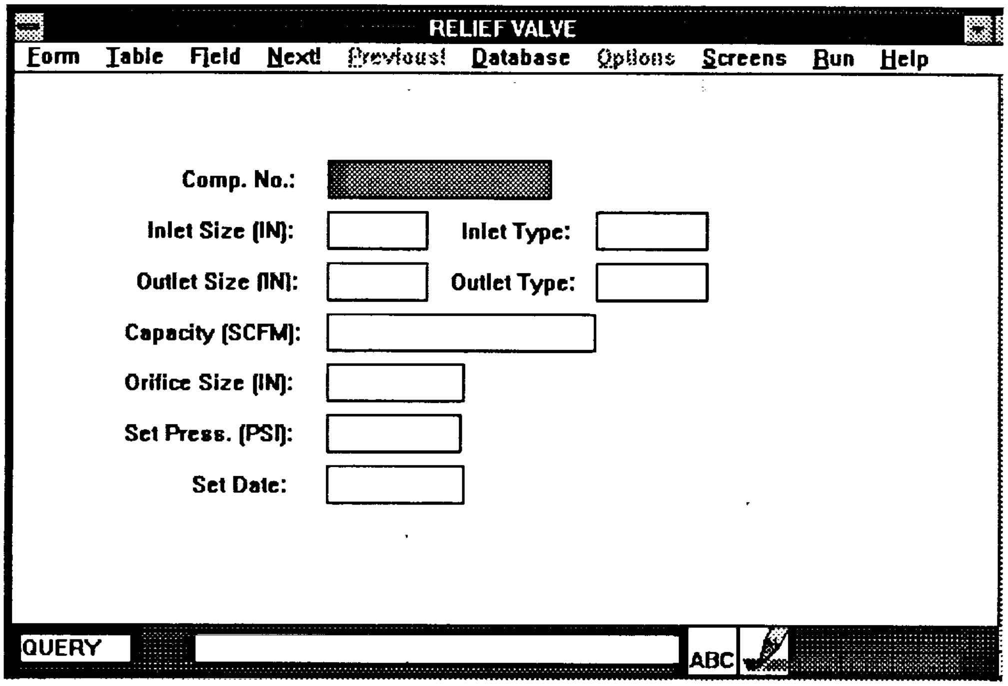


Figure 6. Relief Valve Screen

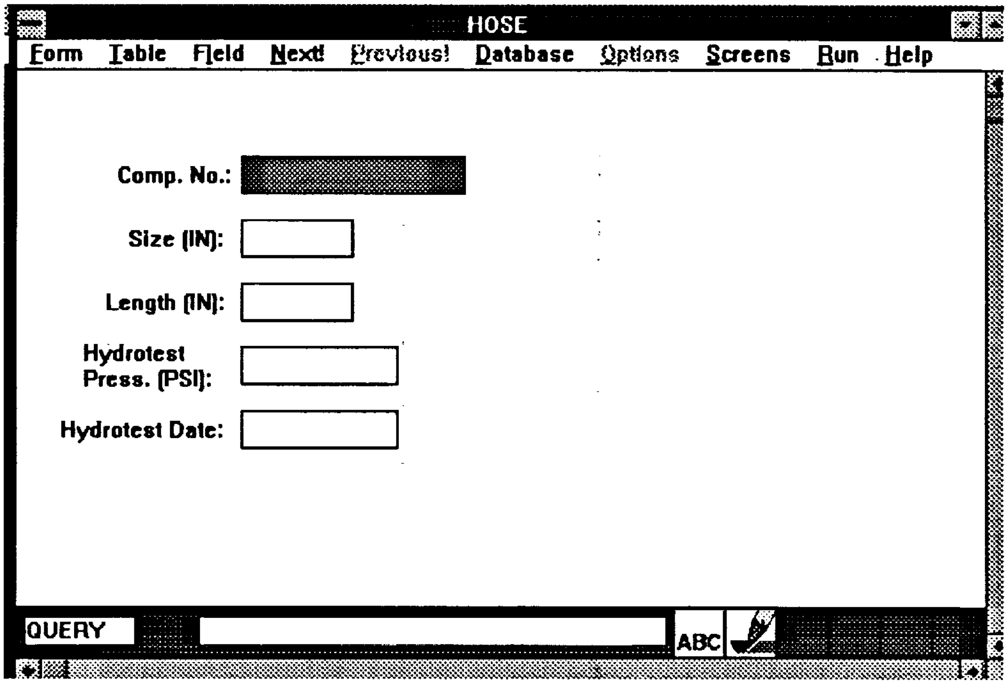


Figure 7. Hose Screen

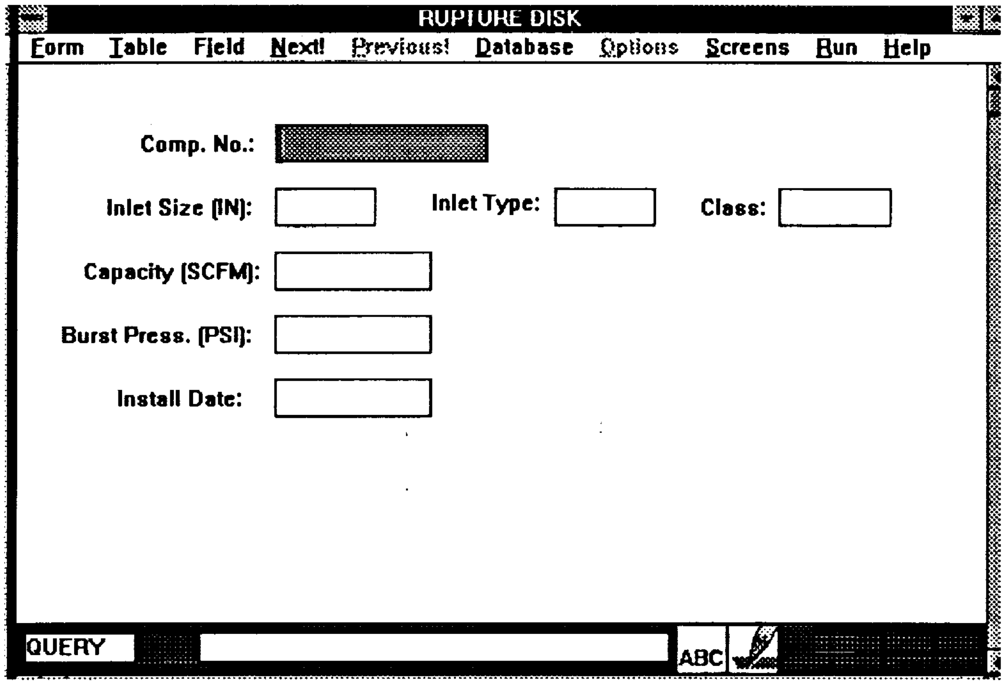


Figure 8. Rupture Disk Screen

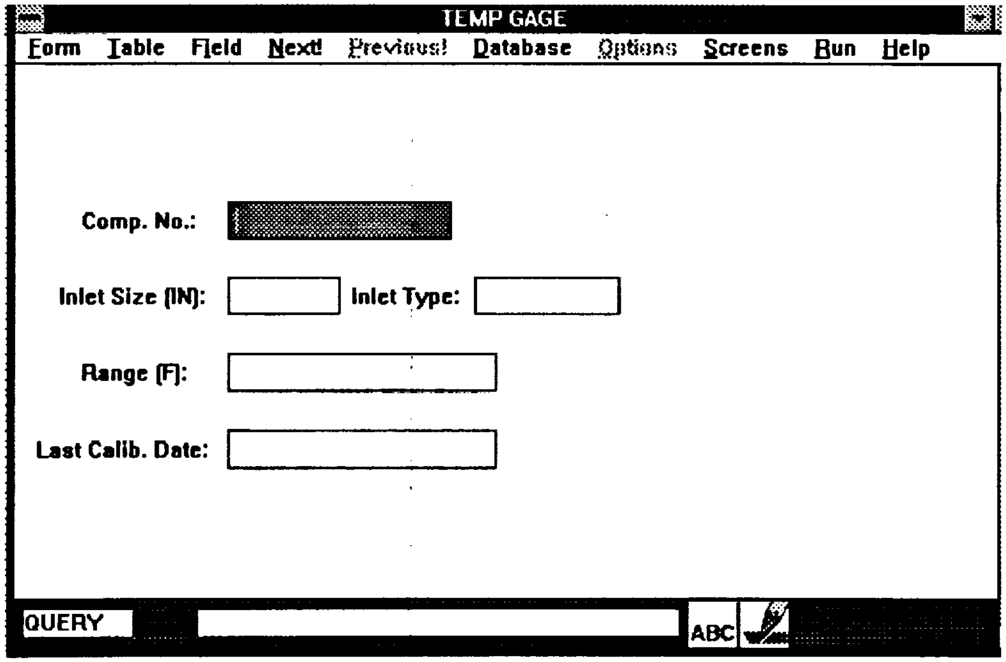
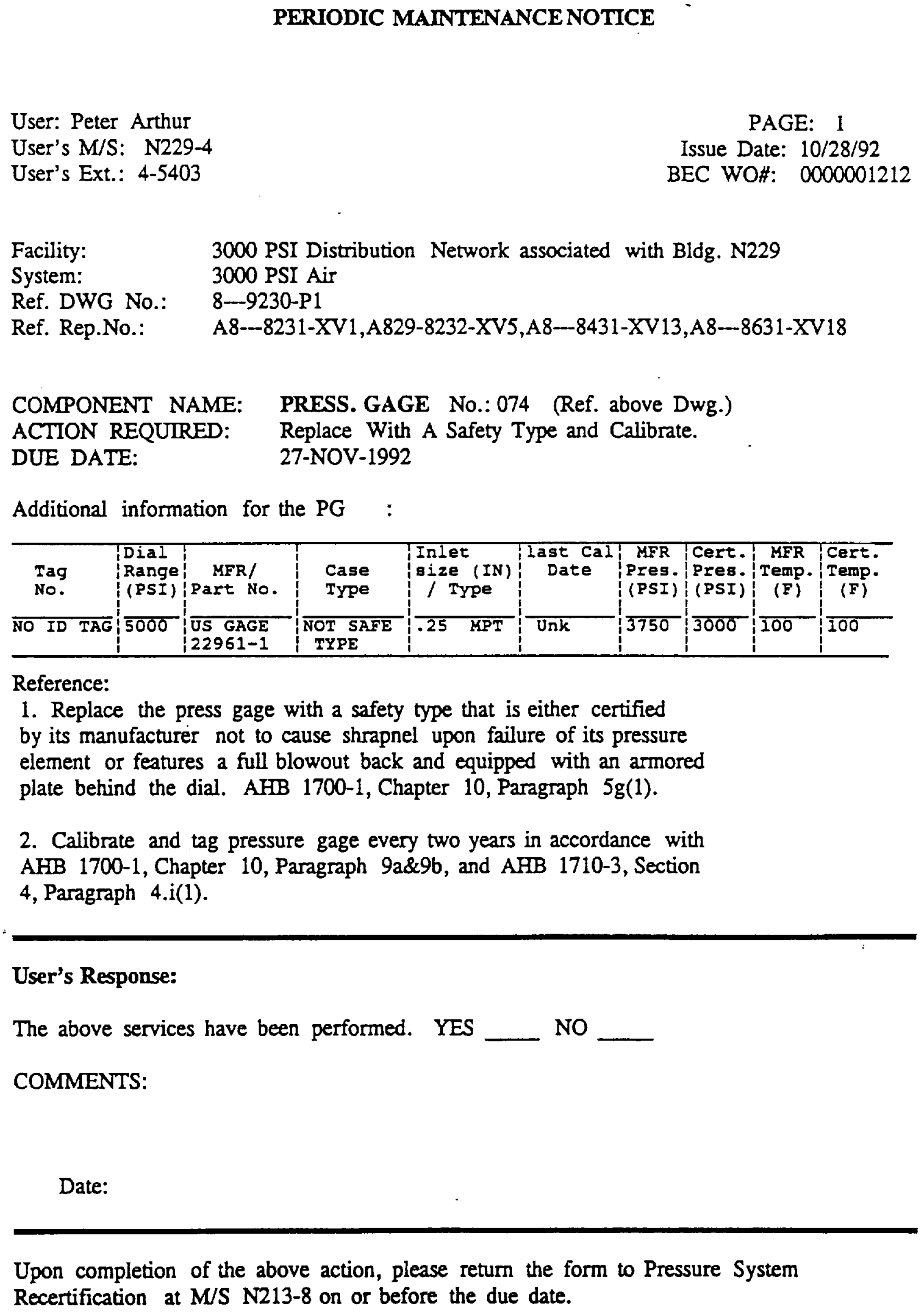


Figure 9. Temperature Gage Screen



PERIODIC MAINTENANCE NOTICE

User: Peter Arthur
User's M/S: N229-4
User's Ext.: 4-5403

PAGE: 1
Issue Date: 10/28/92
BEC WO#: 0000001212

Facility: 3000 PSI Distribution Network associated with Bldg. N229
System: 3000 PSI Air
Ref. DWG No.: 8—9230-P1
Ref. Rep.No.: A8—8231-XV1,A829-8232-XV5,A8—8431-XV13,A8—8631-XV18

COMPONENT NAME: **PRESS. GAGE** No.: 074 (Ref. above Dwg.)
ACTION REQUIRED: Replace With A Safety Type and Calibrate.
DUE DATE: 27-NOV-1992

Additional information for the PG :

Tag No.	Dial Range (PSI)	MFR/ Part No.	Case Type	Inlet size (IN) / Type	last Cal Date	MFR Pres. (PSI)	Cert. Pres. (PSI)	MFR Temp. (F)	Cert. Temp. (F)
NO ID TAG	5000	US GAGE 22961-1	NOT SAFE TYPE	.25 MPT	Unk	3750	3000	100	100

Reference:

1. Replace the press gage with a safety type that is either certified by its manufacturer not to cause shrapnel upon failure of its pressure element or features a full blowout back and equipped with an armored plate behind the dial. AHB 1700-1, Chapter 10, Paragraph 5g(1).

2. Calibrate and tag pressure gage every two years in accordance with AHB 1700-1, Chapter 10, Paragraph 9a&9b, and AHB 1710-3, Section 4, Paragraph 4.i(1).

User's Response:

The above services have been performed. YES ____ NO ____

COMMENTS:

Date:

Upon completion of the above action, please return the form to Pressure System Recertification at M/S N213-8 on or before the due date.

Figure 10. Sample Periodic Maintenance Notice with the associated drawing (next page).

N94-35971

SPACE-BASED CRYSTAL GROWTH AND THERMOCAPILLARY FLOW

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Summary

The demand for larger size of crystal is ever increasing especially in applications associated with the electronic industry, where large and pure electronic crystals (notably silicon) are the essential material to make high-performance computer chips. Crystal growth under weightless conditions has been considered an ideal way to produce bigger and hopefully better crystals. One technique which may benefit from a microgravity environment is the float-zone crystal-growth process (fig. 1), a container-less method for producing high-quality electronic material. In this method, a rod of material to be refined is moved slowly through a heating device which melts a portion of it. Ideally, as the melt resolidifies it does so as a single crystal which is then used as substrate for building microelectronic devices. The possibility of contamination by contact with other material is reduced because of the "float" configuration. However, since the weight of the material contained in the zone is supported by the surface-tension force, the size of the resulting crystal is limited in Earth-based productions; in fact, some materials have properties which prevent this process from being used to manufacture crystals of reasonable size. Consequently, there has been a great deal of interest in exploiting the microgravity environment of space to grow larger size crystals of electronic material using the float-zone method.

