

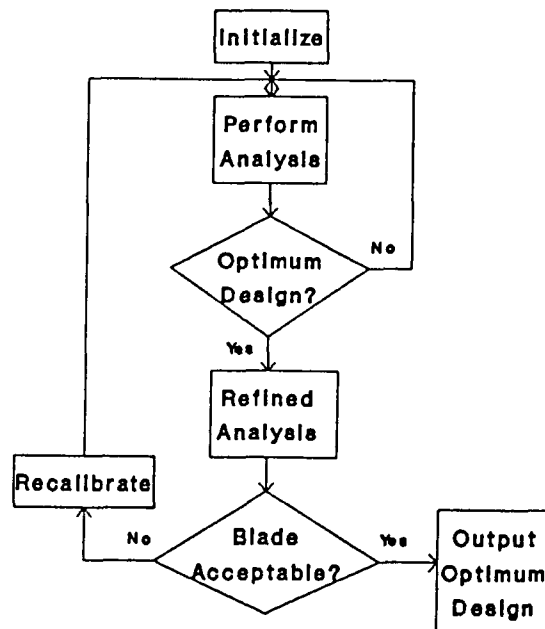
**N89-25165****STRUCTURAL TAILORING OF COUNTER ROTATION PROPFANS****NAS3-23941****K. W. BROWN  
PRATT & WHITNEY AIRCRAFT  
EAST HARTFORD, CT****AND****D. A. HOPKINS  
NASA LEWIS RESEARCH CENTER  
CLEVELAND, OHIO****PRECEDING PAGE BLANK NOT FILMED**

THE STAT PROGRAM PREVIOUSLY APPLIED  
ONLY TO SINGLE ROTATION PROPFANS

The STAT program (refs 1 and 2) was designed for the optimization of single rotation, tractor propfan designs. New propfan designs, however, generally consist of two counter rotating propfan rotors.

STAT is constructed to contain two levels of analysis. An interior loop, consisting of accurate, efficient approximate analyses, is used to perform the primary propfan optimization. Once an optimum design has been obtained, a series of refined analyses are conducted. These analyses, while too computer time expensive for the optimization loop, are of sufficient accuracy to validate the optimized design. Should the design prove to be unacceptable, provisions are made for recalibration of the approximate analyses, for subsequent reoptimization.

- OPTIMIZATIONS ARE PERFORMED USING APPROXIMATE ANALYSES
- REFINED ANALYSES ARE USED TO RECALIBRATE APPROXIMATE SOLUTIONS

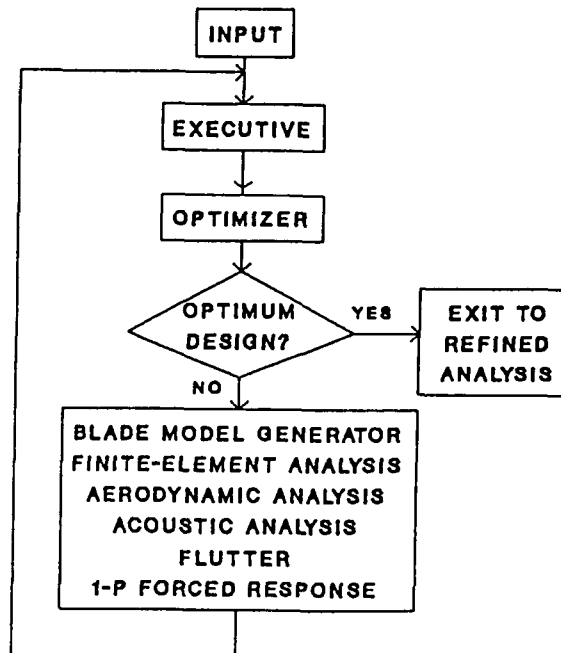


**THE STAT APPROXIMATE OPTIMIZATION  
SYSTEM IS HIGHLY MODULAR**

The STAT system has been constructed such that all analysis packages are highly modular. As appropriate, new analytical capabilities may quickly be installed into the STAT system. This tactic has proved valuable in the process of upgrading STAT for counter rotation propfans.

