STATUS AND FUTURE PLANS OF THE DRONES FOR AERODYNAMIC AND STRUCTURAL TESTING (DAST) PROGRAM

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ABSTRACT

This paper will review the past year's progress in the NASA DAST program. Emphasis will be given to presenting results from flight tests of the ARW-1 research wing. Preliminary loads data and experiences with the active control system for flutter suppression will be included along with comparative results of test and prediction for the flutter boundary of the supercritical research wing and on performance of the flutter suppression system. Status will be given of the ARW-2 research wing. Finally, future plans for a third research wing resulting from solicitation of recommendations from industry and recent study results will be presented.

CONTENTS

- BACKGROUND
- ARW-1 RESULTS TO DATE
- ARW-2 STATUS
- FUTURE PLANS

Figure 1

DAST OBJECTIVES

The DAST program objectives, which have not changed, will be reviewed. The concept of the DAST program is to provide a focus for evaluation and improvement of synthesis and analysis procedures for aerodynamic loads prediction and design of active control systems for load alleviation on wings with significant aeroelastic effects. Major challenges include applications to wings with supercritical airfoil, and tests emphasizing the transonic speed range. The program requires complete solutions to real-world problems since research wings are designed and flight tested. Because of the risky nature of the flight testing, especially with regard to flutter, target drone aircraft are modified for use as test bed aircraft and development of an appropriate test technique has been required. Principal flight vehicle modifications have included the flight control system, data acquisition system, and receiving and transmitting antennas. A test pilot controls the vehicle from a ground cockpit with appropriate displays and experimenters control the flutter system, command wing excitation with sweeps and pulses, and monitor flutter characteristics from a facility specially tailored for this task.

DRONES FOR AERODYNAMIC AND STRUCTURAL TESTING (DAST)

PROVIDE FLIGHT DATA FOR COMPARISON WITH ANALYSIS (AND FOR CASES WHERE ANALYSIS IS INADEQUATE)

DEVELOP TEST TECHNIQUE AND FLIGHT FACILITY FOR "RISKY" FREE FLIGHT TESTING

PRINCIPAL RESEARCH AREAS	EMPHASIS
AERODYNAMIC LOADS MEASUREMENT	TRANSONIC REGION
ACTIVE CONTROL SYSTEMS EVALUATIONS	AEROELASTIC EFFECTS
STRUCTURAL INVESTIGATIONS	
STABILITY AND PERFORMANCE STUDIES	

Figure 2

FEATURES OF DAST RESEARCH WINGS

Again by way of review, a brief description is given of the two transport-type research wings in the currently approved program. The first wing, Aeroelastic Research Wing No. 1 (ARW-1), was designed for M = 0.98 cruise and 2.5 g maneuver, and was purposely designed for flutter with a rapid onset within the flight envelope. Flights are aimed at acquiring data emphasizing validation of a flutter suppression system (FSS) design and aeroelastic effects on aerodynamic loads.

The wing fabrication and test for the second research wing (ARW-2) are sponsored by the ACEE-EET program. This design involved what is believed to be the first exercise of an iterative procedure integrating aerodynamics, structures, and controls technologies in a design loop resulting in flight hardware. Evaluation of multiple active controls systems operating simultaneously, the operation of which is necessary to preserve structural integrity for various flight conditions, is the primary objective of the flight tests on this fuel-conservative-type wing.

ARW-1

- AEROELASTIC WING EXHIBITS "EXPLOSIVE" FLUTTER WITHIN FLIGHT ENVELOPE
- ACTIVE CONTROL FLUTTER SUPPRESSION SYSTEM
- SUPERCRITICAL AIRFOIL

ARW-2

- FUEL CONSERVATIVE WING DESIGN
    - HIGH ASPECT RATIO ($AR = 10.3$)
    - LOW SWEEP ($\Lambda = 25^{0}$)
    - ADVANCED SUPERCRITICAL AIRFOIL
- FIRST REAL EXERCISE OF INTEGRATED DESIGN PROCEDURES RESULTING IN FLIGHT HARDWARE
- MULTIPLE ACTIVE CONTROLS CRITICAL TO FLIGHT OPERATION

Figure 3

ARW-1 FLIGHT TESTS

Three flights were made with the first research wing in the past year. The first flight in October 1979 principally involved overall flight systems evaluations and results led to further work with the flight control system. Good loads data were obtained. The second flight was made in March 1980 and was highly successful. The third flight was conducted in June 1980 and following receipt of data at four data points increasing in Mach number at 4.6 km altitude, flutter was inadvertently encountered in advancing to the fifth data point. The right wing separated from the aircraft, and due to excessive damage to the parachute on emergency deployment, impact velocity was excessive and the airframe was damaged beyond repair.

