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THE OBLIQUE-WING RESEARCH AIRCRAFT: A TEST BED FOR UNSTEADY AERODYNAMIC AND AEROELASTIC RESEARCH

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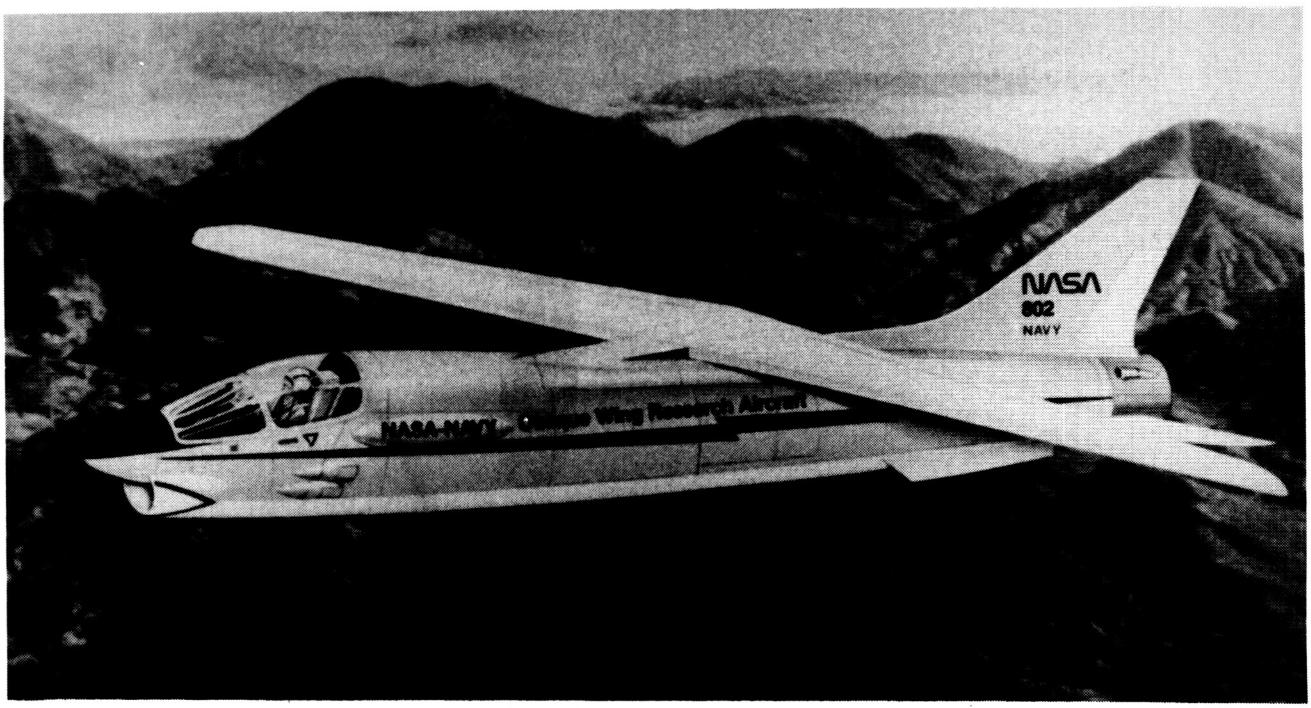
OBLIQUE-WING RESEARCH AIRCRAFT PROGRAM

The advantages of oblique-wings have been the subject of numerous theoretical studies, wind tunnel tests, low speed flight models, and finally a low speed manned demonstrator, the AD-1(ref. 1). An oblique-wing configuration is well suited for a Navy fleet defense mission and a supersonic transport (Mach < 1.6). An excellent review of the historical development of oblique-wing technology is presented in reference 2; references 3 and 4 discuss potential applications. NASA's Oblique-Wing Research Aircraft (OWRA) program is directed at the development and flight test of a full scale supersonic demonstrator which will address the key technological challenges. The specific objectives of the OWRA program are 1) establish the necessary technology base required to translate theoretical and experimental results into practical, mission oriented designs, 2) design, fabrication and flight test an oblique-wing aircraft throughout a realistic flight envelope, and 3) develop and validate design and analysis tools for asymmetric aircraft configurations.



Objectives

- **Establish a technology base for oblique wing concepts which can be applied to mission-oriented aircraft designs**
- **Design, fabricate, and flight test an oblique wing throughout a realistic flight envelope**
- **Develop and evaluate design tools for asymmetric aerodynamic configurations**

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

OBLIQUE-WING AERODYNAMIC ADVANTAGES

Theoretical aerodynamic advantages of oblique wings have been the subject of numerous studies over the years. The variable sweep aspect of course permits optimization with Mach number thus yielding efficient flight for the subsonic cruise/loiter condition while also providing for efficient supersonic dash/cruise capability. As shown in the figure the induced drag is minimized for a zero sweep, maximum aspect ratio condition; this advantage is independent of symmetrically swept or obliquely swept aircraft. In the supersonic regime, the oblique type wing has a significant advantage (over a symmetrically swept wing) in that it produces less wave drag since the wing volume is distributed over a greater length.

