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Application of Machine Learning Techniques for the Prediction of Free Plasma Jet Oscillatory Phenomena and Cloud Classification for In-flight Icing from Experimental Data

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ABSTRACT

This paper presents the application of Machine Learning (ML) techniques to two different experimental data sets.

The first set concerns experiments carried out using the Plasmatron facility, a plasma wind tunnel located at the von Karman Institute for Fluid Dynamics in Belgium [1]. The experiments aim at reproducing the complex flow developing around a spacecraft during atmospheric entry. Prediction of the heating rate which is experienced by the Thermal Protection System (TPS) of the spacecraft remains an imperfect art, consequently, leading to very large safety margins for the vehicle design. On the other hand, failing to correctly predict the heat loads and associated material response of the TPS during the design phase can lead to catastrophic mission failure. To address this problem, experimental facilities are developed to study different aspects of atmospheric entry flows [2]. The facilities are capable of generating high speed flows of plasma which is discharged over testing probes, to characterise and investigate the response of different TPS materials.

Unfortunately, on ground facilities are often subject to spurious physical phenomena, that do not occur in real flights, due to the particular design of the facility itself. In this regard, we investigate the oscillations of the plasma jet generated using the Plasmatron. These oscillations are related to the experimental set up and they do not extrapolate from the reproduced flight. Such

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instabilities are due to a ripple originating from the power supply system and to the entrapment of cold gas within the hot plasma stream expanding in the chamber. Traditionally, the experimental investigation of plasma jet instabilities is performed by analysing the frequency spectrum obtained by applying the Fast Fourier Transforms (FFT) to stacks of high speed camera pictures. The proposed work looks into the application of ML algorithm to determine the main frequency of the oscillations. This frequency can be used for code validation or input for stability studies [3].

Introducing ML in this scenario will allow us to go one step further in the determination of the main frequency from the testing conditions as well as reduce the overall computational cost. Additionally, pictures uncertainty (intensity scale and width of pixels) can be considered and included into the ML framework, generating more robust predictions.

The second data set includes the properties of a large number of atmospheric clouds collected at different geographical locations. Clouds are visible arrays of tiny water droplets which are generated by uplift air motions. As the air raises, its temperature decreases. As soon as the dew point is reached, the air saturates and vapour condensates around cloud condensation nuclei (CCN). CCN are particulate matter found in the air and their origin can be anthropogenic or natural. Examples of anthropogenic and natural CCN sources are soot and salt particles, respectively.

Cloud properties vary according to the number and type of CCN suspended in the air mass. A large number of CCN entails large numbers of cloud particles for the same liquid water content. Generally, the atmospheric concentration of anthropogenic CCN is larger then the one related to natural CCN. Therefore, it is expected that clouds located in continental regions, namely close to large cities and industrial regions, present larger numbers of droplets than those found in oceanic regions.

The study of the micro-physical properties is relevant because it is directly related to the radiative properties of clouds. Furthermore, the knowledge of such properties helps with the estimation of the precipitation efficiency or the study of clouds dynamics. In addition, the industry is interested in this research field because of its potential w.r.t. to in-flight aircraft icing applications. One of the objective is to foresee the most severe ice accretion scenario, to help preventing aircraft flying in hazardous conditions.

In literature, clouds have been divided into two groups: Continental and Maritime/Oceanic [4]. Some other authors claim that maritime clouds can be polluted due to environmental phenomena such as air currents which redistribute the pollution in the atmosphere [5]. Therefore, the fine line between the two cloud types still remains undefined. Furthermore, it remains unclear whether there is any other possible grouping.

To investigate this, we rely on published data set [4], where clouds have been classified as maritime and continental. The set contains cloud properties measurements collected at very diverse geographical locations. The application of ML algorithms could support the division of the data set into clouds of different types, either Maritime/Continental or a third type.

References

[1] B. Bottin, O. Chazot, M. Carbonaro, V. Van der Haegen and S. Paris, Measurement Techniques for High Temperature and Plasma Flows, RTO-EN-8: The VKI Plasmatron Characteristics and Performance, 1999

[2] O. Chazot and F. Panerai, High enthalpy facilities and plasma wind tunnels for aerothermodynamics ground testing. *Nonequilibrium Hypersonic flows*, Ed. Eswar Josyula ARLF.

[3] A. Cipullo, Ground Testing Methodologies Improvement in Plasma Wind Tunnels using Optical Diagnostics. *PhD thesis defended at Seconda Università degli Studi di Napoli*, 2012

[4] N. L. Miles, J. Verlinde et al, Cloud droplet size distributions in low-level stratiform clouds. *Journal of the atmospheric sciences, 57(2), 295-311*, 2000

[5] A. A. Costa, C. J. Oliveira et al, Microphysical observations of warm cumulus clouds in Ceará, Brazil. *Atmospheric Research, 54(2-3), 167-199*, 2000