STAT execution is controlled by an executive module. The ADS optimization package (ref 3) is utilized to select a new geometry for evaluation. Each candidate design is analyzed to determine its efficiency and acoustic emissions characteristics. Structural response, including stress and vibrations, are determined using a large deflection finite-element analysis. Flutter and 1-P forced response analyses are performed using the modal outputs from the finite-element analysis.

- EXECUTIVE SYSTEM CONTROLS MODULE EXECUTION, DATA STORAGE
- ANALYSIS PACKAGES ARE EASILY REPLACED
- OPTIMIZER SELECTS THE NEW CONFIGURATION FOR ANALYSIS



**STAT HAS BEEN ENHANCED TO  
OPTIMIZE COUNTER ROTATION PROPFANS**

To provide for the capability to optimize counter rotation propfans, many of the STAT modules required significant upgrading. The capability to input data for a rear rotor was added to STAT, while preserving the single-stage optimization capability. Counter rotation capabilities were added to the STAT aerodynamic analysis. A second finite-element analysis was added to account for the rear rotor. The acoustics analysis was upgraded from a regression analysis to a closed-form analytical procedure. The STAT objective function was enhanced to properly evaluate the cost of counter rotation propfan configurations.

- **INPUTS - TWO BLADES**
- **AERODYNAMICS - ANALYSIS FOR TWO-STAGE ROTOR**
- **FINITE-ELEMENT ANALYSIS - TWO SEPARATE ANALYSES ARE CONDUCTED**
- **ACOUSTICS - IMPROVED ANALYSIS**
- **OBJECTIVE FUNCTION - ENHANCED FOR TWO-STAGE ROTOR**

**SEVERAL DESIGN VARIABLES AND  
CONSTRAINTS HAVE BEEN ADDED TO STAT**

The original version of STAT allowed for significant variation of the original propfan design. This capability has been maintained in the new version of STAT, with, additionally, a full complement of design variables for the rear rotor, as well as rotor-to-rotor design variables, including blade count, rotor spacing, and rotor rotation speed.

A full set of design constraints is available for the rear rotor, including stress, resonance, flutter, and forced response limits. Additionally, n-P forced response limits have been added, along with axial clashing, total power, and rotor torque split constraints.

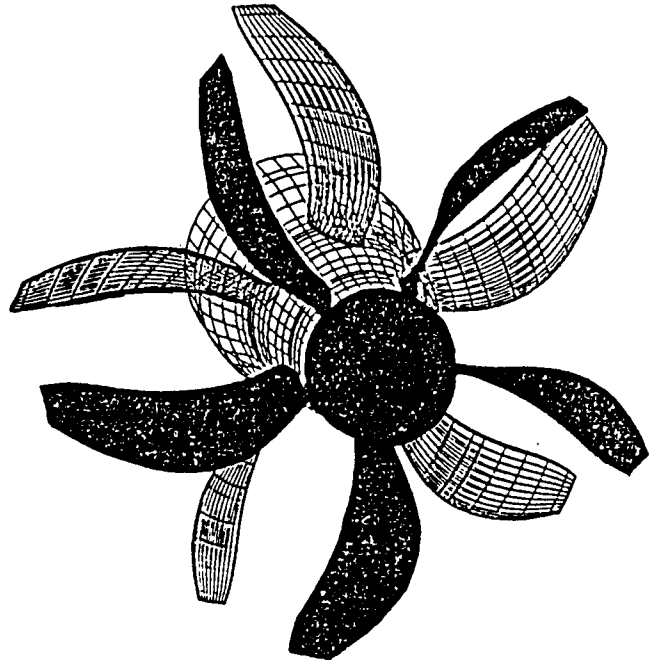
- **ADDED DESIGN VARIABLES:**
  - **REAR ROTOR BLADE DEFINITION**
  - **BLADE COUNT**
  - **ROTOR SPACING**
  - **ROTOR ROTATION SPEED**
  
- **ADDED CONSTRAINTS:**
  - **n-P FORCED RESPONSE**
  - **AXIAL CLASHING**
  - **TOTAL POWER**
  - **TORQUE SPLIT**

STAT IS USING A FULL-SCALE  
CRP VERIFICATION CASE

As verification of the STAT counter rotation optimization capability, the CRP-X1 counter rotation propfan model blade (NAS3-24222) has been selected. Available wind tunnel test data will provide an excellent opportunity to compare the STAT approximate analyses with actual test results.

