12 Application of the final design of the dual thin film probe for total temperature measurements behind a cascade in CT2

12.1 Introduction

The optimized final design of the dual thin film probe is tested for several repeatable test conditions in the VKI Isentropic Light Piston CT2 facility. The gas temperature is also evaluated thanks to a thermocouple placed upstream the cascade. New information about the 'step in temperature in CT2' is identified from the dual thin film probe measurement results.

12.2 Test Conditions and probe design

Measurements are performed in the VKI Isentropic Light Piston Compression Tube facility CT2. The tests are similar to those described in paragraph 11.2. The additional part on this study is that there are two different combinations of the exit Reynolds number and two of the exit Mach number (Table 12-1). The probe is placed behind a cascade, shown in Figure 11-1. The comparison with a fast response thermocouple, type K - *90μm* diameter wires, placed upstream the cascade is promising for the probe. In addition, for this series of tests, the support of the probe is made of Vespel and the sampling frequency is *1kHz*. The design and the dimensions of the probe are the same as those in paragraph 11.2.

Description	High Reynolds number	Low Reynolds number	High Mach number - Supersonic	Low Mach number - Subsonic	Total temperature (K)
Conditions	900,000	450,000	1.1	0.9	340

Table 12-1: Operating conditions in CT2

12.3 Calibrations

The sensitivities of the two gauges and of the Wheatstone bridges are given in Table 12-2. The values are very close to the corresponding ones for the Plexiglas support probe (paragraph 11.3). The Vespel support probe is submitted to the flow in the CT2 facility, when both gauges are in ambient temperature, for the four combinations of the operating conditions of the facility. The wall heat fluxes, when the probe is in a fixed position between two blades are calculated and illustrated in Figure 12-1. The ratio of the two thermal products is considered equal to one for the Vespel support probe as well (paragraph 11.3). The two wall heat fluxes are almost the same for all four cases. Small discrepancies (maximum *10%* for low Reynolds number and *15%* for high Reynolds number) are mainly due to the non-uniformities of the flow field and the noise on the signal.

Gauge	Resistance Thermometer	Wheatstone Bridge
Hot	$T_{W1} = 9.0372\ R_1 - 424.38$	$d_{\Delta R}/d_{\Delta V} = 1.5354$
Cold	$T_{W2} = 8.3914\ R_2 - 424.62$	$d_{\Delta R}/d_{\Delta V} = 1.5855$

Table 12-2: Measurement chain: sensitivity of the gauges (Resistance-temperature calibration) and of the Wheatstone bridges for each gauge for the Vespel support D.T.F.P. in CT2

The wall heat fluxes, while the probe traverses behind the cascade at high exit Mach number are shown in Figure 12-2, when the initial wall temperatures are at ambient level. The higher discrepancies between the two wall heat fluxes (maximum *13%* for low Reynolds number and *30%* for high Reynolds number) compared to the case of the fixed position of the probe are probably the result of additional perturbations in the flow caused by the movement of the ceramic heads during traversing.

