Comments on “Aerothermodynamic effects of controlled heat release within the hypersonic shock layer around a large angle blunt cone” [Phys. Fluids 30, 106103 (2018)]

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Recently, Deep and Jagadeesh published a paper on understanding the aerothermodynamic effects of chromium coating over a large angle blunt cone test model at hypersonic flow conditions. The article concludes that the heat-flux at stagnation point increases by 25.6%, the temperature at stagnation region increases by 5%, and the shock stand-off distance increases by 17% with chromium coating. These findings appear to be ambiguous due to inconsistencies in the manner of calculating the free-stream values, the inappropriate use of measurement techniques and incorrect analysis of experimental data which have been elucidated in this comments.

A. Free-stream conditions:

The article[1] reports free-stream conditions at the exit of nozzle. In the experimental facility used by the researchers[1], the viewing windows are located farther away from the nozzle exit and since the reported experiments require the use of viewing windows, test models have to be placed at least 25 cm away from the nozzle exit for flow visualization over the test model[2,3]. The pitot calibration that was reported earlier for this facility shows that the flow expands from Mach 10 at the nozzle exit to Mach 11 at 25 cm away from the nozzle exit[3]. Such a discrepancy in the Mach number will cause an error of at least 20% in the estimation of the stagnation point heat-flux that is calculated using Fay & Riddell equation[4]. An incorrect freestream calculation will result in a mismatch between the measured heat-flux, and those values computed analytically and numerically unlike what has been shown in Figure 10 of the article[1].

B. Temperature measurements:

The temperature was measured using two color-ratio DSLR pyrometry technique in the article[1]. Deep et al. have provided the details of the measurement technique in Appl. Opt. 56, 8492-8500 (2017)[5].The measurement technique involves two primary assumptions: 1) The luminosity is negligible before and after the test time 2) The shock layer behaves like a gray body with constant emissivity.

In their earlier publication[5], it was mentioned that the DSLR camera was triggered manually just before operating the tunnel, and the exposure time of DSLR camera was maintained for a duration of 4 seconds when the steady test time is only 315 μs. Schuck et al.[6] have shown that the gas temperature is sufficiently high in FPST facilities (such as the one used by the researchers[1]) even after the steady flow duration. Schuck et al.[6] have acquired temporally and spectrally-resolved intensity spectra along the stagnation streamline of a cylinder test model using an optical-fiber-based emission spectroscopy technique at 3.9 and 5.4 MJ/kg enthalpy conditions, and calculated the temperature by fitting a black body function curve to the emission spectra. To reinforce the above argument, some results are reproduced from Anbuselvan[2,3] in Fig. 1 which shows the time history of the luminosity at the midpoint of the shock layer along the stagnation streamline of the hemi-sphere test model. It is shown that the luminosity is considerable beyond the test time. The relative percentage error, $\boldsymbol{e}$**,** due to the assumption of negligible luminosity before and after the test time is calculated using Eq. (1).

$$e = \frac{\bar{X}_1 - \bar{X}_2}{\bar{X}_1} \times 100 \qquad (1)$$

where $\bar{X}_1$ is the average luminosity during the test time (~300 μs) and $\bar{X}_2$ is the average luminosity for a duration of 4 milliseconds. The relative percentage error is found to be 57% and 59% for two runs taken from Anbuselvan[2,3] and shown in Figure 1.

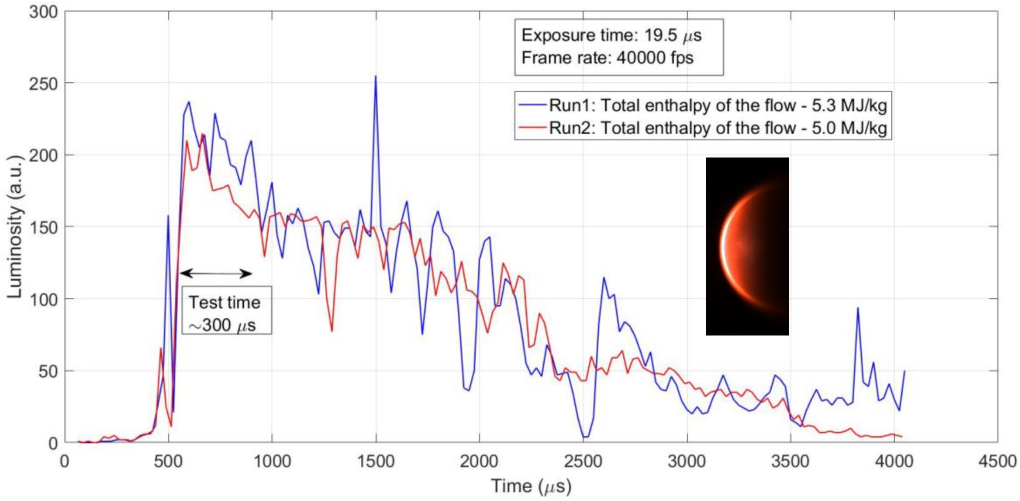


Figure 1: Time history of the luminosity [Plot is generated from the experimental data of Anbuselvan (2017)[3]]

Schuck et al.[6] have also provided some insight about the assumption of graybody with constant emissivity. They showed that the measurements taken of the flow above the stagnation streamline of a cylindrical test model indicate a significantly weaker influence of blackbody radiation than at the stagnation point, with an order of magnitude less incident energy recorded. Since the assumption of graybody with constant emissivity is questionable, the validity of this assumption is significant, which has not been discussed in the articles of Deep at al[1,5].

