# *MEASUREMENT OF THE AERODYNAMIC COEFFICIENTS FOR BASIC SHAPES IN THE HYPERSONIC FLOW REGIME*

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# Introduction

In the years between 1995 and 2015, dedicated research activities were conducted at the Department of Industrial Engineering of the University of Naples “Federico II”, with the ultimate goal of building a Database of aerodynamic coefficients ($C_D$ and $C_L$) for simple-shape bodies (such as spheres, cylinders, cones) in different aerodynamic conditions - with special focus on hypersonic low-density regime.

Such activities included the measurement of:

1) the compressible subsonic forces on a conical cylinder;

2) the compressible subsonic forces on an AGARD “A” model;

3) the forces acting on a conical cylinder in the supersonic regime;

4) the thrust generated by an arc-jet;

5) the forces acting on a bluff cylinder, a hemispherical cylinder, a conical cylinder and a cone with large opening angle in hypersonic low-density conditions;

6) the forces in the supersonic-continuum regime and hypersonic low-density regime for simple geometric shapes, i.e. a cylinder, a sphere, and a bluff cone with different length-to-diameter ratios.

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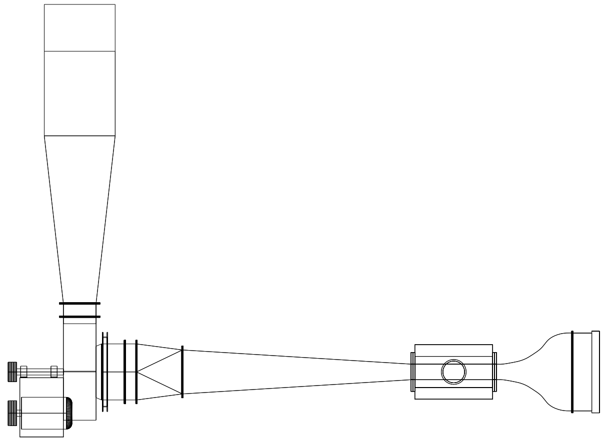
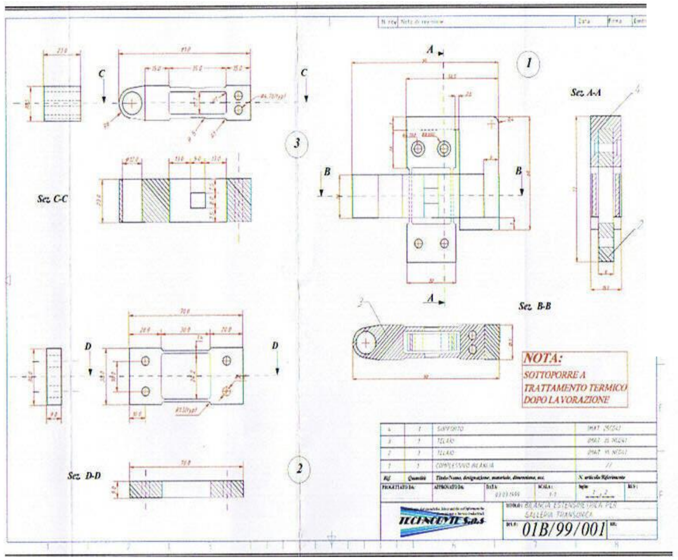
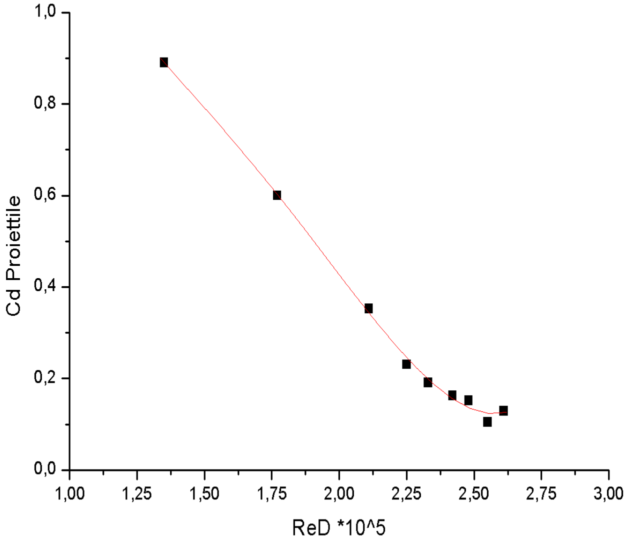
4) the thrust generated by an arc-jet;