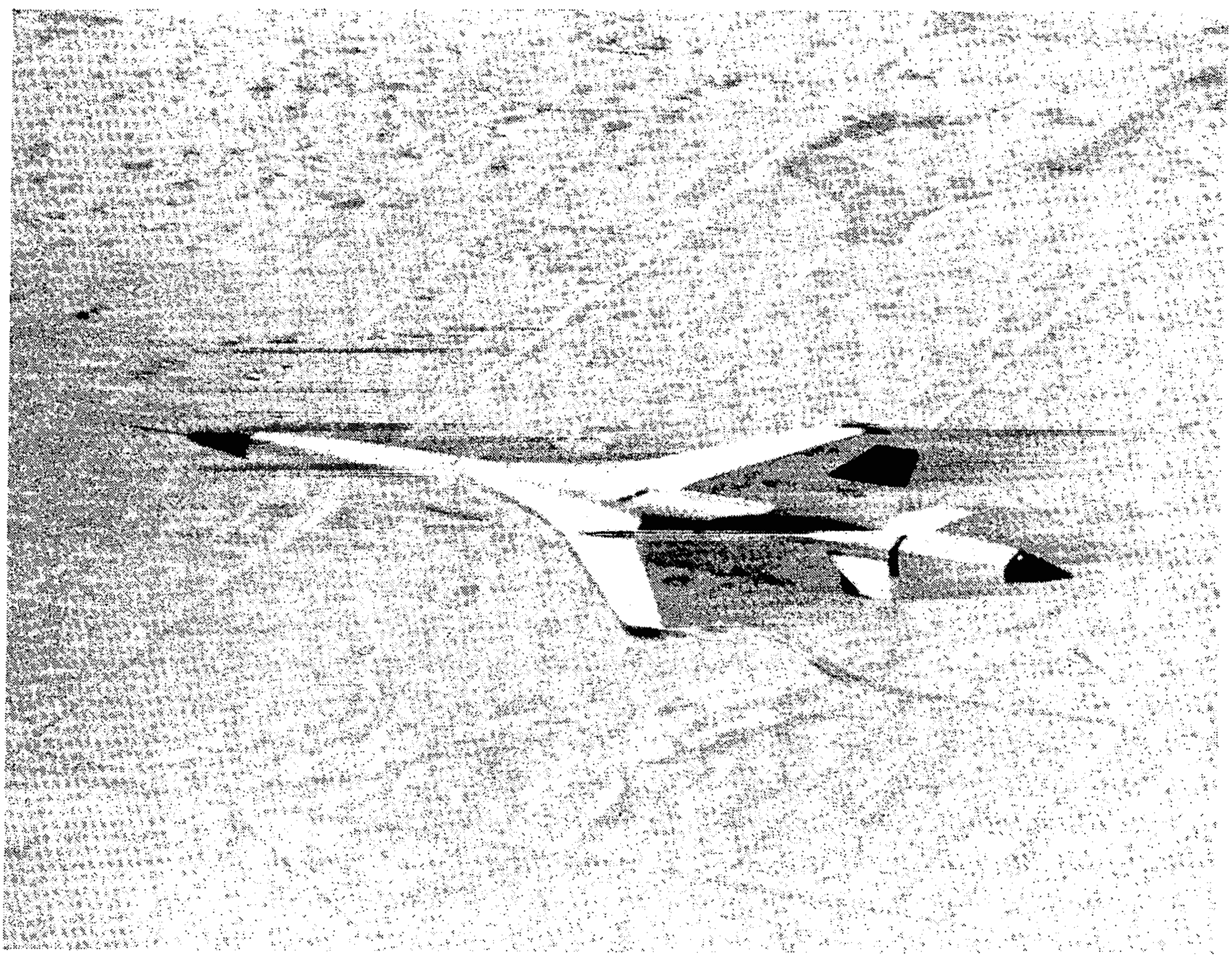

Figure 4

FLUTTER SUPPRESSION SYSTEM CONTROL LAW

The evolution of the flutter suppression system has required numerous modifications, including a major change to the control law prior to the third flight. Effects of higher frequency modes (structural and hydraulic system) resulted in the incorporation of a number of notch filters to compensate for undesirable structural and fluid modes to allow for system stabilization in the hangar. In addition, actuator frequency response was significantly different than the math model used in the earlier analyses. At this time significant parameters affecting actuator frequency response (include effects of mounting and control surface) are not clearly identified; therefore, empirical data must be fed back into the analysis after hardware implementation. As a result of these two factors (added filters and actuator characteristics), it became obvious that the original control law could not provide the goal of 20 percent margin above open loop boundary.

