N88-22390

# THE COMPOSITE BLADE STRUCTURAL ANALYZER (COBSTRAN)

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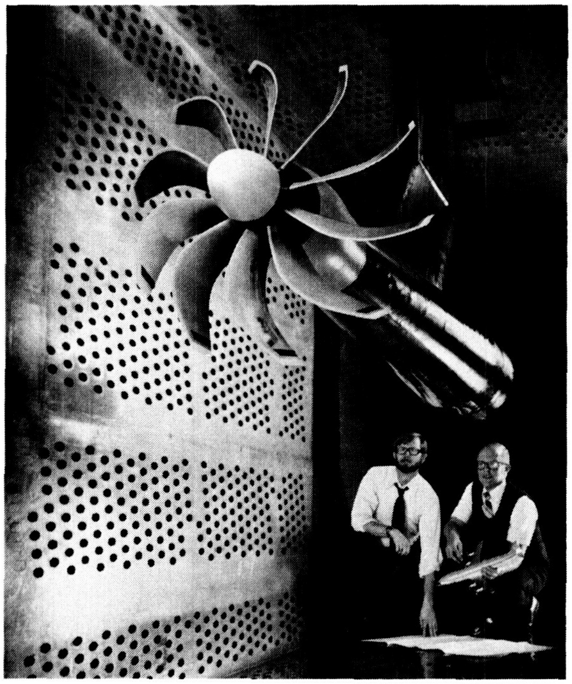
## ABSTRACT

The use and application of the COBSTRAN (COmposite Blade STRuctural ANalyzer) computer code is presented. COBSTRAN was developed at the NASA Lewis Research Center and is currently being used for the design and analysis of aircraft engine ducted and unducted fan blades. The features of COBSTRAN are demonstrated for the modeling and analysis of a scaled-down wind tunnel model propfan blade made from fiber composites. Comparison of analytical and experimental mode shapes and frequencies are shown, verifying the model development and analysis techniques used. The methodologies and programs developed for this analysis are directly applicable to other propfan blades.

TURBOPROP INSTALLATION IN LEWIS RESEARCH CENTER WIND TUNNEL

An advanced turboprop is shown installed for testing in the NASA Lewis Research Center 8 Foot by 6 Foot Transonic Wind Tunnel. This turboprop is 2 ft in diameter with blades swept back at an angle of 60° measured tangent to the leading edge at three-quarter span. The individual blades are twisted about the spanwise axis, swept aft, and curved about the axis of rotation. The blades shown are made of titanium and were tested at speeds up to approximately 8000 rpm.





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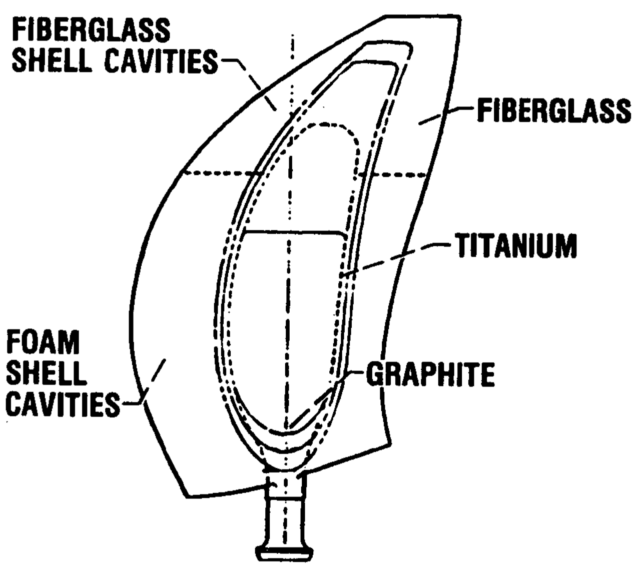
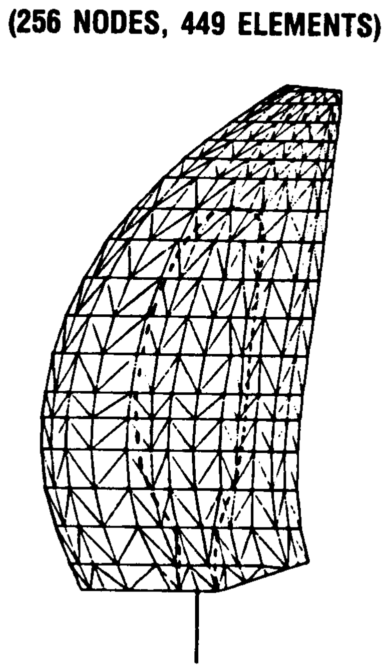
COBSTRAN MODELING OF A SPAR/SHELL COMPOSITE TURBOPROP BLADE

