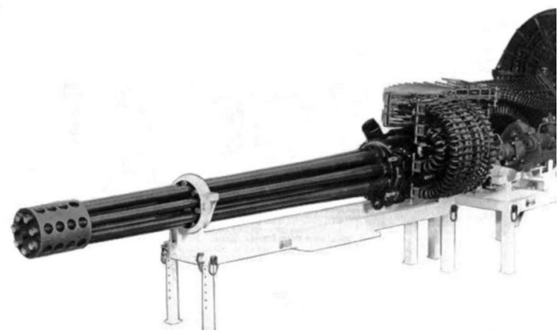
The A-10 Thunderbolt aircraft was designed around its primary, tank-killing weapon, the GAU-8/A Avenger Gatling gun. In the A-10, this Gatling gun fires 0.28 kg depleted uranium shells at a rate of 3900 rounds/minute. The muzzle velocity from the gun is 1070 m/s. The maximum takeoff mass of the A-10 is 22,950 kg, including the gun's 281 kg.

One rumor states that shells leaving the Gatling gun cancel out the thrust from the aircraft's twin GE TF-34-GE100 turbofan engines (each produces 9060 lb_f of thrust). Is this rumor accurate? If the guns were fired continuously, how long would it take for the aircraft to come to rest if its initial speed is 230 m/s (≈ 450 knots)? (Note that in actuality, the Gatling gun is fired only in two second bursts in order to avoid going through the ammunition too quickly and overheating the gun.)

The A-10 Thunderbolt. The Gatling gun is located here.



The GAU-8 Avenger Gatling gun.

A depleted uranium shell used in the Gatling gun (I'm not sure who the person is.)

If Arnold Schwarzenegger, who weighed approximately 250 lb_f in his body-building days, fired this particular Gatling gun (Arnold often uses big guns in his movies), what would be his acceleration?

Schwarzenegger, as a T-800 Terminator, firing a hand-held GE M134 Minigun Gatling gun.

SOLUTION:

Evaluate the momentum flux from the Gatling gun,

$$\int_{CS} u_x \left(\rho \mathbf{u}_{rel} \cdot d\mathbf{A}\right) = (V)\dot{m} \tag{1}$$

where

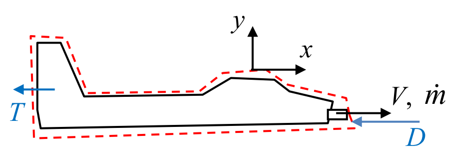
V = 1070 m/s

$\dot{m}$ = (0.28 kg/round)(3900 rounds/min)(min/ 60 s) = 18.2 kg/s

$\Rightarrow$ $\dot{m}V$ = 19.5 kN = 4400 lb_f

Since the thrust from each engine is 9060 lb_f, we see that the rumor is not accurate. Nevertheless, the momentum flux produced by the gun is impressive. It's approximately equivalent to half the thrust of one of the engines.

To determine the deceleration of the aircraft, apply the linear momentum equation in the *x*-direction to a control volume surrounding the aircraft as shown in the following figure. Use a frame of reference fixed to the control volume.



$$\frac{d}{dt}\int_{CV} u_x \rho dV + \int_{CS} u_x \left(\rho \mathbf{u}_{rel} \cdot d\mathbf{A}\right) = F_{B,x} + F_{S,x} - \int_{CV} a_{x/X} \rho dV \tag{2}$$

where

$$\frac{d}{dt}\int_{CV} u_x \rho dV \approx 0 \quad \text{(The mass in the CV has zero velocity in the given FOR.)} \tag{3}$$

$$\int_{CS} u_x \left(\rho \mathbf{u}_{rel} \cdot d\mathbf{A}\right) = (V)\dot{m} - T \quad \text{(where } T \text{ is the thrust, or momentum flux, from the aircraft engines)} \tag{4}$$

$$F_{B,x} = 0 \tag{5}$$

$$F_{S,x} = -D \quad \text{(the drag force on the aircraft)} \tag{6}$$

$$\int_{CV} a_{x/X} \rho dV = \frac{dU}{dt} M_{CV} \tag{7}$$

Substitute and solve for the aircraft acceleration.