In addition to allowing larger crystals to be grown, a microgravity environment would also significantly reduce the magnitude of convection induced by buoyancy forces during the melting stage. This type of convection was once thought to be at least partially responsible for the presence of undesirable nonuniformities in material properties called striations observed in float-zone material. However, past experiments on crystal growth under weightless conditions found that even with the absence of gravity, the float-zone method sometimes still results striations. It is believed that another mechanism is playing a dominant role in the microgravity environment.

Thermocapillary Convection

In float-zone crystal growth, the temperature difference between two ends of the zone produces a surface-tension gradient along the interface between the liquid and the surrounding gas causes a fluid motion in the melt. This type of flow is called thermocapillary convection, and will exist in any gravitational environment. Experiments on this type of convection have found that, under certain conditions, the flow is in a stable circulating state. When the conditions change, the flow also changes to an oscillating, unstable state. The condition is a combination of factors, including temperature differences, the material grown and the size of the crystal. Recent speculation is that the onset of time-dependent thermocapillary convection (ref. 5) is actually responsible for the appearance of the striations and nonuniformity in the final product. Since this mode of flow will exist in crystal-growth process, the stability properties of thermocapillary convection are of possible technological importance.

Experiments have been performed in half-models of the float-zone process, so termed because they are meant to simulate the lower half of a float-zone melt, where the axial buoyancy gradient is stabilizing, meaning the hotter fluid is on top of the colder fluid. In one of the experiments (ref. 1), a liquid bridge is established between a pair of cylindrical rods, which are differentially heated, with the upper rod held at a higher temperature than the lower. For small enough temperature differences, as characterized by a dimensionless parameter called Marangoni number $\mathrm{Ma} = \gamma(T_H - T_C)R/\kappa\mu$ steady convection is observed, while for large values, a transition to oscillatory convection occurs. The additional parameters applying to the definition above are R, the zone radius; γ, the rate of change of surface tension with temperature; μ the dynamic viscosity; and κ, the thermal diffusivity. The experiment described above has motivated stability analyses of the half-zone flow fields which are described in the following sections.

Brief Introduction to Stability Theories

Stability theories have signification applications in fluid mechanics to determine flow states. The theories can be

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divided into two categories: energy theory and linear theory. Energy-stability theory provides a stability limit, under which a flow is guaranteed to be stable against any disturbances. The linear theory, on the other hand, gives a instability limit, above which, the flow is unstable, divided into two categories: energy theory and linear theory. Energy-stability theory provides a stability limit, under which a flow is guaranteed to be stable again regardless the magnitude of the disturbances. The linear theory, on the other hand, gives an instability limit, above which, the flow is unstable, regardless of the magnitude of the disturbances. Figure 2 shows a stability map with the two stability limits marked. The ideal situation, of course, would be for the two limits to coincide, but this occurs only in certain cases.