This scaled-down version of a large advanced turboprop blade (Hirschbein et al., 1985) is designed with an internal solid titanium spar which is extended to form the blade shank. Layers of unidirectional graphite/epoxy plies are attached directly over the spar. The airfoil shell surrounding the spar is made of fiberglass/epoxy cross-weave plies. The shell cavity in the lower two-thirds of the blade is filled with foam and the cavity in the upper-third is filled with fiberglass/epoxy cross-weave plies. The finite element model of this blade was generated by using the COBSTRAN (COmposite Blade STRuctural ANalyzer) code. The model consists of 449 two-dimensional triangular elements and a bar element representing the shank. COBSTRAN calculates the anisotropic material properties at each grid point using laminate theory, and the individual ply properties are calculated by the COBSTRAN composite micromechanics module. Grid point properties are then averaged for each element.

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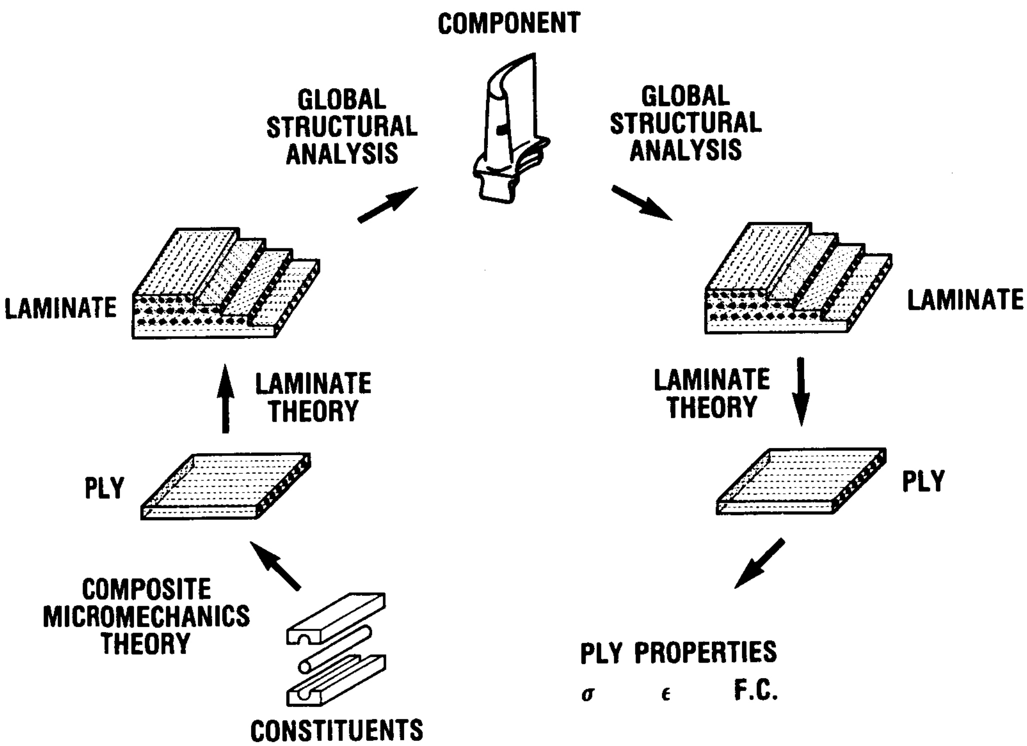
## COBSTRAN ANALYTICAL PROCESS