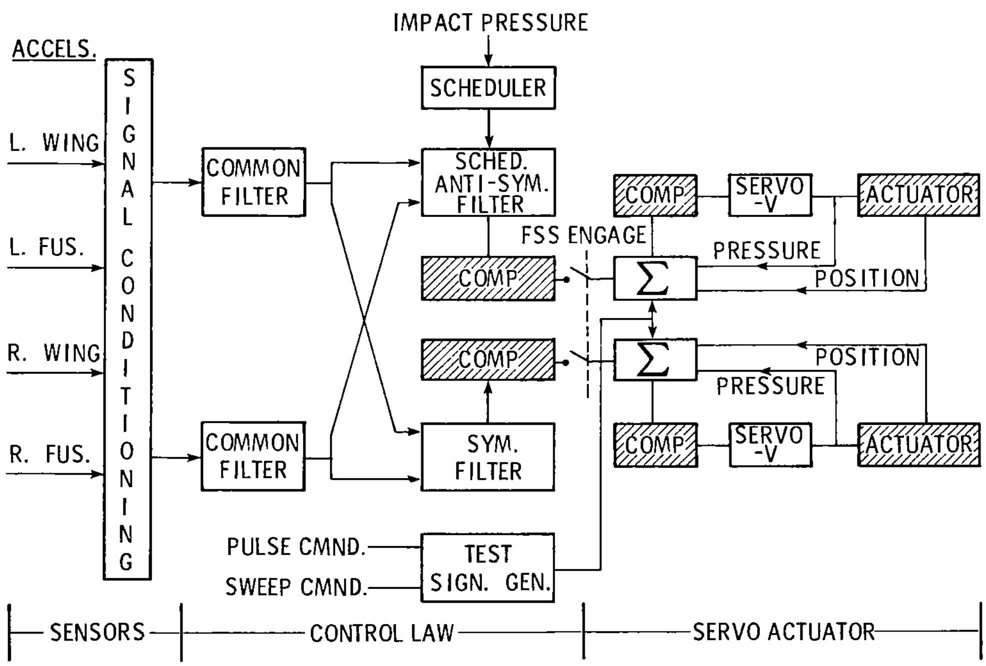

Figure 5

TYPICAL TIME HISTORIES FROM FREQUENCY SWEEPS

The flight data from DAST flights are remarkably free from contamination of any kind. Detailed active control system evaluations in the NASA Transonic Dynamics Tunnel have been difficult due to the high turbulence content in the airflow. Because of the high quality flight data, reliable results can be determined from short (6.8 sec) log sine sweeps from 10-40 Hz. This is very important, since, due to fuel limitations, flights are limited to 20-30 minutes.

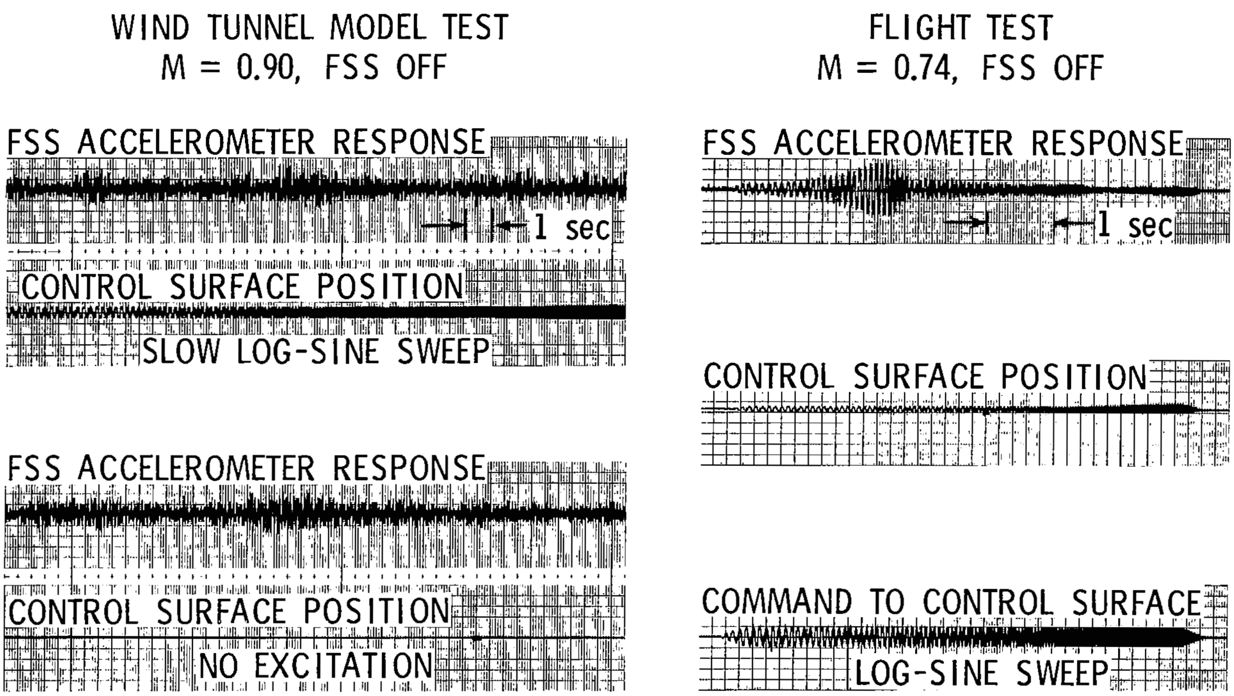

Figure 6

ANALYTICAL-EXPERIMENTAL DATA CORRELATION

Frequency and damping data from the March flight at 6.1 km altitude for the basic wing (FSS off) for both the symmetric and antisymmetric flutter modes indicate that flutter will be encountered at a lower Mach number than predicted analytically. This corresponds to earlier results in the wind tunnel for a supercritical wing at Mach numbers above 0.9. Post-flight analyses indicate improvement in the prediction if (1) the lift curve slope measured on the rigid wind tunnel model is used in place of that resulting from doublet-lattice analysis and (2) modal frequencies derived from the NASTRAN structural model are used rather than matching ground vibration test frequencies with the NASTRAN-derived mode shapes. The reason for the latter is not yet well understood.