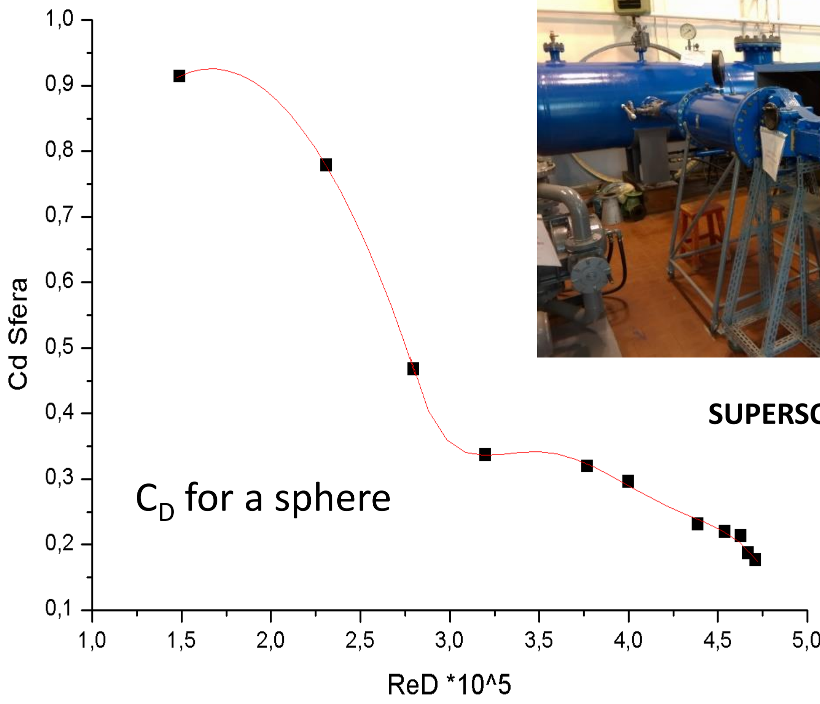
High Velocity Wind Tunnel-Mach 0.6




Extensimetric, 3-components Balance




$C_D$ for a cone-cylinder



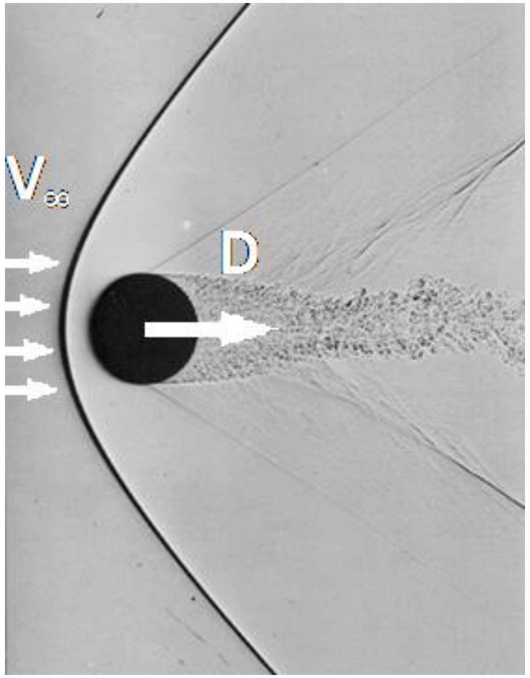

$C_D$ for a sphere

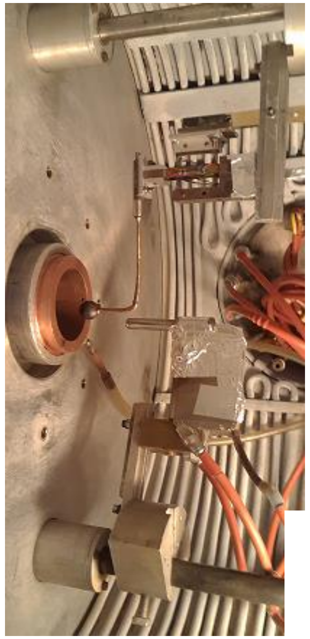
**SUPERSONIC FACILITY**

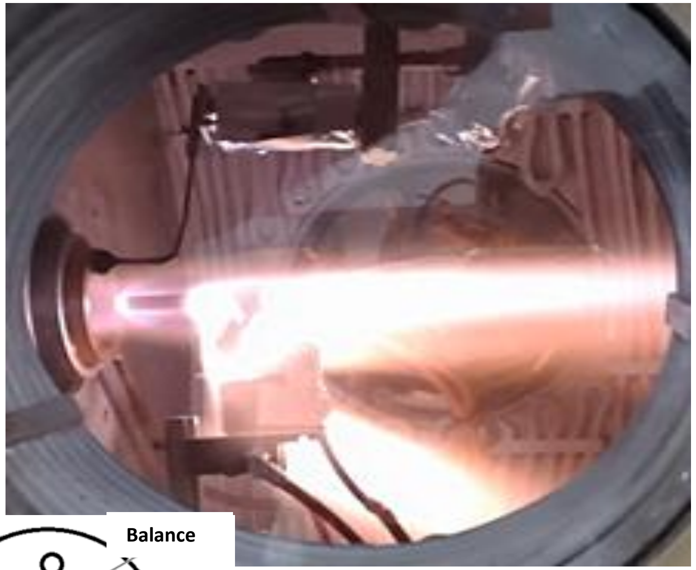
# The sphere and the Schlichting curve 1/2

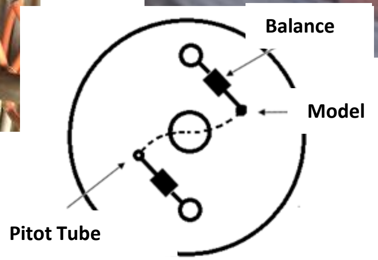
A one-dimensional, strain-gage balance was used (with a full-scale balance capacity of 2 N and an uncertainty of about $\pm$ 0.02 N).