The COBSTRAN code contains an internal databank of constitutive properties for 21 fiber types and 17 matrix types. Starting with these properties the composite ply properties are calculated for each fiber/matrix layer used in the design of the blade (Chamis, 1971). The ply layup at each grid point is determined by COBSTRAN, and the grid point properties are calculated using laminate theory. A global structural finite element analysis model is generated, and the applicable structural analysis is performed. Stress results from this analysis are evaluated and corresponding membrane forces and moments are calculated for each grid point. From these forces and moments, using laminate theory, individual ply stresses, strains, and failure criteria are calculated for each ply layer at each grid point.

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## COBSTRAN GENERATED PLY PROPERTIES VERSUS MANUFACTURER'S TEST VALUES

The COBSTRAN code is designed to generate individual ply properties from the constitutive properties of the fiber and matrix. A unique feature of COBSTRAN, in addition to its internal databank, is that an external user-supplied databank will override the internal databank. This feature is utilized to generate ply properties compatible with a particular manufacturer's test results. The external databank is modified and the COBSTRAN preprocessor is used iteratively to generate the desired properties. The table below shows the results of COBSTRAN generated values versus manufacturer's test values. There exist some discrepancies when isotropic material properties are calculated from fiber and matrix micromechanics equations. However, this representation is necessary because COBSTRAN, internally, requires more ply properties than can be obtained from tests.

| UNITS, ksi | SOURCE | FIBERGLASS (0°/90° CROSS-WEAVE 0.0055-IN. THICK) | PAINT (0°/90° CROSS-WEAVE 0.002-IN. THICK) | GRAPHITE (0°/0° LAY-UP 0.007-IN. THICK) | TITANIUM | FOAM |
|---|---|---|---|---|---|---|
| $E_1$ | COBSTRAN | 3 516 | 2 370 | 13 730 | 16 000 | 9.800 |
| | MFG | 3 510 | 2 370 | 13 800 | 16 000 | 9.800 |
| $E_2$ | COBSTRAN | 3 500 | 2 340 | 1 010 | 16 000 | 9.889 |
| | MFG | 3 510 | 2 370 | 1 090 | 16 000 | 9.800 |
| $E_{12}$ | COBSTRAN | 737 | 511 | 480 | 6 190 | 4.944 |
| | MFG | 767 | 517 | 580 | 6 100 | 3.630 |