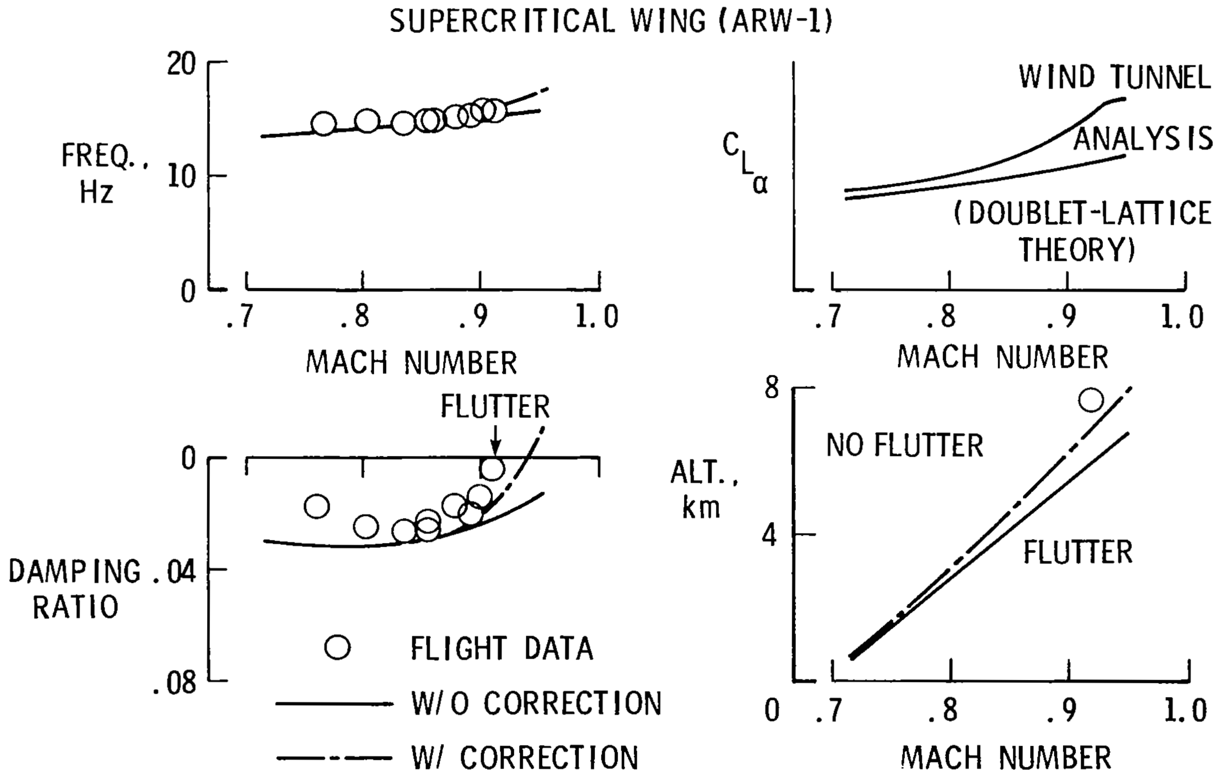

Figure 7

FLUTTER ONSET TIME HISTORY

Flutter was encountered as speed was being increased from one test point to another at a Mach number slightly above 0.8. The procedure was to excite the wing with a symmetric sine sweep and an antisymmetric sine sweep, process to the next higher test point while exciting the wing every 3-4 seconds with symmetric and antisymmetric pulses and observing the response on the strip chart of the wing accelerometer output. The time history of wing tip acceleration during flutter onset can be observed from the FSS accelerometer output scaled to ±10 g peak and subsequently by another accelerometer located at the wing tip which was scaled to ±68 g peak. It was observed that a frequency shift (from about 19 Hz to about 14.5 Hz) occurred at a time corresponding to when control surface amplitude saturation was reached. Since this event would effectively reduce gain and the gain setting was one-half nominal, the frequency shift probably corresponds to a shift to essentially the open-loop condition. Subsequent to this time, the amplitude quadrupled in two cycles. An aft-located mass, designed to be released in emergencies, was released, but apparently due to the rapid buildup was not effective in stopping flutter.