From the standpoint of the float-zone crystal-growth process, energy theory is an attractive technique, since it provides sufficient conditions for stability to disturbances of arbitrary amplitude. If the Marangoni number defined above was taken as the stability parameter, then energy theory provides e value Ma_E, such that for all $Ma < Ma_E$, stability is guaranteed. If the analysis was performed for an actual float-zone melt and if the crystal grower could operate the process to stay within the stability boundary, then striation-free material should be obtained. Energy theory is integral, or global in nature, defining stability in terms of the asymptotic decay of a disturbances-energy functional. Hence it provides good results in case where the mechanism responsible for the instability is of a similar global character.

Numerical Simulation of the Basic Flow Field

In order to perform energy stability analysis, the initial flow state must be determined first. To be related to available experiment results, a half-zone model of the float zones is adopted in this study. The flow domain in an actual half model experiment is very complicated. Figure 3 illustrates the simplified geometric and thermal conditions used in a half-zone model simulation. The basic state of interest is one of swirl-free, axisymmetric thermocapillary convection in a zone with aspect ratio of approximately 1. The momentum and energy equations of fluid flow have been solved numerically with certain assumptions, including nondeformable free-surface and flat interfaces between solid and liquid. The streamlines and isothermal (equal temperature) lines of a basic state in half-zone model are plotted in figure 4.

Energy-Stability Analysis

The energy-stability analysis begins with decomposing flow quantities, velocity, pressure and temperature, into two parts, basic state and disturbances:

$$Q = Q_{basic} + Q'$$

Substitution of the above expression into the governing Navier-Stokes equations and appropriate boundary conditions leads to a system of equations for the disturbance quantity Q'. The non linear disturbance-energy equation is derived from this set of equations. The basic state quantity Q_{basic} is coupled with Q' in this equation which has the following form:

$$\frac{dE}{dt} = -Pr * D + Ma * P + B$$

where the left-hand side is the change rate of the disturbance energy, Pr is a non-dimensional fluid property (Prandtl number); D is a "damping" term; and P is the "production" term; and B is the boundary-condition dependent term. All the terms are integrals of Q_{basic} and Q' over the flow domain. The dominant parameter is Ma. Ma_E is the value of Marangoni number under which the rate of energy change will always be negative, making the disturbances die away as time goes on. Therefore Ma_E is called the energy stability limit. As shown by the above equation, Ma_E depends on fluid parameter Pr and boundary conditions, among other factors. The equation has been solved numerically using a variational method, aided by an inverse-iteration technique for large sparse matrices. The solution was carried out on an IBM 3090 machine. Several assumptions were made in the solution process. One of them was that the disturbance to the flow was axisymmetric. This assumption allows the equations to be real, not complex, thus reducing the computer storage requirement. Another assumption was the nondeformable free surface, which reduced the number of equations to be solved as a coupled system. The results are compared with the experiment data and figure 5 shows the comparison. One notion here is that the experiment was performed using sodium nitrate fluid rather than silicon crystal. This is due to the fact that the molten silicon is an opaque medium and flow visualization is very difficult. The main difference between the two fluids, besides their visibility, is the Prandtl number. The Pr number of silicon is in the order of 0.01 and for sodium nitrate, it is roughly 7. The numerical results are obtained based as closely as possible on simulated experiment settings.

Conclusions and Discussion

There has been a large amount of analytic and numerical work on various aspects of thermocapillary convection. Most of the work provides examples of basic states. A Handful of stability analyses published were on simple flows with analytically defined basic state. The above energy-stability analysis is one of the first stability analysis using numerically determined basic states. Although it is limited by several assumptions because of the available computational resources, the results indicated two important things: (1) energy theory was capable of yielding sufficient conditions for stability of the right order of magnitude; and (2) the more difficult computations are needed to simulate the real flow.

Some follow-up extension work was done after the above study. One of these (ref. 3) has relaxed the assumptions about the disturbances, which improved the agreement with relevant experiment data. Another work in the field (ref. 4) included linear-stability analysis, which complements the results of energy-stability analysis. The combination of the linear limits and energy limit should provide an envelope of desired operating conditions under which the crystal should grow striation-free. However, the current agreement between the theoretic results and experimental data is not completely satisfactory because of the simplifications used in the numerical calculation. Possible steps for future research are: (1) take the influence of free-surface deformation into consideration; (2) modify the inadequacy in the half-zone model; and (3) model the full float-zone instead of the half-zone.

The results of stability analysis on a half-zone model of crystal growth process provided the insight on thermocapillary convection in melting crystals. Since the convection will be the dominant flow mode in microgravity environment, this type of study can be viewed as crucial for any space-based material processing to be successful.

Acknowledgments

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Biography

Yonghong Shen was born in China on Feb. 11, 1958. Shen completed her Undergraduate education, majored in Engineering, in 1982. After short period of working as teaching assistant at a university, she won a scholarship to continue graduate study at Stanford University. She obtained her Masters Degree in Mechanical Engineering in 1983. She then worked in various research and development institutes at Arizona and Illinois. In 1990, She came back to California to have a family. She joined Bentley Engineering Company in February of 1992, and worked on pressure system recertification (Code EEF, MS N213-8, Ext. 4-3035) since then. She is an associate member of American Society of Mechanical Engineers.

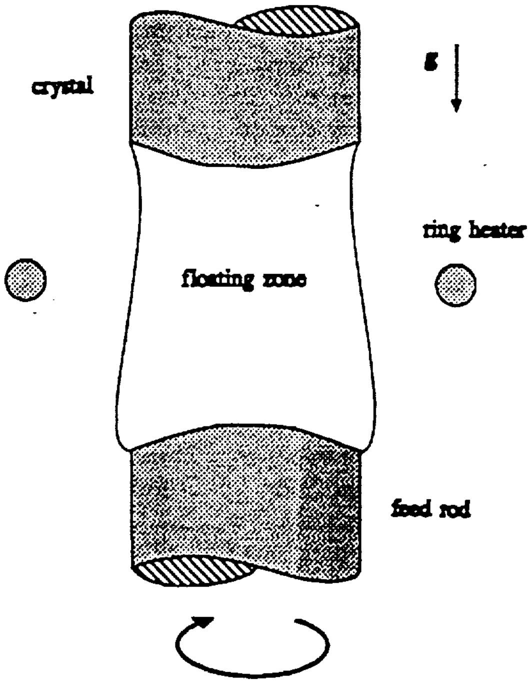

Figure 1. Schematic of the float-zone crystal-growth process

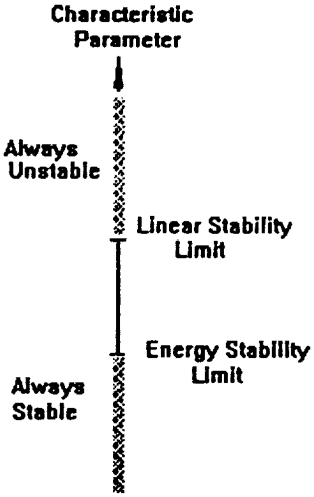

Figure 2. Stability map, showing the boundaries determined using energy and linear theories.

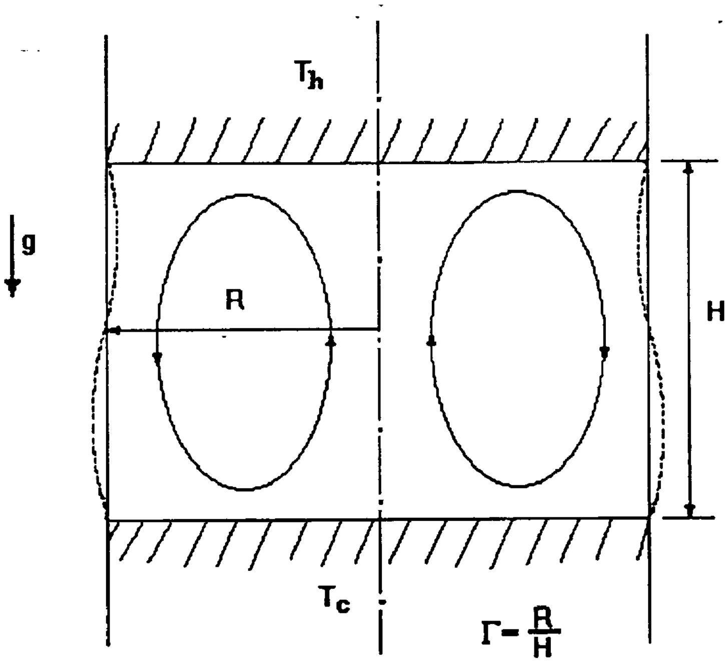

Figure 3. The half-zone model, showing geometric and thermal conditions.