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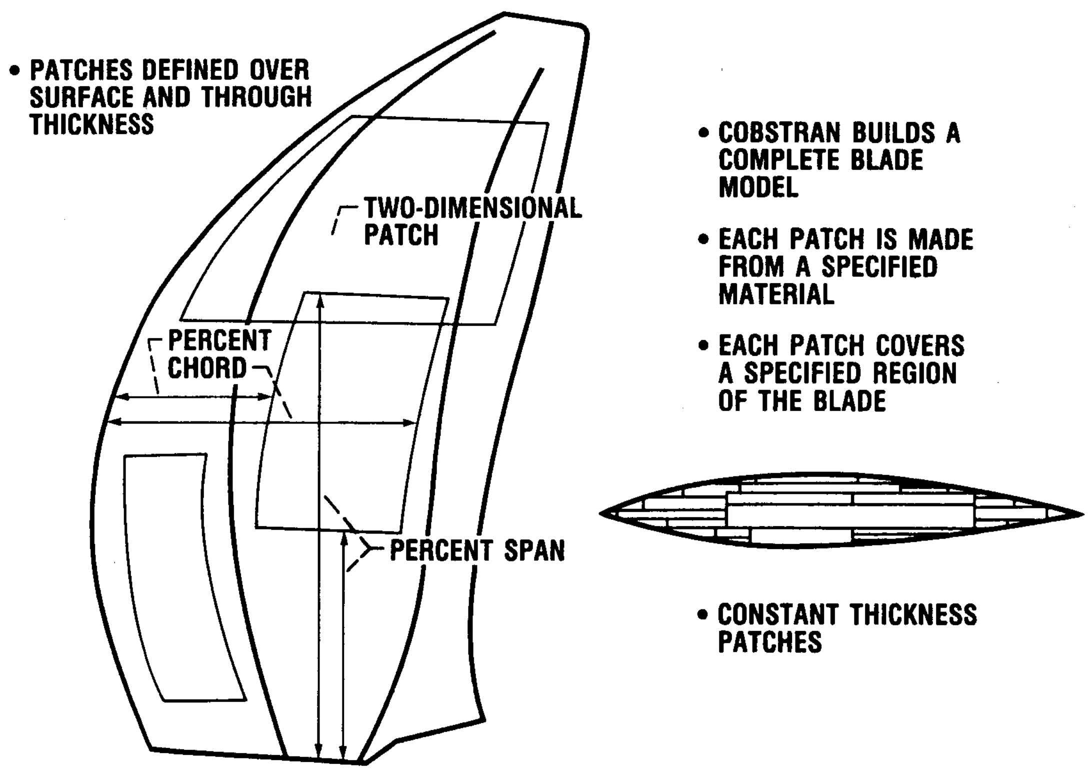
The COBSTRAN code produces an integrated lamination model of an entire blade from user-defined constant thickness patches over the surface of the blade and through the thickness. Each patch is made from a specified material system (fiber, matrix, thickness, orientation angle, fiber volume ratio, etc.) and covers a specified region of the blade defined by percent span and percent chord. The integration of these patches for each grid point is determined by COBSTRAN from a user-supplied global layup order.

## COBSTRAN PLY INPUT REPRESENTATION

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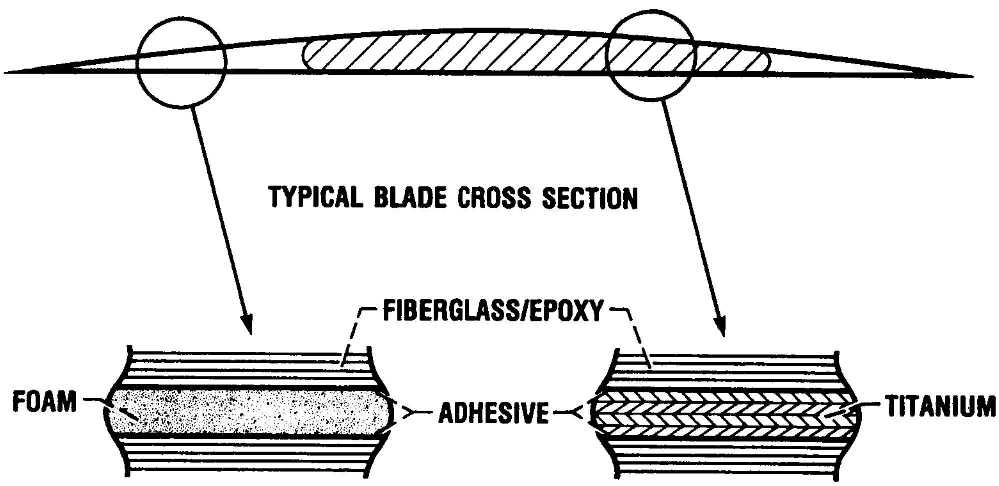
## COBSTRAN TWO-DIMENSIONAL LAMINATED BLADE MODELING

The typical advanced composite turboprop blade cross-section shown is designed utilizing a solid internal metal spar and a composite airfoil shell. Shell cavities in the leading and trailing edges are foam filled. This complex blade structure can be simulated effectively by two-dimensional finite elements with one element through the thickness. By modeling the metal, foam, and adhesive as ply layers and utilizing the COBSTRAN code, the two-dimensional anisotropic material properties are calculated for each grid point by laminate analysis. Grid point properties are then averaged for each element.

