

HIGH PRESSURE TURBINE BLADE STRESS ANALYSIS

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Summary

One of the critical areas in jet engine design is the high pressure turbine (fig. 1). Combinations of high temperature gradients associated with strong transients in both temperature and rotational speed fields, make the stress analyst conscientious about constructing a reasonably good model to study this particular area. The present report pertains to the blade definition and results of the analysis.

Since the same model should later be used to define some dynamic characteristics and certain areas would require a non-linear analysis, NASTRAN was chosen as a convenient program to manage the several alternatives. Previous experiences with the program were highly satisfactory in other areas of jet engine design.

Introduction

The Garrett ATF3 fan jet engine has a high pressure turbine with rotor blade cooling configuration basically a three-cavity, convection-cooled design. The cooling air is distributed to each blade by inserted tubes which also serve the purpose of locking the blades in the disk. The cavities must be designed in such way that the cooling path is optimum for the overall performance of the blade, under centrifugal loads and temperature field, especially considering the transients in both fields.

At design turbine inlet temperature the metal temperature map at 3 sec transient, for a 5-second acceleration in a standard day at sea level condition, is indicated in Figure 2.

The blade has a large amount of twist with a low hub-tip ratio. The object of the present study is to obtain the best mechanical design compatible with the several conditions abovementioned.

Mechanical Design and Model

Due to the strong twist and the centrifugal load a significant torque is developed. Shear stresses resulting from this torque are reduced by the addition of two shear webs in the blade.

A previous stress analysis of the disk fir-tree area defined the blade root stress characteristics (Figure 3). Considering the particular

blade configuration it was decided to analyze the part by using the NASTRAN program selecting the PTRIA2 plate element to constitute the shell-like structure.

The blade was divided into 915 triangular plate elements shown in Figure 4.

NASTRAN Analysis

The analysis consisted of the following three parts:

- a) Stress distribution due to centrifugal forces only, to obtain the rotational speed participation in the overall analysis.
- b) Stress distribution due to combined steady-state thermal and centrifugal loads. This case corresponds to the normal operating conditions.
- c) Stress distribution due to combined transient thermal and centrifugal loads. This case was the particular interest considering both creep and low cycle fatigue analysis and the possibility of defining non-linear material characteristics at local points to establish blade life characteristics.

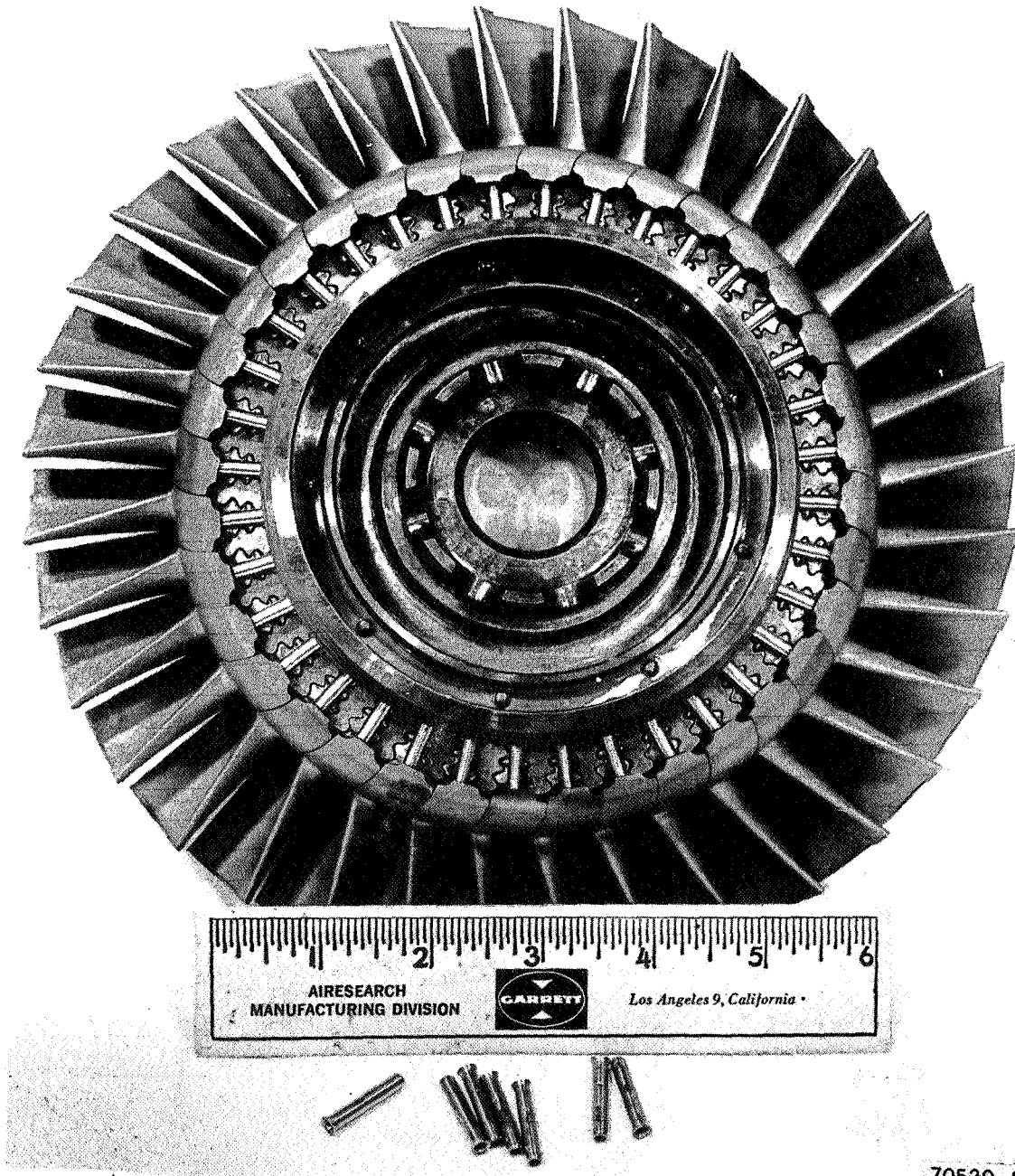
In Figures 5 and 6 several of the stress maps obtained from the computer runs are depicted.