The CRP-X1, scaled to full size, with spar-shell construction, will provide an excellent optimization vehicle to test the capability of STAT.

- TEST CASE BENEFITS FROM CRP-X1 SCALE MODEL TEST EXPERIENCE
- STAT VERIFICATION IS STUDYING A FULL-SIZE CRP
- LAP TYPE OF SPAR-SHELL CONSTRUCTION IS EMPLOYED



CR-STAT VERIFICATION:  
CRP-X1 SCALE-MODEL PROPFAN

STAT approximate analysis results have been compared with detailed finite-element analysis and with available wind tunnel test data for the CRP-X1 solid metal scale-model propfan.

Very good at-speed frequency correlations are noted between both finite-element analyses and data taken from test. Comparisons of maximum radial stress between the two finite-element analyses also show a very good agreement.

- BASELINE CALIBRATION - WIND TUNNEL DATA FROM CRP-X1 SCALE-MODEL PROPFAN

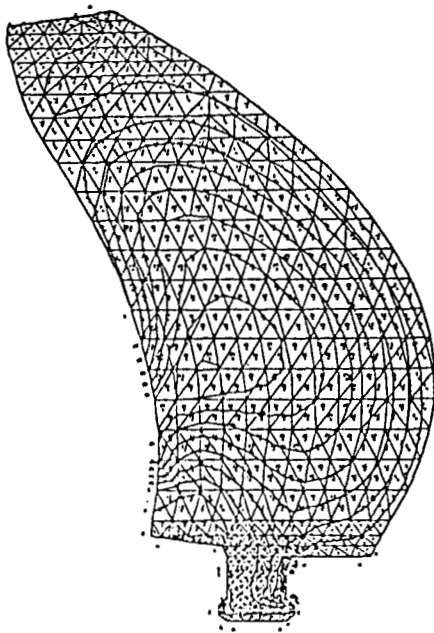
		<u>STAT</u>	<u>REFINED</u>	<u>TEST</u>
• MAX STRESS, KSI		43	42	
• NATURAL FREQUENCY, CPS	f1:	217	215	200
	f2:	488	470	440
	f3:	624	675	680

CRP-X1 APPROXIMATE STRESS DISTRIBUTIONS  
AGREE WITH REFINED ANALYSIS

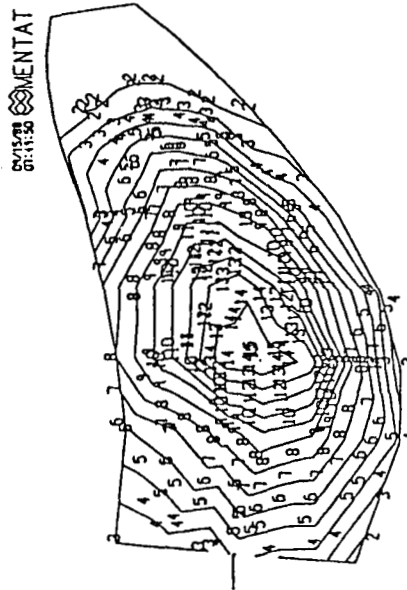
Comparisons of radial stress distributions for the camber side of the front blade of the CRP-X1 show that the approximate STAT finite-element analysis is quite accurate for both stress values and stress distributions. Similar comparisons are noted for other steady stress components.

BESTRAN ANALYSIS

FRONT BLADE  
7650 RPM, Steady Stress ksi  
Cruise Camber Side (Spanwise)