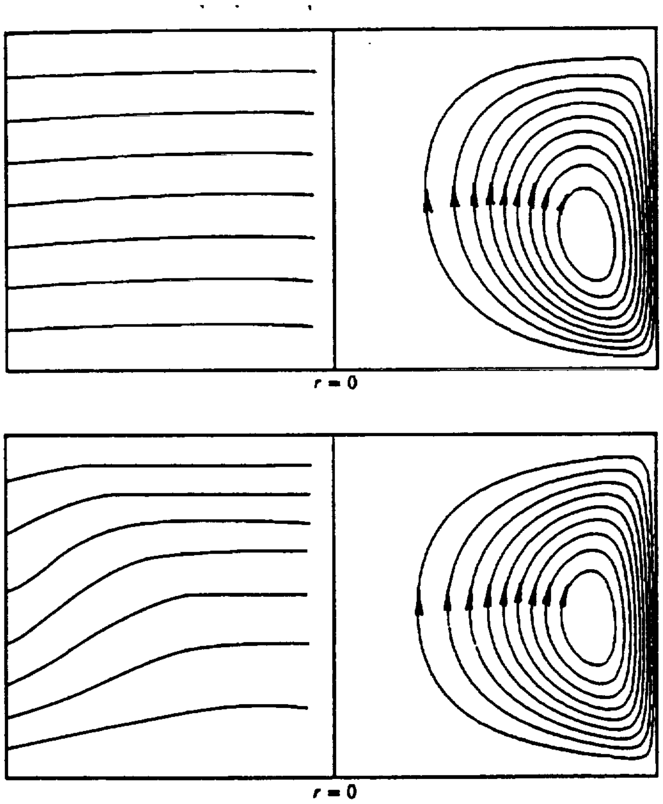

Figure 4. Sample basic-state isothermals and streamlines for aspect ratio G=1, Ma=100, and (a) Pr=0.01 and (b) Pr = 10.

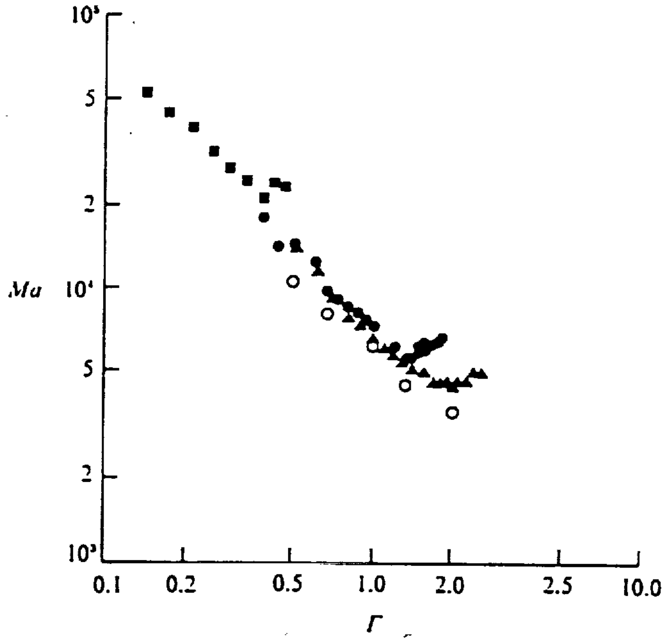

Figure 5. Comparison between result of present computation and model experiment (ref. 1) for various aspect ratios. Present: ○, Experiment: ▲ (radius=2mm), ● (3mm), ■ (10mm).

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GROUND VIBRATION TEST OF THE XV-15 TILTROTOR RESEARCH AIRCRAFT AND PRETEST PREDICTIONS

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Summary

The first comprehensive ground vibration survey was performed on the XV-15 Tiltrotor Research Aircraft to measure the vibration modes of the airframe and to provide data critical for determining whirl flutter stability margins. The aircraft was suspended by the wings with bungee cords and cables. A NASTRAN finite element model was used in the design of the suspension system to minimize its interference with the wing modes. The primary objective of the test was to measure the dynamic characteristics of the wings and pylons for aeroelastic stability analysis. In addition, over 130 accelerometers were placed on the airframe to characterize the fuselage, wing, and tail vibration. Pretest predictions were made with the NASTRAN model as well as correlations with the test data. The results showed that the suspension system provided good isolation necessary for modal measurements.

Introduction

This report documents the results of a ground vibration test of the XV-15 Tiltrotor Research Aircraft. The focus of the test was to acquire vibration data at the rotor hubs. In addition, the vibration of the fuselage was measured to characterize the complete aircraft dynamics.

Figure 1 shows the XV-15 Tiltrotor in flight in the airplane mode, steel-bladed configuration. This aircraft combines the hovering capability of a helicopter and the forward flight speed of an airplane. The XV-15 takes off in helicopter mode with the rotors tilted up. Then the pylons and rotors tilt down during flight to the airplane mode shown in figure 1. It is this airplane mode configuration in which whirl flutter instabilities are predicted to occur (ref. 1). The data acquired during the ground vibration test will be used to improve predictions of aeroelastic stability of the XV-15. The steel-bladed configuration was studied the most closely because the majority of documented XV-15 flight data was acquired with this blade set and can be used to validate stability predictions (refs. 1 and 2). A greater understanding of the instabilities unique to tiltrotors is important in the development of advanced high-speed tiltrotors (refs. 3–5).

In order to measure the vibration modes of the XV-15, a ground vibration test was conducted in January and February of 1992 at NASA Ames Research Center. Figure 2 shows the test setup. The aircraft was tested in both helicopter and airplane modes. In addition, measurements were taken for both steel and composite rotor configurations (simulated by dummy blade weights). This paper documents the results for the baseline configuration: the XV-15 in airplane mode with steel rotor blades.

Ideally, the aircraft should be in a free-free configuration which means that there are no constraints such as resting the aircraft on its landing gear. This was accomplished by suspending the XV-15 from the wings using bungee cords. The suspension system successfully isolated the aircraft, enabling the wings to move freely with minimal interference to the aircraft dynamics.

This test was the first comprehensive ground vibration test of the XV-15. An exploratory test was performed by Bell Helicopter Textron, Inc. in 1978 (ref. 6). However, the aircraft did not contain fuel or have complete pylons and transmissions. Another test was performed at NASA Ames Research Center in 1988. This test provided only a rough measurement of the XV-15 frequencies with the aircraft resting on jacks.

A NASTRAN finite element computer model of the XV-15 was used to predict the effectiveness of the suspension system in isolating the aircraft (ref. 7). The model was modified from a free-free configuration to predict the XV-15 vibration modes and also to determine the effect of the test setup on the results. In particular, the effects of the suspension system, dummy blade weights, and gravity were studied.

Ground Vibration Test

The purpose of the ground vibration test, or shake test, of the XV-15 was to experimentally characterize the structural dynamics of the aircraft. The XV-15 was tested in the helicopter mode with pylons tilted up and also in

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airplane mode with pylons tilted down. In addition, the XV-15 was tested with both steel and composite rotor blade weights.

The aircraft was configured to simulate in-flight conditions. It was fully fueled with 1500 lb of fuel and 180-lb weights were strapped in the pilot and copilot seats. Dummy blade weights replaced the rotors so that the rotor blades would not be damaged during the test. These weights are shown in figure 3 as three groups of steel plates offset 13.5 in. from the hub. They were placed as closely as possible to the hub so that they would add a minimal amount of rotational inertia to the pylons. This was important to match the assumption of aeroelastic analyses which model the rotor weight as a point mass located at the hub's center.

In order to model the free-free condition of zero airspeed flight, the aircraft was suspended with bungee cords. The suspension prevented the XV-15 from resting on the landing gear which would alter the test results. However, the landing gear were extended down as a safety precaution.

The suspension system consisted of an inverted-V system which lifted the aircraft from its wings by a crane 35 feet above the floor (fig. 2). The suspension was attached to the wings 6.8 ft from the centerline at locations designed for lifting the aircraft. Cables and turnbuckles comprised the lower 19 feet of the inverted-V. The turnbuckles allowed for adjustments in length to balance the aircraft left to right. Above the cables, bungee cords stretched to the top of the inverted-V. A total of 40 bungee loops were used, 20 per side, as shown in figure 4. They looped around upper and lower brackets stretching from 4 feet unloaded to 8 feet under the weight of the 14,100-lb aircraft.

The advantage of using bungee cords was that their low spring rate enabled the XV-15 wings to vibrate freely under the support. The combined stiffness of all forty bungee loops was 457 lb/in. which was well below the aircraft stiffness. In order to balance the XV-15 fore and aft, a bungee cord loop with a stiffness of 45 lb/in. stretched from the tail down to the ground.

To measure the vibration of the XV-15, 134 accelerometers were placed on the fuselage, tail, wings, and pylons. They measured acceleration in the vertical, longitudinal, and lateral directions. The most important accelerometers were located at each hub because hub dynamics are a key factor in determining aeroelastic stability. At these locations, rotational as well as linear accelerometers were used. The aircraft was excited using two electrodynamic shakers which applied force at the wing tips.

Figure 3 shows a shaker mounted on a stand applying a vertical force to the wing. The shaker was attached to the wing with a thin metal rod, or stinger, which applied the axial force. This vertical shaker configuration excited wing flapping and torsion modes. The shaker was also positioned to apply a horizontal force to excite in-plane, or chordwise, wing bending modes.

Two types of forcing methods were used. The first was a swept-sine method in which each shaker applied approximately 90 pounds of force sweeping in frequency from 2 to 40 Hz. The shakers could be made to act either in-phase or out-of-phase with each other to excite symmetric and antisymmetric modes, respectively. The second method used was random excitation from 0 to 37.5 Hz. This method used a lower force level and excited both symmetric and antisymmetric modes simultaneously.