Conclusions

As a result of the analysis, minor modifications have been made to reduce the stresses in two critical areas. The forward shear web has been scalloped at the root section to reduce the high shear stresses at the base of the web. Additional material has been added to the trailing edge of the blade by cutting back the core trailing edge at the root of the blade to reduce the peak stress.

With respect to the use of the NASTRAN program itself, several considerations could be summarized. Within an environment where numerous computer programs are in use during the last ten years, there is a natural inertia against starting the use of another large program, especially of the NASTRAN size. However, once the analyst has become more familiar with the several features of NASTRAN he becomes more aware and conscious of the strong analytical possibilities of the present program. For example, in the analysis mentioned above the capability of having a model to run dynamic analysis and non-linear material behavior, plus plotting the model and shapes, was a decisive factor in the use of this program.

TURBINE ROTOR ASSEMBLY



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FIGURE 1

3-SECOND TRANSIENT TEMPERATURES

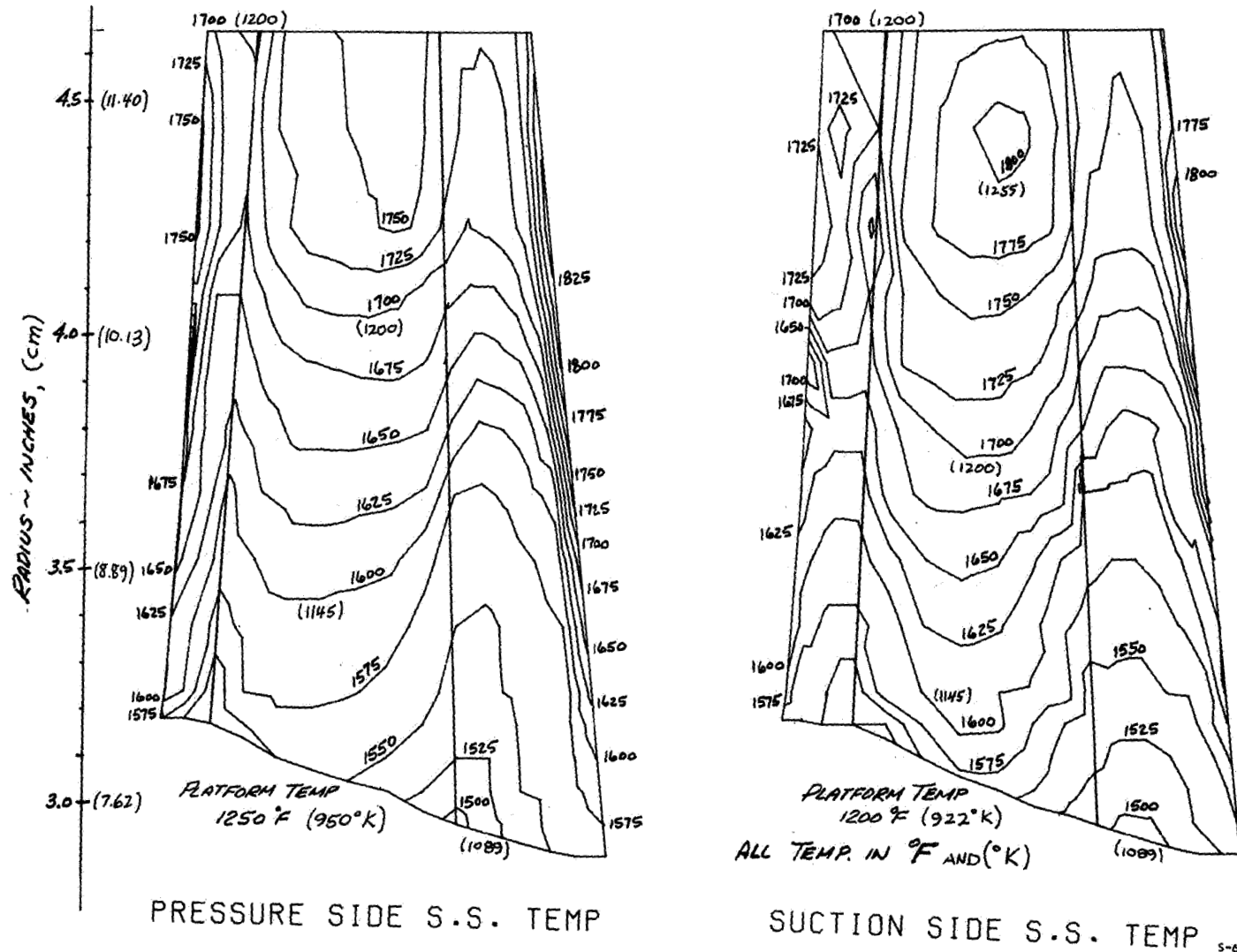


FIGURE 2

EFFECTIVE STRESS LINES FOR HIGH-PRESSURE TURBINE BLADE & DISK FIR-TREE CONNECTION - KSI & (N/m²)