Surpasses Variable Sweep for Mixed Missions

- **Efficient subsonic cruise/loiter**

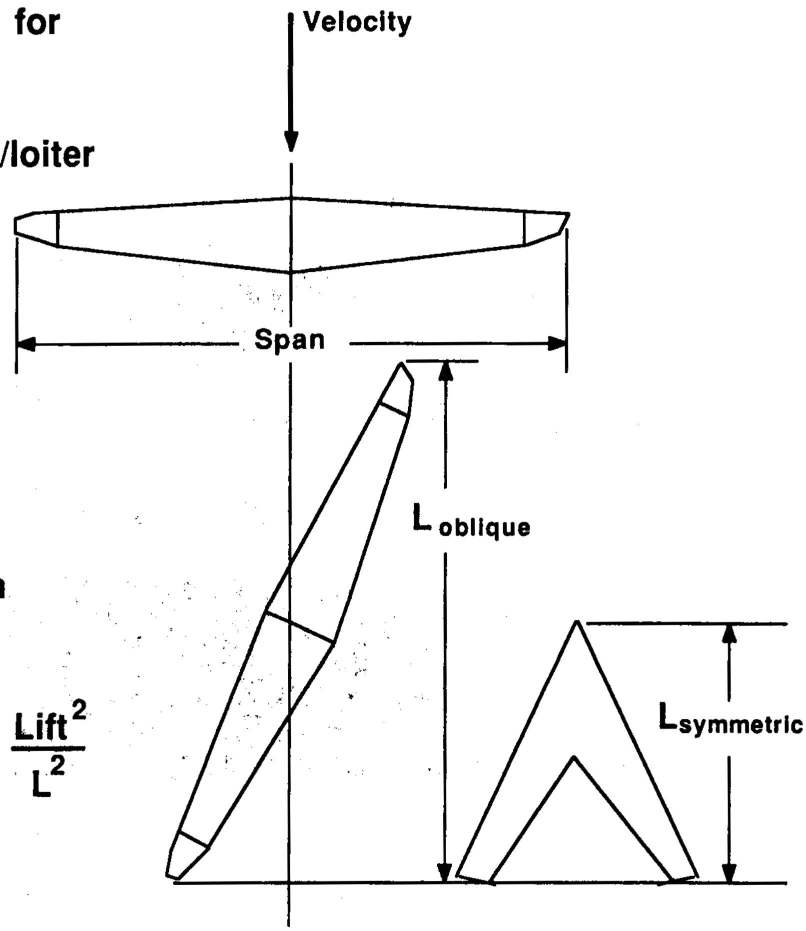
  High aspect ratio

  Drag due to lift $\sim \dfrac{\text{Lift}^2}{\text{Span}^2}$

- **Efficient supersonic dash**

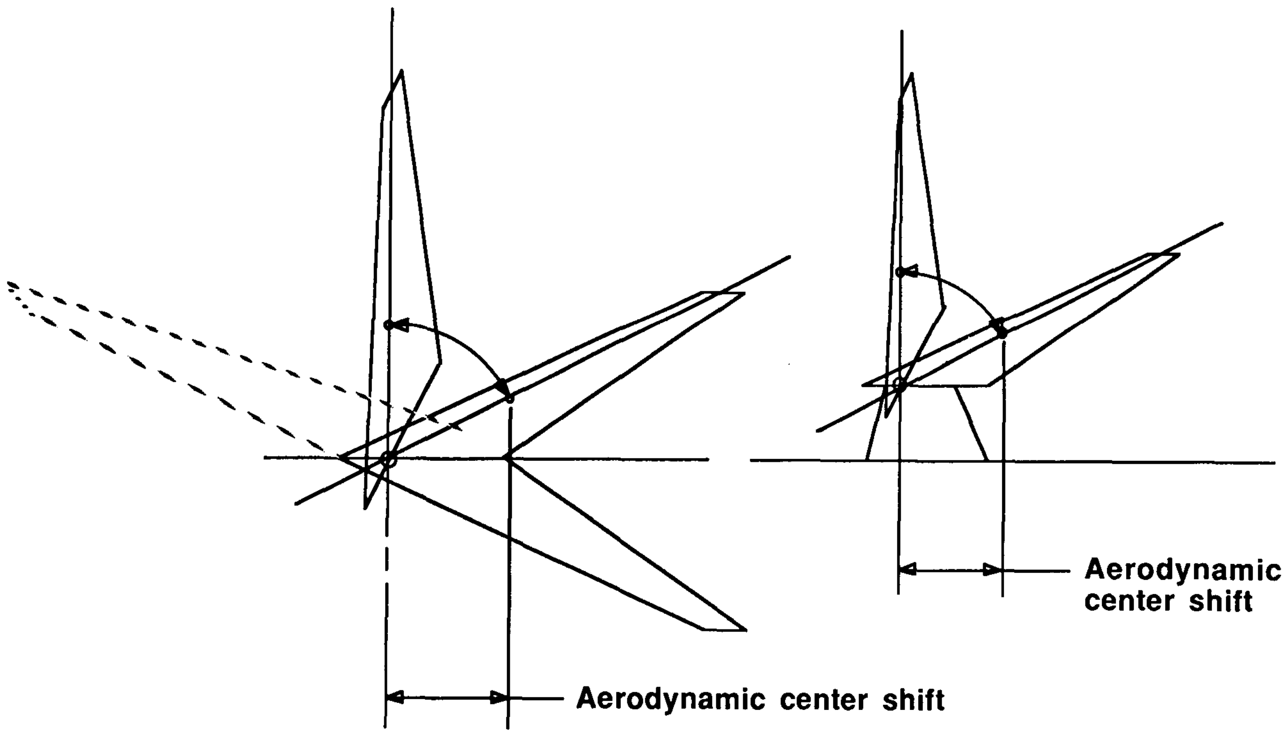
  Low aspect ratio

  Wave drag $\sim \dfrac{\text{Vol}^2}{L^4} + \dfrac{\text{Lift}^2}{L^2}$



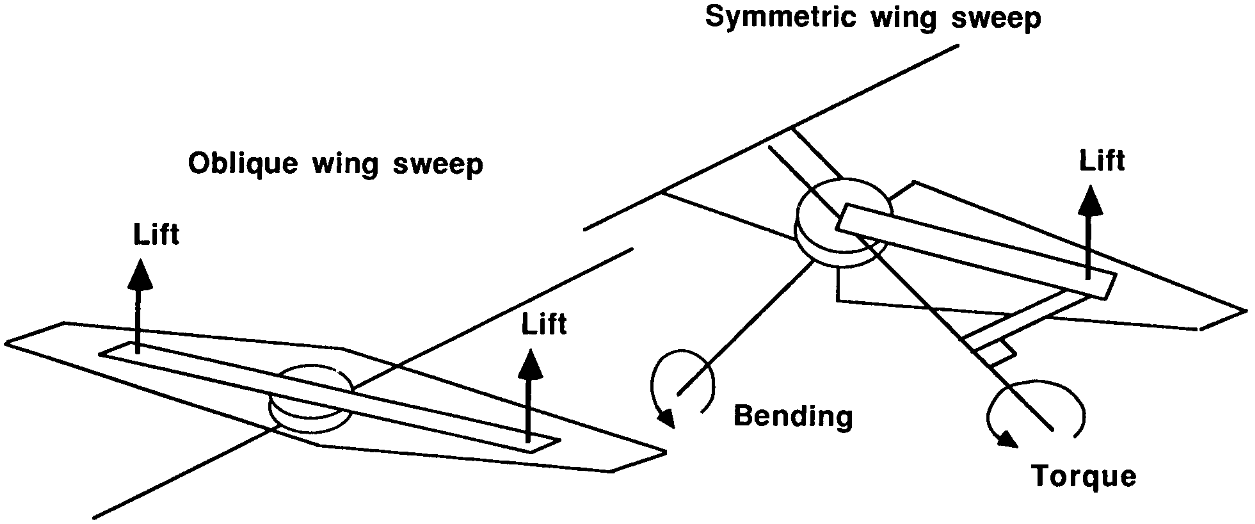
OBLIQUE-WING AERODYNAMIC CENTER SHIFT

An oblique-wing configuration also provides a major advantage in that sweep does not produce an aerodynamic center shift as does a symmetric swept configuration. This minimizes trim drag penalties due to aerodynamic center shifts and reduces tail loads, thus resulting in a lighter structure and eliminating center-of-gravity control as a function of wing sweep.



