Infrared thermography techniques for boundary layer state visualisation

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Abstract

 Infrared (IR) thermography has found wide use in aerothermal research due to its ability to measure full field surface temperatures in a wide range of conditions. IR measurements of the boundary layer state have been demonstrated in many experiments, however there is little information available on the best practices that will ensure measurements are as fast and accurate as possible. IR transition measurements rely on temperature differences between laminar and turbulent regimes, which are dependent on the thermal characteristics of the system. This paper shows how a one-dimensional heat transfer analysis can be used to maximise the Signal-to-Noise-Ratio (SNR) of IR measurements in low and high-speed testing. This can improve the quality of measurements and minimise their complexity, effort and/or intrusion on the flow. Experimental work will be used to validate the analysis and demonstrate the use of IR for rapid testing.

introduction

The rapid decarbonisation needed for power generation and aviation to have sustainable futures requires step changes in aerothermal technology. When working in large design spaces the state of the boundary layer and its resulting loss characteristics are difficult to predict. Standard measurement techniques such as thin-film gauges and oil flow visualisation are intrusive and time consuming, so there is a need for improved testing methods to diagnose changes and develop physical understanding.

This paper demonstrates the use of well-conditioned infrared thermography as a method for rapid diagnosis of boundary layer transition and separation. Low-speed flows require active heating, either at a steady state or transiently by pre-heating. High speed flows can utilise differences in recovery temperature between boundary layer states but may have structural limitations that fix the thermal properties of a test piece. Experimental and computational analyses are carried out to determine best practice in both regimes. Examples of the capabilities of IR are shown and the limitations of the method discussed.

RESULTS and DISCUSSION

A one-dimensional heat transfer analysis on the low-speed case shows that there is an optimal level of insulation between the heat source and flow that maximises the measured temperature difference between laminar and turbulent regions. This is tested on a heated aerofoil with varying insulator thickness over a range of incidences and Reynolds numbers. Experimental results are compared to theory in Fig. 1(a), which shows that the experiment validates theory and that a well-conditioned IR experiment requires sufficient insulation to balance the temperature drop between the boundary layer and insulator. The use of IR for rapid testing is demonstrated in Fig. 1(b), which shows how a transitional laminar separation bubble advances on a NACA 0018 aerofoil as the flow incidence is changed. These measurements could take several hours using oil flow visualisation or even longer with direct instrumentation, but can be completed in under an hour with IR.

A similar analysis performed on the high-speed case shows that an optimal insulator thickness exists as well, however the interaction of the difference in recovery temperature and difference in heat transfer coefficient means that there exists a level of insulation that eliminates any temperature difference. Furthermore, as the high-speed case is not actively heated, this is dependent on transient changes to the temperature of a test piece and so the optimal thermal design depends on the nature of the experiment.

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| **(a) Low speed laminar-turbulent temperature difference when varying insulator Biot number at low and high Reynolds numbers** | **(b) IR visualisation of transition movement on a NACA 0018 as it’s pitched at Re = 400k** |
| **Figure 1. Examples of the use of well-conditioned IR measurements** |