Air Breathing Propulsion Field Exam Question

Department of Aeronautics & Astronautics
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Note: Full credit will not be given without physical justification for answers

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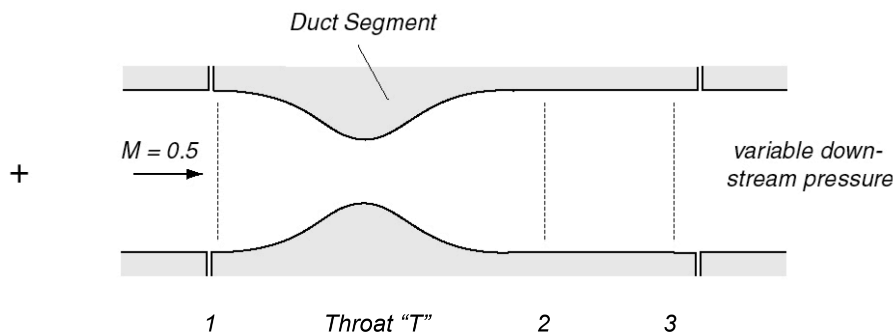
Consider the convergent-divergent duct segment depicted below. The area at station 1 is equal to the area at stations 2 and 3. The upstream conditions are fixed and the upstream Mach number is 0.5. The downstream pressure is variable and the duct walls can be assumed frictionless.



Part I (Weighted 2/3)

The flow is sonic at the throat for all cases considered in this part.

1) Sketch the following flow processes in an *h-s* diagram and explain how the stagnation and static quantities change along the streamwise direction from station 1 to station 3 (indicate stagnation and static states for stations 1, T, 2 and 3):

   a) $p_3 = p_1$, adiabatic and isentropic flow throughout stations 1 to 3

   b) $p_3 < p_1$, adiabatic and isentropic flow throughout stations 1 to 3

   c) $p_3 < p_1$, adiabatic flow throughout, non-isentropic flow between stations T and 2

   d) $p_3 < p_1$, supersonic isentropic flow between stations 1 and 2 and heat addition between station 2 and 3

2) For the above flow processes a), b), c) and d):

   a) Discuss the magnitude and direction of the fluid force that acts on the duct segment.

   b) Rank the forces on the duct, from smallest to largest

   Give physical explanations for your conclusions. You don't have to compute the force but you have to be able to explain how you would find its magnitude and direction.

Part II (Weighted 1/3)

Suppose now that the entire duct system is rotating around an axis coming out of the page as indicated by the cross in the figure above. The flow is adiabatic throughout and the duct walls are again frictionless.

3) What is different compared to the situation in Part I for the cases with no heat addition and isentropic flow throughout? It might be useful to start with a discussion of which quantities are conserved for the stationary system of Part I and the rotating system of Part II, supporting your discussion with equations and concepts.

4) Where in the convergent-divergent duct segment does the flow choke and why? (Does the flow choke upstream of, at, or downstream of the throat?) A physical explanation bolstered by equations is required in addition to the answer.