ANALYSIS OF ATTITUDE AND CONTROL FOR DOCKING PROCESS OF SPACE SHUTTLE

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Abstract

Docking is a type of space rendezvous process to connect a spacecraft to another. Reaction control thrusters are used to achieve the orbit height and appropriate velocity needed for docking. The paper aims at simulating the thrusters of a chaser spacecraft in space at different chamber pressures and corresponding densities, and find out the values of mass flow rate, force output and jet velocity. It is found that as the chamber pressure increases, the force exerted at the outlet increases whereas the velocity of the jet decreases. It is also seen that as the axial distance is increased, the pressure initially increases, fluctuates and then sharply drops.

Keywords: Docking, Space rendezvous, Reaction control thrusters

1. Introduction

Space rendezvous can be defined as the process of joining of two spacecrafts or space objects by aligning them on the same orbit and reducing the distance between them till they are physically connected to each other and relative velocity among the two space objects reduces to zero. Space rendezvous is used for crew transfer, resupply modules etc. There are mainly two means for space rendezvous- Berthing and Docking. Berthing requires a robotic arm to place the mating interface of one spacecraft/space object into the mating interface of the other. Docking is the type of space rendezvous where two space crafts or space objects are connected by direct contact, without any help from a robotic arm.

Docking can be classified on the basis of their mating interface as androgynous (ungendered) or non-androgynous (gendered). Non-androgynous spacecraft have male and female docking design, whereas androgynous docking spacecrafts have identical docking interface on both the spacecraft. Thus, the androgynous docking system is preferable due to its absence of restriction unlike the non-androgynous.

The spacecrafts can be classified into 'chaser' and 'target' spacecrafts when it comes to docking. The spacecraft which is controlled and maneuvered by the on-board computer, astronauts inside the spacecraft or mission control on the earth is called chaser spacecraft. Whereas, the spacecraft which is already in the orbit and is docked with the chaser is called target spacecraft. The chaser after the launch is in a lower orbit than the target spacecraft. Then using the V-bar, R-bar or Z-bar approach, the chaser spacecraft approaches the target spacecraft for docking. The typical docking speed is 0.1ft/s to 0.2ft/s.

The chaser spacecraft consist of a series of thrusters to provide control over its motion. Such a system is called Reaction control system (RCS) which uses thrusters to provide attitude control and motions like roll, pitch, yaw and movements about axes. RCS is used extensively for close maneuvers during docking. They are also used to change orientation, stabilize and even during re-entry.