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## EFFECTS OF MATERIAL PROPERTY COMBINATIONS ON FREE FREQUENCIES

The COBSTRAN code calculates the bending, membrane, transverse shear properties, and the membrane-bending coupling relationship for all elements of the composite turboprop blade. These properties may be selectively used in the finite element analysis. The contribution of a particular material property to the frequency is a function of the blade activity indicated by the mode shape of vibration. Three different material combinations were considered for this study. Coupling was not a factor because of symmetry in the blade layup. Results are compared with holographic test frequencies (Mehmed, 1983). For the column labeled "Bending" bending properties were used to represent bending and membrane properties. Transverse shear effects were considered negligible. For the column labeled "Membrane and Bending" both properties were used separately in the analysis. Transverse shear effects were considered negligible. For the third column, all three properties were used in the analysis.

| MODE | ELEMENT PROPERTIES USED IN ANALYSIS | | | HOLOGRAPHIC TEST RESULTS, Hz |
|---|---|---|---|---|
| | BENDING, Hz | MEMBRANE AND BENDING, Hz | MEMBRANE, BENDING AND TRANSVERSE SHEAR, Hz | |
| 1 | 154 | 158 | 147 | 155 |
| 2 | 338 | 339 | 334 | 326 |
| 3 | 373 | 369 | 364 | 377 |
| 4 | 585 | 571 | 561 | 545 |
| 5 | 655 | 650 | 635 | 638 |
| 6 | 1011 | 1005 | 986 | 921 |

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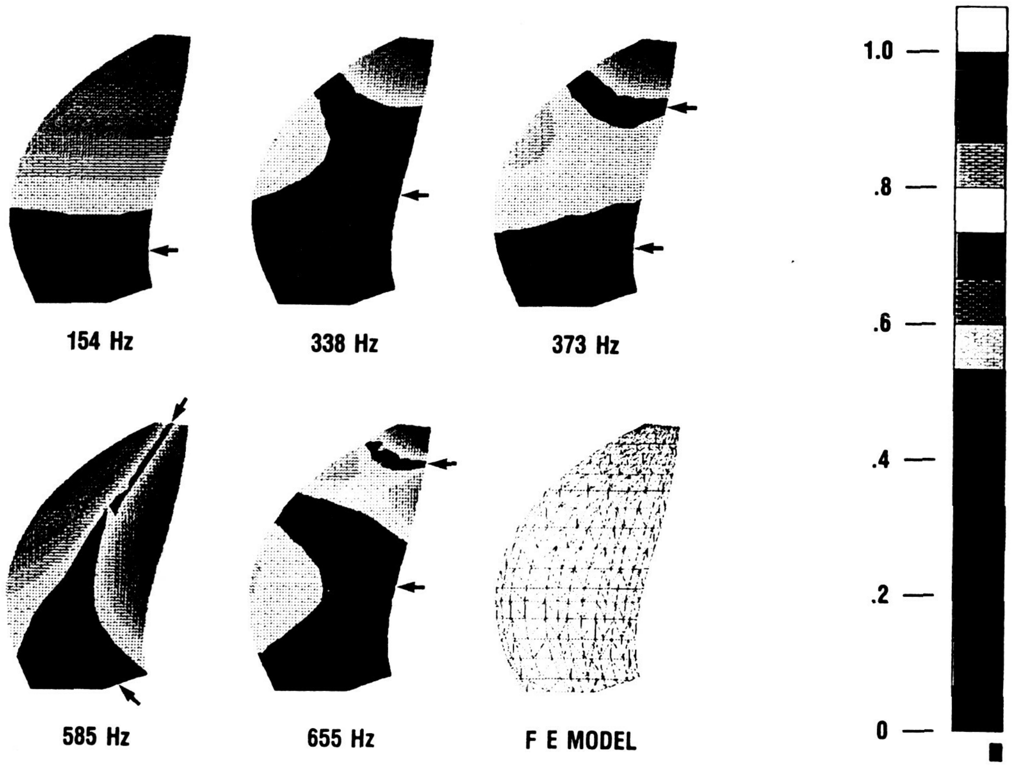
PREDICTED NATURAL FREQUENCIES AND MODE SHAPES