The data acquisition system consisted of a Hewlett-Packard 3565S dynamic analyzer that used Vista software to acquire data (ref. 8). Signals from each of the 134 accelerometers and 2 load cells measuring shaker force were input to the analyzer. The Vista program then computed frequency response functions which provided the frequency and damping of the vibration modes.

Pretest Predictions

The NASTRAN finite element computer model of the XV-15 was used to determine the optimum suspension system configuration and ensure that the suspension modes were not coupled with aircraft modes. The model was also used to predict the XV-15 vibration modes before the ground vibration test began.

The NASTRAN model is shown in figure 5. The actual model is 1036 degrees of freedom and is a half-model taking advantage of the symmetry of the XV-15 about the longitudinal axis. The model was originally created by Bell Helicopter Textron, Inc. in the 1970s to predict free-free modes and frequencies of the XV-15. Modifications were made to this model to better simulate the shake test setup. The additions include the inverted-V suspension system, tail bungee, dummy blade weights, and gravity.

The major components of the suspension system were modeled to predict their impact on the overall system dynamics. The crane hook and cables were modeled using rigid beam elements. The bungee cords were modeled using an element with an axial stiffness of 228 lb/in. equal to the bungee stiffness on the left and right sides of the inverted-V. Weights for the suspension components were distributed onto each node point of the suspension model. The upper and lower brackets were 70 and 30 lb, respectively. The total bungee cord weight was 22 lb, and the combined weight of the cables, turnbuckles and wing hoist attachment was 80 lb on the left and right sides. The weight above the bungee (upper bracket and crane hook) was isolated from the aircraft due to the flexibility of the bungees. However, the weight below the bungees was effectively added to the system dynamics. For this reason, the suspension weight was minimized to prevent alterations to the modes.

The suspension configuration was determined using the NASTRAN model by minimizing the deviation from the free-free modes. It was found that the highest possible inverted-V should be used to minimize lateral forces acting at the wing attachment points. This also allowed the bungees to attach nearly perpendicularly to the XV-15 wings.

The dummy blade weights were modeled as three point masses representing the three steel blades weighing 181 lb each. The blade weights were modeled with an offset of 13.5 in. from the hub as shown in figure 5. This offset matches the distance of the blade weights from the hub in the shake test. The tail bungee, which opposed the nose-down moment of the aircraft, was modeled with a spring element with a stiffness of 45.5 lb/in., also matching the ground vibration test configuration.

Table 1 shows the NASTRAN results for the symmetric and antisymmetric mode shapes for the XV-15 configured in the airplane mode with steel rotor blades. The first column shows the free-free results, which is the baseline case. The second column shows the change in frequency when the suspension system and tail bungee were added. The third column includes the blade weights offset from the hub as compared with a single point mass at the hub. The modes in this last column which include the combined effects of the test setup, were used as a pretest prediction for the ground vibration test. The effect of gravity on the modes was negligible.

Table 1. The symmetric and antisymmetric NASTRAN modes showing the effects of the suspension system and dummy blade weights

Symmetric and antisymmetric modes (Hz)	Free-free XV-15	XV-15 with suspension	XV-15 with suspension and blade weights
Sym. wing flap	3.16	3.06	3.06
Sym. wing chord	5.71	5.55	5.54
Asy. wing flap	6.35	6.31	6.29
Asy. wing chord	7.52	7.10	7.04
Asy. wing torsion	8.13	7.84	7.81
Sym. wing torsion	8.20	7.81	7.73

A comparison of the first two columns in table 1 shows that the suspension system lowers the frequencies from the free-free model. The modes decreased an average of 2.4%. This decrease is due primarily to the added weight of the suspension system and in part to the physical interference of hanging the aircraft from its wings. This was determined by successive design iterations using the NASTRAN model. By comparing columns 2 and 3 it can be seen that the dummy blade weights had a smaller impact on the modes. They caused the frequencies to decrease an average of 1%. These blade weights affected the wing modes as a result of the rotational inertia transferred through the hub.

The support system also introduced low frequency suspension modes in which the XV-15 moves as a rigid body under the flexing of the bungee cords.

The highest frequency suspension mode predicted was 0.96 Hz which was well below the first bending mode of 3.06 Hz. This separation of the suspension modes from the aircraft dynamics was necessary to prevent coupling of the motion and an alteration of the XV-15 dynamics.

Figure 6 illustrates the motion of two modes predicted by the NASTRAN model. The dashed lines represent the mode shapes, whereas the solid lines are the undeflected model. The first is the 0.96 Hz suspension mode which couples a vertical bob of the aircraft with a pitching motion. The first symmetric wing bending mode is also shown. The XV-15 wings are able to vibrate unhindered by the support.

Test Results and Correlation With Predictions

Test results were obtained for both the swept-sine and random excitation methods. The Vista software was used to calculate the frequency response function shown in figure 7, which resulted from a random applied load in the vertical direction from 0 to 12.5 Hz. Each peak represents a vibration mode of the system. The Vista program is used to curve fit each peak and estimate the frequency and damping of each mode. For example, the symmetric wing chordwise bending and torsion modes are identified in figure 7.

A more complete listing of the symmetric and antisymmetric modes are shown in table 2. Here the test data obtained from the swept-sine and random methods are compared with the NASTRAN predictions. Both sets of measured results are higher than the predictions. The swept-sine results are an average of 9% higher whereas the random results are 11% higher than the NASTRAN frequencies. Despite this, the NASTRAN modes were a key means of mode identification and were used for comparison with test data. There was an antisymmetric mode at 5.9 Hz which the NASTRAN model did not predict. This was a faint mode combining lateral tail bending with antisymmetric pylon yaw. In addition, a small symmetric pylon yaw mode at 7.6 Hz was not predicted. However, the NASTRAN finite element model did predict all of the major modes shown in table 2.

It was expected that the XV-15 would exhibit nonlinearities in its structural dynamics. Tiltrotors are in general more nonlinear than airplanes due to the complexities of the wing pylon structure. Table 3 illustrates this nonlinearity by comparing the change in frequency for different force levels. A linear system should exhibit the same frequency despite changing the force applied by the shaker. However, as shown in the figure, the modes increase in frequency as the shaker force is increased.

Table 2. Correlation of test data with NASTRAN predictions. Dashed line indicates a mode not excited

Symmetric and antisymmetric modes (Hz)	NASTRAN model	Test data, swept-sine excitation	Test data, random excitation
Sym. wing flap	3.06	3.43	3.51
Sym. wing chord	5.54	6.41	6.71
Asy. pylon yaw	–	5.87	5.91
Asy. wing flap	6.29	7.47	–
Sym. pylon yaw	–	7.57	7.56
Asy. wing chord	7.04	7.99	–
Asy. wing torsion	7.81	8.31	8.59
Sym. wing torsion	7.73	8.22	8.37

Table 3. Comparison of modal frequencies with varying shaker force. Dashed line indicates a mode not excited

Symmetric and antisymmetric modes (Hz)	Swept-sine, full amplitude	Swept-sine, half-amplitude	Random excitation
Sym. wing flap	3.43	3.45	3.51
Sym. wing chord	6.41	6.70	6.71
Asy. wing flap	7.47	7.52	–
Asy. wing torsion	8.22	8.34	8.37
Sym. wing torsion	8.31	8.43	8.59

The forcing levels were 90 lb for the swept-sine full amplitude, 45 lb for the half-amplitude, and a lower random force for the random force. The differences between the full amplitude swept-sine and the random frequencies was an average of 3%, signifying a fair degree of system nonlinearity. It was for this reason that both swept-sine and random methods were used.

Conclusions

The shake test was a valuable means for determining the structural dynamic characteristics of the XV-15. Previous to this test, the estimated modal frequencies used to determine aeroelastic instabilities were lower than the true XV-15 dynamics. Now the actual modal frequencies measured in the ground vibration test will be used for further stability research. Although the NASTRAN predictions were an average of 9 and 11% lower than the swept-sine and random data, respectively, the finite element model was a valuable tool in modal identification. The major importance of the NASTRAN model was its use as design tool to study the effects of suspension system changes.

The modifications to the NASTRAN finite element model led to a better design of the suspension system. The model was also used to understand the effects of the test setup on the ideal, free-free configuration. The model predicted the effects of the dummy blade weights offset from the hub's center to be minimal. The offsets caused the frequencies to decrease an average of 1%. Moreover, the effect of gravity was negligible.

It was found that the suspension system used in the test gave a good approximation to the ideal, free-free configuration. The bungee cords effectively isolated the aircraft modes from suspension modes that were well below the first wing bending frequency. The inverted-V suspension system and tail bungee were predicted by NASTRAN to lower the frequencies an average of 2.4% from the free-free case. This change is attributed primarily to the weight of the cables and brackets above the wing rather than the bungee cords or suspension modes. However, the change due to the suspension is much less than that due to resting the XV-15 on its landing gear. Also, the degree of interference from the suspension was acceptable, given the system nonlinearity of the XV-15. This was illustrated by the average 3% difference between swept-sine and random forcing methods.

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Biographies

Karen Studebaker has worked for four years as an Aerospace Engineer at NASA Ames Research Center in Moffett Field, California. She works on research related to advanced, civil tiltrotor concepts as well as conventional helicopters. She received a B.A. in Physics from Colgate University in 1986 and an M.S. in Aerospace Engineering from Virginia Tech in 1988.

