Turbine Blade Transient Heat Transfer Computer Code

Raymond E. Gaugler*
NASA Lewis Research Center, Cleveland, Ohio

Abstract

A COMPUTER program, TACT1, to calculate transient and steady-state temperatures, pressures, and coolant flows in a cooled turbine blade or vane with an impingement insert, is described. Input to the program includes a description of the blade geometry, coolant supply conditions, outside thermal boundry conditions, and wheel speed. Coolant side heat transfer coefficients are calculated internally in the program, with the user specifying the mode of heat transfer at each internal flow station. Program output includes the temperature at each node, the coolant pressures and flow rates, and the inside heat transfer coefficients.

The program is used at the NASA Lewis Research Center on an IBM TSS/360-67 computer. The source program consists of approximately 6200 lines of code and the program requires about 60,000 words of storage. Typical running times for the program are about 1.4 s of CPU time per calculational station for a steady-state run, and about 0.4 s of CPU time per station per time step for a transient run.

Contents

The key to creating a usable computer program is to have as simple a geometric model as possible for the system being analyzed. In this program, the emphasis is on a blade or vane with a central coolant plenum and chordwise flow of the coolant after impingement; therefore, it was decided that the primary calculational direction would also be chordwise. The blade is divided into layers which are bounded by chordwise cuts through the blade. Each layer is treated separately in the program, with radial heat conduction in the wall the only communication between layers. Included in this model is the capability to analyze a blade with a ceramic thermal barrier coating.

Figure 1 shows the details of the geometric model for a single slice of a blade, showing the breakdown of the blade or vane into calculational stations and nodes. Each calculational station consists of five nodes, located at: 1) the outer surface, 2) the interface between coating and blade metal, 3) a point midway through the wall metal, 4) the wall inner surface, and 5) a midcoolant channel location.

For input to the program, the following basic elements of the geometry are needed for each station: 1) the thickness of the wall coating and the wall metal and coolant channel width, 2) the chordwise distance of each node from the adjacent lower numbered node, and 3) the radial span for this slice. In addition, depending on the mode of heat transfer specified, the user must supply diameter and spacing for impingement holes or the diameter and spacing for pin fins. References 1 and 2 describe in detail the input to TACT1 and the program itself.

Presented as Paper 78-92 at the AIAA 16th Aerospace Sciences Meeting, Huntsville, Ala., Jan. 16-18, 1978; submitted Feb. 9, 1978; synoptic received June 22, 1978. Backup papers, Refs. 1 and 2 and AIAA Paper 78-92. Full AIAA paper available from AIAA Library, 750 Third Avenue, New York, N.Y. 10017. Price: microfiche, $2.00; hard copy, $5.00. **Order must be accompanied by remittance.**

Index categories: Thermal Modeling and Analysis; Airbreathing Propulsion.

*Aerospace Engineer.

The numerical solution for the temperatures throughout the blade involves writing a transient energy balance equation for each node and forming a set of equations to be solved for the temperature distribution. Similarly, the coolant pressure distribution is determined by writing the transient momentum equation for flow between adjacent fluid nodes and solving the resulting set of equations for static pressures.

The nodal energy balances are linearized one-dimensional heat conduction equations at the outside node, the junction of cladding and metal node, and the inside wall surface node. At the midmetal node, a linearized three-dimensional heat conduction equation is used. In the coolant channel, energy and momentum equations for one-dimensional compressible flow including friction and heat transfer are written for the elemental channel length between two coolant nodes. The equations used are presented in Ref. 1.

Three different modes of coolant side heat transfer are built into the program. The user must indicate the mode to be used at each station. Built-in correlations are available for: 1) impingement, including separate correlations for the stagnation point in the concave leading edge and for stations where crossflow is present, 2) forced convection channel flow, and 3) forced convection over an equilateral triangular array of pin fins. In addition, the program has two general correlations that may be used in place of the specific impingement correlations by including the appropriate constants in the input.

The program contains the capability to calculate local film cooling from a row of holes or a slot. However, due to a program requirement for continuous rearward flow in the coolant channel, the use of the film cooling option must be limited. If local film cooling is included, the user has the option of specifying the outside heat transfer coefficient for the film-cooled case directly, or specifying an unblown heat transfer coefficient and letting the program calculate an effectiveness.