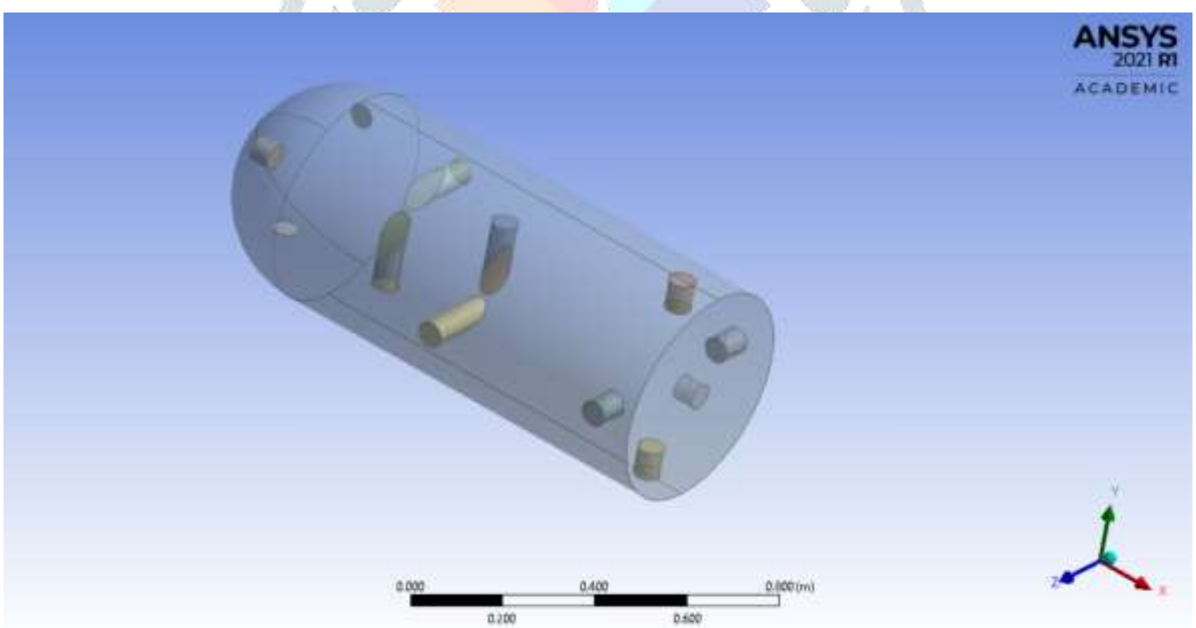


Figure 1: RCS thrusters shown on spacecraft

2. Methods

A cylindrical spacecraft with a hemispherical nose is considered for the process. There are 1 main thruster, 1 reverse thruster, 4 axial thrusters and 4 tangential thrusters. Two tangential thrusters in opposite direction to each other can be used to create a roll motion. Two tangential thrusters in same direction or an axial thruster in the same direction can be used to create pitch or yaw motion. The docking mechanism is assumed to be androgynous and the docking interface is present at the nose, coincident with the longitudinal axis of the spacecraft.

The temperature, pressure and density values corresponding to the altitude (-5000m to 1000000m) is taken from U.S. Standard Atmosphere, 1976. The average height of the International Space Station is 408km from the Earth. The velocities (v) and forces (F) from the main thruster, reverse thruster, axial and tangential thrusters are found out from the mass flow rate ($\dot{m}$), area (A) and density (ρ) values using the formula $\dot{m} = \rho A v$

CATIA V5 was used to make the body and thrusters of the spacecraft. ANSYS Academic 2021 R1 was used to apply materials, for simulations and for calculations to find out values of mass flow rate, area and force using CFX Post of ANSYS.