STAT APPROXIMATE ANALYSIS

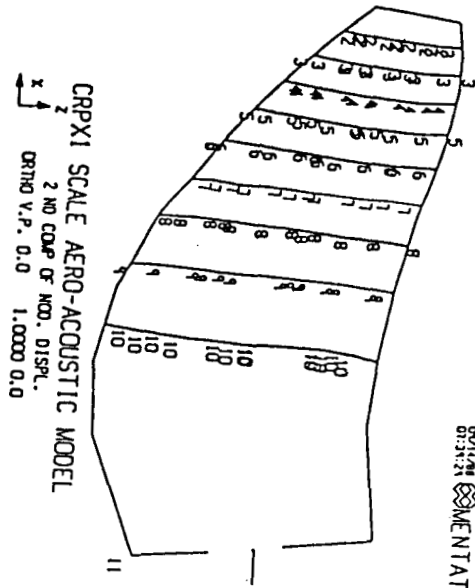
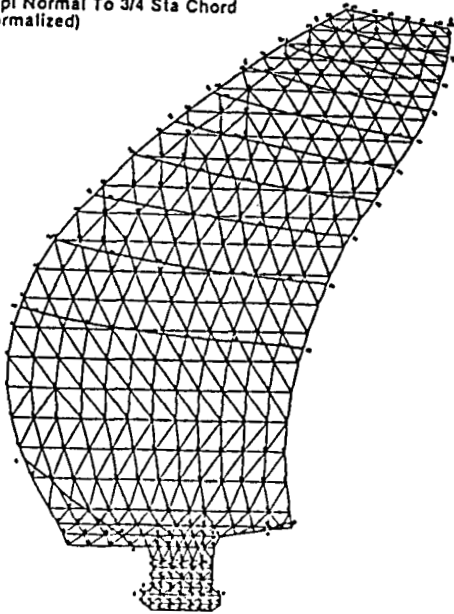




FIRST BENDING MODE SHAPES AGREE  
BETWEEN APPROXIMATE AND DETAILED ANALYSIS

First mode eigenvector comparisons between refined BESTRAN analysis and approximate STAT analysis show very good agreement. Mode shape differences, particularly differences in angular orientation of equi-deflection lines, have been shown important to the STAT flutter stability prediction.

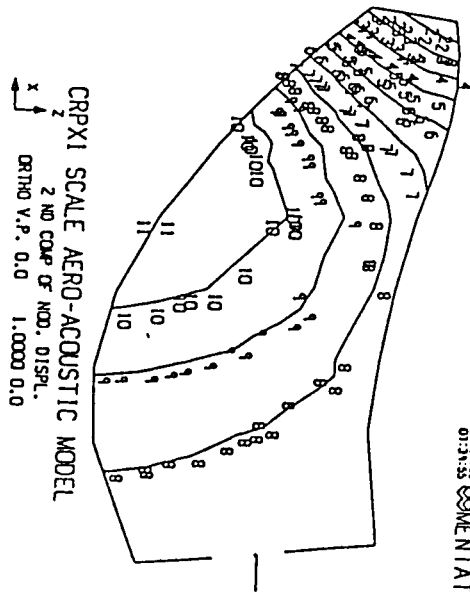
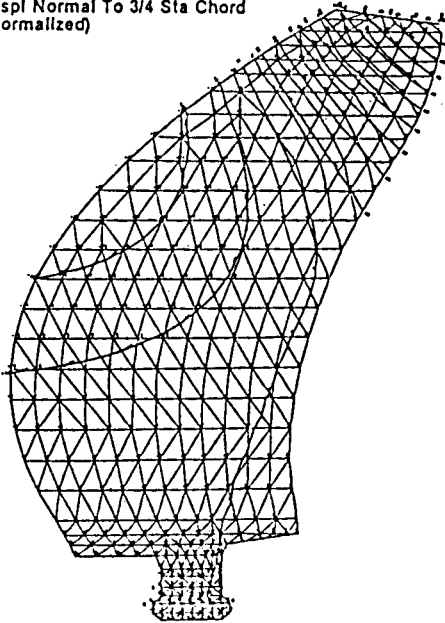
FRONT BLADE  
7650 RPM, Mode 1 217.3 CPS  
Displ Normal To 3/4 Sta Chord  
(Normalized)



SECOND BENDING MODE SHAPES AGREE  
BETWEEN APPROXIMATE AND DETAILED ANALYSIS

For the second bending mode, very good frequency and mode shape correlations are also noted.