OBLIQUE-WING STRUCTURAL ADVANTAGE

An oblique-wing configuration has a number of significant structural advantages over a symmetrically swept wing configuration, the most obvious being a single pivot requirement. A single pivot results in both cost and weight savings and other factors that accrue from maintaining one as opposed to two pivots. On an oblique-wing, the lift forces pass essentially through the center of the pivot independent of sweep angle, thus minimizing bending and torque loads transmitted through the pivot. For symmetrical swept configurations, offset lift forces produce significant bending and torque forces transmitted through the pivot, which in turn requires a 'beefed-up' pivot/substructure assembly and results in a major weight penalty.



- **Pivot torque and bending loads avoided**
- **Inboard wing torque loads avoided**
- **Single pivot**

OWRA UNSTEADY PRESSURE MEASUREMENT EXPERIMENT

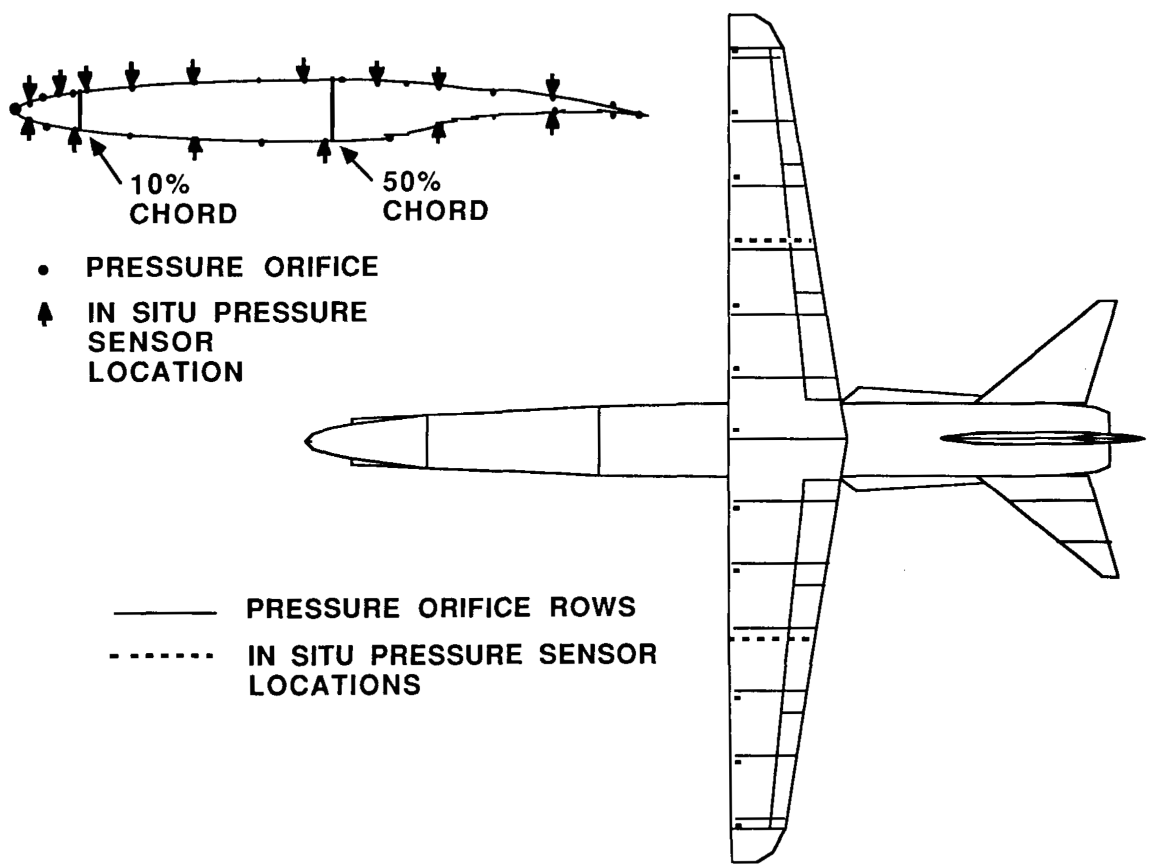
Efficient aircraft design increasingly relies on predictions; therefore, in an attempt to improve vehicle aeroelastic design and prediction techniques, an experiment will be implemented on the OWRA which will measure unsteady pressures. The unsteady pressure survey will use remote sensing (pneumatic lines) to measure pressures on thirteen chords covering the full span of the wing; each chord will consist of approximately 30 orifices and will be sampled 400 times per second. The approach is similar to that reported for the laboratory experiment of reference 5 and the wind tunnel test of reference 6. A limited number of in situ measurements will be taken and used to correct the pneumatic measurements for magnitude and phase. Controlled data will be gathered using preprogrammed aileron excitation algorithms. The data base will be used for correlation with currently used unsteady aero codes and will also provide a valuable data base for evaluation of future codes. It is anticipated that the unsteady pressure measurements will prove valuable in analysis of other unique flow phenomena and provide insight into effects such as vortex flow patterns and vortex and/or shock induced oscillations should they occur.

Objectives:

- **Develop unsteady pressure data base**
  - **Full span**
  - **13 chords; 30 orifices/chord**
  - **400 samples per second**
- **Correlation with current unsteady codes**
- **Data base for future code development**
- **Identify unique flow phenomena**
  - **Vortex flow**
  - **Vortex / shock induced oscillations**