The obtained data were correlated with the outcomes of numerical simulations conducted using the DS2G software and with other experimental values available in the literature (in particular, the published data used for these comparisons were selected in such a way that the test conditions in terms of free-stream Mach number, $M_\infty$, were as close as possible to the selected test conditions, Zuppardi and Esposito, 2001).







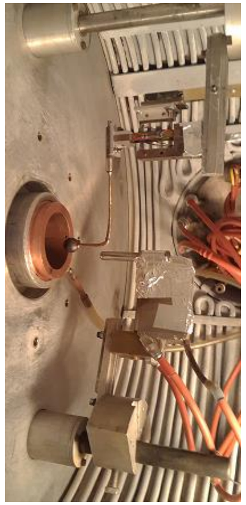

Nitrogen

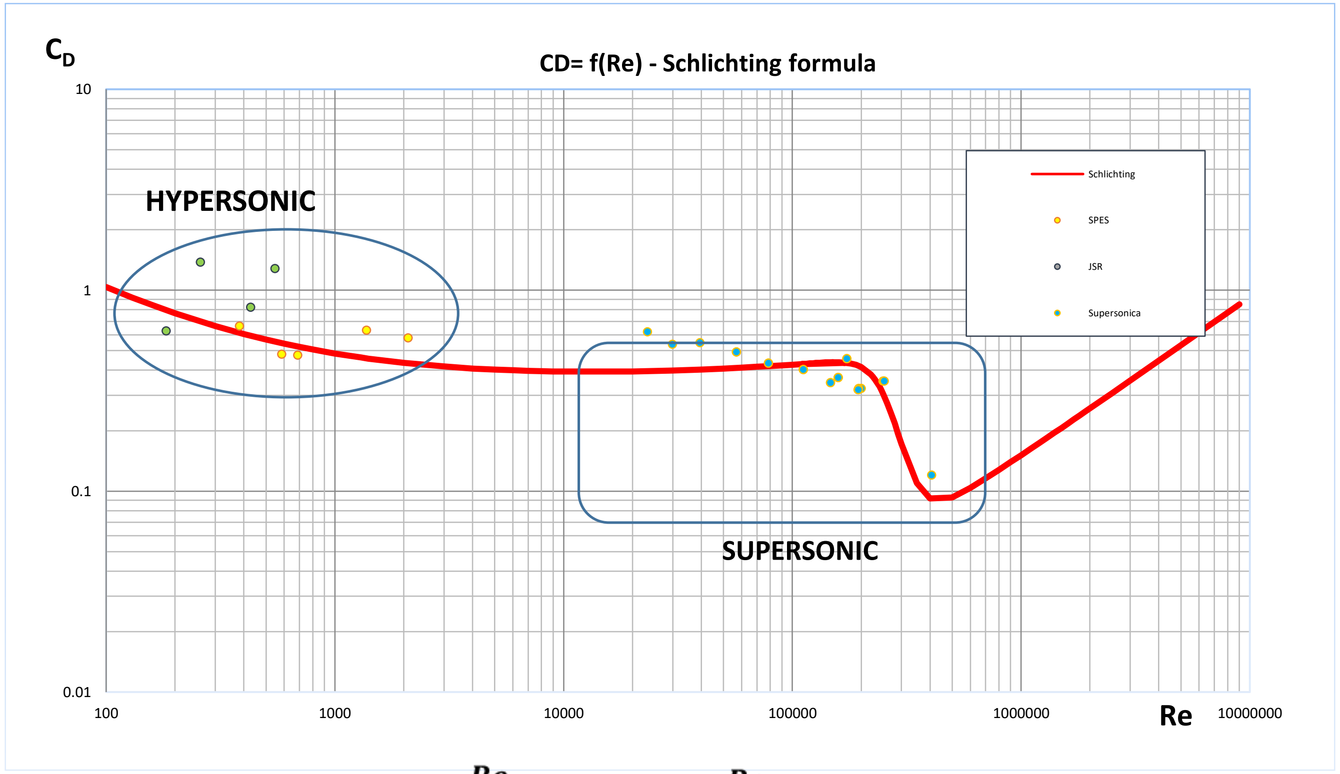
G. Zuppardi, **A. Esposito** “Blowdown arc facility for low-density hypersonic wind tunnel testing”, *Journal of Spacecraft and Rockets*, 38 (6), pp. 946-948, Nov-Dec. 2001

# The Sphere and the Schlichting curve 2/2

- In such a framework, and through the combined use of the two distinct (supersonic and hypersonic) facilities, data were obtained sufficient to verify the validity of the well-known Schlichting curve for spherical bodies in the range of Reynolds numbers from about $10^2$ up to about $10^6$.

