CONTROLLED IMPACT DEMONSTRATION
AIRFRAME BENDING BRIDGES

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There are two issues at stake here. One issue concerns occupant load protection (what type of loads did the occupant see), and most of the CID workshop discussions dealt with the loads that the seat or occupant would see. Another issue is whether the airframe provides a protective shell for the occupant. The bending moment bridges that will be discussed address that issue.

We have seen several goals and objectives in most of the CID presentations. These are much the same as those that you've seen previously. These goals and objectives come from the CID program plan itself and relate to the moment bridges themselves.

One goal is the calibration of the "KRASH" and "DYCAST" models for transport aircraft. The FAA uses computer analysis techniques to predict the response of CID during impact. The moment bridges can provide a direct correlation between the predictive loads or moments that the models will predict and what was experienced during the actual impact.

Another goal is to examine structural failure mechanisms and correlate with analytical predictions. Regarding failure mechanisms, do or do we not break the fuselage shell? There has been quite a bit of discussion, with respect to the analytical models, concerning the potential occurrence of a break in the fuselage shell.

As the third goal we would like to provide baseline metal crash data to support the NASA composite crash dynamics research; of course, any structural data would provide that.

Primary CID Goals/Objectives

- Calibration of "Krash" and "Dycast" Models to Transport Aircraft
- Examine Structural Failure Mechanisms and Correlate with Analytical Predictions
- Provide Baseline Metal Crash Data to Support NASA Composite Crash Dynamics Research

Now, what do the moment bridges provide? Well, they in fact do address those objectives directly. You can say they may be directly related to and correlated with the analyses, both KRASH and DYCAST. We have a direct correlation between predicted and measured moments. The moment bridges provide an understanding of fuselage loading and breakup. Should the fuselage break, the moment bridges were located so that they could detect the time and location of the break. The moment bridges also can provide an assessment of the dynamic and static fuselage strength capability. They can actually measure the strength capability during the impact for comparison with analytical techniques. Bending moment bridges are the highest and best use of available instrumentation--any structural instrumentation falls into that category.

BENEFITS OF FUSELAGE INSTRUMENTATION

- MAY BE DIRECTLY RELATED TO AND CORRELATED WITH ANALYSIS (DYCAST/KRASH)
- PROVIDES AN UNDERSTANDING OF FUSELAGE LOADING AND BREAK-UP
- ASSESS DYNAMIC/STATIC FUSELAGE STRENGTH CAPABILITY
- HIGHEST AND BEST USE OF AVAILABLE INSTRUMENTATION

The overall scheme that was used for the moment bridge instrumentation makes use of a total of 12 fuselage bending bridges distributed along the length of the fuselage. Eight were distributed to measure vertical bending, and there were four bridges that would measure lateral bending. A typical distribution is shown on this diagram. The lateral bridges were installed, but they were not calibrated due to some schedule and also cost problems. The lateral bridges were essentially installed to detect unsymmetrical loads in an impact that is or appears to be symmetrical, and should there be some unsymmetrical loading, to detect and measure that loading. CID did have an unsymmetrical impact and maybe a little bit of data was lost due to a lack of lateral bending bridge calibration.

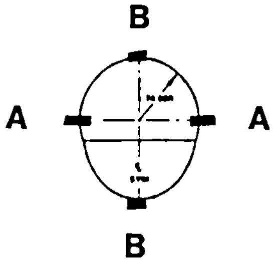
Overall Fuselage Instrumentation

Total of 12 Fuselage Bending Bridges Distributed Along Fuselage Length

8 Vertical Bending B-B

4 Lateral Bending A-A

Bending Bridges



Fuselage Crossection

This represents just a brief depiction of where the bridges are located on the airframe. These stations are roughly the same locations where the accelerometers were located along the circumference of the fuselage.

Moment bridges were located at Station 410. These were installed to assess the nose loads. There is a production break located in this area. There is some discussion whether or not airframes break at production breaks. Should a fuselage break occur in the area of the production break during the test, the moment in that vicinity would be measured.

Station 510 was located essentially to assess the forward fuselage load just aft of the actual nose load itself.

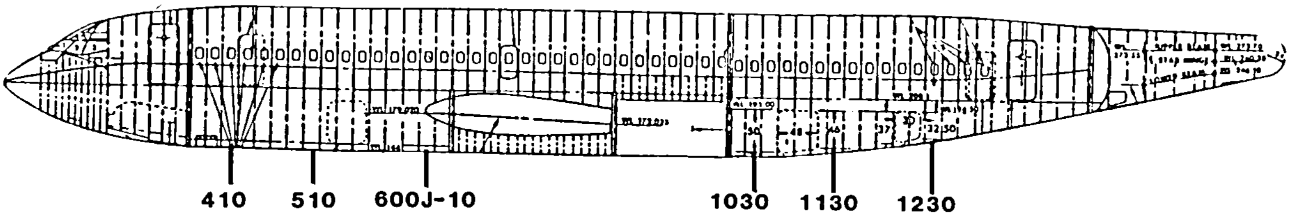
Station 600J-10 was located to assess fuselage loads at the forward edge of the wing box. There is also a manufacturing break in the same vicinity.

Station 1030 was located to assess fuselage loads aft of the wing box and at the aft edge of the main gear cavity.

Station 1130 was located to assess aft fuselage load. It is in the area of a manufacturing break and in the transition area where the fuselage cross section starts necking down.

Station 1250 was located to assess aft fuselage loads outside of the lower fuselage ground contact area to see what type of loads one might get there from the cantilevered overhang of the fuselage itself.

Rationale For Locations of Fuselage instrumentation



STA. 410 - ASSESS NOSE LOAD
- PRODUCTION BREAK

STA. 510 - ASSESS FWD FUSELAGE LOAD

STA. 600J-10 - ASSESS FWD FUSELAGE LOAD
- FWD EDGE OF WING BOX
- MANUFACTURING BREAK

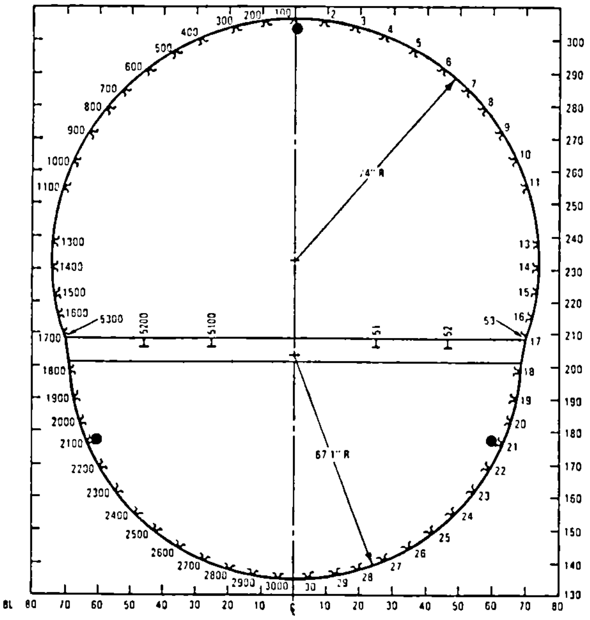
STA. 1030 - ASSESS AFT FUSELAGE LOAD
- AFT OF WING BOX
- AFT EDGE OF MAIN GEAR CAVITY

