Guidelines: Please turn in neat and clean exam solutions that give all the formulae that you have used as well as details that are required for the grader to understand your solution. Attach these sheets to your solutions.

Student’s Name:.................................................... Student’s SU email:........................................

Question (40 pts)

Describe under what conditions may a flow be regarded as hypersonic. This is an open-ended question, and therefore both creativity and rigor will be graded positively. However, physically incorrect statements will be graded negatively.

Problem (60 pts)

A subscale model of the Apollo Command Module used for investigation of re-entry pressure distributions and heat fluxes during the Apollo Program is shown in Fig. 1. The model consists of a spherical forebody of radius $r_n = 1.2D$, where $D$ is the base diameter, along with a rounded conical frustrum afterbody of semi-angle $35^\circ$. In the calculations below, assume a calorically perfect gas with $\gamma = 1.4$, and neglect the effect of the rounded corners (i.e., $r_c/r_n \rightarrow 0$).

Figure 1: Sketch of the Apollo capsule model.
a) (30 pts) Using the modified Newtonian theory, provide an expression of the local surface pressure acting on the spherical forebody normalized with the stagnation pressure $P_0^2$ behind a normal shock, as a function of the dimensionless tangential coordinate $s/r_n$, the free-stream Mach number $Ma_\infty$, the adiabatic coefficient $\gamma$, and the angle of attack $\alpha$, with $0 \leq \alpha \leq 35^\circ$. Compare your analytical predictions with the experimental measurements at the NASA Langley Mach-8 variable-density wind tunnel (see Fig. 2), and interpret the results. The experimental data can be downloaded in .txt format from https://web.stanford.edu/~jurzay/ME356_files/Jonesdata.txt

![Figure 2: Experimental measurements of the surface pressure by R. A. Jones, NASA TM X-919 (1964).](image)

b) (30 pts) Derive expressions of for the lift ($C_L$) and drag ($C_D$) coefficients using the modified Newtonian theory as a function of the free-stream Mach number $Ma_\infty$, the adiabatic coefficient $\gamma$, and the angle of attack $\alpha$, with $0 \leq \alpha \leq 35^\circ$. Use $\pi D^2/4$ as the reference area for both coefficients. Plot your analytical predictions of $C_L$ and $C_D$ as a function of $Ma_\infty$ for $\alpha = 0$ and $\alpha = 27.5^\circ$. Use these analytical expressions to calculate the angle of attack $\alpha$ at which the maximum lift-to-drag ratio $L/D$ of this Apollo capsule model is achieved at hypersonically large Mach numbers, $Ma_\infty \to \infty$. 