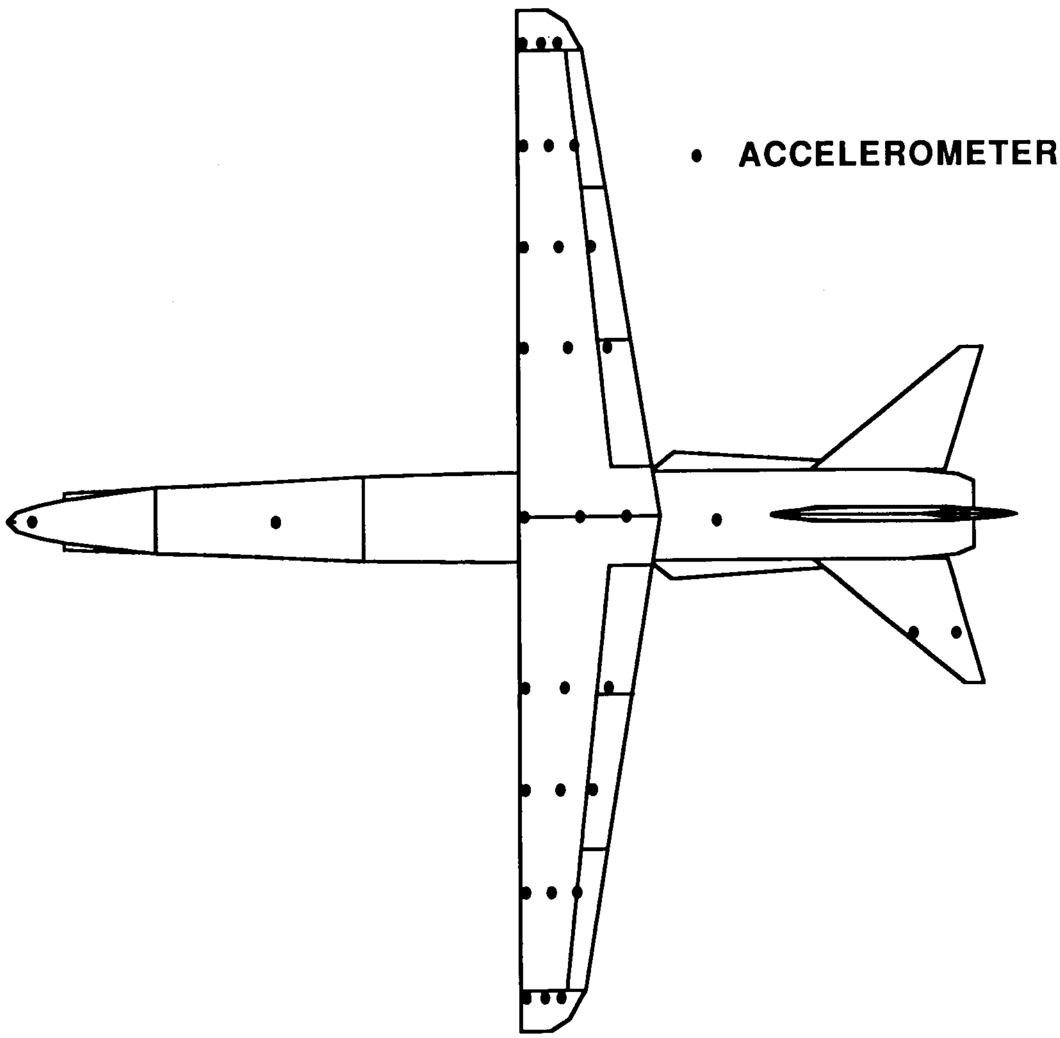
OWRA UNSTEADY PRESSURE SENSOR LAYOUT

A pressure sensing system will be implemented on the OWRA which will be capable of measuring both static and unsteady pressures. The primary system will acquire data pneumatically using remotely located electronically scanned pressure (ESP) modules located either in front of the forward spar or aft of the rear spar. This arrangement will provide a cost effective and readily maintainable system since access to the wing box will not be possible after it is sealed. The pneumatic system will consist of equal lengths of tubing connecting the orifices and the transducer. Current plans call for use of approximately 4 foot lengths of 0.060 " ID tubing. The data will be corrected based on in situ unsteady pressure measurements made at two chord locations and one in situ measurement made for each of the other chord locations. At the maximum skew angle of 65 degrees, the left wing overlays the left horizontal stabilizer and as such, leads to interesting aerodynamic interactions. In order to assist in analysis of this effect, unsteady pressures will also be measured for two horizontal tail chord locations.



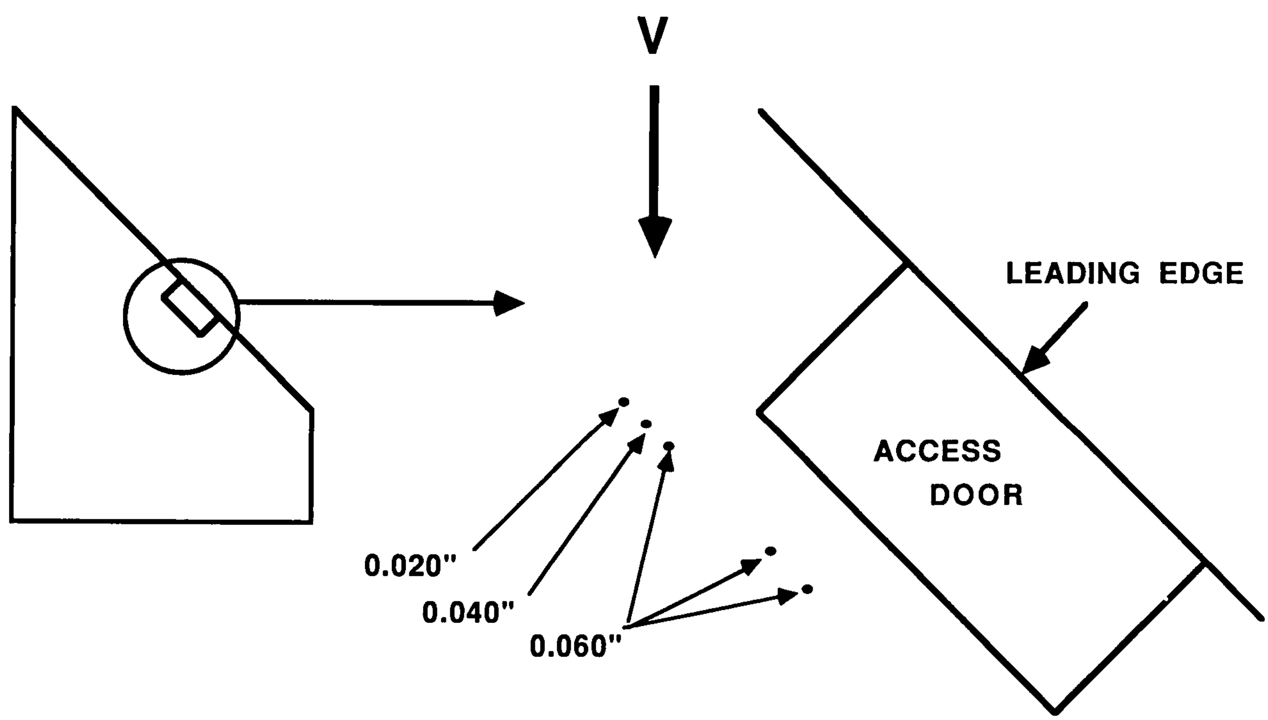
OWRA MODAL RESPONSE SURVEY LAYOUT

Correlation of predicted and experimental unsteady aerodynamics requires an accurate mode shape of the wing. The figure below illustrates the planview layout for accelerometers used for defining the wing mode shape. In addition, these accelerometers will in general meet the requirements for flutter and aeroservoelastic stability clearance work. The unsymmetric nature of the OWRA leads to unsymmetrical leading edge suction forces which could in turn develop significant in-plane wing motion. Therefore triaxial accelerometers will be located along the wing. Additional accelerometers will also be located on the fuselage to identify later bending and torsional characteristics. The sample rate of the accelerometers will be identical to the rate used for unsteady pressure measurements.