FRONT BLADE  
7650 RPM, Mode 2 464.2 CPS  
Displ Normal To 3/4 Sta Chord  
(Normalized)

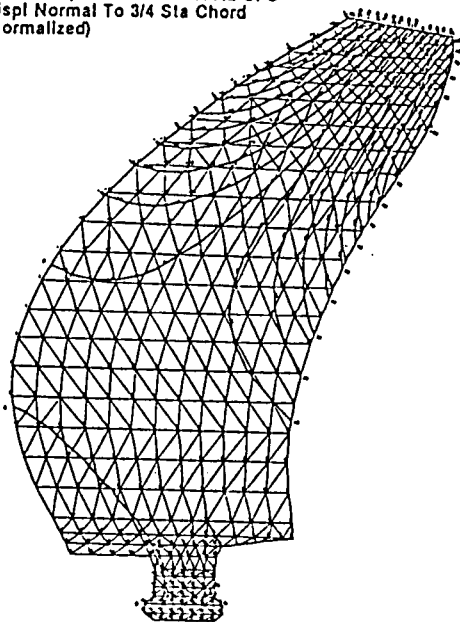


FIRST TORSION MODE SHAPES AGREE  
BETWEEN APPROXIMATE AND DETAILED ANALYSIS

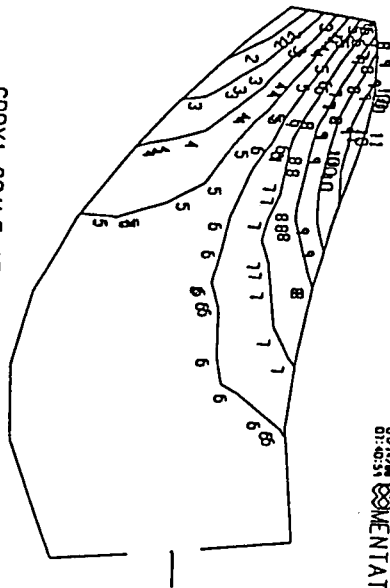
Very good correlations are also noted for the first torsion mode. For higher modes, larger differences occur. However, for approximate optimizations, the STAT analysis gives a dependable level of accuracy.

FRONT BLADE

7650 RPM, Mode 3 677.2 CPS  
Displ Normal To 3/4 Sta Chord  
(Normalized)



CRPX1 SCALE AERO-ACOUSTIC MODEL  
2 NO COP OF MOD. 01SP.L.  
ORHO V.P. 0.0 1.0000 0.0



**A FULL-SIZE CRP  
OPTIMIZATION IS IN PROGRESS**

The geometry of the CRP-X1 counter rotation propfan has been expanded to a 12-foot diameter, full-size rotor. A metal spar, fiberglass shell construction has been employed for this full-size CRP optimization. Several bugs in the system have been removed, and we are currently nearly ready to run this full scale counter rotation propfan optimization.

- CRP-X1 GEOMETRY HAS BEEN SCALED TO FULL SIZE
- SPAR-SHELL COMPOSITE CONSTRUCTION WILL BE EMPLOYED
- THE OPTIMIZATION IS NEARLY READY TO RUN

## CONCLUSIONS

In conclusion, the STAT program has been enhanced for the tailoring of counter rotation propfans. Due to the modular nature of STAT's construction, this enhancement was possible by enhancing only the separate analysis modules, with only minor system modifications required.

The new STAT approximate analyses have shown excellent correlations with available CRP test data. A full-scale CRP optimization is currently being performed.

- STAT'S MODULAR FORM ALLOWED CONVERSION TO CRP OPTIMIZATION
- STAT APPROXIMATE ANALYSES GIVE GOOD CORRELATION WITH BOTH DETAILED ANALYSIS AND TEST
- WE WILL SOON HAVE CRP OPTIMIZATION RESULTS

## REFERENCES

1. Brown, K. W.; Harvey, P. R.; and Chamis, C. C.: Structural Tailoring of Advanced Turboprops. AIAA/ASME/ASCE/AHS 28th Structures, Structural Dynamics, and Materials Conference, Monterey, Ca., April, 1987.
2. Brown, K. W.: Structural Tailoring of Advanced Turboprops (STAT). NASA CR 180861, 1988.
3. Vanderplaats, G. N.; Sugimoto, H.; and Sprague, C. M.: ADS-1: A New General Purpose Optimization Program. AIAA 24th Structures, Structural Dynamics, and Materials Conference, Lake Tahoe, Nevada, May, 1983.