Electric Feed System Pump Design Calculation Procedure

The following document outlines the theory and procedures used to calculate impeller and housing dimensions for the Portland State Aerospace Society's Electric Feed System (EFS) for bipropellant rocket engines.

The calculations required to reach these results are based on the following inputs:

- R_{mixed}: The ratio of liquid oxygen to fuel
- P_p: The required pressure inside the pump chamber
- P_i: Pressure at pump inlet
- U_{ss}: Suction specific speed (typically between 7000-12000)
- η: Target pump efficiency
- L: Impeller hub to tip ratio
- Ψ: Stage Head Coefficient
- f: Thrust

Rocket Model

For the rocket model, a specific impulse of $I_{sp} = 221.4$ $[s]$ will be used. Then the required mass flow rate for both fluids can be found as:

$$\dot{m}_{Total} = \frac{f}{g \cdot I_{sp}}$$

Where g is the gravitational constant. With this value, the mass flow rate required for each fluid can be calculated using the mixture ratio provided as user input.

$$\dot{m}_{LOX} = \frac{\dot{m}_{Total}}{1 + \frac{1}{R_{mixed}}}$$
$$\dot{m}_{IPA} = \frac{\dot{m}_{Total}}{1 + R_{mixed}}$$

A loss factor $F_{Loss} = 1.15$ is then used to calculate the pressure gain needed.

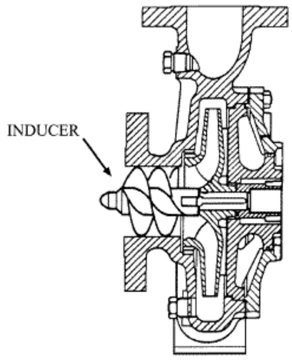
$$\Delta P = P_p \times L_{Loss} - P_i$$

Pump Design

The number of stages to be used in the pump is dependent on the pressure rise per stage, ΔP_s. This value is the maximum allowable pressure rise for a single stage, after which additional stages must be added. a value of $\Delta P_s = 47\ [Mpa] = 6817\ [psi]$ is used. Then the number of stages, N, is found as the following (rounding up the nearest whole integer):

$$N = \frac{\Delta P}{\Delta P_s}$$

Note that an inducer inlet flow coefficient, ϕ, is used for dimensioning purposes if an inducer is to be used in the pump design in addition to the impeller(s). This value is $\phi = 0.1$ if an inducer is used.



The volumetric flow of the fluids is used to calculate the pump rotational speed, n_{RPM}, and pump specific speed, n_s. These values are calculated using the density of each fluid:

$$Q = \frac{\dot{m}}{\rho}$$

The required head rise, vapor pressure head, and inlet head for each fluid (in feet) can be found as:

$$H_p = 144 \times \frac{\Delta P}{\rho}$$
$$H_i = 144 \times \frac{P_i}{\rho}$$
$$H_v = 144 \times \frac{P_v}{\rho}$$

The impeller tip speed, u_t, gives us the tangential speed of the outermost diameter of the impeller. This value can be calculated as:

$$u_t = \phi = \sqrt{\frac{2 \cdot g \cdot H_p}{N}}$$

The available net pressure suction head, $NPSH_a$ is calculated as:

$$NPSH_a = H_i - H_v$$

With a Thoma Parameter of $\tau = 2$, the rotational $NPSH$ is calculated as:

$$NPSH_r = \frac{NPSH_a}{2}$$

Now, the rotational speed n_{RPM} and specific speed n_s can be found.

$$n_{RPM} = \frac{U_{ss} * NPSH_r^{\frac{1}{4}}}{21.2 * \sqrt{Q}}$$
$$n_s = \frac{2 \cdot U_{ss}}{2 \cdot \pi}$$

Note: The calculated value of n_s can be compared with *Table 10-2* for validation.

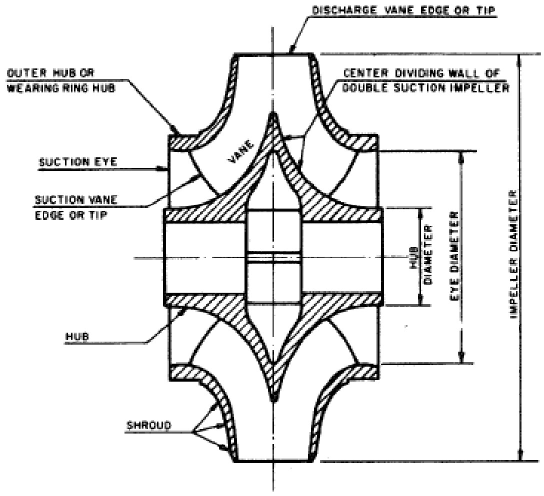
Impeller Design

The calculated impeller dimensions are shown in the figure to the right. The impeller discharge diameter, D_o, and eye (or inlet) diameter, D_i, are found as:

$$D_o = \frac{u_t}{2 \cdot n_s}$$

$$D_i = \left(\frac{4 * Q}{\pi \cdot \phi \cdot n_{rad} \cdot (1 - L^2)} \right)^{\frac{1}{3}}$$

Note that for D_i, n is in radians, not RPM. To find D_H, calculate the following:



$$D_H = D_o \cdot L$$

Based on the calculated discharge diameter, the housing diameter for the pump can be estimated as:

$$D_p \approx D_o \cdot 1.152$$

Motor Requirements

The power required from each motor in order to drive the pumps is calculated as follows:

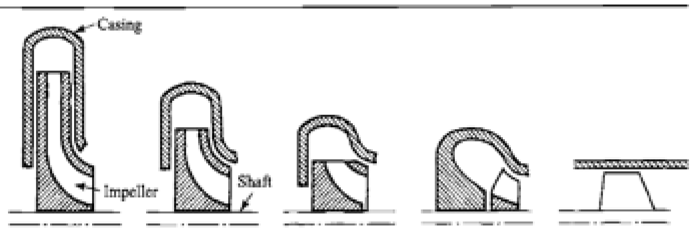
$$P_{Req} = \frac{\dot{m} \cdot H_p}{(0.738)\mu} \frac{1}{1000} = \frac{\dot{m} \cdot H_p}{738\mu}$$

From this, the load torque can be calculated:

$$T = (9.5488)(1000)\frac{P_{Req}}{n_{RPM}} = (9548.8)\frac{P_{Req}}{n_{RPM}}$$

Ideal ranges for pump specific speed n_s for different impeller types

TABLE 10-2

	Impeller type				
	Radial	Francis	Mixed flow	Near axial	Axial
Basic shape (half section)					
Specific speed N_s					
U.S. nomenclature	500–1000	1000–2000	2000–3000	3000–6000	Above 8000
SI consistent units	0.2–0.3	0.4	0.6–0.8	1.0–2.0	Above 2.5
Efficiency %	50–80	60–90	70–92	76–88	75–82