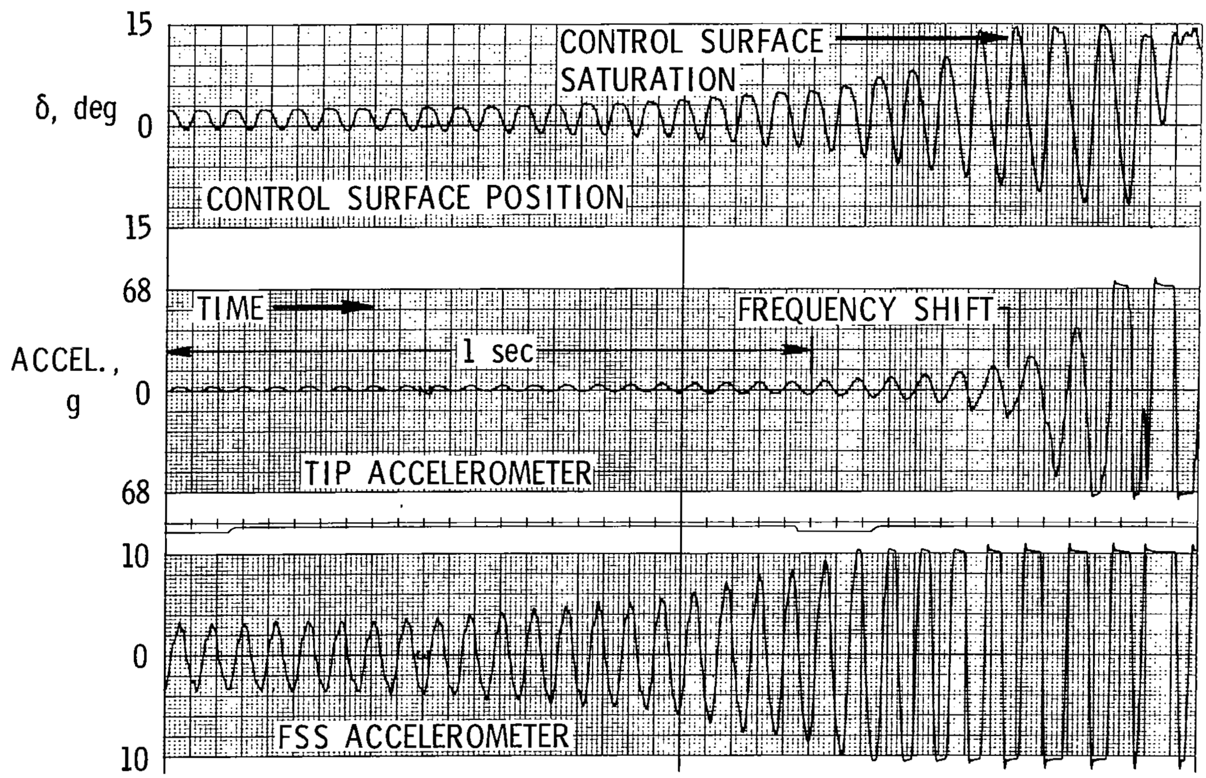

Figure 8

CORRELATION OF SYSTEM ON- AND OFF-FLIGHT DATA WITH PREDICTION

It has been determined that one-half the nominal gain was inadvertently implemented in the flight hardware for the third flight. Post-flight analyses have indicated the system to become unstable at a Mach number above 0.8 at one-half nominal gain if the NASTRAN model is used to describe the structural characteristics. A comparison of predicted frequency and damping with analysis indicates that even at Mach numbers well below 0.9, in this case near 0.8, analysis is unconservative. Frequency predictions are very close to measured values. (A significant note to be made is that the analysis does not predict instability at one-half nominal gain if ground vibration test frequencies are used with mode shapes of the NASTRAN model.)

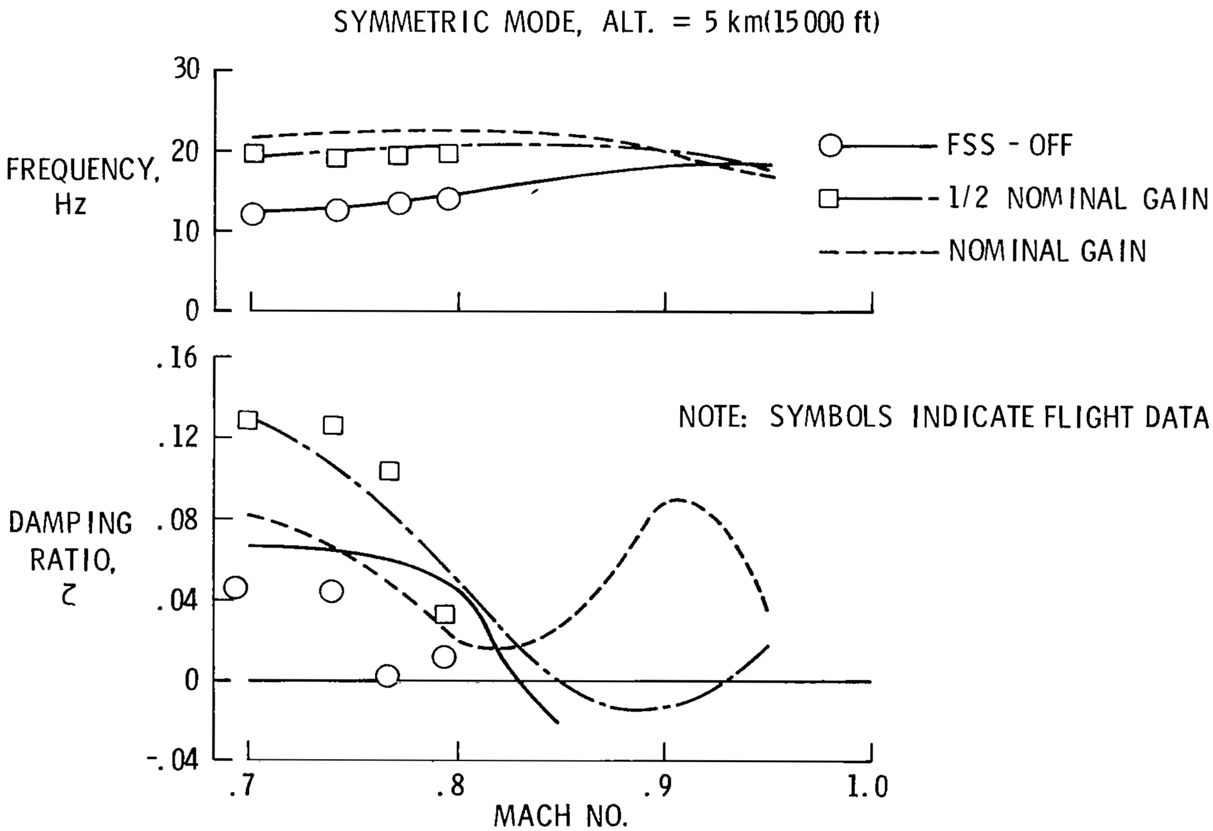

Figure 9

DETERMINATION OF SYSTEM-OFF CHARACTERISTICS WITH SYSTEM ON

Early in the program it was planned that suitable system-off (open loop) data would be obtained with the system on (closed loop), using transfer function analyses, if the data were uncontaminated by noise. This procedure has been recently demonstrated for some store flutter investigations in the wind tunnel, but was unsuccessful on the DAST ARW-1 dynamically scaled wind-tunnel model, apparently due to high turbulence content in the airflow. Flight results to date are encouraging, although scatter is seen in the two damping estimates closest to the zero damping axis on the one set of data.