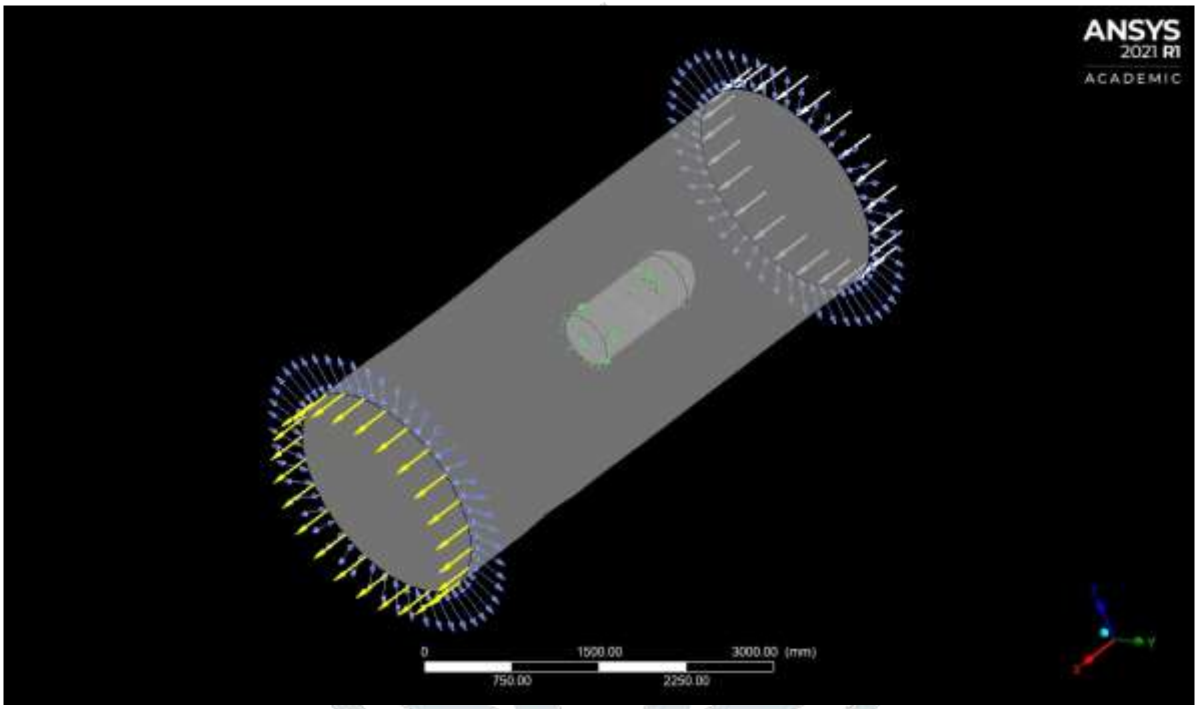


Figure 2: Spacecraft shown with boundary conditions applied

3. Boundary Conditions

- Pressure values: 10bar, 27.58bar, 34.47bar, 48.26bar, 55.16bar, 62.05bar, 68.95bar
- Corresponding densities are: 10.04kgm^{-3}, 25.29kgm^{-3}, 31.38kgm^{-3}, 43.57kgm^{-3}, 49.66kgm^{-3}, 55.74kgm^{-3}, 61.83kgm^{-3}
- Temperature is taken as 400K

4. Results

Pressure (bar)	Density (kgm^{-3})	Area (m^2)	Mass flow rate (kgs^{-1})	Velocity (ms^{-1})	Force (N)
10	10.04	0.0121523	4.44997	36.47244584	5530.6
27.58	25.29	0.0121523	7.39304	24.05557511	15264.5
34.47	31.38	0.0121523	8.26571	21.67548095	19080.7
48.26	43.57	0.0121523	9.78142	18.47378415	26719.6
55.16	49.66	0.0121523	10.4578	17.32906515	30542.3
62.05	55.74	0.0121523	11.0921	16.37526473	34359.7
68.95	61.83	0.0121523	11.6929	15.5619676	38182.8

Table 1: Main thruster

Pressure (bar)	Density (kgm^{-3})	Area (m^2)	Mass flow rate (kgs^{-1})	Velocity (ms^{-1})	Force (N)
10	10.04	0.0121523	4.41768	36.20779343	68.4432
27.58	25.29	0.0121523	7.3411	23.88657203	189.322
34.47	31.38	0.0121523	8.20801	21.52417207	236.732
48.26	43.57	0.0121523	9.71378	18.34603514	331.663
55.16	49.66	0.0121523	10.3857	17.20959207	379.178
62.05	55.74	0.0121523	11.0159	16.26277068	426.635
68.95	61.83	0.0121523	11.6129	15.45549637	474.168

Table 2: Axial thruster

Pressure (bar)	Density (kgm^{-3})	Area (m^2)	Mass flow rate (kgs^{-1})	Velocity (ms^{-1})	Force (N)
10	10.04	0.00277688	4.44546	159.4504985	57.32
27.58	25.29	0.00277688	7.41259	105.5514096	157.744
34.47	31.38	0.00277688	8.29737	95.22048845	186.523
48.26	43.57	0.00277688	9.82942	81.24248892	232.28
55.16	49.66	0.00277688	10.5125	76.23285433	254.039
62.05	55.74	0.00277688	11.1532	72.05687328	281.051
68.95	61.83	0.00277688	11.7564	68.47278543	283.369

