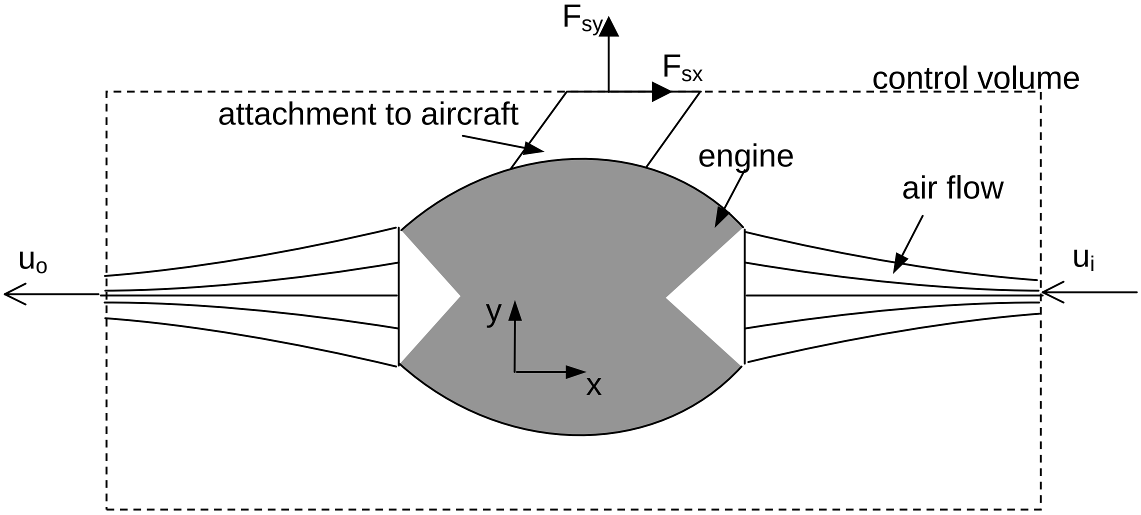
4.2. Jet thrust

The reaction of a jet can be used to propel an aircraft or a ship. The jet is a fast moving stream of fluid. For the *steady* motion of such a craft, the force exerted by the jet can be calculated using the **force-momentum principle**. For steady flow, the co-ordinate axes must be fixed to the moving craft, so that the velocities are measured *relative* to the craft.

e.g. consider a jet engine attached to an aircraft. The aircraft moves to the right with a velocity u_i .Therefore, relative to the aircraft, the air at intake moves with a velocity u_i to the left. The fluid leaving the engine has a relative velocity u_o. Let the mass flow rate be $\dot{m}$:



Consider a control volume that is large enough to enclose the entire engine, and the fluid entering and leaving it. Both inlet and outlet are at atmospheric pressure, so that there are no pressure forces on the control volume. The structural forces F_{sx} and F_{sy} are the forces exerted by the engine on the fluid.

In the x-direction:

$$\sum F_x = \sum \dot{M}_{outx} - \sum \dot{M}_{inx}$$

$\therefore \quad F_{sx} = \dot{m}(-u_0) - \dot{m}(-u_i)$ The negative signs are because the directions of the velocities are in the negative sense, according to my specified co-ordinate axes.

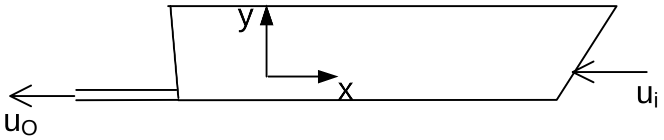
Thus, $F_{sx} = \dot{m}(u_i - u_o)$

Therefore, the force exerted by the fluid on the aircraft, which is the thrust, T is: $T = -F_{sx} = \dot{m}(u_o - u_i)$

The exit velocity u_o is much higher than the inlet velocity. It may be accelerated by a simple change of section, however, more usually, it will be increased by the use of a turbine.

Example

A boat is powered by hydraulic propulsion. When travelling at a speed of 4.49 ms^{-1}, water is taken in through a hole in the bow, and ejected through a nozzle of area 0.0465 m^2 in the stern, at a volume flow rate of 2.832 m^3s^{-1}. The density of the sea water is 1026 kg m^{-3}. Determine the thrust on the boat.



u_i ,the speed of entry of water relative to the boat is 4.49 ms^{-1}.

$$u_o = \frac{\dot{V}}{A_o} = \frac{2.832}{0.0465} = 60.903 \ \text{ms}^{-1}$$

Since the volume flow rate leaving the boat is 2.832 m^3s^{-1} , u_o is the jet velocity relative to the boat.

The thrust on the boat is, therefore,

$$T = -F_{sx} = \dot{m}(u_o - u_i) = 1026 * 2.832 * (60.903 - 4.49) = 163.9 \ \text{kN}$$

Further reading:

Bacon and Stephens, Fluid Mechanics for Technicians 3/4	5.7
Bacon and Stephens, Mechanical Technology	32.6
Massey, Mechanics of fluids	4.3.3
White, Fluid Mechanics	3.4

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