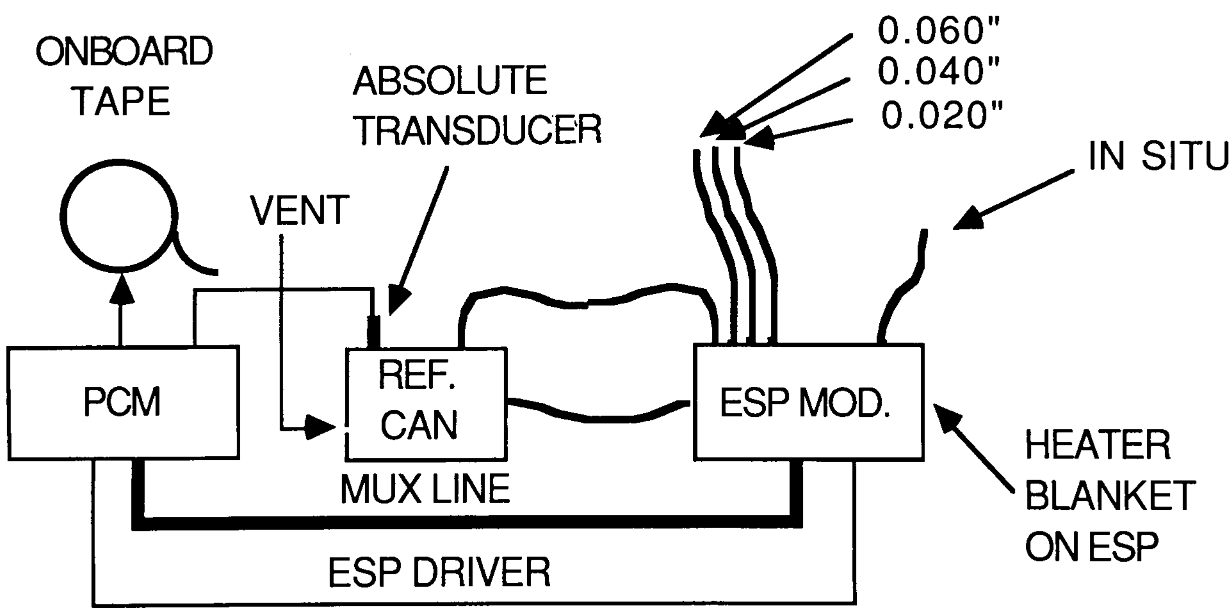
F-15 UNSTEADY PRESSURE EXPERIMENT

A validation of the unsteady pressure measurement system proposed for the OWRA was conducted on an F-15 experimental aircraft at Dryden. The validation consisted primarily of a parametric evaluation of line length and orifice/tubing diameters. An auxiliary objective was to demonstrate that the ESP module could be driven and data recorded at 500 samples/sec in a flight environment with no adverse effects on data quality. The experiment consisted of orifices located at 10% chord, one-half inch apart, and approximately mid-span on the upper surface of the right wing of the F-15. The orifice/tubing inside diameters evaluated were 0.020, 0.040, and 0.060 inches with tubing lengths of two, four, and eight feet being changeable between flights. An in situ measurement consisted of a 0.060 inch orifice/tubing diameter connected to the same ESP module but with a minimal line length, six inches. Flights to date have obtained excellent quality data for both two and four foot line lengths.



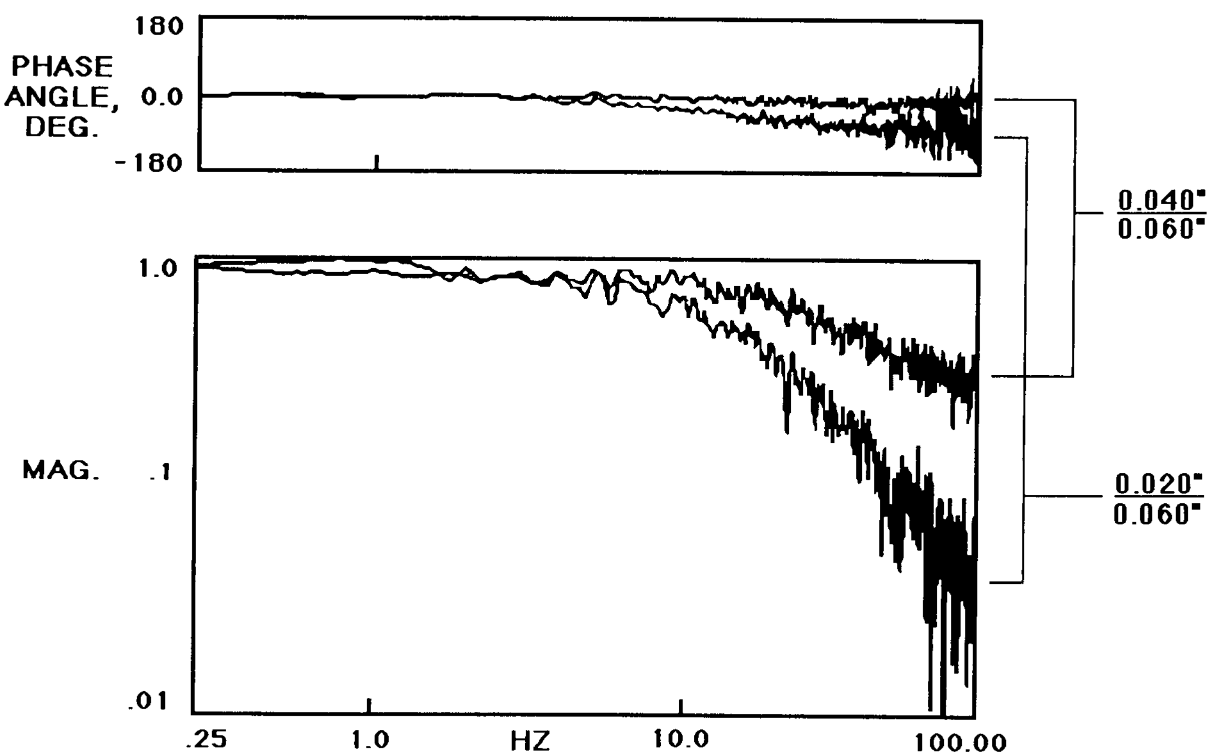
F-15 UNSTEADY PRESSURE SYSTEM SCHEMATIC

An end-to-end schematic of the instrumentation system used in the F-15 experiment is presented in the figure below. The ESP module consists of 32 flush-diaphragm, strain-gage-type differential-pressure transducers. The reference side of the ESP module is connected to an ambient pressure reservoir which is vented to the interior wing cavity. The purpose of the reservoir is to allow the reference pressure (backside of the ESP differential transducer) to adjust to changes in altitude without any high frequency pressure oscillations. The module multiplexes the individual port measurements with the output routed to a 10 bit PCM system and recorded on on-board tape. There is no signal conditioning of the individual ESP port data prior to multiplexing. The ESP module transducers are ranged for +/- 5 psi. The ESP module is operated and data was recorded at 250 sps for the first few flights and subsequently increased to 500 sps. A heater blanket was installed to maintain a constant temperature on the ESP module. A check on the quality of the PSI transducer is obtained by plumbing one of the ports directly to the reservoir. The absolute transducer on the reference can allows for the absolute chordwise pressure measurements as well. A factor which makes the ESP transducer outstanding for dynamic pressure measurements is its minimal internal volume. The internal diameter of each ESP port is 0.040 inch with no increase in diameter at the diaphragm face and as such the transducer volume can be analytically modeled as a 0.040 inch ID line length extension to the orifice connecting tubing.