HYPERSONIC FACILITY



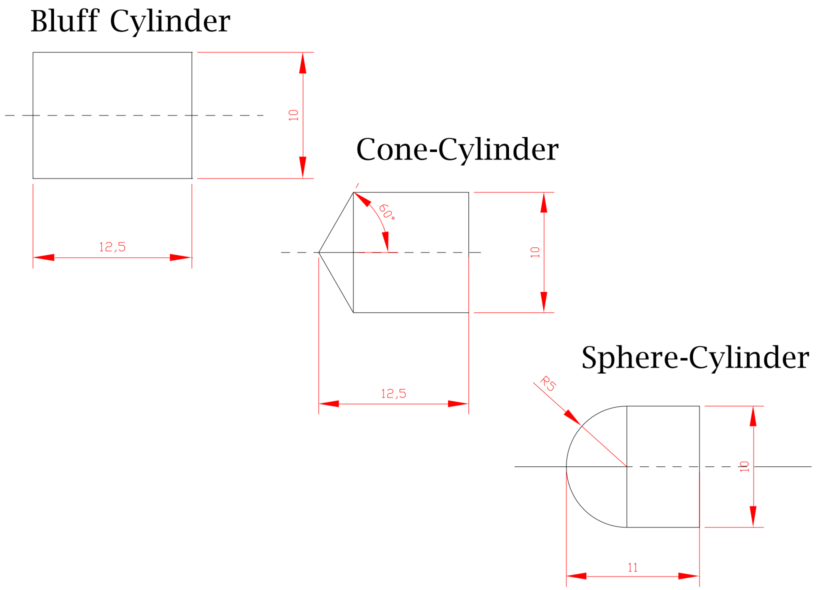


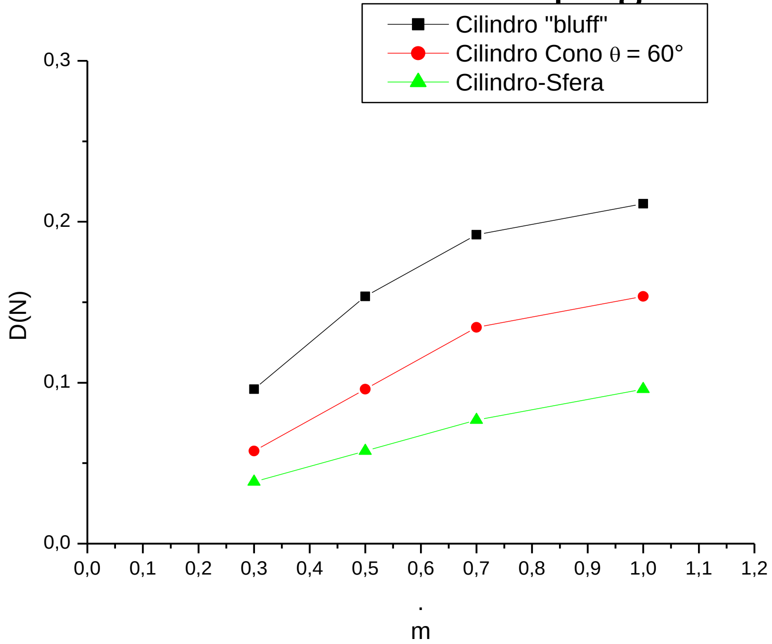

$$C_D = \frac{2,6(\frac{Re}{5,0})}{1+(\frac{Re}{5})^{1,52}} + \frac{0,411(\frac{Re}{263000})^{-7,94}}{1+(\frac{Re}{263000})^{-8,0}} + \frac{(Re)^{0,80}}{461000}$$

SUPERSONIC FACILITY

# Cones and Cylinders in Hypersonic Low Density Flow (1/2)

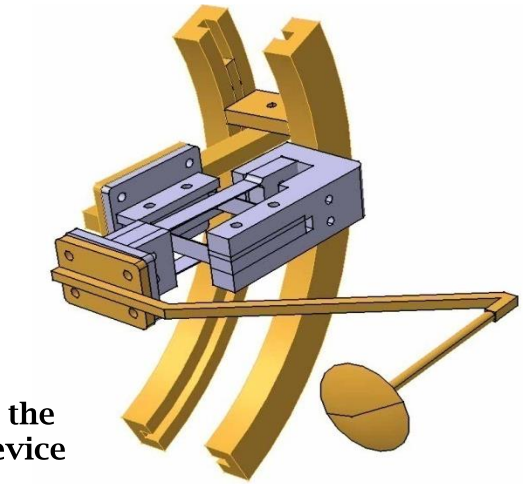
Additional relevant (technical) information about the test campaign for the hypersonic regime can be summarized as follows.