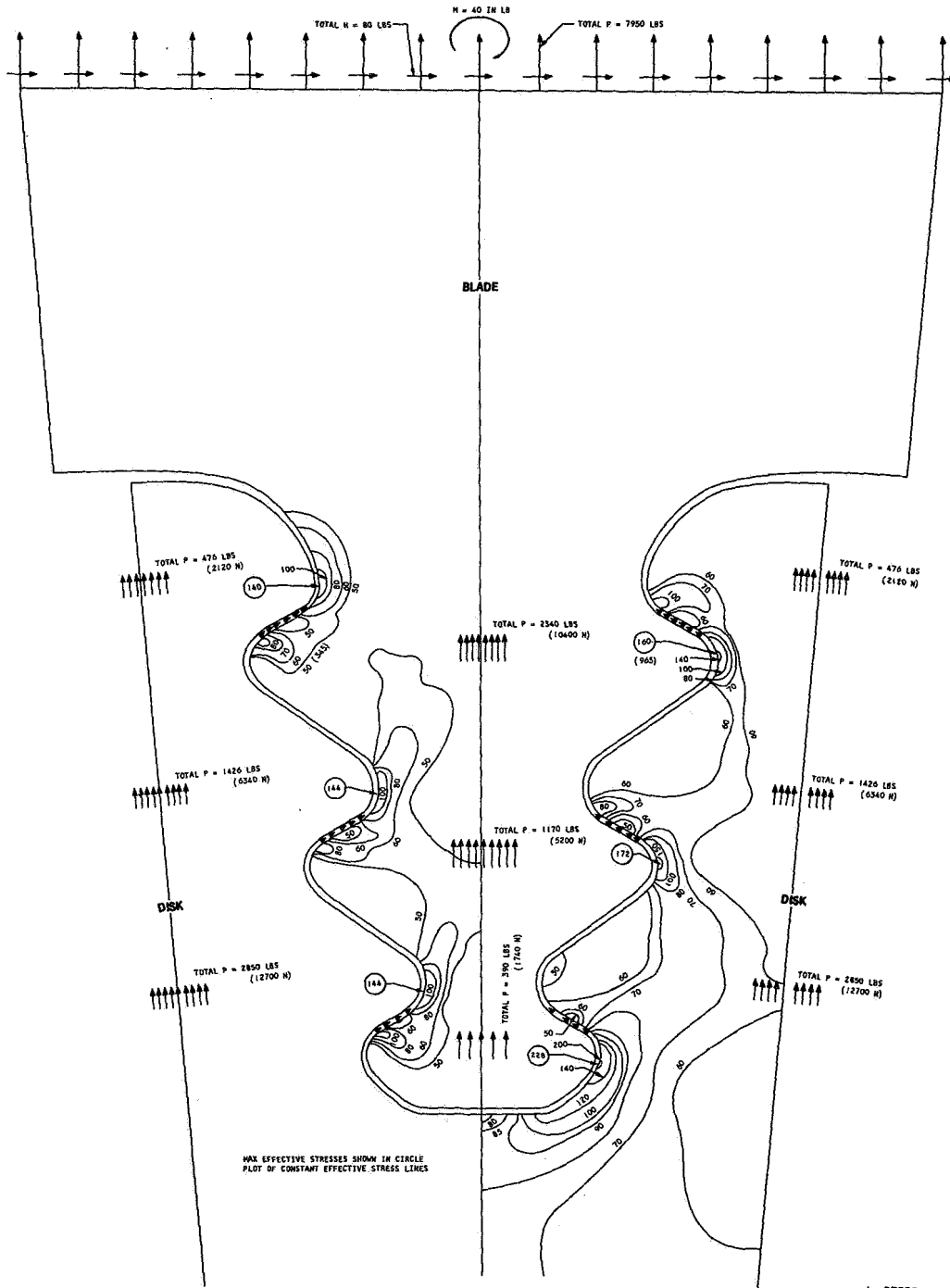