Table 3: Tangential thruster

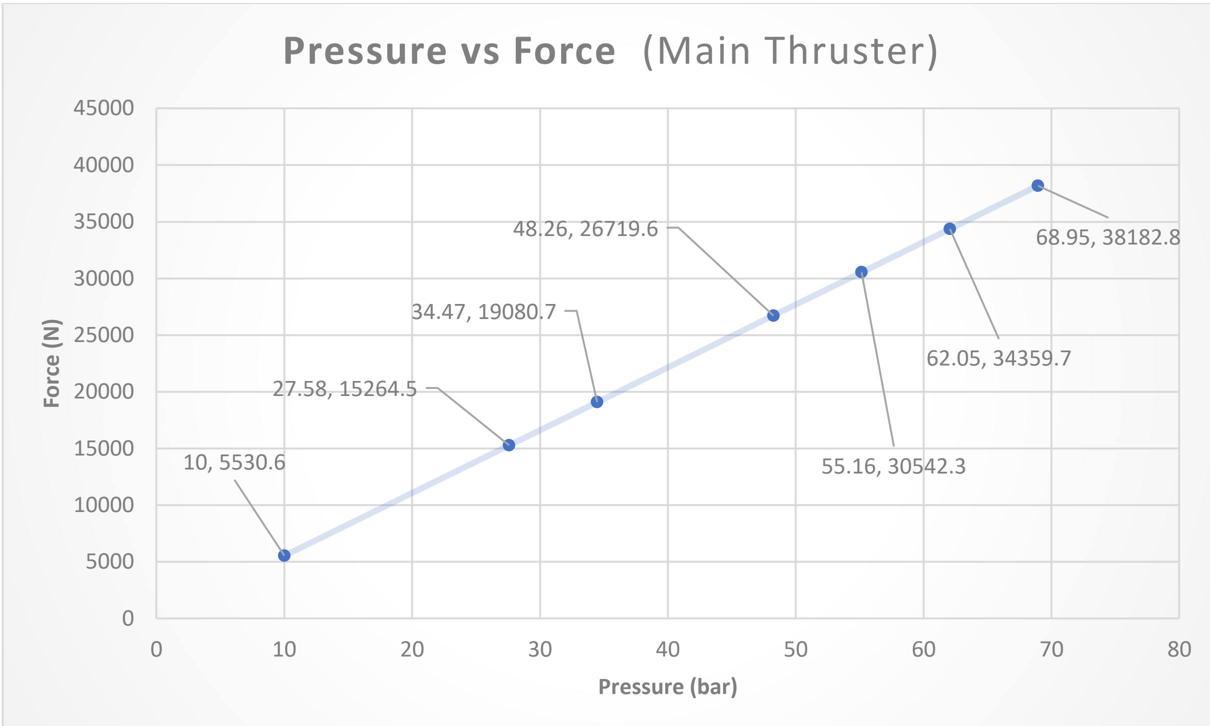
Pressure (bar)	Density (kgm^{-3})	Area (m^2)	Mass flow rate (kgs^{-1})	Velocity (ms^{-1})	Force (N)
10	10.04	0.00279688	4.44751	158.3832998	5528.86
27.58	25.29	0.00279688	7.38907	104.4641123	15260
34.47	31.38	0.00279688	8.26129	94.12849069	19075
48.26	43.57	0.00279688	9.77622	80.22497176	26711.8
55.16	49.66	0.00279688	10.4522	75.25357955	30533.4
62.05	55.74	0.00279688	11.0862	71.11183924	34349.7
68.95	61.83	0.00279688	11.6868	67.58067605	38171.8