STA. 1130 - ASSESS AFT FUSELAGE LOAD
- MANUFACTURING BREAK
- TRANSITION AREA

STA. 1250 - ASSESS AFT FUSELAGE LOAD
- OUTSIDE OF LOWER FUSELAGE GROUND CONTACT AREA

This depicts the strain gage locations at Station 510. Station 510 only had a vertical bending bridge installed. The two strain gages located on the upper crown of the figure and the two located on stringers 2900 and 29 on either side of the fuselage are wired to form a four arm bending bridge. They were calibrated, and the procedure will be discussed later. The actual location and stringer placement of the strain gages were based on a review of the stress analysis of the airframe. Primary structural members that would give a high stress reading per the airframe structural analysis were selected. All of the strain gages were located on fuselage cross-sections in the same manner.

Body Station 510 Bending Bridges



- Vertical Bending

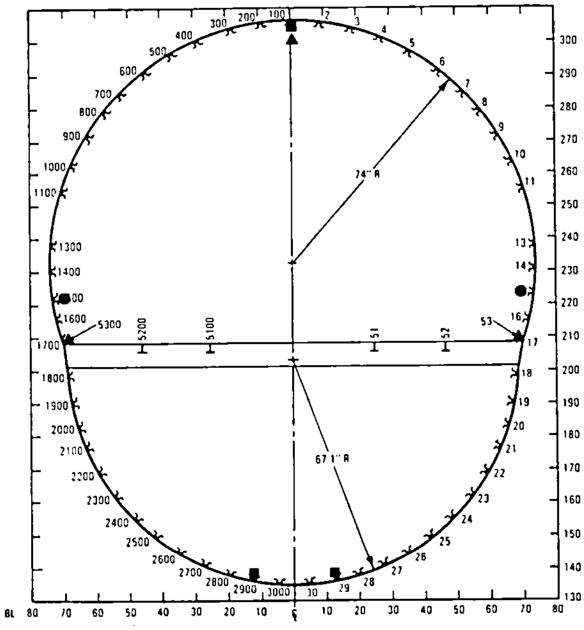
Typical Cross Section With Stiffner Locations - Rear View

At Station 600J-10, the same strain gage installation philosophy was used. A vertical bending bridge is installed with strain gages located at the upper crown and floor line locations. A double bending bridge is installed at this station and also at Station 1030. Fuselage bending is measured both between the upper crown and the floor line and at the lower part of the fuselage itself.

The lateral bending bridges are located on stringers 1500 and 15 which are somewhat the outermost members on the fuselage cross section.

Some of the rationale for a double vertical bridge was on Stations 600J and 1030. These locations should experience the highest bending moments. It was desired to have redundant bridges, first of all, so that we could actually measure the highest bending moment should any single bridge lose signal. Secondly, it was also desired to assess how the bridges may differ between strain gages located on the lower crown of the fuselage and strain gages located near the floor line, should there be a difference in readings during the actual impact due to the fuselage crush. The two bending moment time history traces should record identically. If one finds a significant departure in the two traces, the credibility of the lower bending bridge may be lost.

Body Station 600J-10 Bending Bridges



- ▲ **Vertical Bending Floor**
- ■ **Vertical Bending Lower**
- ● **Lateral Bending**

Typical Cross Section With Stiffener Locations - Rear View

The bending bridges were calibrated by applying known loads at known distances to the bridges themselves. There were a couple of calibration schemes proposed and this depicts the calibration procedure that was selected. First, all the onboard equipment was documented to identify the weight distribution of the aircraft for the 1 g static condition in order to correct the measured moments to zero moment reference.

Down loads were applied to the horizontal stabilizer in 21% load increments by placing load shot bags on the horizontal stabilizer up to a 12,800 lb total load. This load equals approximately 15% of the airplane's design limit load at Station 1030. The moment resulting from the 1 g cantilever overload of the aft fuselage also equals about 15% of the airplane's design limit load at Station 1030. Thus, the aft fuselage calibration load ranged from 15-30% of the airplane's design limit load.

The nose gear reaction was also recorded for each load level by a load cell installed directly in line with the nose gear strut. This provided for a simultaneous calibration of both the forward and aft fuselage bending bridges.

The aft bridge calibration used the distributed weight on the horizontal stabilizer as the known load; the forward bridge used the change in the nose gear strut load as the known load.

Fuselage Calibration Procedure

On Board Equipment Documented

Down Load Applied to Horizontal Stabilizers

- Distributed Lead Shot Bags
- 16-21% Load Increments
- 12800# Total Load

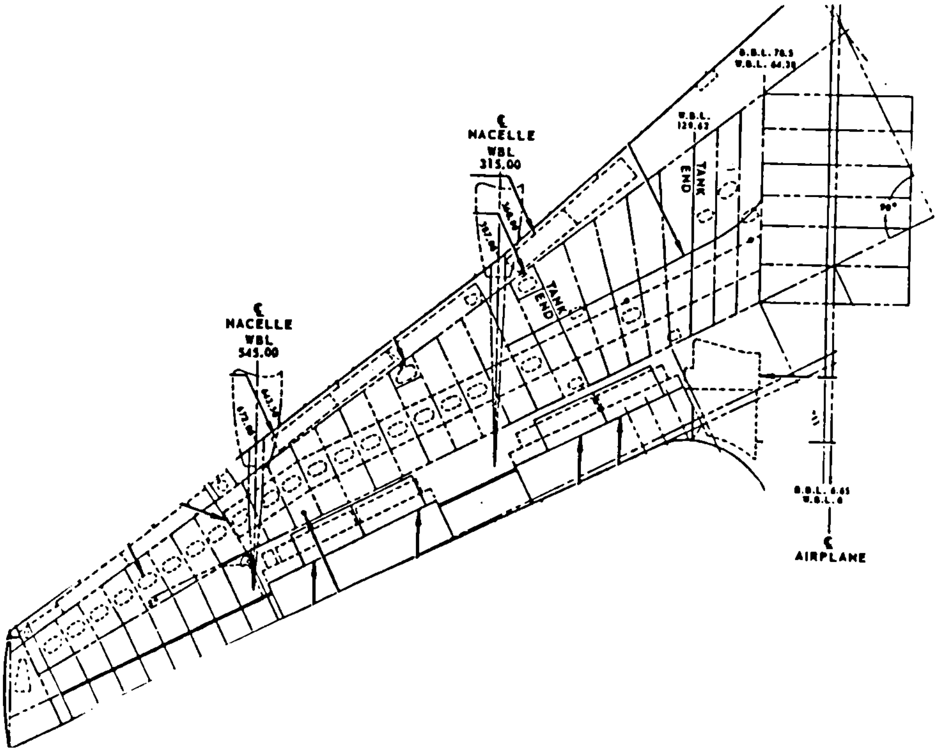
Nose Gear Reaction Recorded for Each Load Increment VIA Load Cell