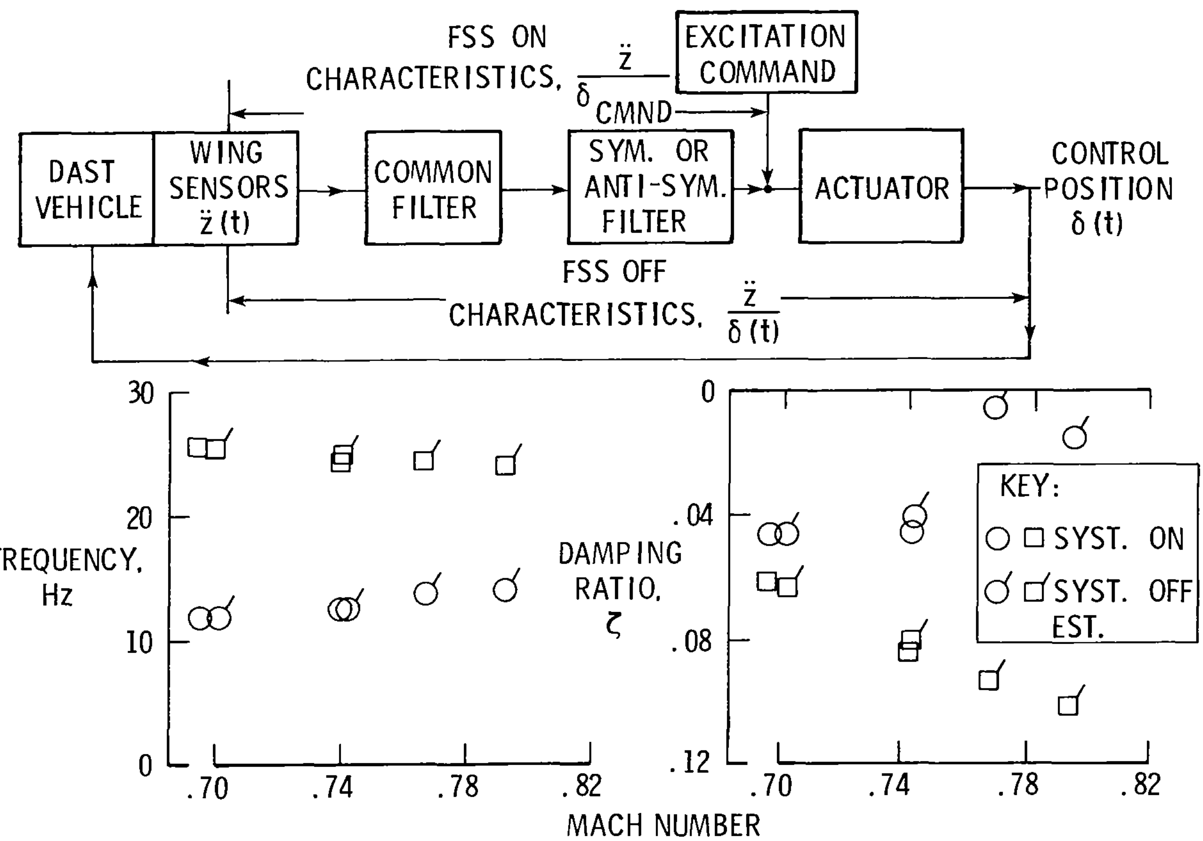

Figure 10

ARW-1 STATUS

Activity is underway to rebuild the ARW-1 and re-establish flight status as quickly as possible. Essentially all electronic equipment, for both controlling vehicle functions and the FSS, is reusable. A significant number of spare parts are on hand and another Firebee II target drone will be modified for ARW-1 tests. System improvements under consideration include a refinement to speed control of the flight vehicle, adjustment in criteria for tip ballast release, and tailoring the parachute deployment sequence to be more adaptable to emergency situations.

- WING IS BEING REBUILT USING SPARES AND MAXIMUM USE OF REFURBISHABLE COMPONENTS
- ANOTHER FLIGHT VEHICLE IN PREPARATION
- VEHICLE SYSTEM MODIFICATIONS UNDER CONSIDERATION
  - SPEED CONTROL
  - PARACHUTE DEPLOYMENT SEQUENCE
  - FLUTTER ARRESTER

Figure 11

ARW-2 ACTIVITY

The DAST ARW-2 design is complete and fabrication is continuing. The design includes maneuver load alleviation (MLA), gust load alleviation (GLA), flutter suppression (FSS), and relaxed static stability (RSS). The high aspect ratio supercritical wing has both inboard and outboard active control surfaces; vehicle control is through a differentially moving horizontal tail. Two major contracts have been implemented to provide the active control systems and machined components for the wing. Fabrication of the wing skins, hydraulic system, instrumentation system, and wing assembly will all be performed at Langley. The wing will be instrumented to measure quasi-steady loads with calibrated strain gage bridges, and pressure orifices; in addition, one row of orifices near the tip will be employed to measure unsteady surface pressures. The test vehicle and flight control system will be developed by the Dryden Center. A means of drag enhancement, probably a speed brake arrangement, will be incorporated in the vehicle systems in order to expand the level flight envelope of the ARW-2 configuration.