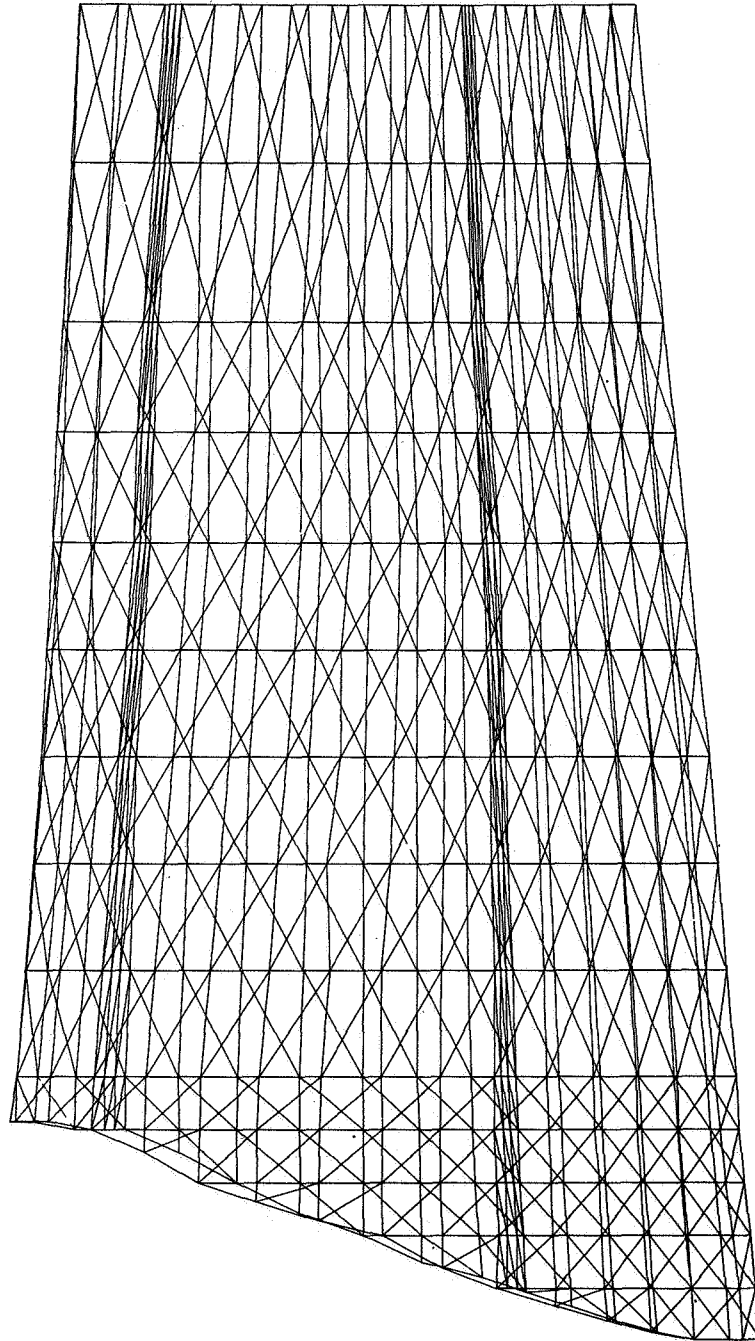