Simultaneous Calibration of Both Fwd/Aft Fuselage Bending Bridges

Wing bending bridges were also installed on CID. Depicted here are the approximate locations of the wing bending bridges. One bridge is located just outward of the closing member of the wing and the landing gear cavity. This location is also the end of the inboard fuel tank. Another bending bridge is located just outboard of the inner nacelle. These bridges only measure vertical loading.

The wing bending bridges are used to measure the magnitude of the wing loads during impact to assess the proximity of those moments to design loads. These moment bridges would also measure the wing loading should a wing be fractured.

Locations of Wing Bending Bridges



The wing calibration procedure was very similar to that used for the fuselage. First, the fuel load was documented so one would again know what the initial conditions were prior to start of calibration. Downloads were applied inboard of the wing tip, again by means of distributed lead shot bags in 25 percent load increments up to a total load of 5,000 lb on each wing tip. Both wings and the inboard and outboard wing bridges were calibrated simultaneously.

Wing Calibration Procedure

Fuel Load Documented

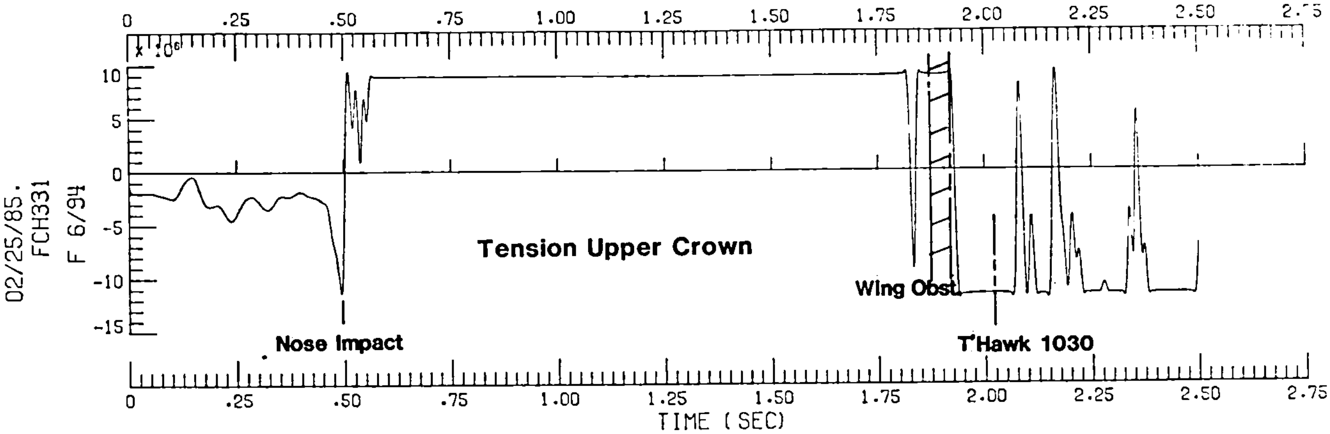
Down Load Applied Inboard of Wing Tip

- Distributed Lead Shot Bags
- 25% Load Increments
- 5000# Total Load (Each Wing)

Simultaneous Calibration of Both Wings and InBd/OutBd Wing Bending Bridges

The analysis of the moment bridge is incomplete at this time and all these comments represent nothing more than a cursory analysis. B.S. 410 is the forward fuselage bridge and it was located close to the point of impact. The range on the moment bridges was initially proposed to be somewhere between 2 times to about 2-1/4 times limit load. It was felt that the bridges would behave linearly beyond limit load based on some static testing of fuselage shells. Those tests show compressive instability failures of the fuselage shell and linear behavior up to ultimate load levels. Based on the instrumentation listing, the bending bridge ranges were limited to a little less than limit load. That restricted range didn't make too much of a difference, except in a few isolated cases.

Fuselage B.S. 410 Vertical Bending



This trace illustrates the aircraft impact, obstruction encounter, and the aircraft's response to those events. Analysis of this time history can find:

Wing Impact
Nose Impact
Wing Obstruction Encounter
Fuselage Impact with the Tomahawk

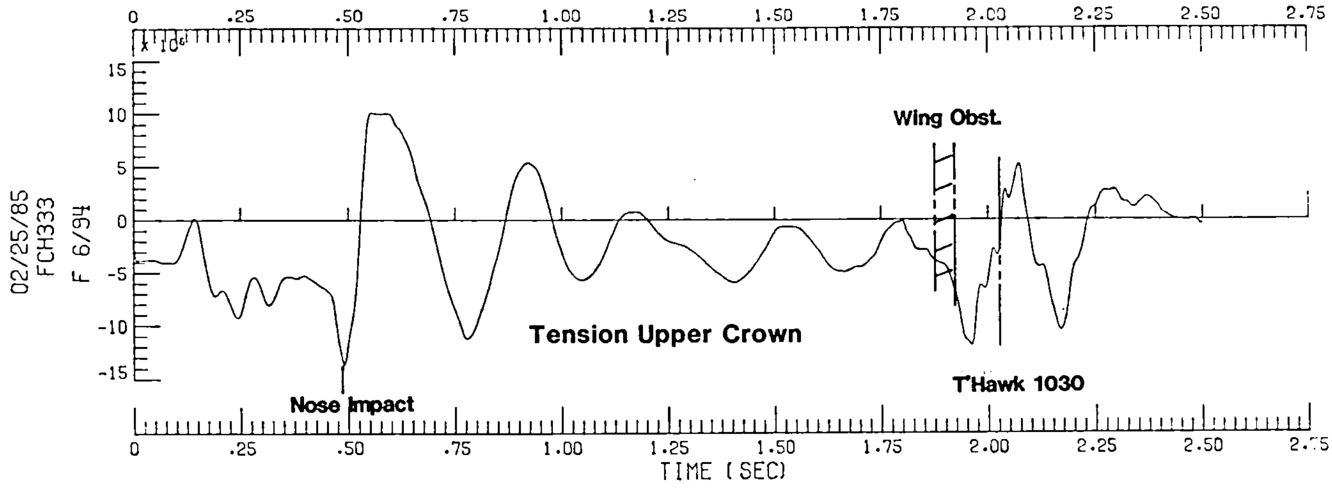
The time intervals identified on the moment bridge trace for those events correlate well with both photographic data and the accelerometer time histories.