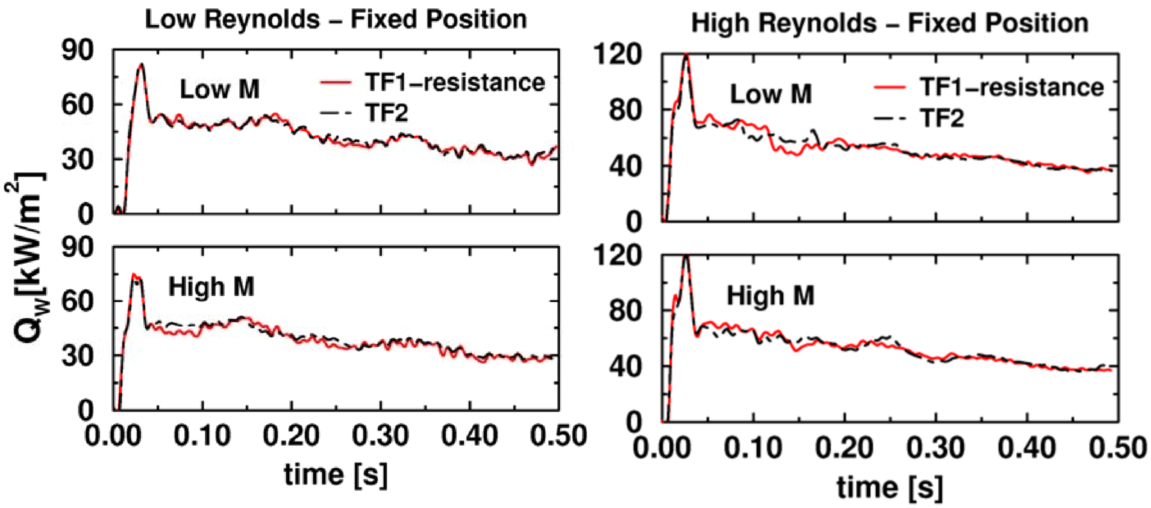

Figure 12-1: Wall heat fluxes during calibration of the Vespel support D.T.F.P. in CT2 for four operational conditions, while the probe is between two blades in a stable position

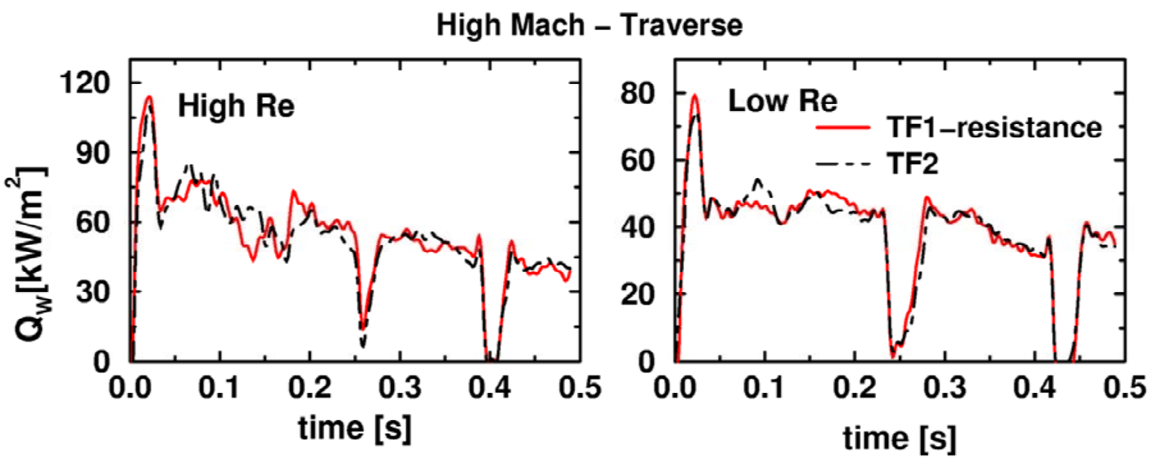

Figure 12-2: Wall heat fluxes during calibration of the Vespel support D.T.F.P. in CT2 for two operational conditions, while the probe traverses behind the cascade

Measurements in CT2 with the Vespel support probe

In Figure 12-3, the wall temperatures (first graph), the corresponding wall heat fluxes (third graph) and the gas temperature calculation results (second graph) are illustrated for the Vespel support probe. For this experiment, the nominal value of the gas temperature is *340K* and high exit Mach number, high exit Reynolds number are chosen as operating conditions. The cold hemispherical head is operated at initial temperature values close to the measured gas temperature (*357.6 K*) as the other head is heated till *447.5K*. Both wall temperature signals are low pass filtered at *100Hz* and the gas temperature calculation results are shown in the middle graph. Compared to the experiments with the Plexiglas probe (paragraph 11.4.1), an interesting additional observation is the high peak of gas temperature of more than *30 K* that is measured at the beginning of the test. This temperature peak is due to the sudden discharge of the pressurized air of the tube into the test section, which is almost at vacuum conditions just before the test.

