# Convective heat flux determination using surface temperature history measurements and an inverse calculation method

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## (ABSTRACT)

Effective gages and methods to measure heat transfer have been established over decades. The combined measurement of skin friction and heat flux using one single gage on the other hand, presents unique opportunities and, with them, unique technical problems. One of the most important criteria in designing such a sensor is the physical size of the gage to minimize both the interference of the flow and the mass of these devices. In most cases the mass is an important criteria, because these devices are installed in aircraft. The mass also influences the time response of these devices.

The overall objective of this study is, therefore, to develop a small, accurate and cost-effective gage that can be used to measure heat flux and can also be combined with a skin friction sensor. The method proposed in this study is a coaxial surface thermocouple. By using the temperature history and a computer program, the heat flux through the surface can be obtained through an iterative inverse method, making use of regularization and the introduction of bias. To ensure that the heat flux through the gage is the same as the heat flux through the rest of the surface, the gage is manufactured from a material very similar to the rest of the surface. A one-dimensional approach was followed, and a look at some two-dimensional effects was necessary to verify any shortcomings of the one-dimensional assumption.

Walker developed a computer program based on an inverse approach capable of predicting the heat flux through a surface from the measured surface temperature history. The biggest advantages of this method are its stability and the small amount of noise induced into the system. The drawback of the program as originally written by Walker, is its limitation to semi-infinite objects, or objects with a fixed temperature at the interior boundary. To remove this limitation for surfaces with a finite thickness, a second thermocouple was installed into the system some distance below the first thermocouple. By extending the computer program, these two unsteady temperatures can be used to predict the heat flux through a surface of finite thickness. As part of this study, the effect of noise induced by the Cook-Felderman technique found in the literature was investigated in detail, and it was concluded that the method proposed in this study is superior to the Cook-Felderman method.

Heat flux measurements with the current method compared well with measurements recorded with a commercially-available layered heat flux gage for a test case of a model turbine blade in a linear cascade. The model was aluminum and a special aluminum/constantan thermocouple was used. In all cases evaluated, the difference was less than 20%. This agreement is deemed acceptable since the conventional layered heat flux gage is subject to measurement uncertainties. Conventional layered heat flux gages on their own can measure surface heat flux accurately for specific applications. These gages are, however, too large and expensive to install in a skin-friction gage. The results from the method introduced in this study are somewhat noisier than those from the heat flux gages, but the size of the current gage is much smaller when using a coaxial thermocouple to measure the surface temperature history. A coaxial thermocouple gage is also much more robust, cheaper and simpler to manufacture than the other types of heat flux sensors. Finally, it is important to note that no calibration of the current gage is required.

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