FIGURE 3

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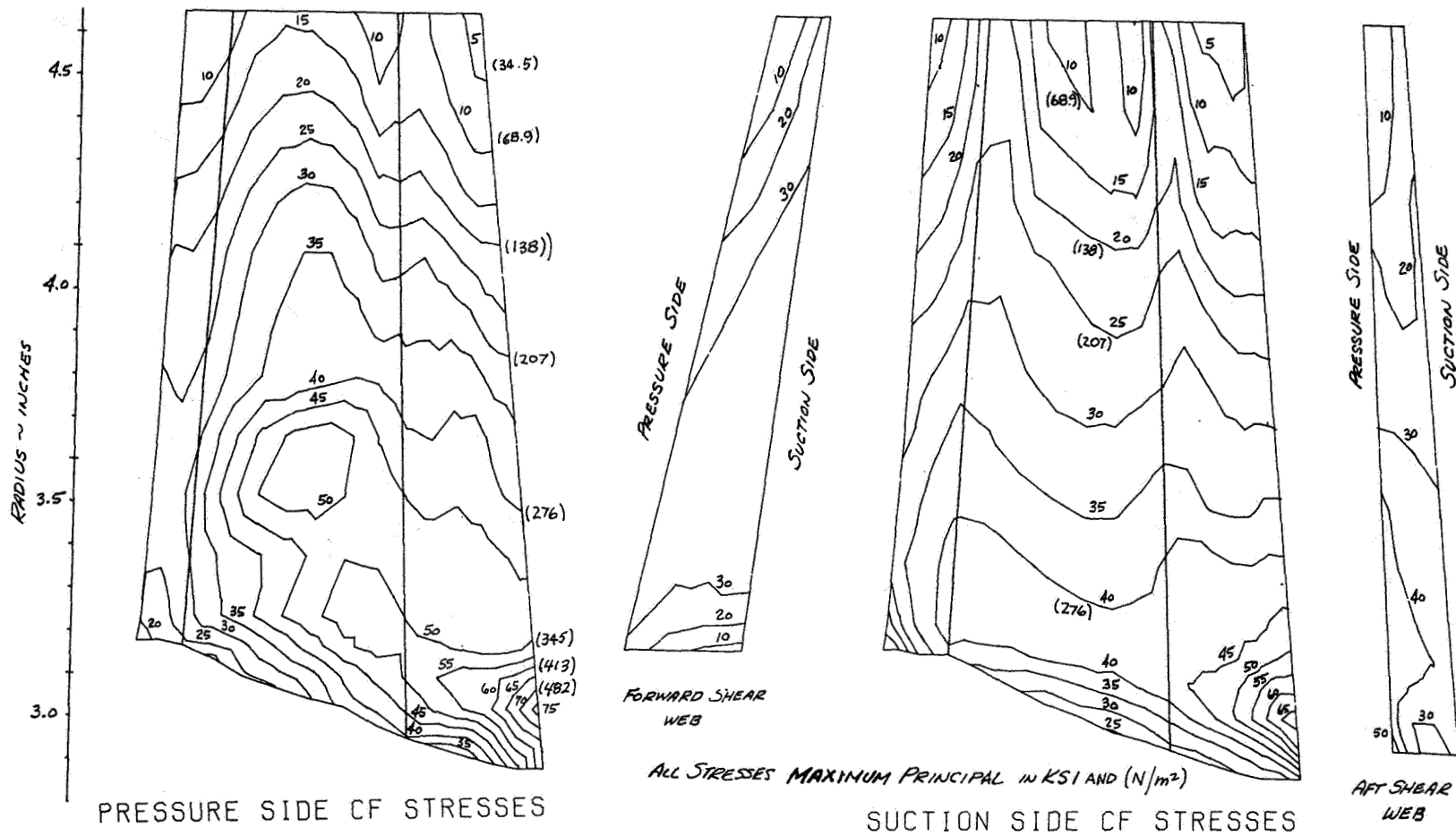
ANALYTICAL MODEL OF THE THREE CAVITY HIGH-PRESSURE TURBINE BLADE