The first five calculated frequencies and mode shapes are represented for a composite turboprop blade. The finite element model used for this analysis was generated by utilizing the COBSTRAN code. Eigenvectors were normalized to the maximum tip displacement. The solid black surfaces (see arrows) indicate areas of zero or negligible motion during each natural vibration mode. Predicting these mode shapes is important to understanding and analyzing blade flutter characteristics.

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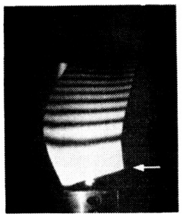
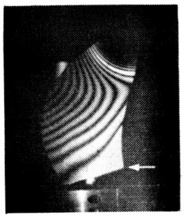
MEASURED NATURAL FREQUENCIES AND MODE SHAPES

The first seven frequencies and mode shapes shown were experimentally determined. The composite blade was acoustically excited and photographed with a holographic technique (Mehmed, 1983). The solid bright surfaces (see arrows) indicate areas of zero or negligible motion during each natural vibration mode. These frequencies and mode shapes are comparable to those calculated with a finite element model generated by the COBSTRAN code.

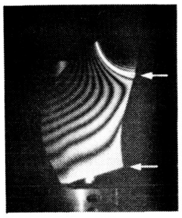
## MEASURED NATURAL FREQUENCIES AND MODE SHAPES



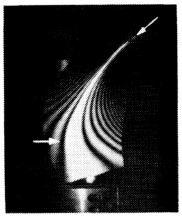
1F
155 Hz



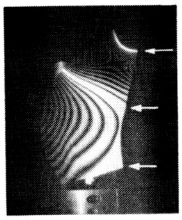
1E
326 Hz



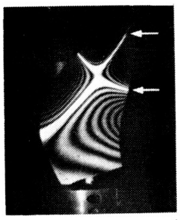
2F
377 Hz



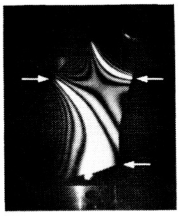
1T
545 Hz



3F
638 Hz



2T
921 Hz



4F
996 Hz

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## FREQUENCY SENSITIVITY TO STRUCTURAL AND LOAD CONSIDERATIONS

The ability to predict frequencies and mode shapes early in the design phase is important to the development of composite turboprop blades. The effects of airloads, protective paint, and a shank (instrumentation) hole on frequencies have been studied. Airloads and shank hole effects were not significant considerations in the analysis of this turboprop blade. However, the protective paint layer, 0.002-in. thick, did affect the frequency calculations. The paint on the blade surface tended to reduce the calculated frequencies enough to be included in all analyses. The last column shows results from an independent finite element analysis (Nagle et al., 1986).

[NATURAL FREQUENCIES (Hz) AT 7484 rpm, AIRLOADS AT 35 000-ft ALTITUDE.]