The B.S. 510 moment time history appears to be a single one-degree-of-freedom damped response. Analysis of that trace can also determine the frequency of response and the structural damping.

The zero moment reference line has yet to be determined; however, it appears as if the airframe is oscillating about the 1 g static load condition.

A little flat spot was noted on one of the peaks where the moment bridge range was slightly exceeded.

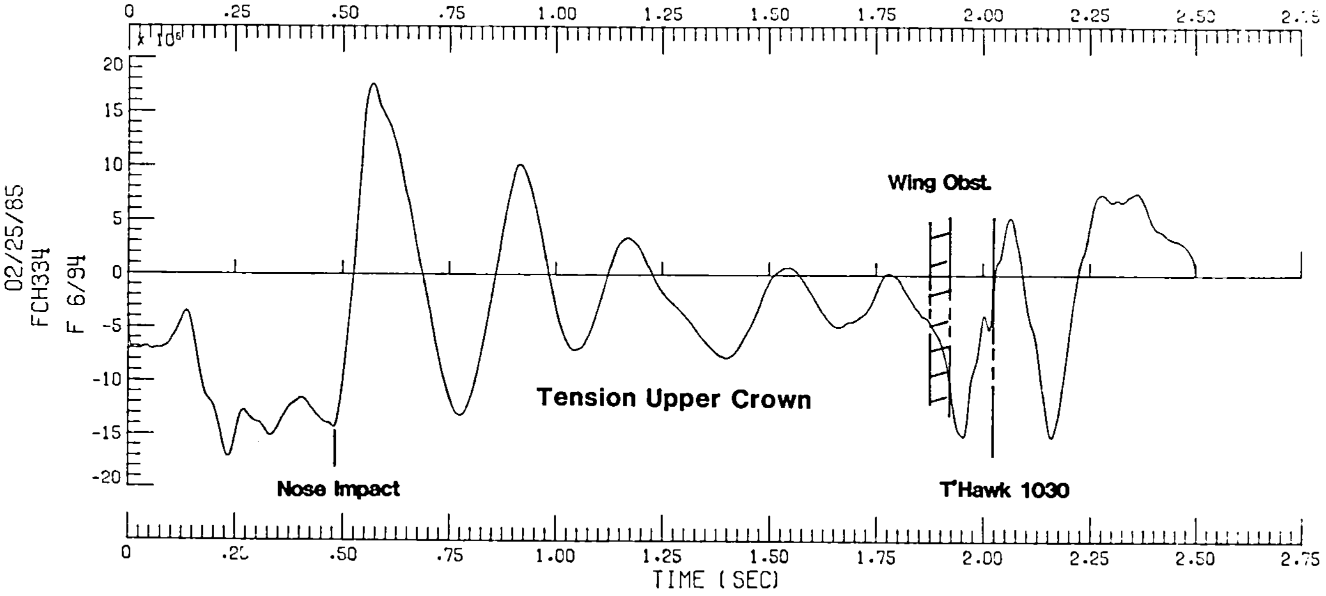
Fuselage B.S. 510 Vertical Bending



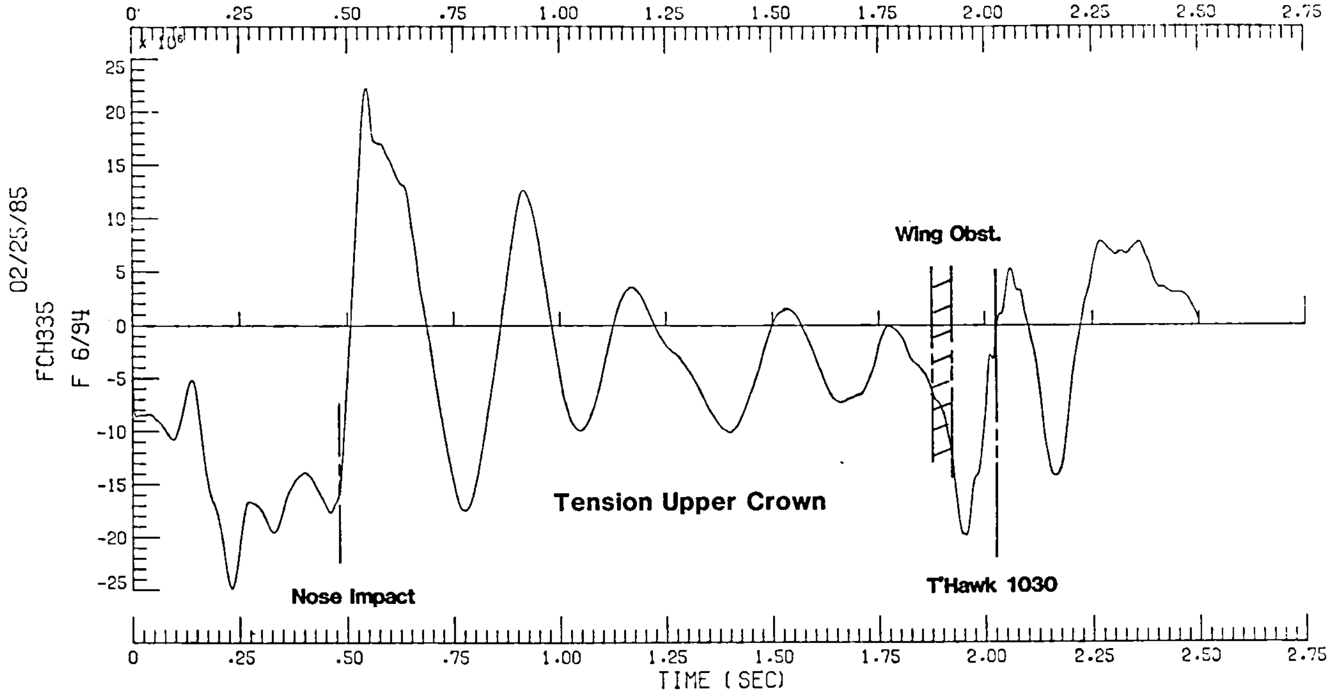
The 600J-10 time history looks essentially identical to the B.S. 510 time history. One can see the same type of response and the same time reference for the events which took place. Looking at some of the peak moment values, estimating a zero moment reference and using some ratios, one can determine airframe accelerations that seem to match measured accelerometer data. Integrating the acceleration estimates in a simplistic way results in finding velocity change estimates at B.S. 600J-10 and at Station 510 that seem to match the measured data. It appears as if the moment bridges could be used to estimate the initial impact conditions. One can see a consistency here between B.S. 510 and B.S. 600J-10. A consistency of the wave shape, frequency damping and response is noted. It appears as if the bending moment bridges performed well.

