8.57 **IDENTIFY:** $a = -\frac{v_{ex}}{m}\frac{dm}{dt}$. Assume that dm/dt is constant over the 5.0 s interval, since *m* doesn't change much during that interval. The thrust is $F = -v_{ex}\frac{dm}{dt}$.

SET UP: Take *m* to have the constant value $110\text{ kg} + 70\text{ kg} = 180\text{ kg}$. dm/dt is negative since the mass of the MMU decreases as gas is ejected.

EXECUTE: **(a)** $\frac{dm}{dt} = -\frac{m}{v_{ex}}a = -\left(\frac{180\text{ kg}}{490\text{ m/s}}\right)(0.029\text{ m/s}^2) = -0.0106\text{ kg/s}$. In 5.0 s the mass that is ejected is $(0.0106\text{ kg/s})(5.0\text{ s}) = 0.053\text{ kg}$.

(b) $F = -v_{ex}\frac{dm}{dt} = -(490\text{ m/s})(-0.0106\text{ kg/s}) = 5.19\text{ N}$.

EVALUATE: The mass change in the 5.0 s is a very small fraction of the total mass *m*, so it is accurate to take *m* to be constant.

8.58 **IDENTIFY** and **SET UP:** Apply Eq. 8.39: $a = -\frac{v_{ex}}{m}\frac{dm}{dt}$. Solve for dm/dt.

EXECUTE:

$$\frac{dm}{dt} = -\frac{ma}{v_{ex}} = -\frac{(6000\text{ kg})(25.0\text{ m/s}^2)}{2000\text{ m/s}} = -75.0\text{ kg/s}.$$

So in 1 s the rocket must eject 75.0 kg of gas.

EVALUATE: We have approximated dm/dt by $\Delta m/\Delta t$. We have assumed that 25.0 m/s^2 is the average acceleration for the first second.

8.59 **IDENTIFY:** Use Eq. 8.39, applied to a finite time interval. Solve for v_{ex}.

SET UP: $\frac{\Delta m}{\Delta t} = -\frac{m}{160}$.

EXECUTE: $a = -\frac{v_{ex}}{m}\frac{\Delta m}{\Delta t}$. $v_{ex} = -\frac{a}{\left(\frac{\Delta m}{\Delta t}/m\right)} = \frac{-15.0\text{ m/s}^2}{\left(-\frac{m}{160}\right)/m} = 2.40\times10^3\text{ m/s} = 2.40\text{ km/s}$

EVALUATE: The acceleration is proportional to the speed of the exhaust gas and to the rate at which mass is ejected.

8.60 **IDENTIFY** and **SET UP:** $(F_{av})\Delta t = J$ relates the impulse *J* to the average thrust F_{av}. Eq. 8.38 applied to a finite time interval gives $F_{av} = -v_{ex}\frac{\Delta m}{\Delta t}$. $v - v_0 = v_{ex}\ln\left(\frac{m_0}{m}\right)$. The remaining mass *m* after 1.70 s is 0.0133 kg.

EXECUTE: **(a)** $F = \frac{J}{\Delta t} = \frac{10.0\text{ N}\cdot\text{s}}{1.70\text{ s}} = 5.88\text{ N}$. $F_{av}/F_{max} = 0.442$.

(b) $v_{ex} = -\frac{F_{av}\Delta t}{-0.0125\text{ kg}} = 800\text{ m/s}$.

(c) $v_0 = 0$ and $v = v_{ex}\ln\left(\frac{m_0}{m}\right) = (800\text{ m/s})\ln\left(\frac{0.0258\text{ kg}}{0.0133\text{ kg}}\right) = 530\text{ m/s}$.

EVALUATE: The acceleration of the rocket is not constant. It increases as the mass remaining decreases.

8.61 **IDENTIFY:** $v - v_0 = v_{ex}\ln\left(\frac{m_0}{m}\right)$.

SET UP: $v_0 = 0$.

EXECUTE: $\ln\left(\frac{m_0}{m}\right) = \frac{v}{v_{ex}} = \frac{8.00\times10^3\text{ m/s}}{2100\text{ m/s}} = 3.81$ and $\frac{m_0}{m} = e^{3.81} = 45.2$.

EVALUATE: Note that the final speed of the rocket is greater than the relative speed of the exhaust gas.

8.62 **IDENTIFY** and **SET UP:** Use Eq. 8.40: $v - v_0 = v_{ex} \ln(m_0/m)$.

$v_0 = 0$ ("fired from rest"), so $v/v_{ex} = \ln(m_0/m)$.

Thus $m_0/m = e^{v/v_{ex}}$, or $m/m_0 = e^{-v/v_{ex}}$.

If v is the final speed then m is the mass left when all the fuel has been expended; m/m_0 is the fraction of the initial mass that is not fuel.

(a) EXECUTE: $v = 1.00\times10^{-3}c = 3.00\times10^{5}$ m/s gives

$$m/m_0 = e^{-(3.00\times10^5 \text{ m/s})/(2000 \text{ m/s})} = 7.2\times10^{-66}.$$

EVALUATE: This is clearly not feasible, for so little of the initial mass to not be fuel.

(b) EXECUTE: $v = 3000$ m/s gives $m/m_0 = e^{-(3000 \text{ m/s})/(2000 \text{ m/s})} = 0.223$.

EVALUATE: 22.3% of the total initial mass not fuel, so 77.7% is fuel; this is possible.