5.1 The effect of 2-D heat flow

The investigation of 2-D effects is very important, since all the methods used here for obtaining heat flux from surface temperature data are only applicable in case of 1-D heat flow in the solid. By using some data obtained with multiple HFS gages, the effects of 2-D heat flow can be studied. The other blade used in the experimental set-up was a multi-gage blade, instrumented with 18 sensors. Six different positions on the blade were studied. Each position thus had three gages:

- A Kulite for pressure measurements,
- A HFS heat flux gage and
- A surface thermocouple (Copper/Constantan).

This particular blade is used to investigate the effects of film cooling on the heat flux to the blade. The film is established by means of blowing cooled air through small holes on the blade surface. The air is cooled by liquid nitrogen.

In the tunnel, the flow is assumed to be 2-D i.e. not varying in the spanwise direction. This means that for the duration of the experiment the amount of heat that flows laterally through the side windows (see *figure 4.9*) can be assumed to be negligible. The convective flux is thus expected to be at most 2-D. In this chapter we will take a closer look at this 2-D flux and how dominant this is. If the 2-D effects in the solid are not too large, the new data reduction code will be considered reliable, because the code models conduction in one direction only.

5.2 The estimation of 2-D effects

In the case of the blade, the following approach was taken to do the desired evaluations of 2-D heat flow. Although the blade is of such a high conductivity (Aluminum is know for its high thermal conductivity) that it might be assumed to be isothermal in the specific area considered, that assumption depends strongly on the variation of the flux over the surface and the properties of the solid.

A slab with the same material, relative length and relative thickness as the blade used in the experiments, was used as the "test" piece for numerical studies. This allowed us to estimate 2-D effects fairly easily. Looking at the blade profile, the heat flux gages were spaced at intervals of approximately 10.3mm along the curved surface of the blade. In the modeling of the blade, a slab (51.5mm x 10mm x 25mm) was used. 25 different heat sources were used to input the flux to the blade. The measured fluxes were used for every 6th source. The fluxes for the other sources were obtained through linear interpolation. To show how the slab is related to the original blade the following figure was included.

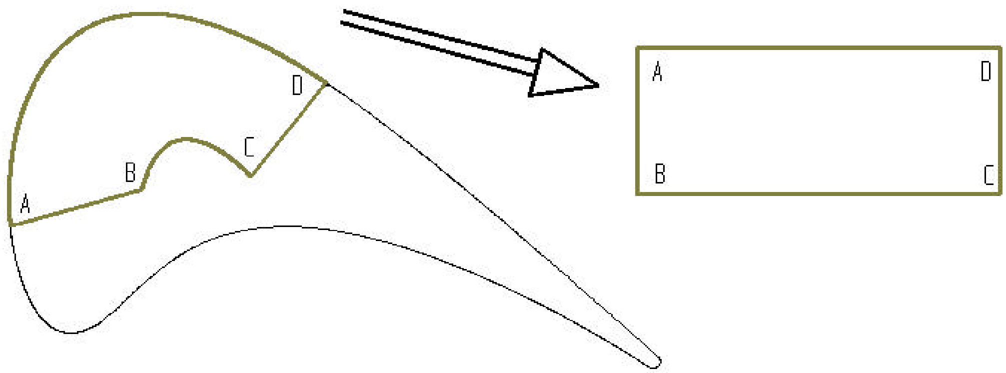

Figure 5.1 Illustrating the origin of the slab.

A schematic drawing of the slab is shown in *figure 5.2* with the reference points A, B, C and D.