An analytical design method of light-piston wind tunnels is described by Jones et al. (1973). The operating principle of such kind of facility is examined and the necessary equations are established. Upstream of the test section, after the compression of the air in the tube, the wall heat flux is also measured by a gauge being initially at ambient temperature. The characteristic high peak of heat flux at the beginning of the test for around *5ms* introduces the concept of a possible peak in temperature. Later, the same operating principle is used by Porreca and Denos (2000) in order to predict numerically the transient behavior of the VKI Isentropic Light Piston Compression Tube facility, CT3. The total temperature peak at the beginning of the test in the settling chamber is due to the sudden compression of the air in the test section (from almost vacuum -shutter closed- to the pressure of the tube -shutter just opened-).

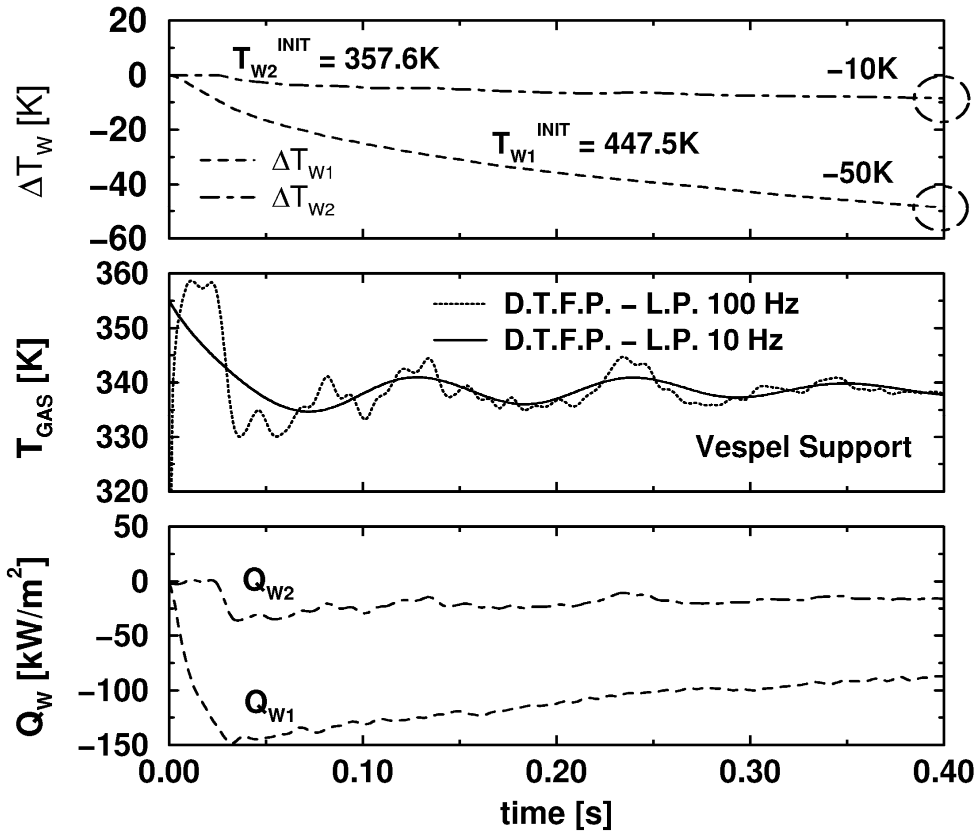

Figure 12-3: Wall temperatures, gas temperature calculations and corresponding wall heat fluxes for high Reynolds and High Mach numbers using the Vespel support D.T.F.P. in CT2

In Figure 12-4, the gas temperature measurements of the dual thin film probe (in solid line) are also compared with the ones of the thermocouple (in dot-dashed line) for four different flow conditions (Table 12-1). The heating of the gauges reaches high values so that the cold gauge (T_{W2}) is operated at an initial wall temperature close to the gas temperature. Note that the case of high Reynolds number – high Mach number (first graph) is the same as the one shown in Figure 12-3. It is clear on Figure 12-4 that the thermocouple cannot capture the temperature peak at the beginning of the test due to high inertia of its prongs. In addition, it seems that the probe is able to operate well at both subsonic and supersonic Mach numbers. Although there is a shock wave in front of each hemisphere at supersonic Mach numbers and the static temperature changes before and after the shock waves, the total temperature stays constant.