F-15 UNSTEADY PRESSURE TRANSFER FUNCTION ANALYSIS

A transfer function analysis was performed on approximately one minute of data obtained in a moderate g wind up turn at a high subsonic Mach number. Using the 0.060" tubing as the reference, both the 0.040" and 0.020" tubing show little attenuation to at least 10 Hz although the 0.020" tubing does attenuate at a much more rapid rate than the 0.040" tubing once the break frequency is past. The poorer characteristics of the 0.020" tubing are also indicated by its significantly worse phase angle. Although not plotted on this figure, the coherence of the two transfer functions was also determined. For the 0.040" transfer function, the coherence starts at one (perfect correlation) for low frequencies and gradually decreases to one-half (reasonably good correlation) at 100 Hz. The 0.020" transfer function also starts at a coherence of one for low frequencies but degrades to a value of zero (no correlation) at approximately 80 Hz.



OWRA FLUTTER MODEL TEST

Unique aerodynamic characteristics of oblique-wing configurations have the potential for producing unusual flutter type characteristics and/or other instabilities. A wind tunnel flutter model test will be performed in the TDT to both provide data for validation of aeroelastic analysis codes prior to first flight and to support an efficient and rapid envelope clearing process. In order to maximize the return on the test, the model will be designed to flutter (or encounter some other type of instability unique to oblique-wing configurations) within the tunnel. Identification of transonic flutter/instability characteristics is of prime importance. There are tentative plans to obtain limited unsteady pressure measurements for both code validation and correlation with flight results. Preliminary studies have been performed to identify critical DOF for flutter model tests of oblique configurations. An 'oblique' mode has been identified with a 5 DOF model which still retains its characteristics with the three rotational DOF's.

Problem: Unique, unsymmetrical configuration presents potential for unusual flutter type instabilities. No flight experience is available for oblique-wing configurations.

Objectives:

- Design model to flutter; test in TDT
- Identify transonic flutter characteristics
- Correlate with predictions
- Identification of unique instability phenomena
- Limited unsteady pressure measurements

Status:

- Identify important DOF
- Preliminary study has identified an 'oblique' mode

FLUTTER/AEROSERVOELASTIC CODE VALIDATION

An interdisciplinary analysis code (STARS), which is capable of performing flutter and aeroservoelastic analyses, has been developed. The structures module has a large library of elements and in conjunction with numerical analysis routines, is capable of efficiently performing statics, vibration, buckling, and dynamic response analysis of structures. In order to accommodate unsymmetrical supersonic conditions, the potential gradient method (PGM) unsteady aero code of Appa is being implemented into the aero module of STARS; subsonic unsteady aero code will continue to be doublet lattice. Linear flutter models are developed and transformed to the body axis coordinate system and are subsequently augmented with the control law. Stability analysis is performed using hybrid techniques. The major research benefit of the OWRA program will be validation of design and analysis tools. As such, the structural model will be validated and updated based on ground vibration test (GVT) results. The unsteady aero codes will be correlated with experimentally measured unsteady pressures.

STARS: In-house analytical code

- **Specialized structural modeling**
- **Efficient matrix manipulation**
- **Implement PGM code**

Validate structural model

- **Fuselage GVT**
- **Wing GVT**
- **Complete A/C GVT**

Validate unsteady aero code with flight data

HIGH ANGLE OF ATTACK AERODYNAMICS

As angle of attack increases, the F-8 OWRA will exhibit non-linearities in all flight axes. At high wing sweeps the increase in spanwise flow and the formation of a leading edge vortex can occur at relatively low angles of attack (6 to 8 deg). Because of the asymmetry of the vehicle these effects will not be balanced in the lateral directional axis. At higher angles of attack, regions of spanwise flow also form in an asymmetric pattern, generally progressing from the trailing wing tip. In addition to these characteristics, which will effect the vehicle flight dynamics, other unusual features have been observed in water tunnel studies such as the interaction of parallel spanwise vortices on the leading wing panel. Further water tunnel studies will be conducted this summer to document the flight configuration and to note distinctions between the various preliminary design planforms. A comprehensive computational fluid dynamics (CFD) analysis is underway at Ames-Moffett to develop a Reynolds averaged Navier-Stokes solution of the complete vehicle. Preliminary results of the wing alone at an angle of attack of 10 deg show good correlation of the spanwise flow and vortex formation with the water tunnel results. During the flight program, unsteady pressure data will be used to identify vortex flow and regions of separated flow. The vehicle is also equipped with a tail mounted camera which can be used for tuft studies and smoke flow visualization. Flight measurements of the vehicle forces and moments will be used for correlation with the flow visualization results. A similar correlation was made during the AD-1 flight program.

Characteristics

- Significant spanwise flow
- Strong spanwise vortices
- Asymmetric regions of separated flow
- Potential dynamic interaction of vortices

Data Sources

- Water tunnel studies
- Reynolds averaged Navier Stokes solutions
- Flight testing
  - Unsteady pressures
  - Flow visualization, tufts and smoke
  - Measured vehicle forces and moments

OWRA FLIGHT DEFLECTION EXPERIMENT

In order to support research activities on the OWRA, an accurate determination of the wings deflected shape in flight is required to validate the wing stiffness and load distribution predictions which, because of the wings unconventional attitude, could produce some unpredicted pressure distributions. The deflections will also be used for definition of in-flight shape for correlation of CFD codes with flight determined static pressure distributions. The electro-optical system to be used has been developed at Dryden and used quite successfully on both the HiMAT and X-29 aircraft.