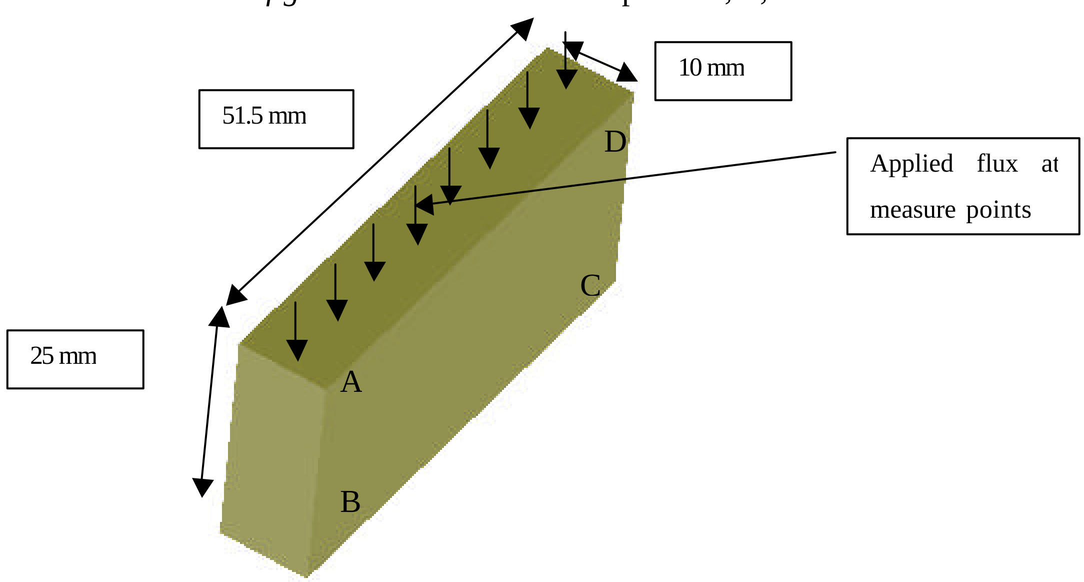

Figure 5.2 The slab used for 1-D verification.

The depth was chosen to be 25mm, because the thermocouple at the inner location in the blade was 25mm below the surface. The width of the slab was set at 10mm, for the sake of the illustration. The width is not important since 3-D heat transfer is not considered. The side faces of the slab were given an adiabatic boundary condition. The bottom (Side BC) was given a temperature boundary. At a certain point in time during a test (in this case 4s) the fluxes recorded by the heat flux gages was used. Four seconds was chosen, because the differences in the fluxes measured by the heat flux gages at this point in time were the greatest. The fluxes measured by the 6 HFS gages as a function of time are shown in *figure 5.3*. The values at 4s are listed in Table 5.1.

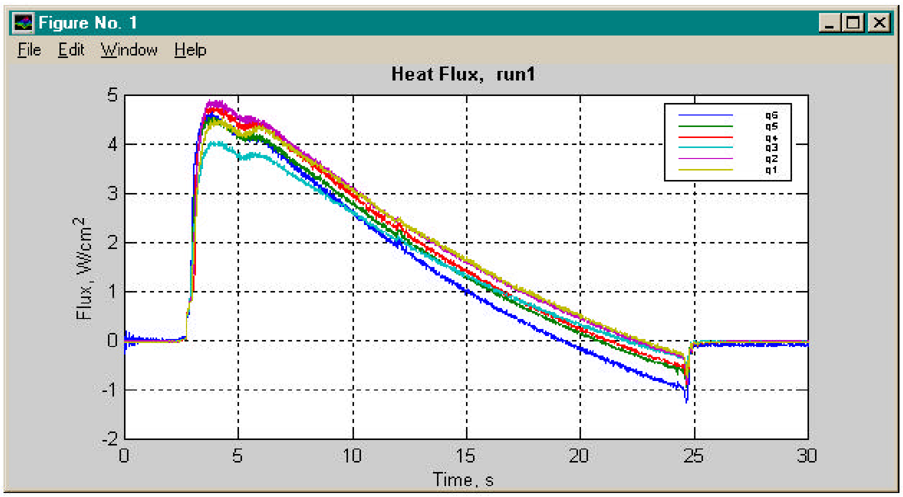

Figure 5.3 The six heat flux values measured along the blade surface.

Table 5.1 The six heat flux values at 4 seconds.