Further, the DSLR image can suffer due to parasitic reflections from the stainless steel walls of the tunnel test section (see Fig. 12 of article[1]) which would further increase the ambiguity of the temperature measurement.

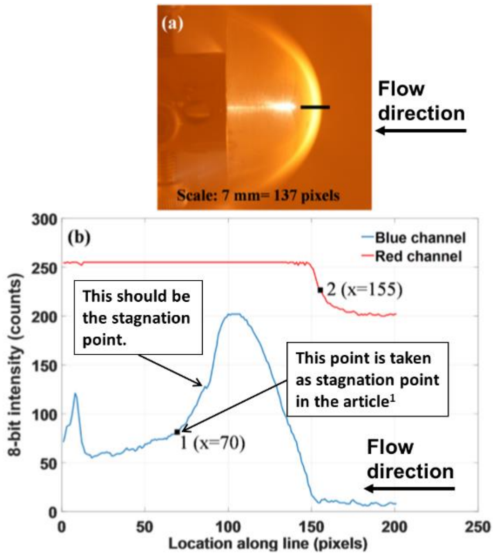
C. Heat-flux measurements:

The heat-flux was measured using Platinum-based thin-film sensors in the article[1]. Past studies[3,7,8] have shown that the performance of thin-film sensors are poor for the reported enthalpy conditions . When thin-film sensors are subjected to high enthalpy flow conditions, the sensors are eroded from the substrate thereby modifying its resistance due to the erosion. This would cause poor repeatability and adds uncertainties to the measurements. This has been discussed in Flaherty et al.[7] and Anbuselvan et al[3,8]. Flaherty et al.[7] have reported that the survival of thin film gage at the stagnation point was zero in an expansion tube facility for stagnation enthalpies ranging from 4.09 to 7.52 MJ/kg. Flaherty et al.[7] have also observed that the changes in resistance were typically about 500% between successive shots which can amount to a substantial error in the heat-flux values. For the same reasons, thermocouples are generally used to measure the stagnation point heat-flux of blunt bodies at the reported experimental test condition[7,9].

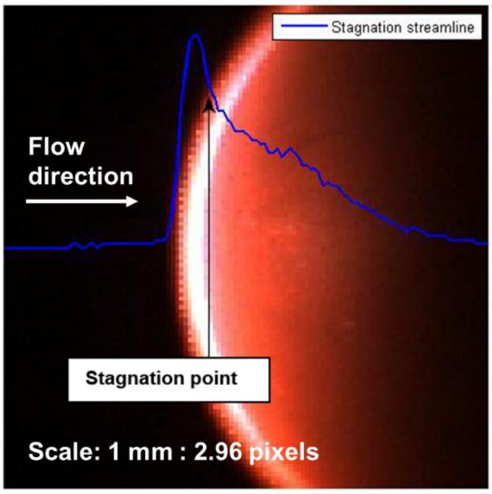
On further inspecting the heat-flux signal (see Fig. 9 of article[1]), it may be observed that the signal oscillates by an amount of 40 to 50 W/cm^2 in both the test cases. This will lead to fluctuations of 33% to 41% about the reported mean heat-flux value of 122.11 W/cm^2 for the uncoated test model and 26% to 33% about the reported mean heat-flux value of 153.34 W/cm^2 for the chromium coated test model case. The reported increase of 25.6% in the stagnation point heat-flux can be best judged only after these fluctuations are also taken into account for uncertainty calculations.

D. Shock stand-off distance measurements:

The shock stand-off distance was measured from schlieren images and DSLR images in the article[1]. There are three aspects regarding the shock stand-off distance measurements.



(a) Reproduced from the article[1] (Edited)



(b) Reproduced from the experimental data reported in Anbuselvan[2,3]

Figure 2: Spatial variation of pixel intensity along the stagnation streamline of test models

1. Data analysis: To take a closer look at the procedure used to estimate the shock stand-off distance, Figure 2a has been edited from the article[1] and is being reproduced here for the sake of clarity. The points 1 and 2 in Figure 2a were taken based on the gradient values. Such a choice of the threshold is quite arbitrary with no physically intuitive arguments. For example, consider Figure 2b which is reproduced from the experimental data set of Anbuselvan[2,3]. The images were captured over a hemispherical test model in FPST facility at ~5.3 MJ/kg total enthalpy flow condition. The pixel intensity scan along the stagnation streamline has been plotted over its corresponding image (see Figure 2b) which shows the data points corresponding to the stagnation point and the edge of the shock wave. Since Fig. 2a follows a similar trend, the point 1 in the article[1] cannot correspond to the stagnation point. Similar discussion holds for point 2 as well. This would cause an error of more than 10% in the shock stand-off distance measurement.

2. Uncertainty due to image resolution: The image resolution was not provided for Schlieren images in the article[1]. The uncertainty calculation should include the image resolution while reporting shock stand-off distance.

3. Quantification error due to long exposure time: The exposure time of DSLR is maintained for a duration of 4 seconds whereas the test time is only for 315 µs. A DSLR camera's image is a time-integration of the starting flow, the test gas (air) and the subsequent driven gas (helium) flow, during each of which the shape of the shock wave changes. The determination of shock standoff distance from such an image would be inaccurate in impulse facilities like FPST.

CONCLUSION

The incorrect Mach number that was used in estimating the free-stream conditions, the unproven assumptions made while estimating the temperature, the wrong choice of heat flux sensor, and the unaddressed uncertainties in shock stand-off measurement have been brought out in this article. In the light of these, the conclusions drawn by the authors regarding the heat flux, temperature and shock stand-off distances appear to be dubious. With such levels of uncertainty, the data from this article[1] should be taken with utmost caution by the research community.

REFERENCES

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