| MODE | FREQUENCY, Hz | | | | |
|---|---|---|---|---|---|
| | WITH AIRLOADS, WITH PAINT, WITH SHANK HOLE | WITHOUT AIRLOADS, WITH PAINT, WITH SHANK HOLE | WITH AIRLOADS, WITHOUT PAINT, WITH SHANK HOLE | WITH AIRLOADS, WITH PAINT, WITHOUT SHANK HOLE | WITH AIRLOADS, WITHOUT PAINT, WITHOUT SHANK HOLE (F.E. ANALYSIS) |
| 1 | 202.30 | 202.04 | 205.13 | 202.15 | 207.5 |
| 2 | 366.28 | 366.34 | 374.16 | 367.07 | 376.0 |
| 3 | 461.41 | 459.83 | 462.08 | 460.07 | 468.6 |
| 4 | 623.32 | 626.27 | 634.05 | 626.40 | 642.5 |
| 5 | ------ | 780.39 | 786.05 | 780.67 | 782.3 |

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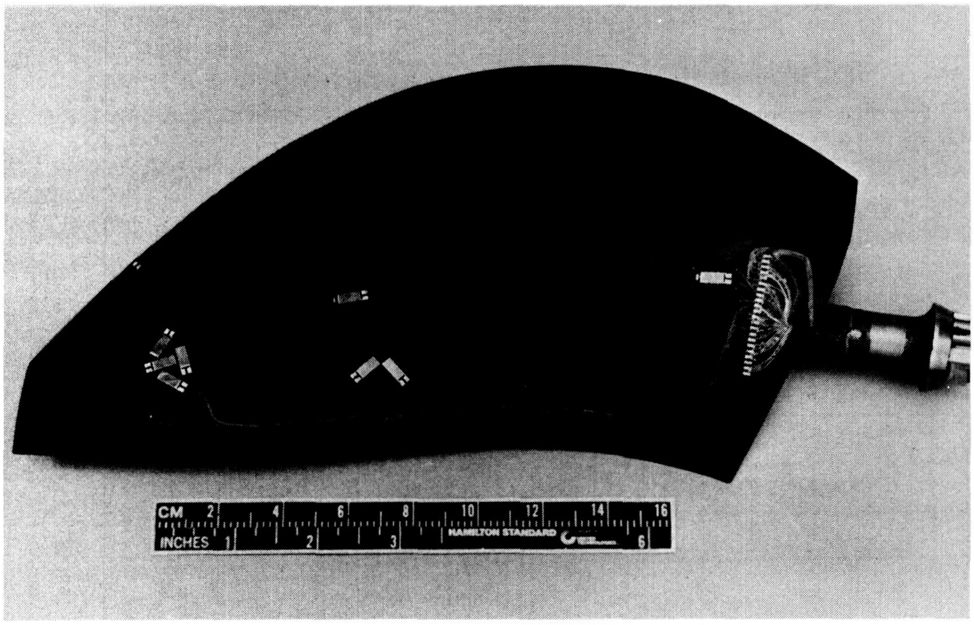
## TURBOPROP BLADE INSTRUMENTED FOR STRAIN MEASUREMENT

This instrumented turboprop blade was used to evaluate strain results during vibration testing. The COBSTRAN code was used to determine strain gage placement prior to testing. COBSTRAN calculates the strains in all ply layers at each grid point. Relative strain values were calculated by using the normalized eigenvectors as displacements. This identified the areas of largest strain for each vibration mode. During rotational tests the critical strain conditions were flagged by knowing the relation between the measured strains and high strain areas.

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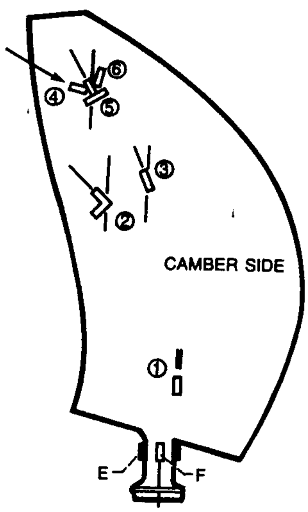
## PREDICTED VERSUS MEASURED NORMALIZED SURFACE STRAINS

The first figure shows the position of six strain gages on the camber surface of a composite turboprop blade. Gage positions were determined with the COBSTRAN code. The blade was excited in the third mode of vibration. The table shows the results of measured (Mehmed, 1983) and calculated strains for this vibration mode. The actual strains were very small and difficult to measure. Both sets of data were normalized to gage number 4. Gage number 2 failed and therefore is not shown in the table. Comparison was good overall, with gage number 1 showing the largest discrepancy. This gage was located on the thickest part of the blade, the most difficult area to measure strain.