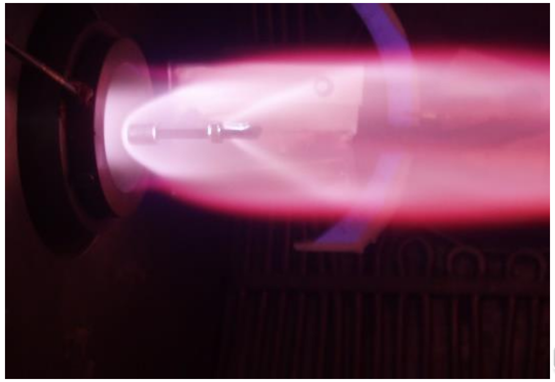




I = 300A

α = 0°



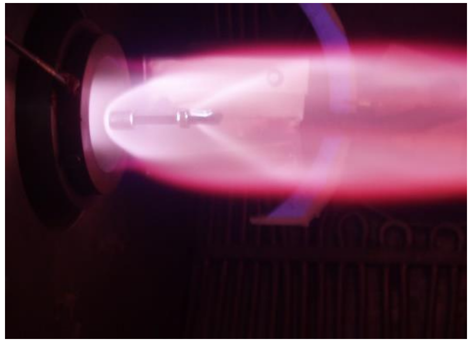
Model mounted on the Balance and AoA device