OBJECTIVE

Evaluate the ability of analytical codes to predict structural loads and deflections and pressure distributions

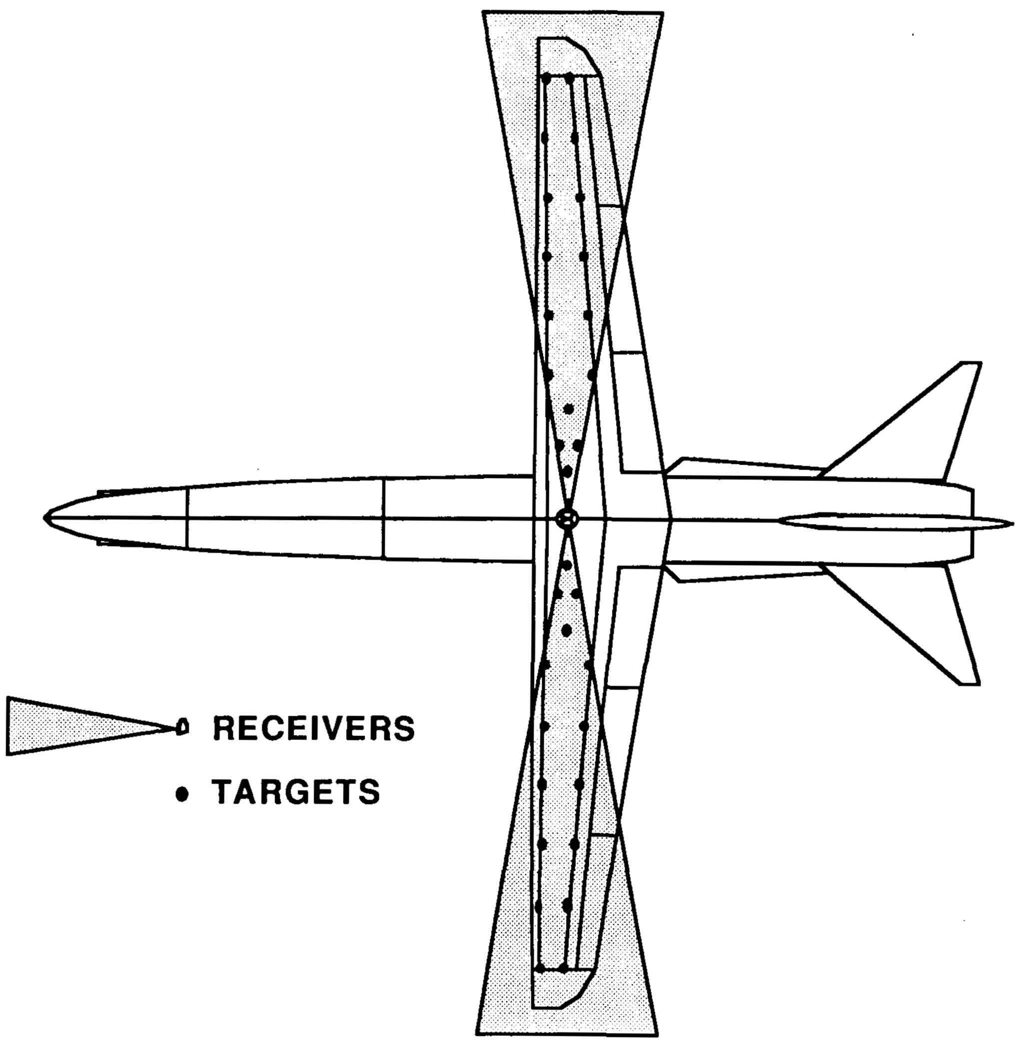
APPROACH

Measure in-flight deflections to correlate with predictions

Define in-flight shape for correlation of pressure data with CFD codes

OWRA FLIGHT DEFLECTION MEASUREMENT SYSTEM

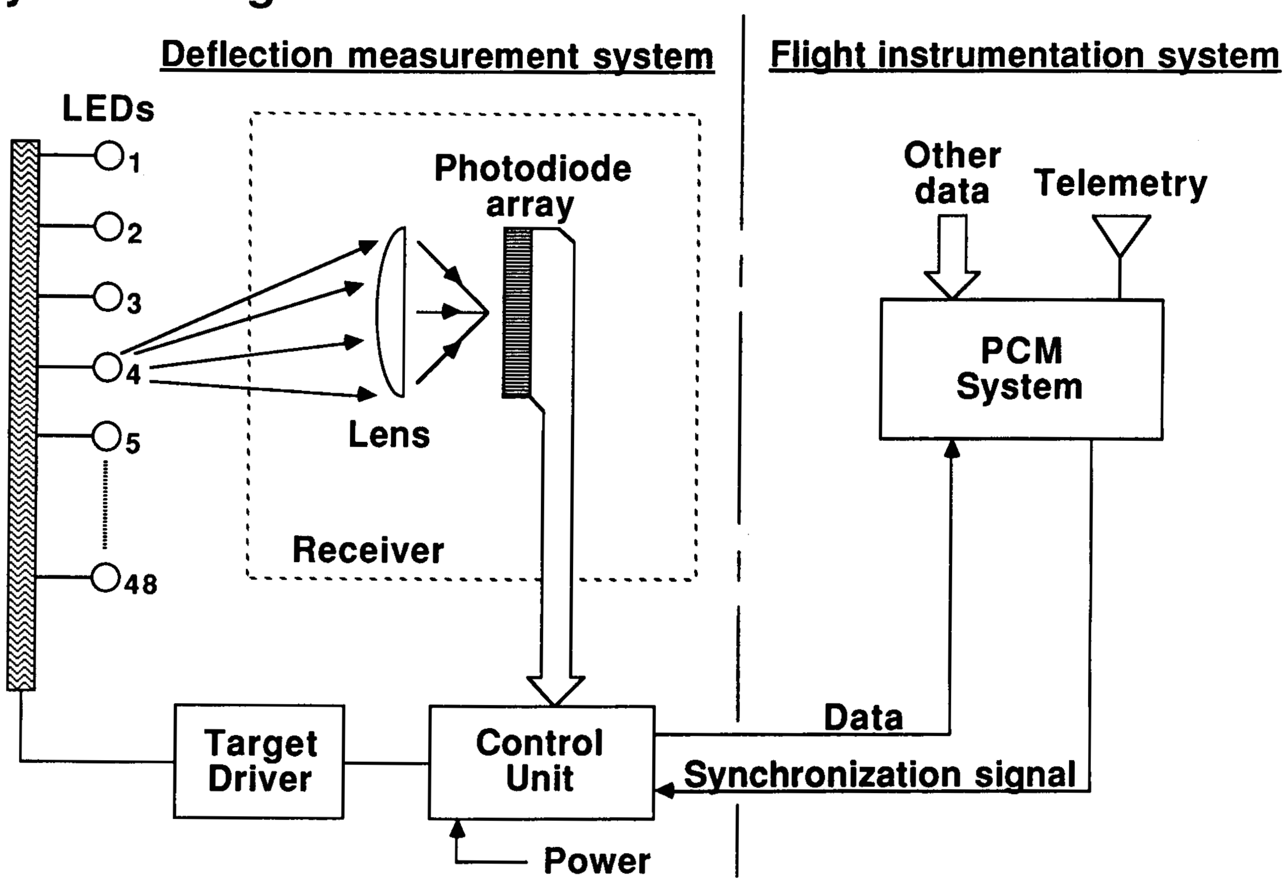
The flight deflection measurement system is electro-optical and consists of wing located targets emitting a light source which is in turn received by a wing center line located receiver. The system to be implemented on the OWRA will have the targets located on the wing upper surface just over the wings fore and aft spars. The system is capable of measuring both bending deflections and twist angles. Sixteen targets per wing semi-span will be installed; the targets have a spherical section shape with a base diameter of approximately 1.5 inches and a height of 1 inch. The receiver (located at the wing pivot) will be housed in an aerodynamically shaped blister with a height of approximately six inches and slightly larger base dimensions. The entire deflection measurement system will be removable so as not to interfere with either the static or unsteady pressure experimental data.