Anita Abrego is a senior at the University of Washington in Seattle completing a B.S. in Aeronautical Engineering. She works as a NASA Coop Student at NASA Ames Research Center in Moffett Field.

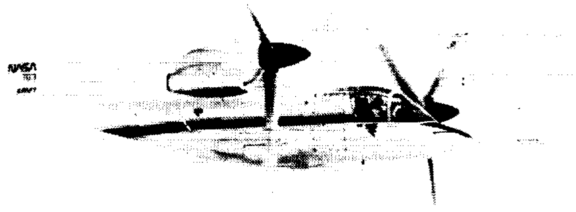


Figure 1. XV-15 Tiltrotor Research Aircraft in airplane mode with steel-bladed rotors.

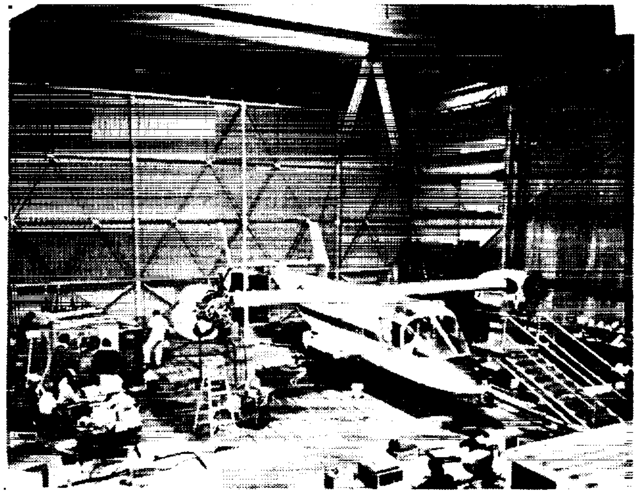


Figure 2. The XV-15 ground vibration test setup.

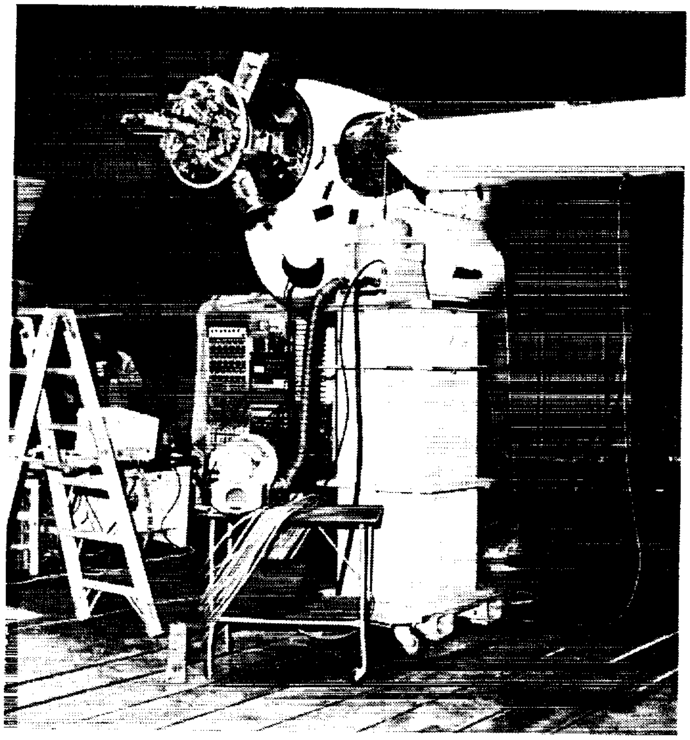


Figure 3. XV-15 hub showing the dummy blade weights and the electrodynamic shaker applying vertical force to the wing.

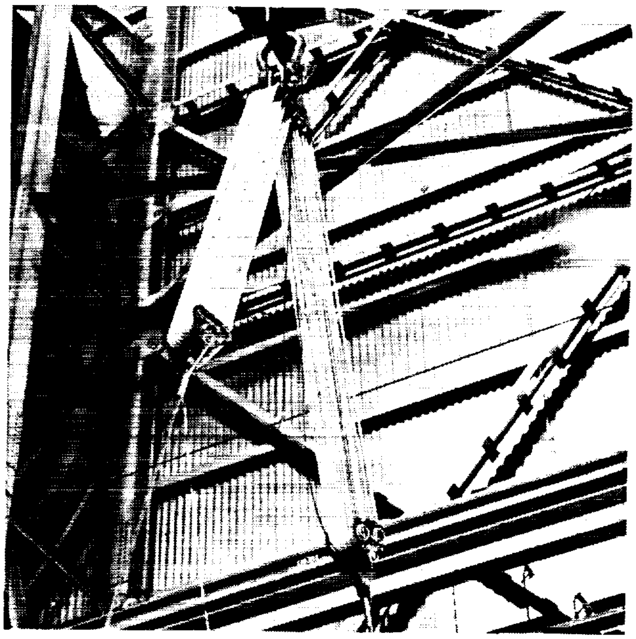


Figure 4. The 40 bungee loops which isolated the suspension system from the aircraft dynamics.

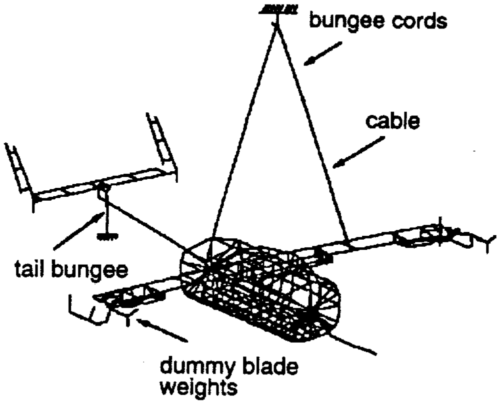
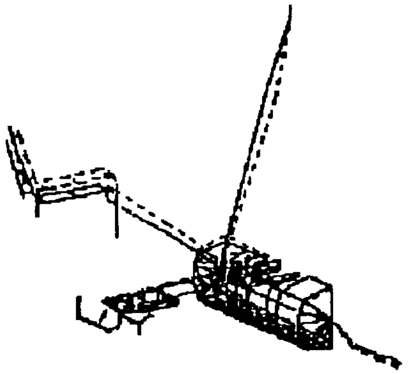
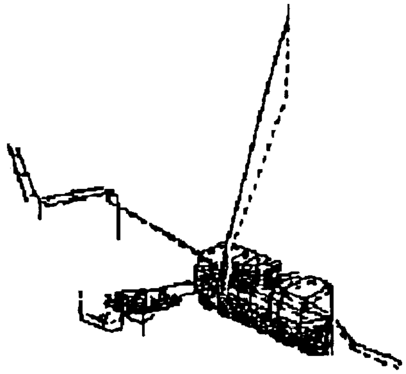


Figure 5. The NASTRAN finite element model of the XV-15.



Pitch rigid body mode, 0.96 Hz



Symmetric flapwise wing bending, 3.06 Hz

Figure 6. Two mode shapes predicted by NASTRAN.

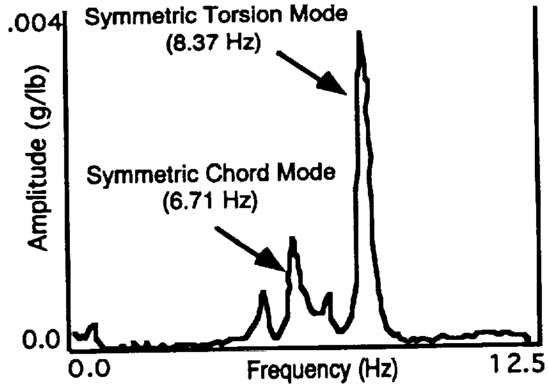


Figure 7. Frequency response function from random, vertical excitation.

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BUILDING ON THE FOUNDATION FOR AN ENGINEERING CAREER

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Summary

A predictable and preventable hurdle stops a majority of young women from entering the scientific and technical fields. This cuts down the individual's career possibilities, and cuts in half the pool of potential U.S. engineers later available to industry. The waste of talent does not advance our country's competitive position.

The typical American adolescent girl has acquired all the basic mathematical skills needed to pursue science and math, but, from adolescence on, she does not build the foundation of science and math courses that she would need later in life to work in engineering.

Several questions are addressed: Why are some young women stopped cold in their mathematical tracks during adolescence? What is the influence of psychology, including discussion of the personality traits quantifiably shared by women in technical fields? How should the school system adapt to keep their female charges learning math and science?

Introduction

Several recent studies indicate a disturbing possibility that young women are typically stopped cold in their mathematical tracks during adolescence. The typical adolescent girl does not build the foundation of science and math courses that she will need later in life to work in engineering. This has the end result of limiting the number of young women who are later able to work in the scientific and technical fields.

Before adolescence, many different articles (refs. 1 and 2) have discussed studies showing girls competing equally with or out-performing boys in the fields of study most important to the technical professions: mathematics and science. However, after girls reach adolescence, their average performance and participation in these fields drops significantly.