Imposing the initial wall temperature of one of the gauges close to the gas temperature requires a first good estimation of the gas temperature value prior to the test. Thus, a series of tests were performed for the four different flow conditions by imposing random initial wall temperatures, whose difference was still high enough. The measured gas temperature was between the two wall temperatures. The comparison between the probe and the thermocouple results is shown in Figure 12-5. The agreement between the two techniques leads to the conclusion that the probe can determine the gas temperature independently of the choice of the initial wall temperatures once the wall heat flux ratio is negative (see Eq. (45)).

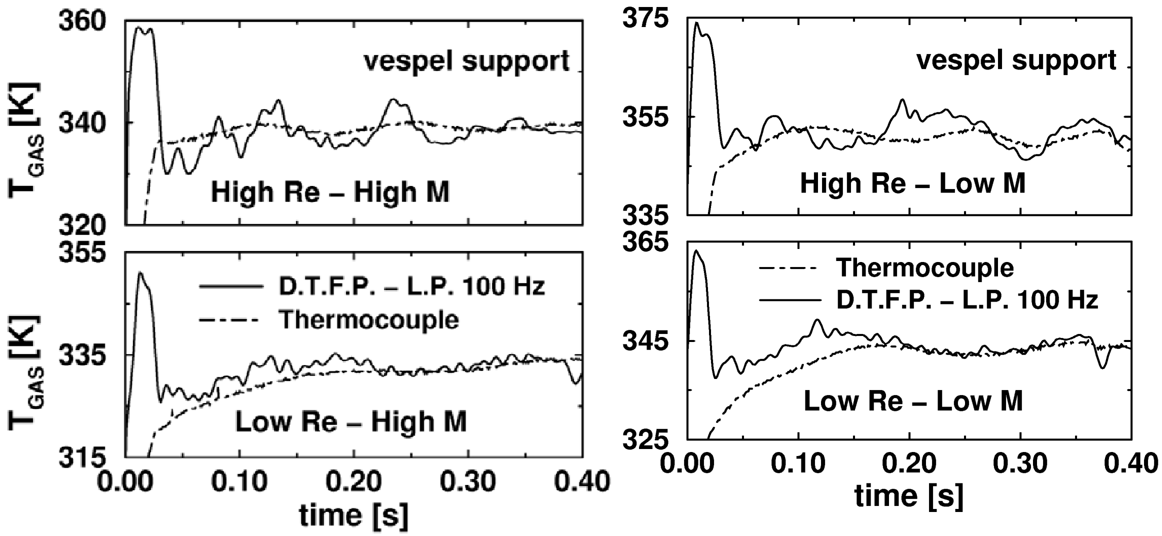

Figure 12-4: Comparison of the gas temperature between the Vespel support D.T.F. P. and the thermocouple for four flow conditions in CT2 [initial T_{W2} close to T_{GAS}]