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FIGURE 4

HIGH-PRESSURE TURBINE BLADE CENTRIFUGAL STRESS



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FIGURE 5

3-SECOND TRANSIENT THERMAL & CENTRIFUGAL STRESS

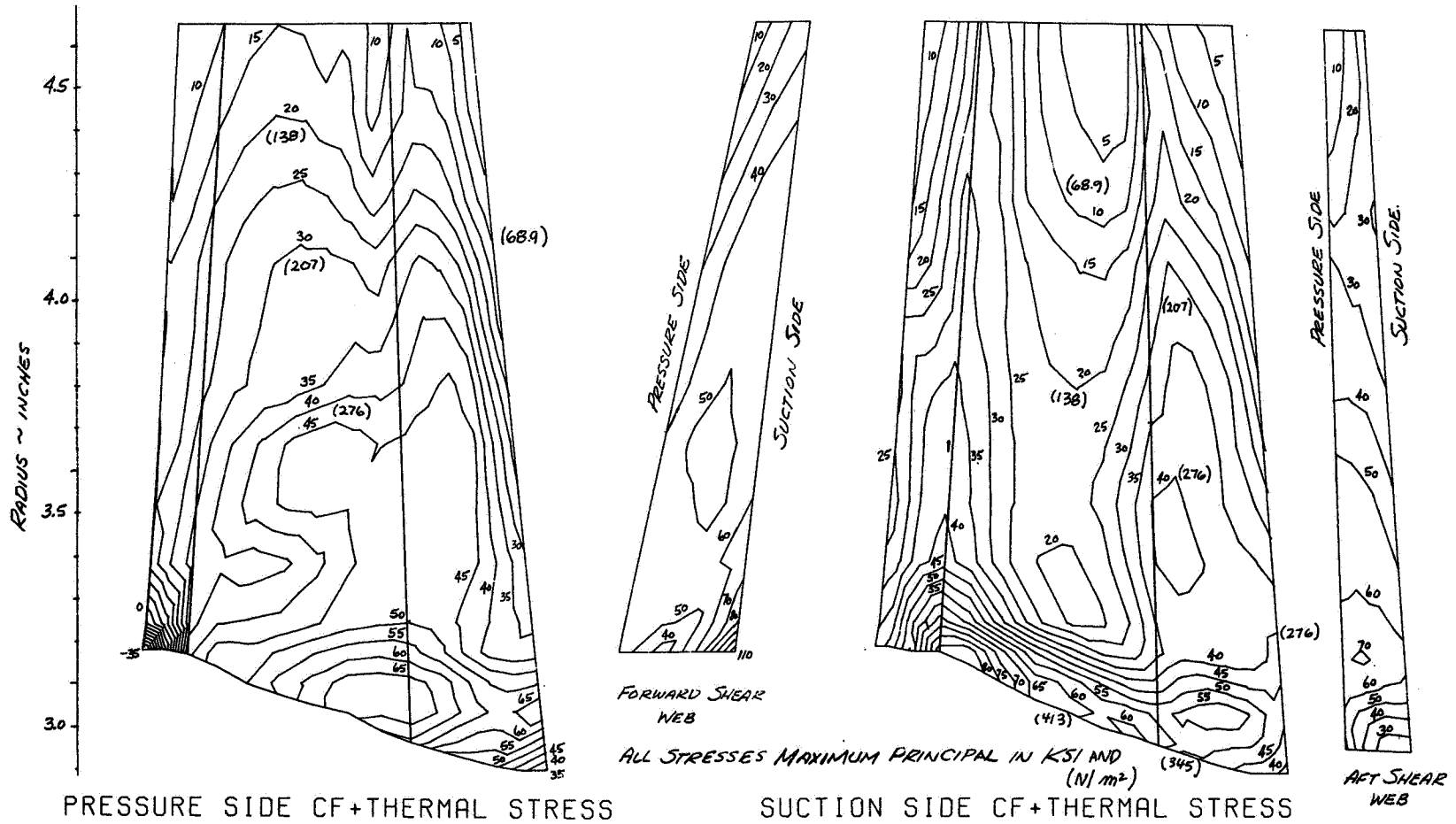


FIGURE 6