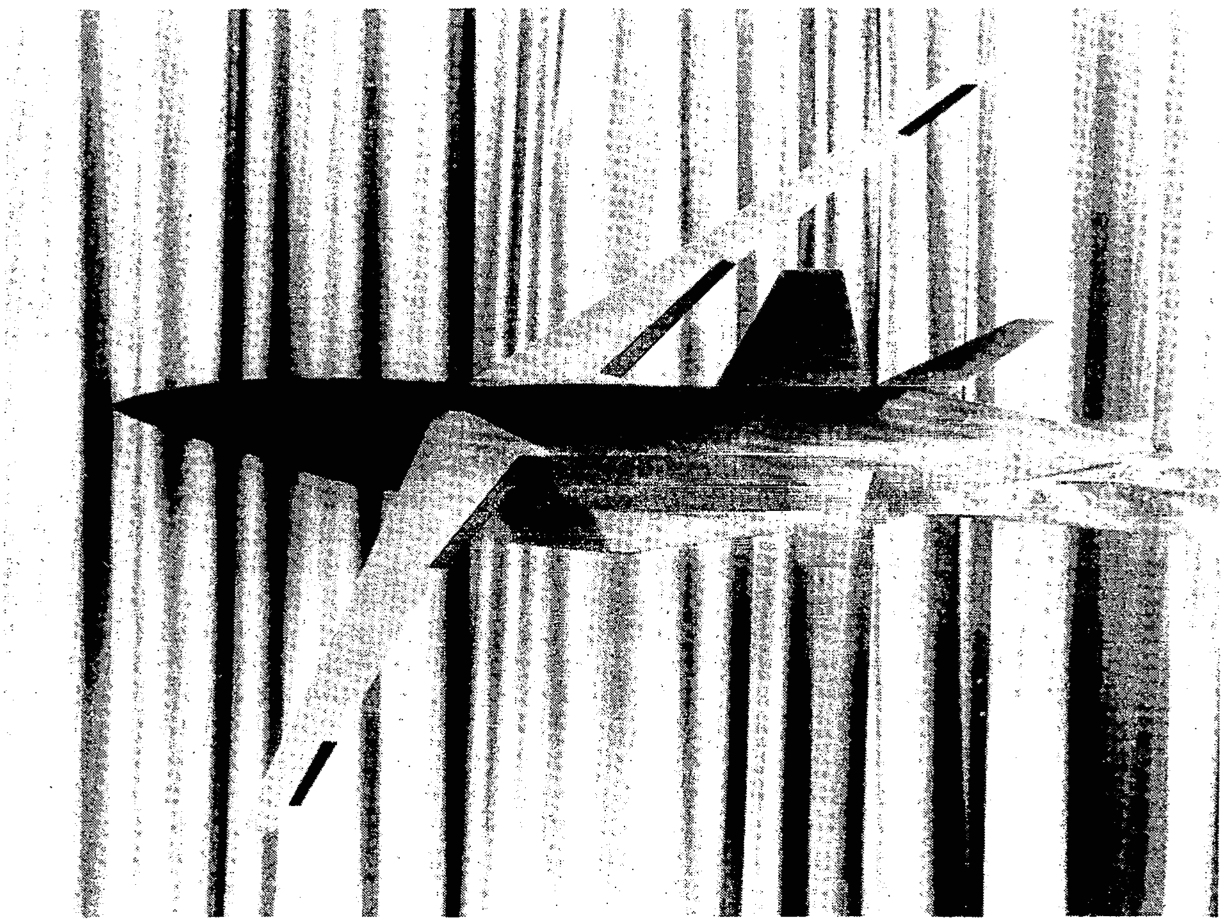

Figure 12

ARW-2 TEST CONDITIONS

The principal flight test conditions selected for ARW-2 include the MLA test point of M = 0.4 at 3.0 km (10 000 ft), the GLA test point of M = 0.6 at 2.1 km (7000 ft), the FSS test point of M = 0.86 at 4.6 km (15 000 ft), and the RSS test point of M = 0.80 at 13.7 km (45 000 ft). Balsa flow vanes will be used on the pitot head to sense turbulence input and turbulence encounters will be necessary to evaluate the GLA. These were selected to correspond as closely as possible to the various design conditions. Other test points will be selected within the flight envelope for loads evaluations and the active control systems will be evaluated at those test points also.