The effect persists to the highest levels of education. The National Research Council (ref. 3) regularly surveys Ph.D. scientists and engineers in the United States. In their highlights from the 1989 survey, they reported that among doctoral scientists and engineers, the proportion of women grew from 8.6 percent in 1973 to 17.3 percent in 1989. Women represented approximately one-third of the Ph.D.'s in psychology and the medical sciences, but less than 5 percent of the Ph.D.'s in engineering. Women are going on to higher education, increasing both in numbers and percentages, but they are apparently avoiding engineering.

One explosive new study (ref. 4) states bluntly that schools are shortchanging girls. Recent studies have shown that during adolescence, girls suffer a significant drop in self-esteem, which affects their performance. Other studies have shown (ref. 5) that women in technical fields share certain personality traits. Are these the same traits that helped these individuals avoid or survive a drop in self-esteem and performance experienced by the average adolescent girl? How can the school system change to keep these students performing in math and science during this phase of their lives? Studies suggest an emphasis on cooperation and problem solving (ref. 6) rather than competition does reduce alienation of these students. In addition, science and math events tailored to girls (ref. 7) appear to convince them that science and math are fundamental to many careers.

Physical changes accompanying adolescence are probably no more difficult for girls than for boys, because radical physical changes take place in all adolescents. There is no evidence of a significant difference in overall mental capabilities, although intriguing differences in some components of mathematical thought, such as pattern recognition and spatial resolution, have been uncovered. The societal forces appear to simply be harsher on girls, and to be responsible for the adverse changes in mathematical performance.

Why do the majority of adolescent girls appear to lose interest in mathematics? Why are other students unimpeded, as is proved by the growing representation of women in the technical fields?

Regardless of the causes, it is important to take steps to help adolescent girls get past this predictable hurdle in their lives. It is important to keep girls involved in learning mathematics and science to keep their future options

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open. After a brief overview of current developmental theory, the results of recent studies are summarized in the following sections. Proposed solutions are repeated in the summary.

Background: Psychological Framework

A condensed outline of current psychological developmental theory is sketched out below to provide a framework for discussion of adolescence and pre-adolescence.

The personality is defined by psychiatrists as the sum total of all an individual's experience, because it is believed that every event that happens to a person has an impact on their personality (ref. 10). There are three main schools of thought on development of the personality:

- heredity vs. environment
- mechanistic vs. organismic
- critical periods

The heredity vs. environment theory refers to the well-known nature vs. nurture issue. The mechanistic vs. organismic theory argues that a person is either like a mechanism, rigid and unchangeably responding to events in life, or more like an organism, evolving and flexibly changing when necessary. The critical period theory asserts that a person is staged to learn and evolve only at certain critical times in life. The critical period theory is the cornerstone of Erickson's "eight stages of man" model, which is almost universally accepted today. For this reason, it is discussed below.

Erickson's eight stages of psychosocial development (ref. 8) are shown in table 1. Erickson's framework for development covers a model for development over the individual's entire life. Few age limits are shown in the table, because each person has a different maturation rate. Psychiatrists believe that most individuals do not progress through all stages completely. The stages of life relevant to this discussion are latency and adolescence.

Latency is the period of life from ages 6 to 12 for most people. This is a joyous time for children, as they are expanding their horizons and grasping new concepts. Their attention is easily engaged, and they repeatedly experience a sense of mastery over new skills . In grades 1 to 7, they learn to read, to write, to solve problems in mathematics, to ride a bike, etc. The crisis of latency is the clash between the active industry of learning and the developing feeling of inferiority. For the first time they are cognitively aware of shortcomings in themselves. Self-doubt, possibly even shame, over one's self or family now comes to the forefront of consciousness. Positive role modeling can have a significant impact here, before the child becomes a teenager. The most important relationships center around the school and the neighborhood.

Adolescence is the next period of life. Because this stage is so variable for different people, Erickson provides no age delimiters. The central crisis at this stage of life is that of ego identity versus role confusion. The ego identity or sense of self is strong, and children want to be treated more as individuals. Freedom, independence and the right to choose one's own friends, clothes, or books become important to them. This is when children start to question authority, in particular, their parents. They mentally put a distance between themselves and their families, and want their friends to replace their parents as the center of their social lives. This is the time when children are "launched" into the world. Role confusion refers to the sorting of sexuality and of where they fit in the world. They already know where they fit in their families. This stage can be very painful for some children. They feel a strong need to be in agreement with their peers, rather than conforming to their parents. The leadership models at this stage are usually an idealized teacher, a rock star or movie star, or the most popular and attractive child at school. The smartest adolescents never appear to be idealized by their peers.

Erickson's theory asserts that the social clues and cues are different for the two genders as they grow. The media, role models, books, schools, parents and relatives all send out subtle, or not so subtle, messages about what is expected of a person.

Children absorb new information and messages constantly. According to Piaget (ref. 9), it is the job, or the life's work, of children to develop the ability to measure things out, to delay gratification with some degree of stability and internalized control, and to be able to understand and conceptualize differences. Piaget did widely accepted work on how children organize information, how they take in new concepts and information and gradually learn to apply it to the environment. They are constantly adjusting their ideas, synthesizing new information and using the new synthesis in new applications.

Piaget gave an example to illustrate the changes in the child's process of thought. Witnessing a one-gallon container of water being poured into a tall, narrow, empty container, a younger child will insist that the tall container holds more fluid, because it is so much taller. An older child understands that the two containers hold the same amount of fluid, because the child saw that all the water came from the one gallon container.

Adolescence is an important time in life. According to English and Finch (ref. 10), an adolescent has several jobs at this stage of life.

- to attain emancipation from the parents
- to choose a vocation
- to accept their sexual identity and goals
- to integrate their personality in the direction of altruistic goals
- for girls: to make the difficult choice between a career, homemaking, or only recently, a balance of both career and homemaking.

Regardless of psychiatric theory, most girls do not choose a vocation at this stage of life. There are two probable causes. First, the marriage-versus-career choice may consume so much of their energy that they are unable to focus beyond that conflict, although many girls try to deny the existence of the conflict entirely. Second, girls are not forced or encouraged to choose a vocation by the adults in their lives, their parents and counselors.

In summary, theories of psychological development provide a framework for understanding the changes and conflicts confronting the adolescent girl.

Non-traditional Women?

In her study and overview of the literature on women in male-dominated professions, Ashburn (ref. 5) reported that

> "those women who have entered the top professional fields have had to have extraordinary motivation, thick skins, exceptional ability, and some unusual pattern of socialization in order to reach their occupational destinations. Intelligence and education are apparently not sufficient conditions to predict professional achievement."

Asburn painted a stark picture in the 1977 work. The stereotype existed in the popular literature of the professional women as the masculine, dominating, aggressive, insensitive, probably less-than-competent woman in a man's world.

This stereotype was not affirmed by statistical analysis of available surveys and personality inventories, which portrayed a positive image of actual professional women. The personalities of women in non-traditional occupations exhibited four main focal points: independence, intelligence, feelings and ego-strength. They were more independent and inner-directed than the average, they were not as sociable, and they were more radical and adventurous. Presumably because they are a minority both among women and among professionals, they had less ego-strength and were less self-assured. Like all women, women scientists had been trained to be supportive of others, to listen, to stroke. Ashburn remarked that these behaviors were probably incompatible with aggressive professionalism and ego-strength. In a typical finding, female and male medical students were equally intelligent, effective, aggressive, etc., but the women placed more importance on relationships, were more accepting of feelings, and more alert to moral and ethical issues.

Psychiatrists attempting to explain and categorize women making non-traditional career choices have produced two theories: the "deviance" hypothesis and the "enrichment" hypothesis. The "deviance" hypothesis asserts that such women are deviants from traditional middle America, in what appears to be a tautology. The "enrichment" hypothesis asserted that women who chose nontraditional work have been exposed to more alternatives and recognize a greater variety of options for women, often by contact with a different culture or a variety of jobs. Ashburn cited quantitative evidence for the enrichment hypothesis.

Things have changed to a large extent since large numbers of women returned to the work force outside the home. Women don't have time to "think pink" anymore. Up to the 1960s, gender differences had more cultural relevance than today, and they determined a person's role in life to a greater extent.

In summary, analysis of personality surveys of women scientists showed an unusual constellation of personality traits and experiences. These traits may have been necessary for these women to survive the school system and embark on scientific careers.

The Impact of the School

For the AAUW report, Bailey (ref. 4) surveyed a large body of recent statistical studies on the effect of the school system on female students. Bower (ref. 1) and Brush (ref. 11) recently summarized this and other related work for a wider audience. One statistical study indicated that girls suffer from a large drop in self-esteem when they become teenagers. Girls also expressed less interest in professional careers, less interest in math and science, and less confidence in themselves than did boys. The students with higher self-esteem liked science and math more than the average student in the study.

The effect on self-esteem was measured by surveying 2400 girls and 600 boys, aged 9 to 16. One fourth of the students were Black or Hispanic. The students were from 36 schools spread across the United States. The survey included questions about a student's sense of well-being, if they liked themselves, etc. The study reported sharp drops in self-esteem as the students began junior high school for both sexes, but that the number of girls who were unhappy with themselves was greater, and the loss of self-esteem was worse in girls.