Time (s)	Flux 1 (W/cm^2)	Flux 2	Flux 3	Flux 4	Flux 5	Flux 6
4	4.43	4.77	3.96	4.67	4.46	4.54

Using these fluxes and the geometry of the slab, 25 heat sources were defined and mounted on the 51.5 x 10mm face of the slab. Using the computer program *"FlowTherm"* [29] a transient solution after 1s gave the temperature distribution in *figure 5.4*. It is clear that the result of the 2-D flow of heat into the solid is not visible to such an extent that it will cause any problem in assuming that the temperature field in the solid blade is 1-D. The isotherm lines in the figure are almost parallel to the surface i.e. the heat flow is almost 1-D.

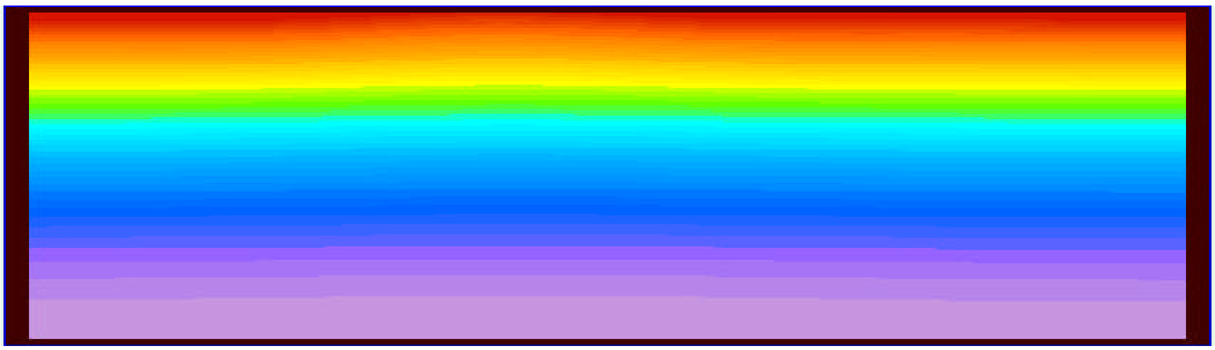

Figure 5.4 FlowTherm calculation of the temperature profiles the slab after 1s.

A transient solution after 4s as seen in *figure 5.5* still supports the 1-D approximation.

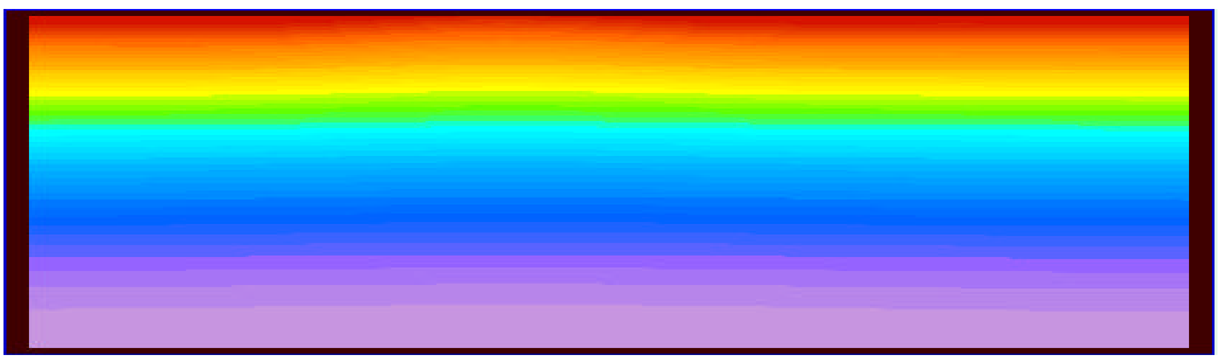

Figure 5.5 FlowTherm calculation of the temperature profiles the slab after 4s.

Looking at the two figures above, it is clear that the 2-D effects in these cases are not significant. This test case is, however, an idealization of the actual blade. The most advanced verification of the 2-D effects will be found when the blade is instrumented with more heat flux gages all over the surface of the blade and these fluxes can then be used as the boundary condition on a complex heat conduction program that will make use of the entire geometry of the blade to calculate the temperature profiles through the blade as a function of time. This would, however, be a very difficult task, because to manufacture a blade with so many gages will be very expensive and complicated. Nonetheless, the model problem studied is taken as justification of the 1-D assumption in the calculation methods.