A conceptual design of an impingement-cooled blade for an advanced high-pressure turbine is used to demonstrate the program. Two cases were run—a rapid engine acceleration

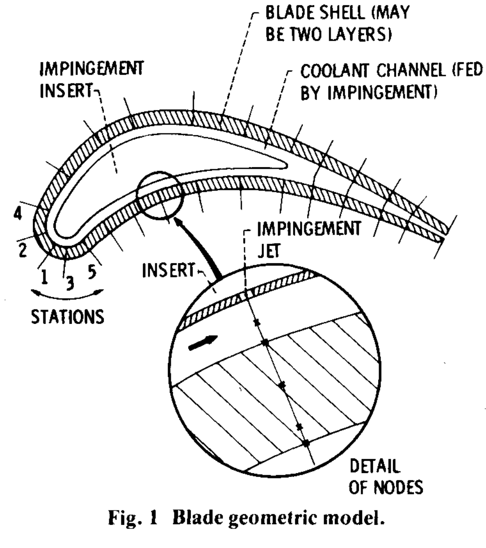

Fig. 1 Blade geometric model.

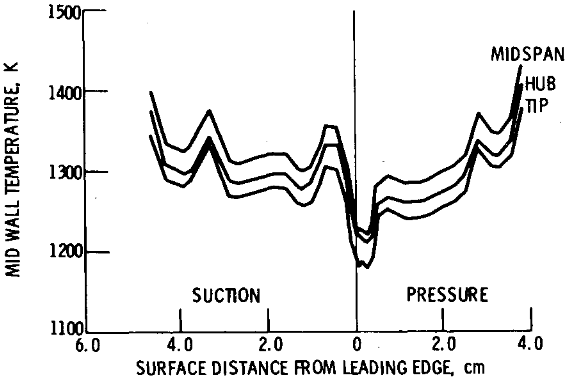

Fig. 2 Midwall steady-state temperature distribution.

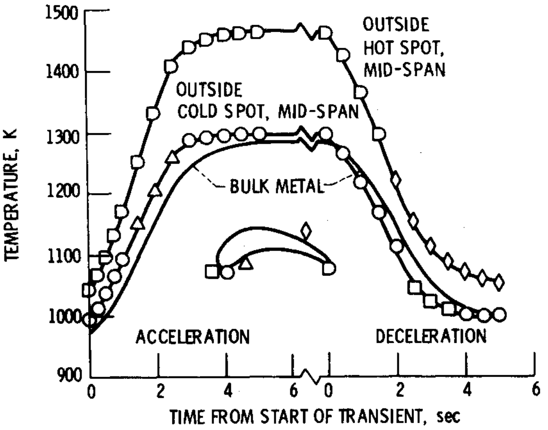

Fig. 3 Transient behavior of blade temperatures.

transient and a similar engine deceleration. The transient calculations were carried out to 5 s, using 0.25-s time steps. Running times on the TSS/360-67 computer were about 3200 s of CPU time for each 5-s transient.

The blade considered has a span of 3.81 cm and is divided into three slices. The hot gas heat transfer coefficients were calculated from a cylinder leading-edge correlation and the STAN5 boundary-layer computer program of Ref. 3.

Figures 2 and 3 are representative output from the TACT1 computations. Figure 2 shows the high-speed steady-state temperature distribution around the blade for a slice at the blade hub region, a slice at the blade midspan region, and a slice at the blade tip region. The temperatures plotted in Fig. 2 are midwall temperatures. Although the hub and tip regions have the same hot gas conditions and cooling configurations for this problem, the tip region runs cooler due to the coolant having a higher pressure in this region.

Figure 3 presents the transient behavior of some of the temperatures. The three curves are for the outside surface midspan hot spot, the outside surface midspan cold spot, and the overall bulk metal temperature. The symbols on the curves indicate the location on the blade of the hot and cold spots. Note that the locations of the midspan hot spot and cold spot change during the transient.

References

[1] Gaugler, R.E., "TACT1, A Computer Program for the Transient Thermal Analysis of a Cooled Turbine Blade or Vane Equipped With a Coolant Insert. I-Users Manual," NASA TP-1271, 1978.

[2] Gaugler, R.E., "TACT1, A Computer Program for the Transient Thermal Analysis of a Cooled Turbine Blade or Vane Equipped With a Coolant Insert. II-Programmer's Manual," NASA TP (to be published).

[3] Crawford, M.E. and Kays, W.M., "STAN5 - A Program for Numerical Computation of Two-Dimensional Internal and External Boundary Layer Flows," NASA CR-2742, 1976.