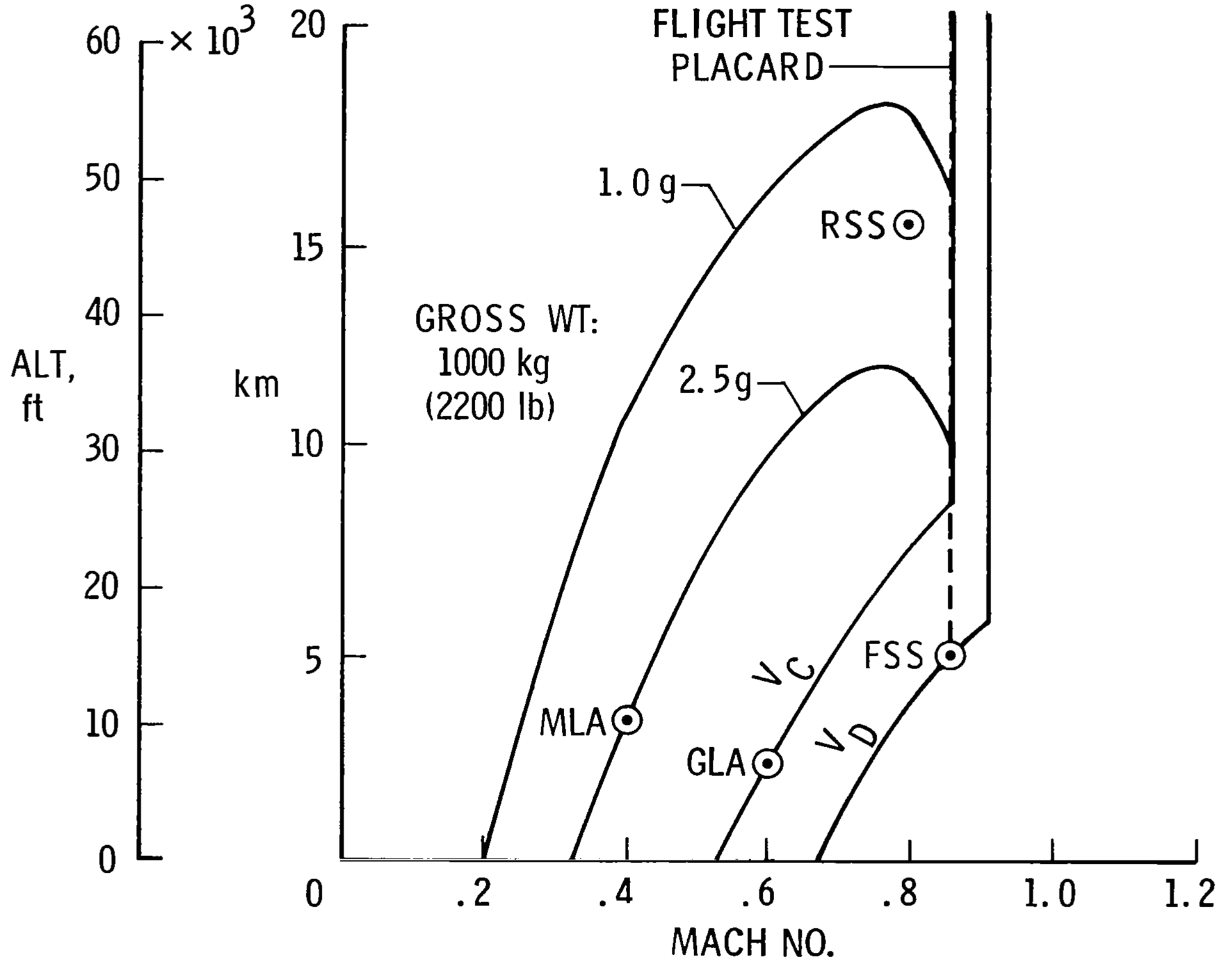

Figure 13

UNSTEADY PRESSURE MEASUREMENTS ARE CONTINUING

The rigid semispan model of an EET-type wing (Æ = 10.3, supercritical airfoil) equipped with leading- and trailing-edge control surfaces has had two test entries to date in the Langley Transonic Dynamics Tunnel. Results from the first test series which included one inboard and one outboard trailing-edge control surface are in the process of being published. Additional data were acquired from trailing-edge control surfaces and one outboard leading-edge control surface in an entry completed in August of this year. The next entry is planned for mid-year 1981.

PURPOSE

- EFFECTS OF OSCILLATING CONTROL SURFACES ON UNSTEADY AERODYNAMIC PRESSURES
- DATA BASE FOR DESIGN AND VALIDATION OF THEORY

STATUS

- INITIAL TESTS COMPLETED SPRING 1979
  - ONE INBOARD AND ONE OUTBOARD T. E. CONTROL SURFACE
- SECOND TEST SERIES COMPLETED AUGUST 1980
  - ADDITIONAL T. E. DATA AND ONE OUTBOARD L. E. SURFACE
  - DATA REDUCTION UNDERWAY
- NEXT ENTRY PLANNED FOR MID-1981

Figure 14

FUTURE DAST STUDIES

In cooperation with the Aerospace Flutter and Dynamics Council, solicitations were made to all pertinent segments of the aerospace community to determine consensus on DAST contributions and appropriate follow-on research. A compilation of responses resulted in consensus that NASA should conduct research in the areas of tailored composite structures combined with continued active controls studies with some emphasis on acquiring unsteady pressure measurements in flight. From the standpoint of pursuing energy-efficient transport technology, a configuration with aspect ratio higher than ARW-2 with simulated engines and nacelles (mass and aerodynamic effects), designed with load control through use of tailored orientation of composite laminates in combination with active controls, would appear to be a good candidate. Some preliminary design studies are planned during the next year.

- HIGH PRIORITY TECHNOLOGY AREAS IDENTIFIED
  - UNSTEADY PRESSURE MEASUREMENTS
  - TAILORED COMPOSITE STRUCTURES
  - ACTIVE CONTROLS
- TRANSPORT CONFIGURATION
  - HIGH ASPECT RATIO (~12)
  - SIMULATED ENGINES AND NACELLES
  - COMBINED ACTIVE CONTROLS AND TAILORED COMPOSITES

Figure 15

DAST STATUS SUMMARY

- THREE FLIGHTS COMPLETED WITH ARW-1
  - FLIGHTS TO RESUME LATE 1981
- ARW-2 FABRICATION PROGESSSING
  - FLIGHTS EXPECTED TO BEGIN LATE 1982
- DAST FOLLOW-ON FOCUS IDENTIFIED

Figure 16