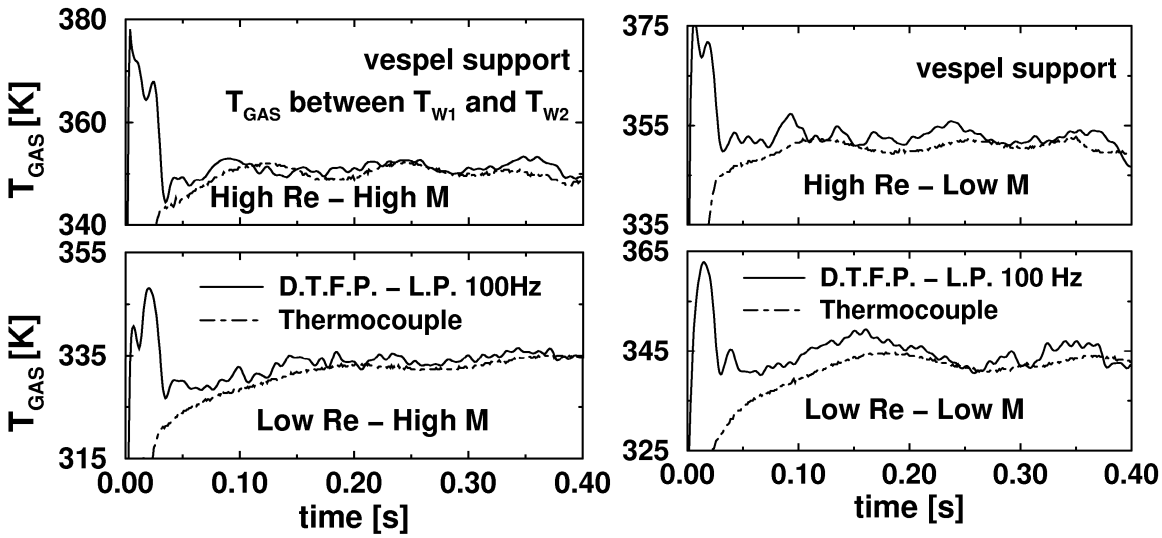

Figure 12-5: Comparison of the gas temperature between the Vespel support D.T.F. P. and the thermocouple for four flow conditions in CT2 [T_{GAS} between initial T_{W1} and T_{W2}]

The last series of tests is performed by imposing the wall temperature of the hot gauge (T_{W1}) (instead of the cold gauge (T_{W2})) close to the gas temperature. The heating for this case was the lowest of the two previous ones and thus promising for situations where the gas temperature will be higher. The results of the tests are illustrated in Figure 12-6 for the four operating conditions. The agreement with the values obtained by the thermocouple is obvious.

Combining all the available test results, the general conclusion is that the gas temperature calculations are possible either by imposing one of the initial wall temperatures close to the gas temperature or by forcing enough difference between the two initial wall temperatures. In Figure 12-7, the initial wall temperature difference between the two hemispherical heads is shown as a function of the initial wall temperature of the heated hemisphere. The higher the heating is for the hot gauge, the higher the initial temperature difference between the two gauges becomes.

The results from the measurements in CT2 with the Vespel support probe are also published by Iliopoulou and Arts (2005).

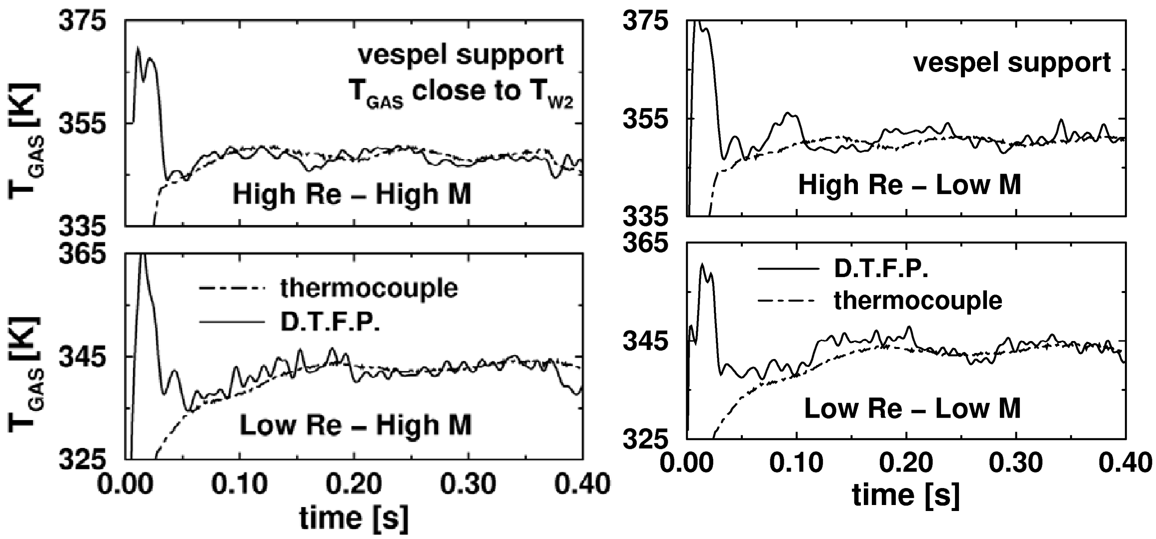

Figure 12-6: Comparison of the gas temperature between the Vespel support D.T.F. P. and the thermocouple for four flow conditions in CT2 [initial T_{W1} close to T_{GAS}]

The dual thin film probe also moves along a line downstream of two blades (Figure 12-8). The position of the two wakes can easily be determined, however, the gas temperature value suffers from accuracy when the probe is behind a blade, because of the high three dimensionality of the flow inside the wakes and the low spatial resolution of the probe (More information is given in paragraph 11.4.2).