**STRAINS NORMALIZED TO GAGE NUMBER 4 (THIRD MODE OF VIBRATION)**

| GAGE NUMBER | MEASURED DATA | COBSTRAN ANALYSIS |
|---|---|---|
| 1 | 0.152 | 0.106 |
| 3 | .386 | .340 |
| 4 | 1.000 | 1.000 |
| 5 | .519 | .650 |
| 6 | .122 | .144 |
| E | .377 | .440 |
| F | .152 | .138 |

**NOTE: GAGES E AND F SHOWN OUT OF TRUE CIRCUMFERENTIAL POSITION**

**LOCATION AND ORIENTATION OF STRAIN GAGES ON CAMBER/ CONVEX SURFACE**

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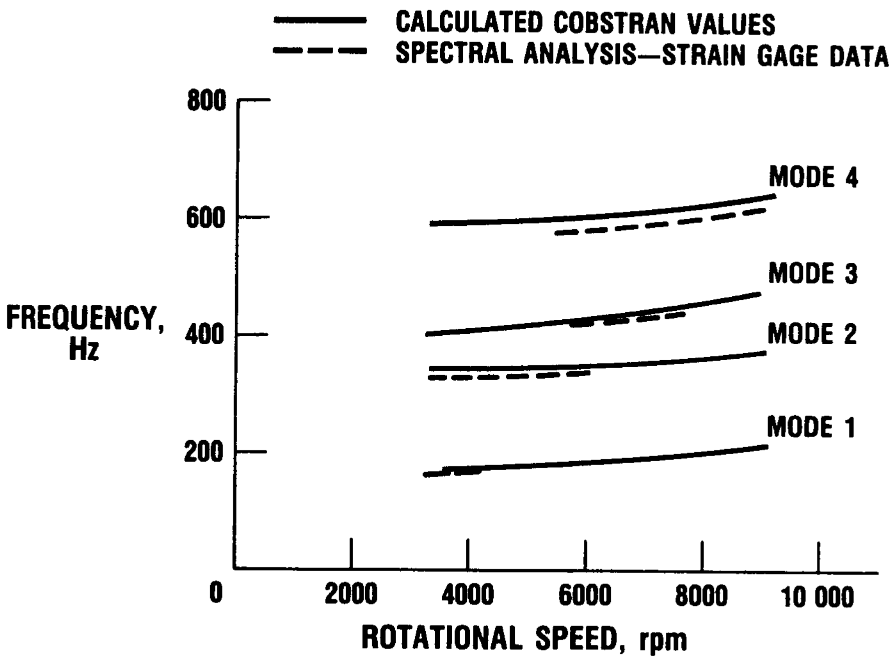
## CALCULATED AND TEST FREQUENCIES VERSUS ROTATIONAL SPEED

The ability to predict blade frequencies when a blade is subjected to centrifugal forces is important in the design of composite turboprop blades (Aiello and Chamis, 1982). The calculated frequencies were generated by using a finite element model that was generated by the COBSTRAN code. These are indicated by the solid lines. The measured frequencies were obtained by spectral analysis of strain gage data resulting from tests in the NASA Lewis 9 Foot by 15 Foot Wind Tunnel (Mehmed, 1983) and are indicated by the dashed lines.

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Aiello, R.A. and Chamis, C.C., 1982, "Large Displacement and Stability Analysis of Nonlinear Propeller Structures, NASA TM-82850.

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Mehmed, O., 1983, "SR7A Propfan Model Blade S/N 16: Vibration Test Results and Blade Strain Gage Limits for SR7A."

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