ELECTRO-OPTICAL FLIGHT DEFLECTION MEASUREMENT SYSTEM

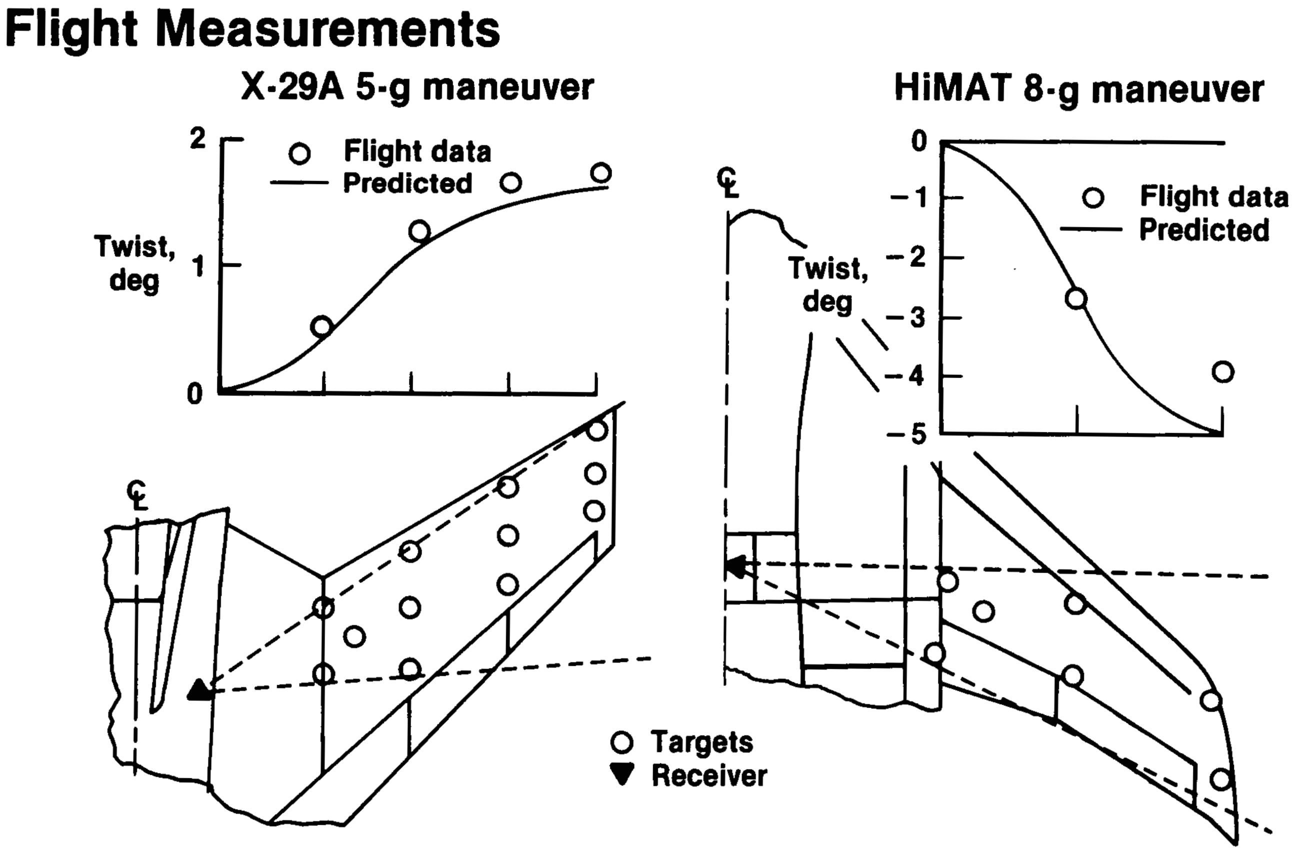
The major elements of the deflection measurement system are a control unit, two receivers, two target drivers, and the targets. The targets house an LED which is turned on and off sequentially as a command is cycled through the various targets. Light from the target LED is then sensed by the receiver and is focused on a light sensitive diode array. The signal produced by the diode array is proportional to the wing deflection. This signal is sent to the control unit which, in turn, sends it to the PCMQ system for recording on magnetic tape or telemetering to a ground station for real time display. The control unit contains all of the measuring logic for operation of the system, and the target driver serves as a relay in providing from 2 to 5 amperes of pulsed current to each target. The system has a resolution of approximately 0.03 inch at a 10 foot range and a sample rate of approximately 7 sps for each target.

System Diagram



FLIGHT DETERMINED DEFLECTION MEASUREMENT RESULTS

The electro-optical deflection measurement system has been used successfully to obtain flight results on both the HiMAT and X-29A research aircraft as illustrated in this figure. The X-29A flight measured wing panel streamwise twist distributions are derived from front and rear spar deflections measured during a 5 g wind up turn maneuver and are compared to calculated twist data. Also shown are HiMAT flight measurements compared to NASTRAN calculated data for the 8 g maneuver design point. The deflection measurements of the HiMAT wing played a major role in evaluating the performance of the aeroelastically tailored composite wing.



OWRA SCHEDULE

The preliminary design phase of the project is complete and has resulted in a wing configuration for which construction is ready to be initiated. The wing area of the current configuration is 300 sq. ft. and is a 50% increase over the feasibility study design. Wing final design and construction will begin this summer and be complete in mid 1990. Testing of the flight configuration force and moment model will begin this fall and upon completion, work can be initiated on the rigid body flight control system. Upon receipt of the wing, extensive ground testing will be conducted to verify loads and dynamic structural modeling. Extensive systems checkout will be conducted with emphasis on the wing and fault tolerant processor (FTP) based flight control system. A first flight is anticipated for early 1991.

Wing construction - July 1987 - July 1990

Systems checkout - July 1990 - April 1991

First flight - May 1991

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