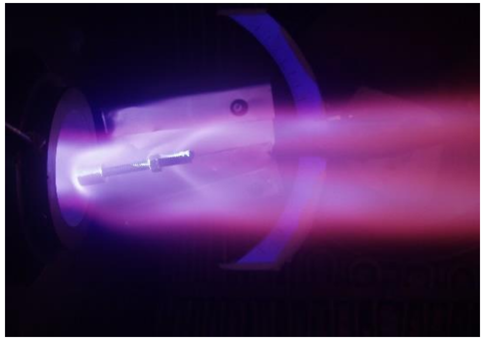
Argon

# Cones and Cylinders in Hypersonic Low Density Flow (1/2)

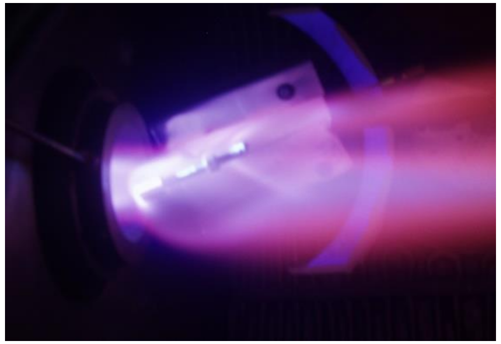
$\alpha = 0°$



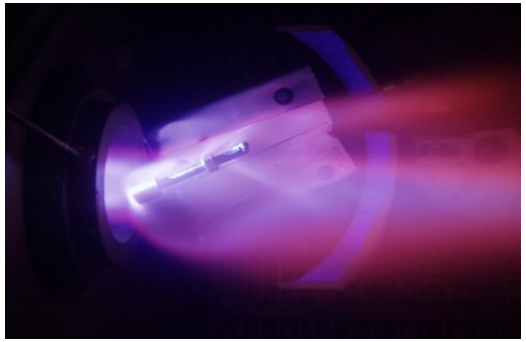
$\alpha = 10°$

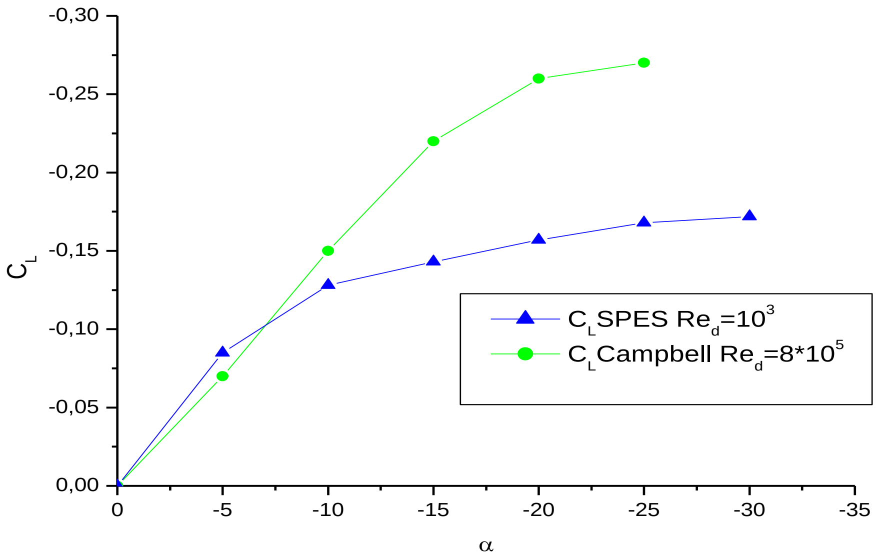


$\alpha = 20°$

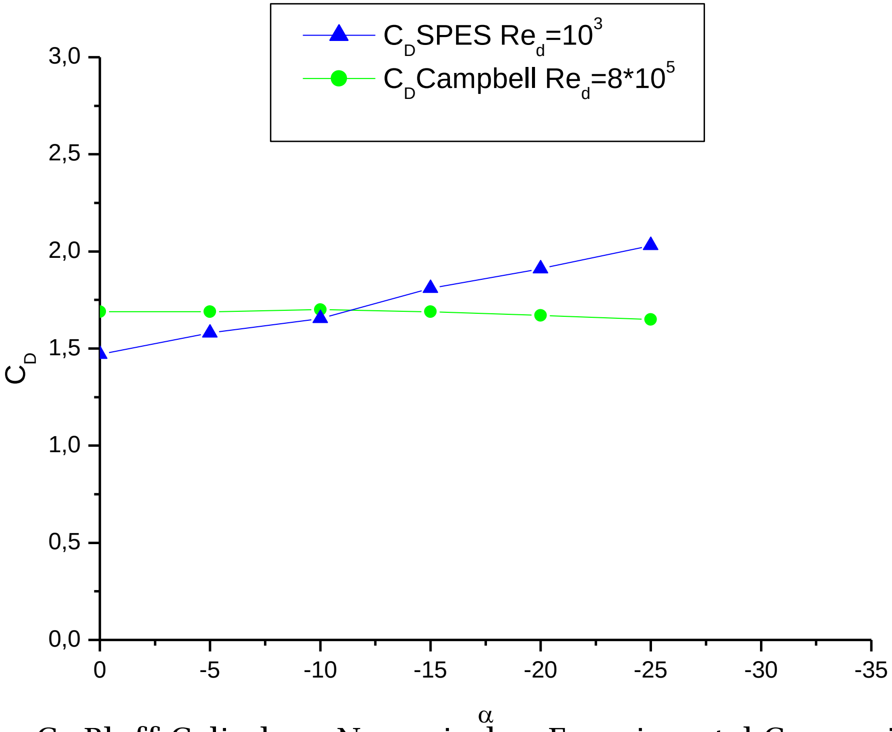


$\alpha = 30°$






$C_L$ Bluff Cylinder – Numerical vs Experimental Comparison




$C_D$ Bluff Cylinder – Numerical vs Experimental Comparison

G. Zuppardi, **A. Esposito** “Blowdown arc facility for low-density hypersonic wind tunnel testing”, *Journal of Spacecraft and Rockets*, 38 (6), pp. 946-948, Nov-Dec. 2001

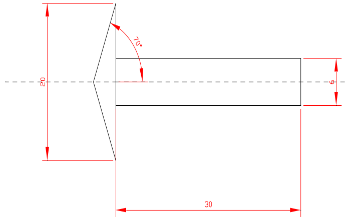
# Large-angle Cone in Hypersonic Low Density Flow (1/3)

Blunt-cone model: the considered test gas was argon with a mass flow rate of 0.5/1 (g/s). Two values of the arc electrical current were considered, namely, 300 and 400 A.

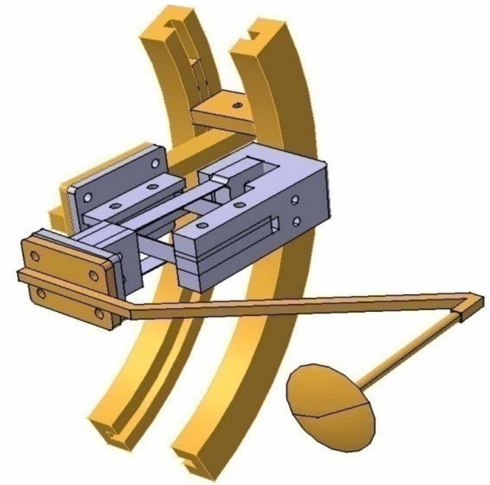
Following the same approach undertaken for the sphere, the results were compared both with other available experimental measurements and with the predictions of a Direct Simulation Monte Carlo (DSMC) software.

Despite some inconsistencies with respect to other published experimental data, reasonable agreement was obtained with the DSMC results for relatively small angles of attack (the observed mismatch at higher angles being probably due to interference effects, Russo et al., 2008).