The B.S. 600J-10 peak moments exceeded those at B.S. 510 as expected.

Fuselage B.S. 600J-10 Vertical Bending (Floor)



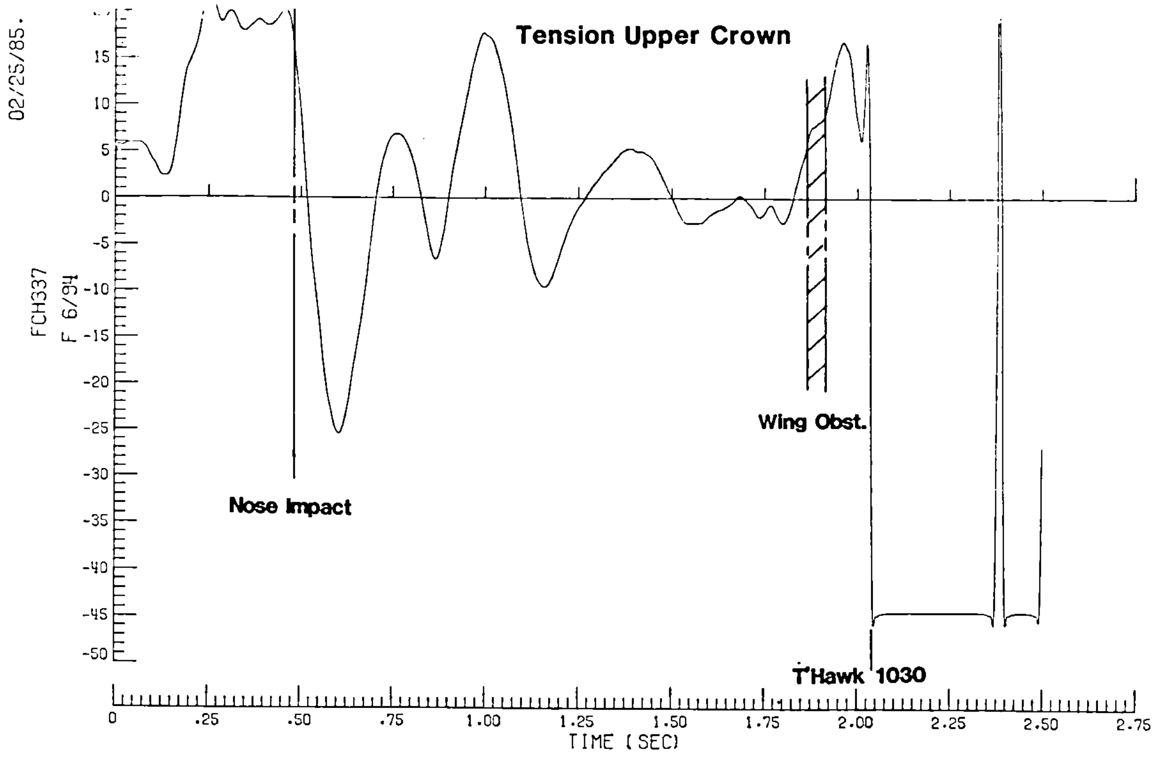
The 600J-10 lower bridge response looks just like the responses of the other bridges located in the forward fuselage. The 600J-10 (Floor) and 600J-10 (Lower) moment bridges possess the same response, shapes and magnitudes. There is consistency of readings between the bridges. This consistency of response also reflects on the technicians that installed these bridges. They did an excellent job and deserve a lot of credit for the placement and wiring of these bridges.


Fuselage B.S. 600J-10 Vertical Bending (Lower)

The shape of the aft fuselage moment time histories differs from those in the forward fuselage. The aircraft did experience both a vertical and lateral impact and that is reflected in the response of the aft fuselage moment bridges. These bridges appear to contain a vertical mode coupled with an airframe torsional mode induced by the lateral motion of the empennage.