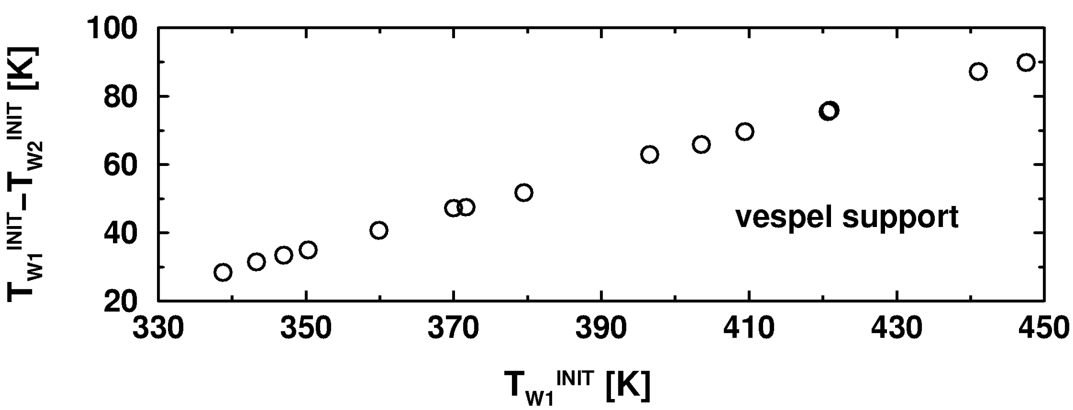

Figure 12-7: Initial wall temperature difference between the gauges (Vespel support D.T.F.P. in CT2)

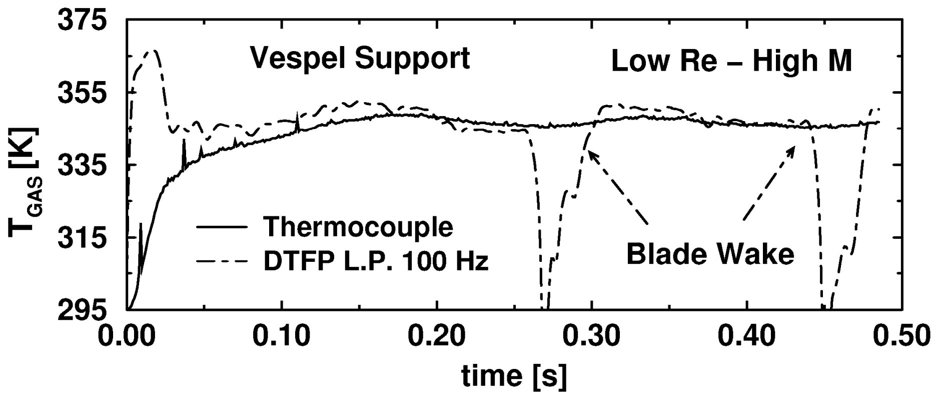

Figure 12-8: Travers of the Vespel support D.T.F.P. behind two blades in CT2

12.4 References

Iliopoulou V., Arts T., 2005, '*The dual thin-film probe for high frequency flow temperature measurements'*, Proc. 6th conf. on Turbomachinery, Fluid Dynamics and Thermodynamics, Lille, France – to be published in Proc. of the Institution of Mech. Eng. Part A 'J. of Power and Energy'

Jones T.V., Schultz D.L., Hendley A.D., 1973, *'On the flow in an isentropic light piston tunnel'*, Reports and Memoranda no 3731, Dept. Engineering and Science, University of Oxford, Great Britain

Porreca L., Denos R., 2002, '*Turbine stage mass flow evaluation in a compression tube facility'*, Proc., 16th Symposium on Measuring Techniques, Cambridge, Great Britain