Girls rarely play with boys after age 5. However, girls and boys do compete in the classroom. Scholastics is the only area that the two groups interact or compete in. Girls and boys act and learn in different ways, but coeducational schools tailor their instructional methods to the learning style of boys (ref. 1), emphasizing, for example, competition. This has the result of causing girls to doubt their academic abilities.

Coeducation itself appeared to have a detrimental effect on the girls learning. Gilligan (ref. 6) showed that small mixed-sex groups have been shown to have an adverse effect on girl's learning. Girls who said they did poorly in math and science blamed themselves, but boys who said they were unsuccessful in math and science blamed the subject itself, saying they thought it was useless.

Ashburn (ref. 5) proposed an interesting new perspective on the value and significance of competitive drive, citing studies on the motivations of scientists. Almost 40% of the men but only 25% of the women gave the "publish or perish" or the competitive atmosphere of their institutions as a strong motivation, whereas 75% of the women and almost half of the men cited "fascination with the problem" or a preference for research as a reason. Also, considering recent scandals among scientists, the value of competitiveness must be questioned. A competitive environment has been repeatedly shown (ref. 2) to discourage girls, and a cooperative environment has been shown to encourage girls. Gilligan (ref. 6) reported that girls generally learn best and had the greatest self-confidence working in collaboration with other students and teachers, rather than in competitive situations. Boys, on the other hand, did best on competitive tasks or in games with a strict set of rules.

Kimball (ref. 2) summarized a formidable body of academic literature, relying on statistical analyses of girls' performance in mathematics. The article focused on a significant, well-documented, but largely ignored finding: that girls receive better grades in math than boys, although boys do better on standardized test than girls, as has been much publicized.

Sex-correlated difference in mathematics performance on standardized tests appear in grades 8 or 9, and generally favor boys. Older studies or studies reflecting smaller sample sizes reported larger sex-related differences on standardized tests than do more recent studies. Meta-analysis indicates that this probably reflects recent improvements in girls' performance in mathematics, due to reduced stereotyping of math as a male domain and increases in the number of math classes girls currently take as opposed to reflecting a change in publication policy allowing studies showing small-magnitude effects to be published.

However, when mathematics grades are used to analyze differences in mathematical performance between girls and boys, the opposite trend is observed (ref. 2). Differences, when measurable, almost always favor girls, and this holds consistently across high school and college samples.

This is particularly surprising because many studies have shown that the classroom environment is less favorable to girls than to boys. Boys receive more of the teacher's attention, are more active in class, and receive more encouraging remarks.

To illustrate, in grade 2, boys had more academic contact with teachers, a difference that has been estimated amounting to 6 hours of instruction over one year. Studies of grades 5 to 9 found few overall differences, however, when math and sciences classes were separately studied, trends appeared correlating the students role-related expectancies with their performance. One surprising finding indicated that the students who received the most attention in these classes were high-achieving boys and the low-achieving girls. In high school classes for older students, consistent differences in treatment are still found. For example, girls received 84% of the discouraging comments and 30% of the encouraging comments.

Overall the classroom appeared to be an unfavorable and depriving environment (refs. 1 and 2) for girls when compared against boys' experiences.

This may account for the fact that girls are consistently less confident of their math abilities than boys. Mathematics may serve as a red flag to indicate a student's confidence level (ref. 2), because students with low confidence may tend to avoid math, where one is likely to make highly visible errors. Highly confident students may prefer math to more subjective verbal subjects, because in math the student is likely to be able to demonstrate, to objectively prove, her/his ability by the successful solution of a math problem.

That boys take more elective math courses than girls has been well-documented. In addition, studies have shown that boys have more experience outside the classroom related to science and math than do girls. However, the effect of enriching experiences with mathematics outside the classroom has not been well studied. One aspect of such extracurricular experience is toys. One study (ref. 2) of a group of girls in accelerated math and science classes documented that,

> "a commonly remembered experience was trouble convincing their parents to buy them toys such as Legos. In particular, chemistry sets had been much desired with little success unless they were only children, the oldest of several girls, or separated from their brothers by a large age span."

Specific studies are needed to relate the extent of extracurricular math experiences to mathematical or scientific achievement, to determine the significance, if any, of experience with mathematics or science outside the classroom.

Why do girls take fewer math classes than boys, given their higher grades? Kimball suggests that the girls' lesser extracurricular math and science experience, and a presumed rote approach to mathematics undermines their confidence and their motivation for pursuing math courses. Studies suggest that, even when they did very well in their current math classes, girls were more likely to believe this resulted from hard work than innate ability, so they did not regard this as proof that they would continue to excel in math. Sex-role conflict plays a role as well, in terms of discrimination, stereotyping, and downplaying of even a gifted girl's achievements in science or math. In addition, the conflict between motherhood and a demanding career may reduce a girl's interest in pursuing an engineering or scientific career.

Kimball recommended that good math grades earned by girls be taken seriously, by parents teachers, counselors, and the girls themselves. Grades are an important measure of achievement, and it is unclear why grades show an opposite trend of girls' and boys' abilities from that of standardized tests.

It is believed that good grades have not been used to help girls fulfill their potential, due to the low expectations for the girls' future held by the parents and other significant adults. Parents and teachers can be influenced, even by popular media reports, to take a girl's good grades seriously. This may in turn improve the girl's confidence and performance, and encourage her to take more math courses.

A recent article by Brush (ref. 11) probes why women are still under-represented in the sciences at this time, and proves that the early school and social environments are not solely responsible for the shortage of women in engineering and science. The obstacles of the college and work environment may even override earlier effects.

A great deal of effort has gone into recruiting women into technical fields, but not to keep women from dropping out. Furthermore, in light of the institutional barriers still in place, Brush suggests that individual women may in fact be even acting in their own better interest to drop out of these fields. This work summarized an extensive body of literature on the chilling effect of the college and the work environment on women's careers. The following have been quantitatively demonstrated or are strongly suspected to be effective obstacles to women's success in science and engineering: stereotypes of scientists, textbook stereotyping, publicity about older, dubious studies on women's supposed mathematical inferiority, bias in the Scholastic Aptitude Test, financial aid cutbacks, sexist and combative attitudes among students and scientists, and the glass ceiling. Brush's recommendations are included with other recommendations in the summary.

The current laws, books, and newspaper want ads, have either fundamentally or superficially reduced sexual stereotyping. On toys and in commercials, the "doers" still tend to be boys, with the girls depicted as "helpers". This is progress from the "helpless" image portrayed before the 1960s. In the 1978 edition of a well-known physics text, the earlier illustrations, all featuring males, were replaced with new illustrations, which could be construed as either male or female.

The large body of data on cognitive sex differences has been publicized and has a strong impact on popular thought, but objective examination shows dubious claims have been made. Brush shows that no significance can be attached, for example, to the differences in spatial perception abilities favoring boys for two main reasons: the effect is small, e.g., one-half of one standard deviation, and the effect is inconsistent with spatial ability measurements in cultures where this ability has some actual relevance in everyday life. In addition, recent studies have shown girls outperforming boys on a different component of mathematical thought, that of pattern recognition. Brush suggests publicizing the recent studies, to defuse the popular belief that it has been somehow scientifically proven that girls are "inferior" in math.

On the effects of the tenure and similar promotion systems, Brush points out that it is counterproductive to discourage women from entering science for fear of a temporary drop in productivity due to time spent caring for young children, and it is also counterproductive to discourage highly intelligent citizens who are scientists and engineers from having children.

Summary and Conclusion

The focus of this work is on fostering survival of the adolescent girl through the earlier school years without her getting sidetracked from the mathematical and scientific curriculum. Regardless of the environment awaiting her, it is impossible for her to enter the scientific and technical fields without the right educational background.

Specific remedies proposed include improving the school system's treatment of its female charges, emphasizing grades in counseling and scholarship decisions, de-emphasizing the SAT, publicizing recent research that refutes stereotypes on females' mathematical abilities, reducing the emphasis on competitiveness, funding long-term intervention programs for girls, and tearing down institutional barriers that conflict with family life.

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Table 1: Erickson's eight stages of psychosocial development

Stage/age	Conflict	Significant relations	Favorable outcome
Oral-sensory (0–12 mos.)	Trust versus mistrust	Primary caretaker	Trust and optimism
Muscular (12–36 mos.)	Autonomy versus shame	Parents	Self-assertion, self-control, feelings of adequacy
Locomotor (3–6 yrs.)	Initiative versus guilt	Family	Sense of initiative, purpose, direction
Latency (6–12 yrs.)	Industry versus inferiority	School, neighborhood	Productivity and competence in physical, intellectual and social skills
Adolescence	Identity versus role confusion	Peers, leader models	Integrated image of oneself as a unique person
Early adulthood	Intimacy versus isolation	Partners in friendship, sex, etc.	Ability to form close personal relationships and make career commitments
Middle adulthood	Generativity versus stagnation	Shared labor and household	Concern for future generations
Maturity	Integrity versus despair	"Mankind"	Sense of satisfaction with one's life; ability to face death without despair

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The NASA Ames Research Center Advisory Committee for Women (ACW) sponsored the second ACW Technical Paper Contest for Ames women in order to increase the visibility of, and to encourage writing for publication by Ames women scientists, engineers, and technicians. The topics of the contest papers mirrored in the topics of the 1993 Society of Women Engineers (SWE) National Convention, which included technological, workplace, global, and family issues.

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