**Large-angle Cone**

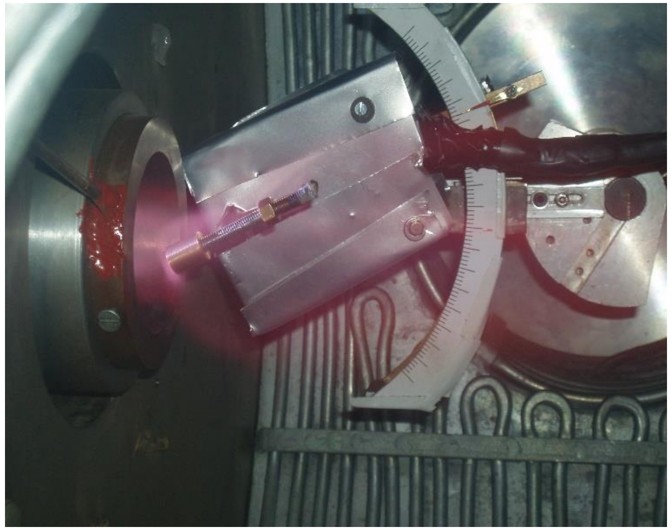


**Model mounted on the Balance and AoA device**



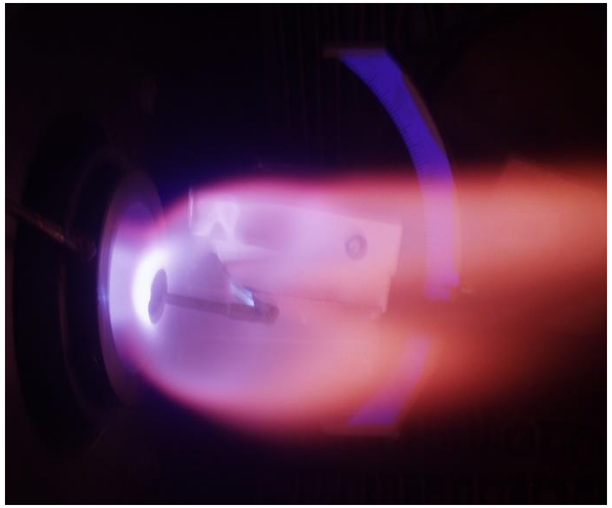
**Small Planetary Entry Simulator (SPES)**

**Preliminary Test**

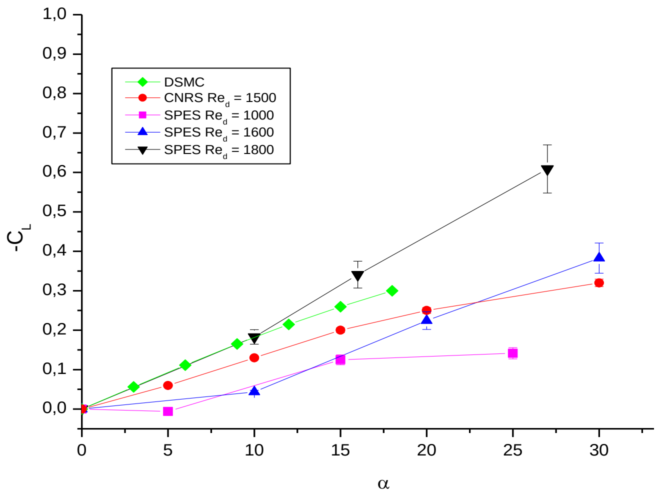


G. P. Russo, G Zuppardi, **A Esposito** “Computed vs. measured force coefficients on a cone in a small arc facility”, Proceedings of the Institution of Mechanical Engineers, Part G, *Journal of Aerospace Engineering*, 222 (3), pp.403-409, 2008

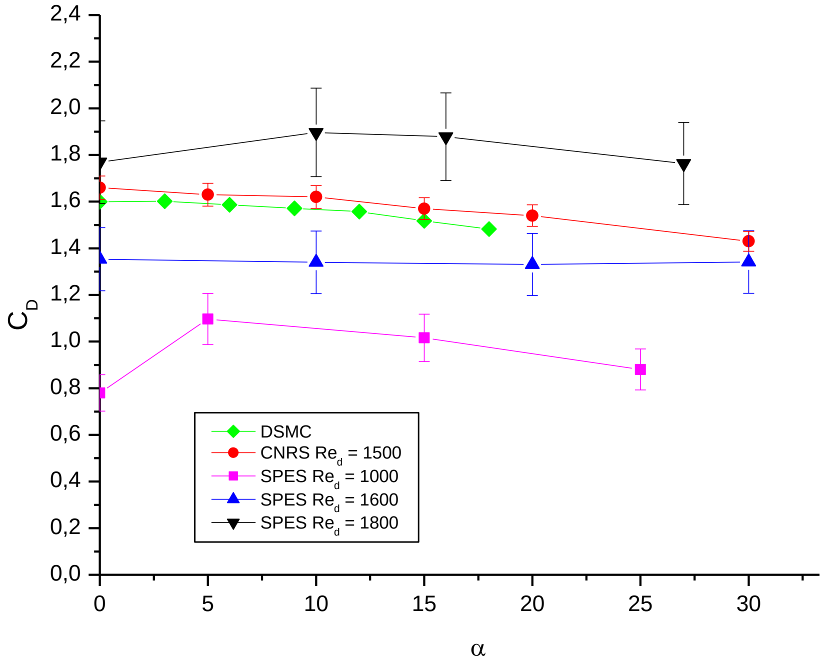
# Large-angle Cone in Hypersonic Low Density Flow (2/3)