Table 4: Reverse thruster

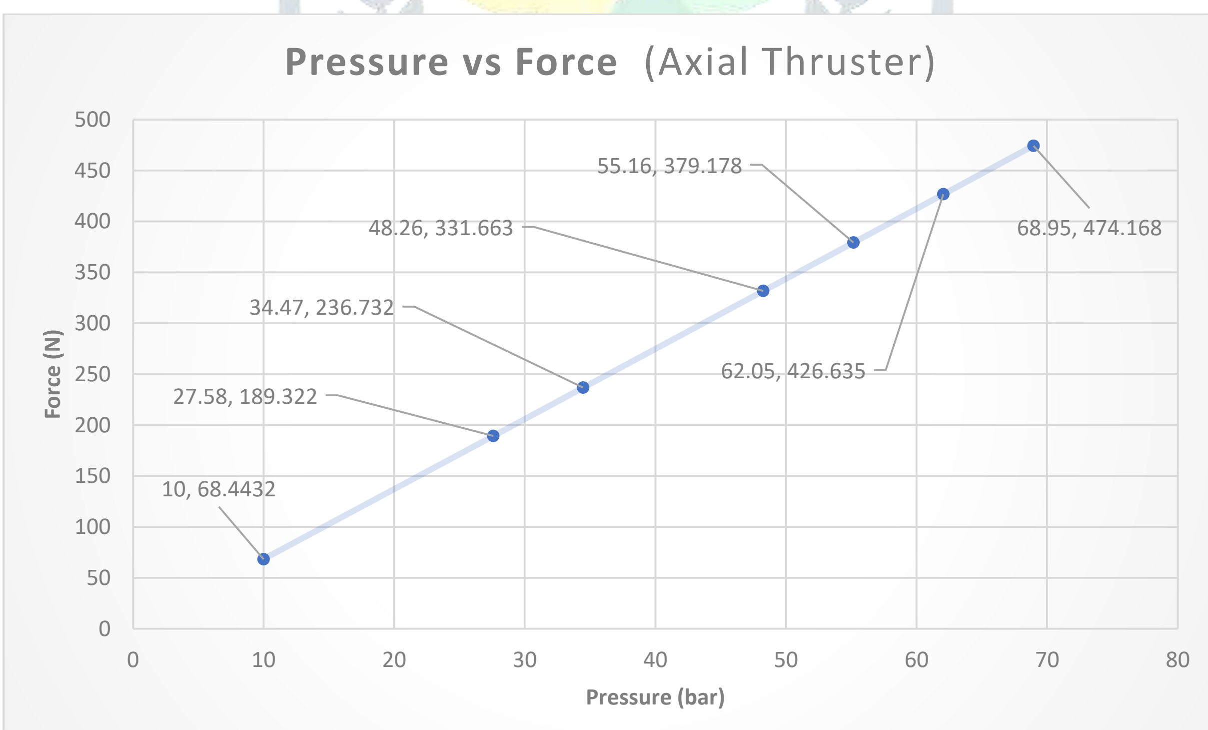
Graphs are made between Chamber pressure vs Force at outlet.

For Axial and Tangential thrusters, Pressure vs Axial Distance graphs are considered.

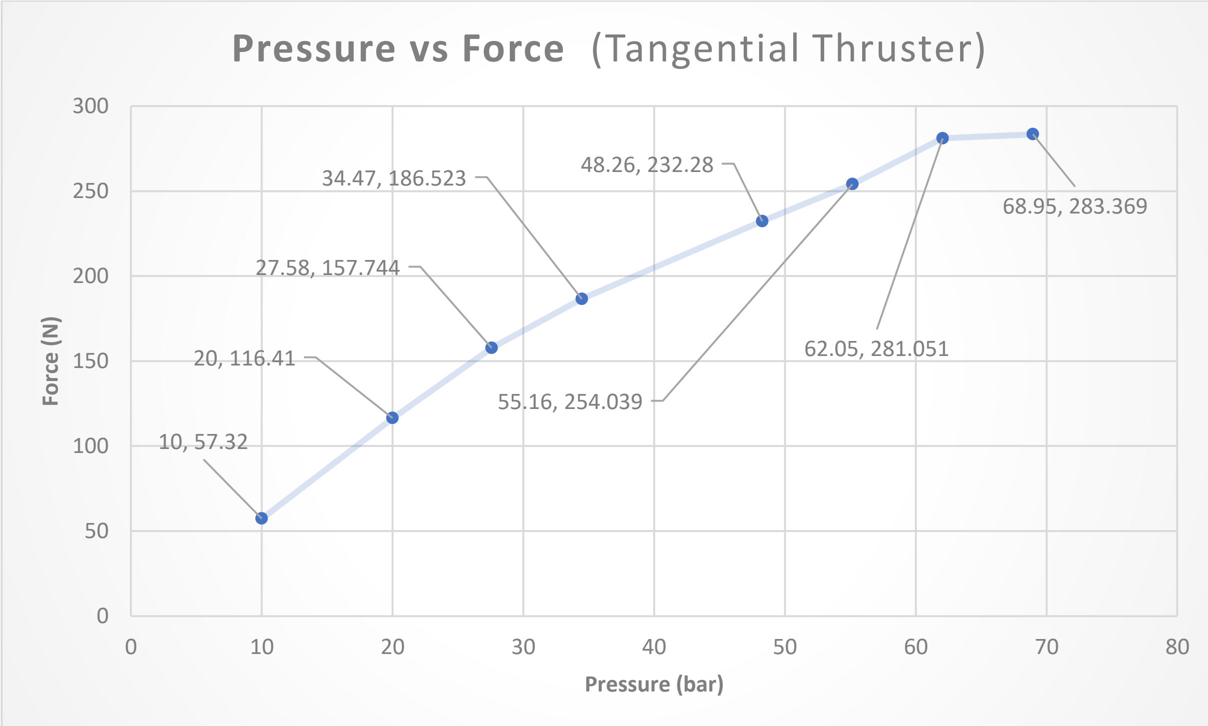
Main thruster, Reverse thruster and one Axial thruster and one Tangential thruster are considered for the calculations and respective tables and graphs.