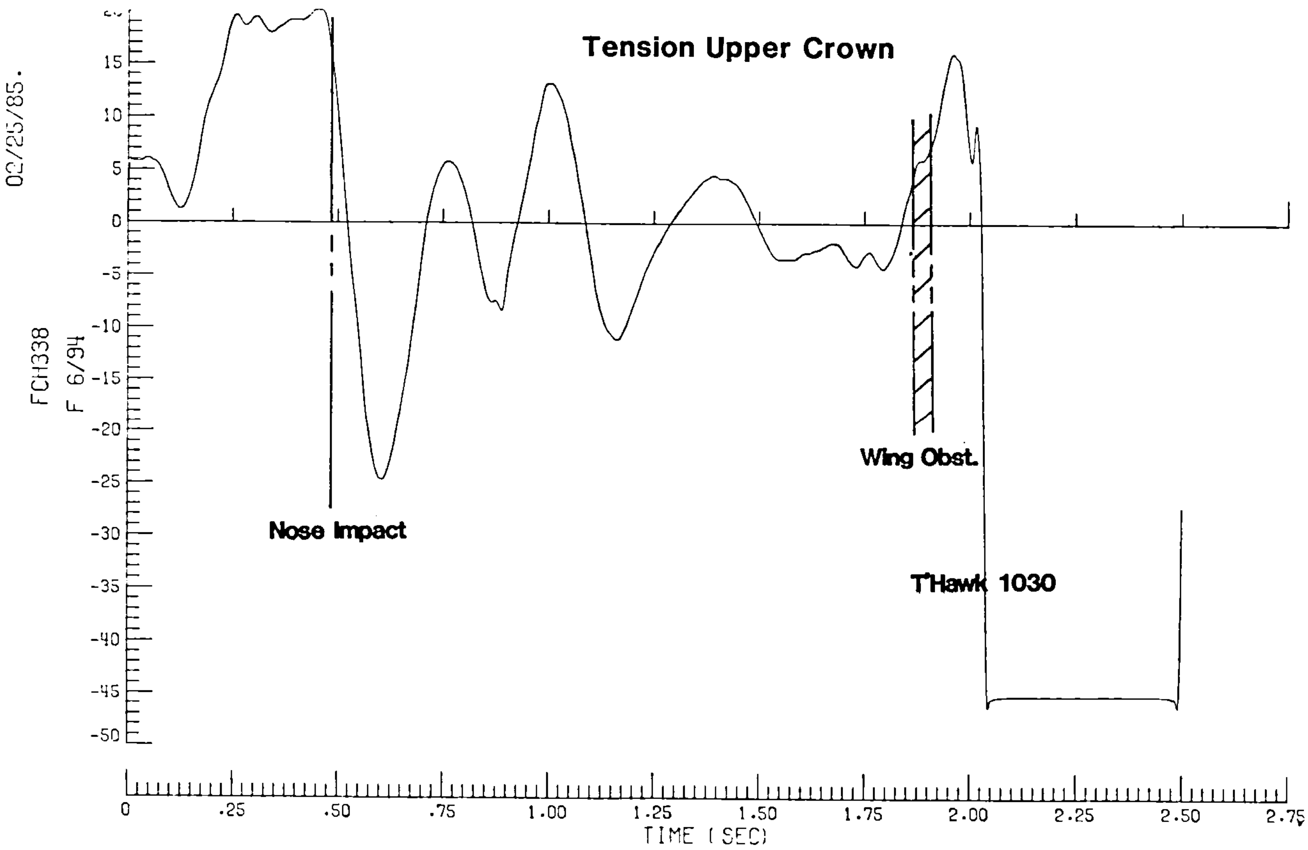
The significant events can again by observed on the moment bridge time history. It can readily be seen where the tomahawk destroyed the B.S. 1030 moment bridge with the corresponding loss of signal.

Fuselage B.S. 1030 Vertical Bending (Floor)



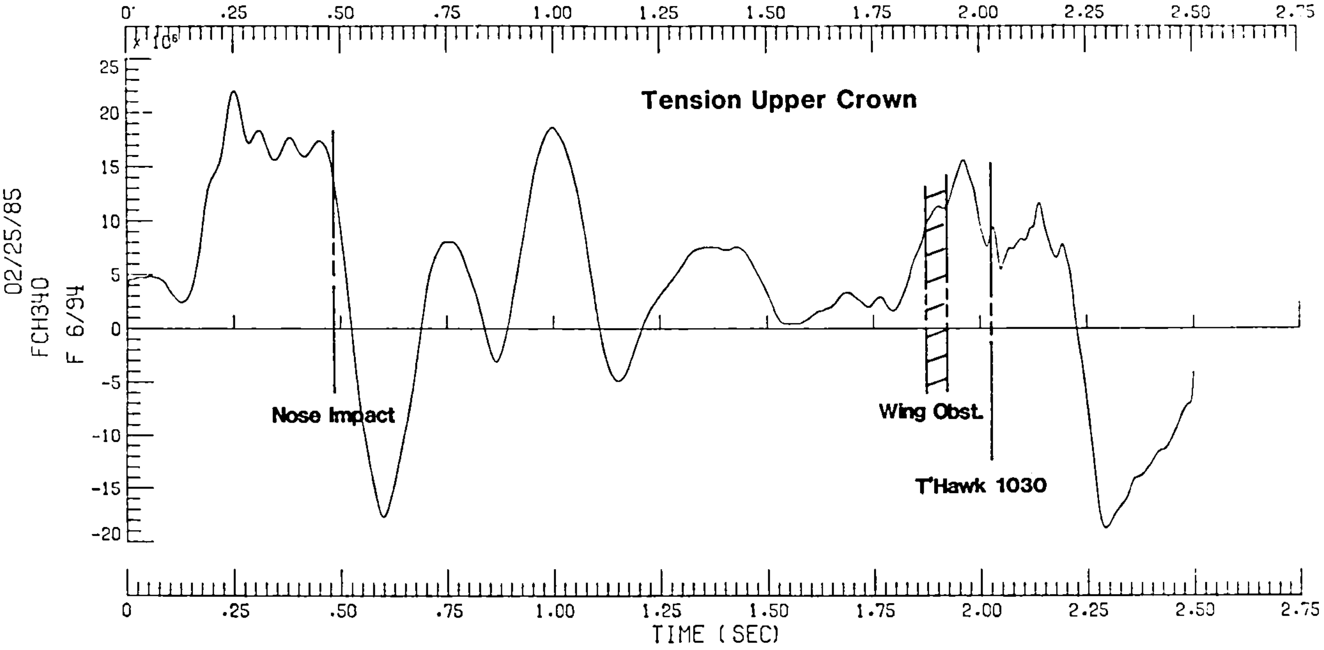
The B.S. 1030 (Lower) bridge response is essentially identical to that at B.S. 1030 (Floor). There again exists a consistency of data.

Fuselage B.S. 1030 Vertical Bending (Lower)



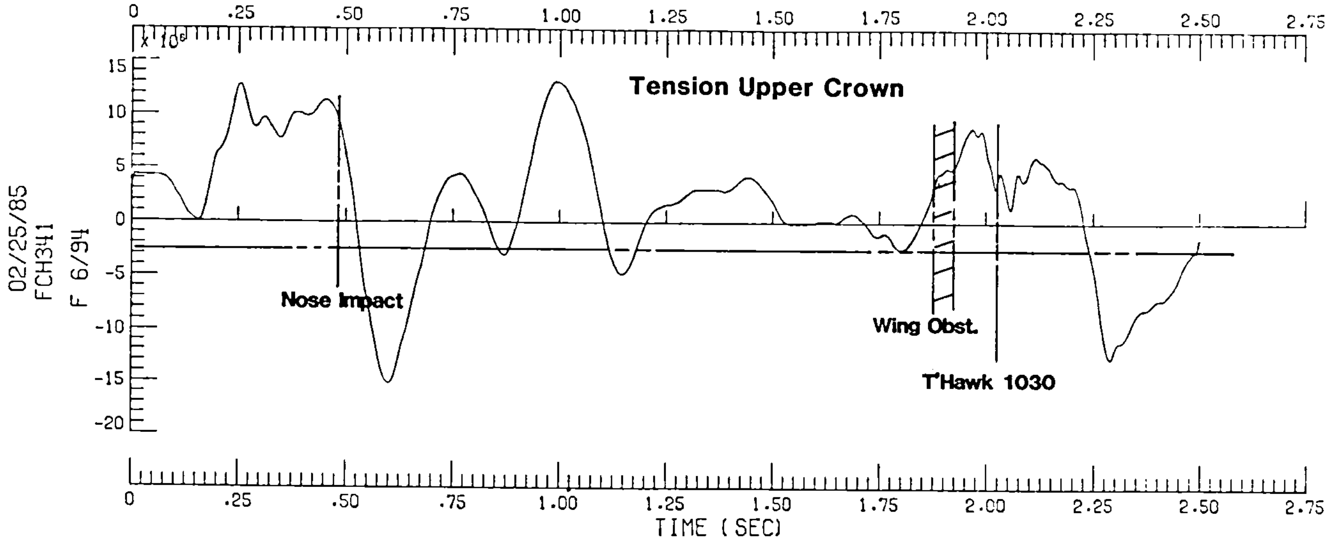
The B.S. 1030 moment bridge again demonstrates consistency of data. The magnitudes of the moments at B.S. 1130 are less than those at B.S. 1030 as expected.

