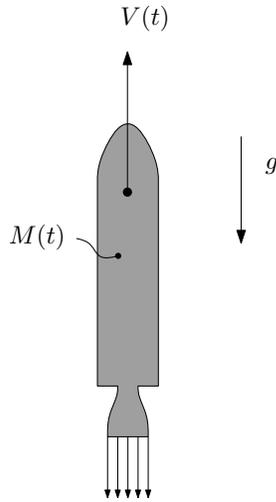


MIT Department of Mechanical Engineering  
2.25 Advanced Fluid Mechanics

**Problem 5.20**

*This problem is from “Advanced Fluid Mechanics Problems” by A.H. Shapiro and A.A. Sonin*



After its second booster has been fired, a space vehicle finds itself outside the earth’s atmosphere, moving vertically upward at a speed  $V_0$  against gravity  $g$ . Its total mass at that point is  $M_0$ . At  $t = 0$ , the vehicle’s third stage is turned on and the rocket burns propellant at a mass rate  $m_r$  kg/s, ejecting gas from the exit plane (area  $A_e$ ) at speed  $V_e$  relative to the rocket.

Show that if the gravitational acceleration remains essentially constant at the vehicle during the rocket firing, the velocity  $V(t)$  of the vehicle after time  $t$  will be given by

$$V(t) - V_0 = V_e \ln \frac{M_0}{M(t)} - \frac{g[M_0 - M(t)]}{\dot{m}_r}$$

where  $M(t)$  is the mass of the system at time  $t$ . Assume that although the pressure of the gas at the rocket exit plane is  $P_e$  (the rocket exhaust is supersonic, and hence the pressure at the exit is not balanced with the zero pressure of space), the effect of the finite exit plane pressure on the thrust is negligible.

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