Small AoA

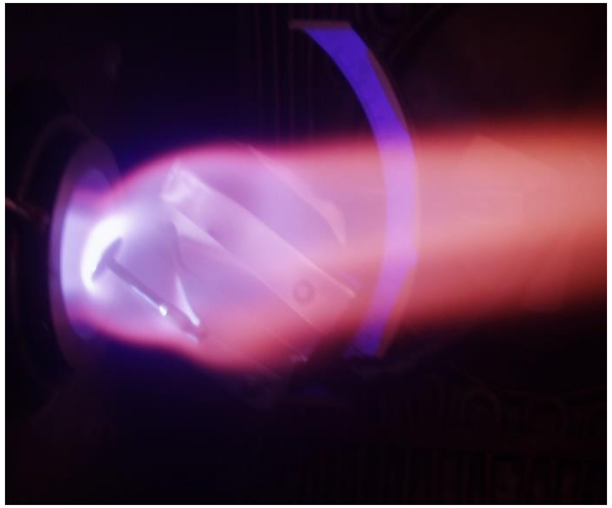



$C_L$ - Experimental vs Numerical Comparison




$C_D$ - Experimental vs Numerical Comparison

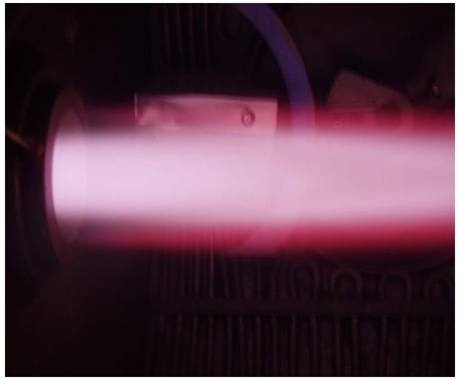
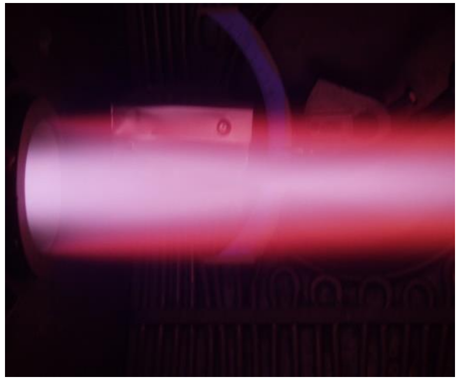
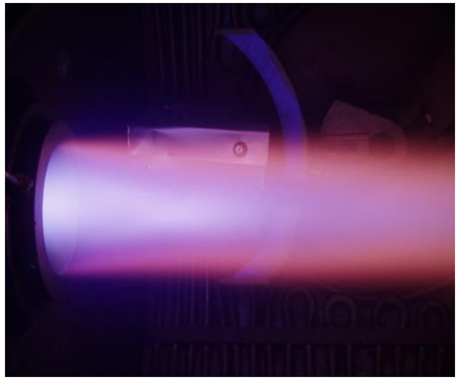
Flow Visualization (filtered photo) at small (a) and large (b) Angles of Attack (AoA)



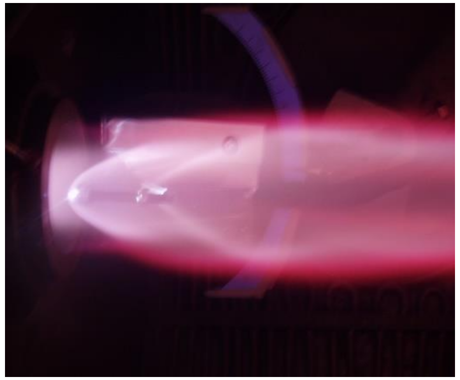
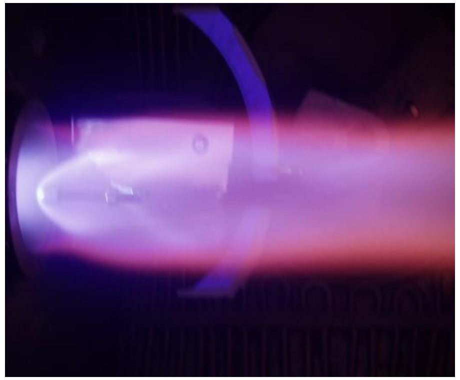
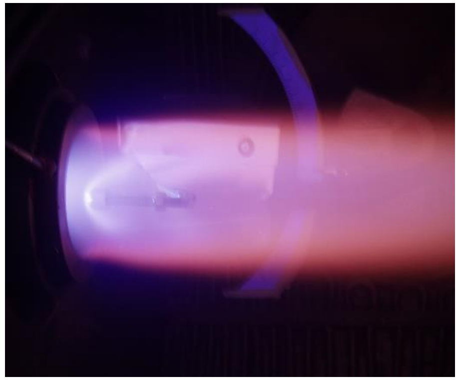
Large AoA

G. P. Russo, G Zuppardi, **A Esposito** "Computed vs. measured force coefficients on a cone in a small arc facility", Proceedings of the Institution of Mechanical Engineers, Part G, *Journal of Aerospace Engineering*, 222 (3), pp.403-409, 2008

# Large-angle Cone in Hypersonic Low Density Flow (3/3)

$\dot{m} = 1g/s$ $\dot{m} = 0.5g/s$ $\dot{m} = 0.3g/s$

Visualization (filtered photos) of Rarefaction in Hypersonic Low Density Flows

# Thank You for Your attention!

- Questions?