Fuselage B.S. 1130 Vertical Bending



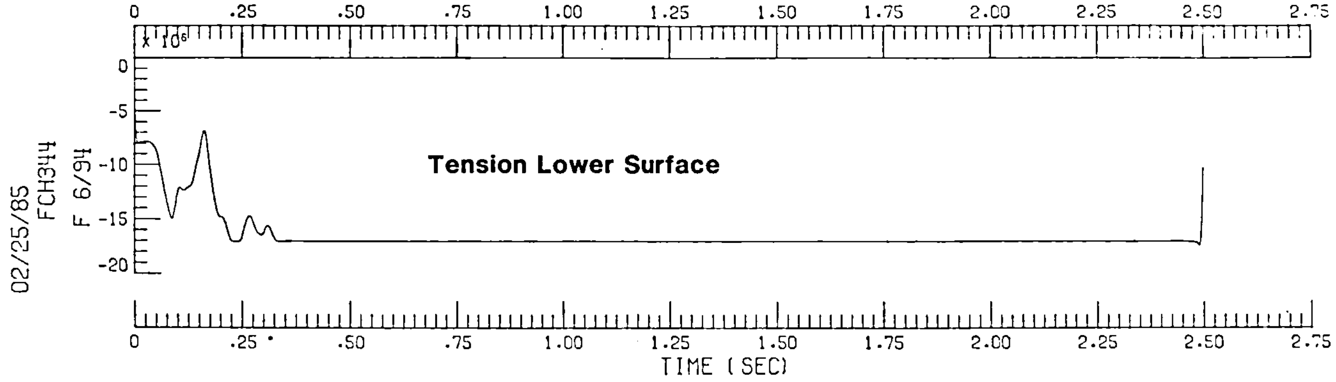
The basic response is again consistent with the other aft fuselage bridges. The magnitudes of the moments does again decrease as one goes aft along the fuselage.

Fuselage B.S. 1250 Vertical Bending



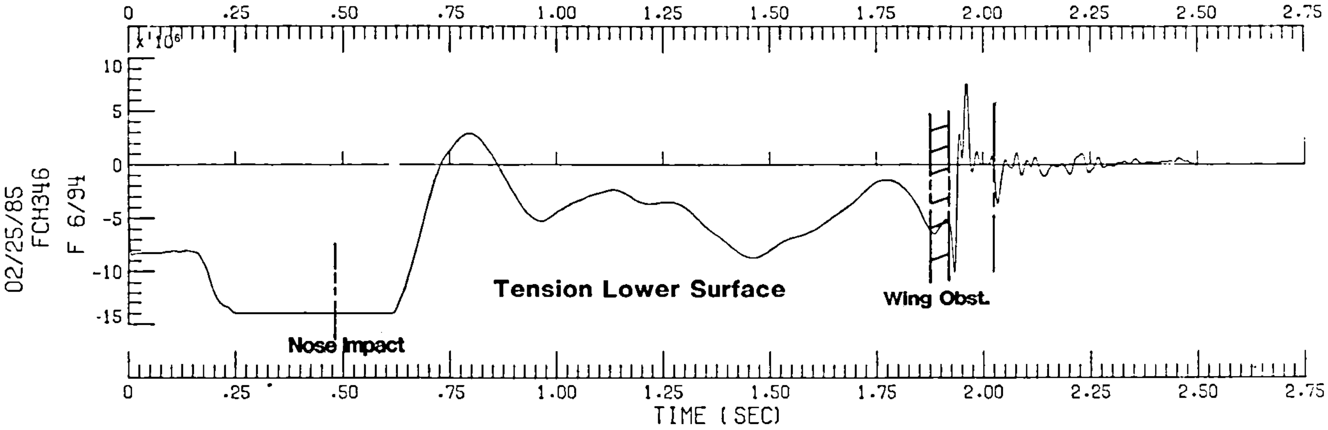
The signal from this bridge was lost soon after impact. The strain gages on the lower arm of this bridge were exposed and were not protected from ground impact and were most likely scrubbed off the surface of the wing by the ground impact.