$$V\dot{m} - T = -D - \frac{dU}{dt} M_{CV} \tag{8}$$

Note that when the aircraft flies at a steady speed (just prior to firing the gun), the thrust from the engines will equal the drag acting on the aircraft, *i.e.*, $T = D$. Thus,

$$\frac{dU}{dt} = -\frac{V\dot{m}}{M_{CV}} \tag{9}$$

Using the given data,

$\dot{m}V$ = 19.5 kN

M_{CV} = 22,950 kg

$\Rightarrow$ dU/dt = -0.85 m/s^2 = -0.086g where g is the acceleration due to gravity (= 9.81 m/s^2)

To determine the time it takes for the aircraft to come to rest, re-write Eq. (8) taking into account the change in mass of the aircraft due to the loss of bullet mass (neglect the loss in mass due to the loss of fuel). Also, treat the drag force as varying with the square of the aircraft speed (roughly true in practice).

$$V\dot{m} - T = -cU^2 - \frac{dU}{dt}M_{CV}\,, \tag{10}$$

$$\left(M_0 - \dot{m}t\right)\frac{dU}{dt} + cU^2 = T - V\dot{m}\,, \tag{11}$$

where the constant c is found by equating the thrust T to the drag D at the given initial speed, U_0,

$$D = cU_0^2 = T \Rightarrow c = \frac{T}{U_0^2}\,. \tag{12}$$

Substitute and simplify.

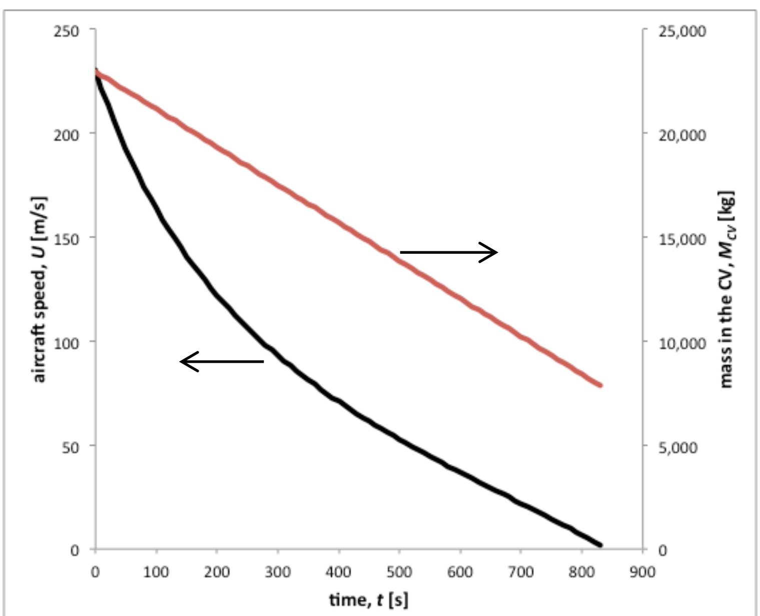
$$\left(M_0 - \dot{m}t\right)\frac{dU}{dt} + \frac{T}{U_0^2}U^2 = T - V\dot{m}\,, \tag{13}$$

$$\frac{dU}{dt} = \frac{T - V\dot{m} - \frac{T}{U_0^2}U^2}{\left(M_0 - \dot{m}t\right)}\,. \tag{14}$$

Solve this equation numerically given the following data,

M_0 = 22,950 kg
$\dot{m}$ = 18.2 kg/s
T = 18,120 N
U_0 = 230 m/s
V = 1070 m/s
$U(0)$ = 230 m/s (= U_0)

The time for the aircraft to come to rest is approximately 830 s (= 13.8 min). Of course, the mass of bullets would run out long before this limit is reached. Hence, we needn't worry about the plane coming to rest due to firing the Gatling gun.



Arnold Schwarzenegger has a mass of

$M_{\text{Arnold}} = 250\ \text{lb}_f = 250\ \text{lb}_m = 113\ \text{kg}$

Drawing a control volume around Arnold and the gun, which has a mass of 281 kg, and using Eq. (9) gives,

$\Rightarrow \boxed{dU/dt = -49\ \text{m/s}^2 = -5.0g}$ where g is the acceleration due to gravity ($= 9.81\ \text{m/s}^2$)

Thus, even holding such a massive gun, Arnold and the gun would go flying backwards as soon as the gun is fired.