L/H Wing (OutBd) Vertical Bending



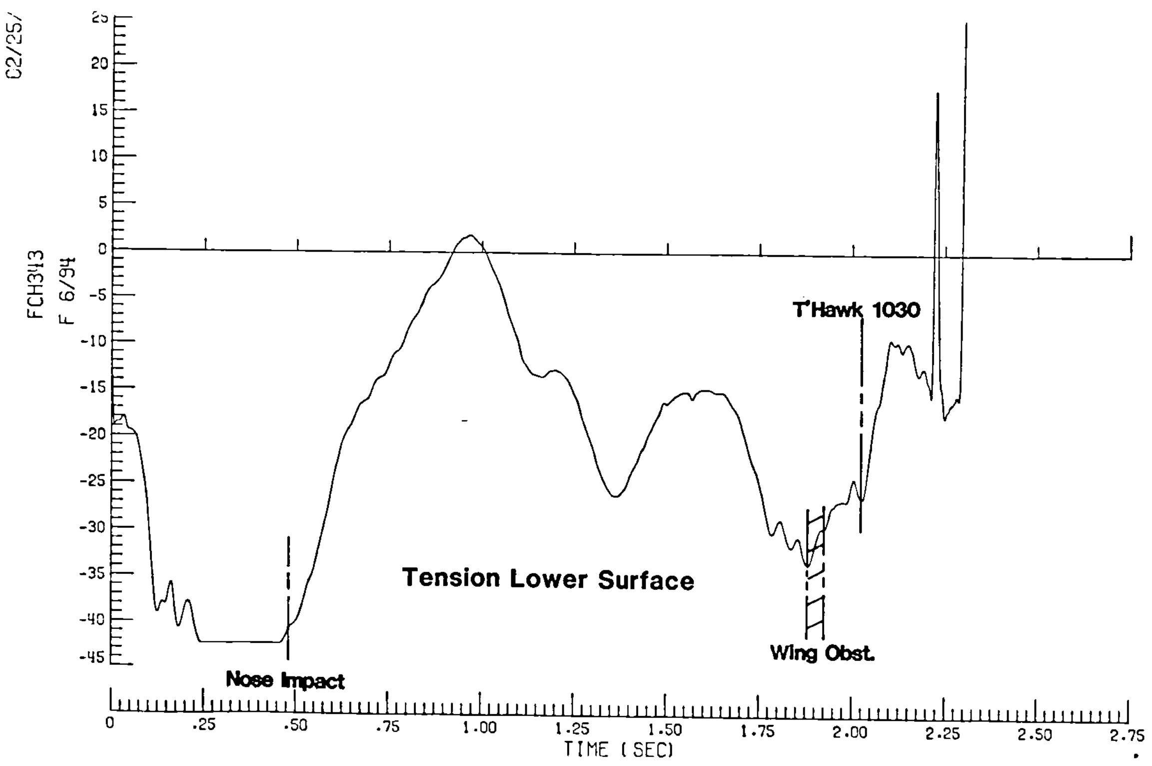
This data has yet to be analyzed; however, the encounter with the ground obstacles and subsequent loss of signal are evident. The range of the bridge was exceeded during the nose impact.

R/H Wing (OutBd) Vertical Bending



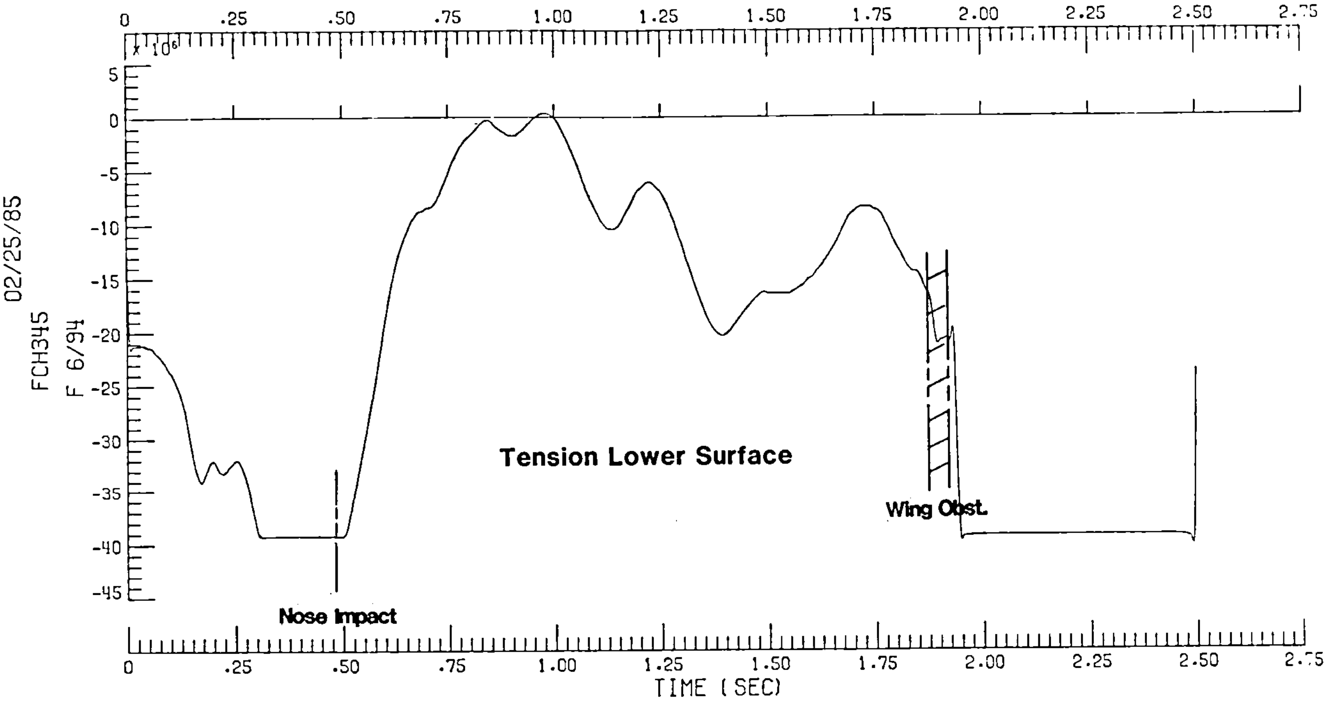
Data was recorded by the L/H wing inboard bridge. The L/H wing made ground contact. The significant events are again depicted. The range of this bridge was exceeded during nose impact. This bridge lost signal subsequent to impact with the ground obstructions.

L/H Wing (InBd) Vertical Bending



The R/H wing and L/H inboard bridges surprisingly contain almost identical responses (including magnitudes). That wouldn't be expected since the left wing made ground contact, whereas the right wing never did strike the ground. The nearly identical response between these wing bridges is not widely understood at this time.

R/H Wing (InBd) Vertical Bending



The bending bridges did achieve their goals and objectives. The data traces do provide some insight with respect to airframe loads and structural response. They demonstrate quite clearly what's happening to the airframe.

A direct quantification of metal airframe loads was measured by the moment bridges.

The measured moments can be correlated with the KRASH and DYCAST computer models.

The bending bridge data support airframe failure mechanisms analysis and provide residual airframe strength estimation. It did not appear as if any of the bending bridges on the airframe exceeded limit loads. (The observed airframe fracture was due to the fuselage encounter with the tomahawk which tore out the keel beam.)

The airframe bridges can be used to estimate the impact conditions and those estimates are correlating with some of the other data measurements.

Structural response, frequency and structural damping are readily measured by the moment bridges.

Bending Bridge Instrumentation Achieved Goals/Objectives

Data Traces Provide Insight with Respect to Airframe Loads and Structural Response

Airframe Loads

- Direct Quantification of Baseline Metal Airframe Loads
- Measured Moments can be Correlated with Krash/Dycast Models
- Supports Analysis of Failure Mechanisms and Estimation of Residual Airframe Strength
- May be Used to Estimate Impact Conditions

Structural Response

- Frequency
- Structural Damping