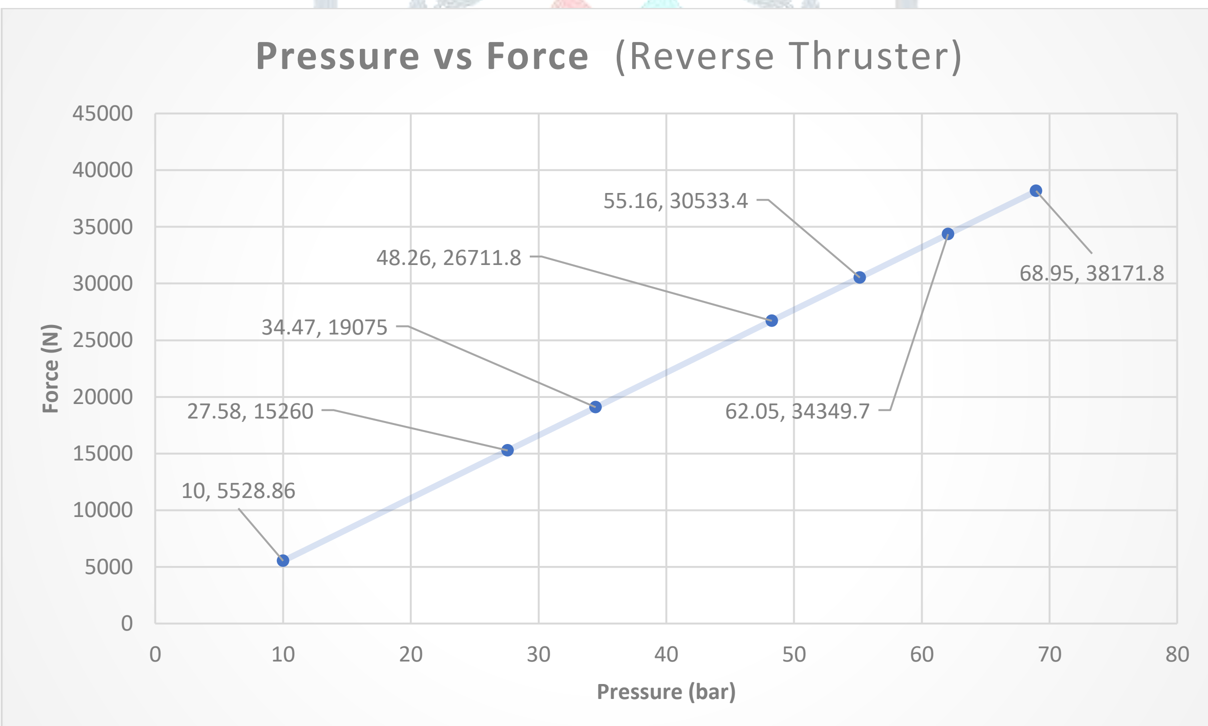
Graph 1: Chamber Pressure vs Force at outlet for Main thruster



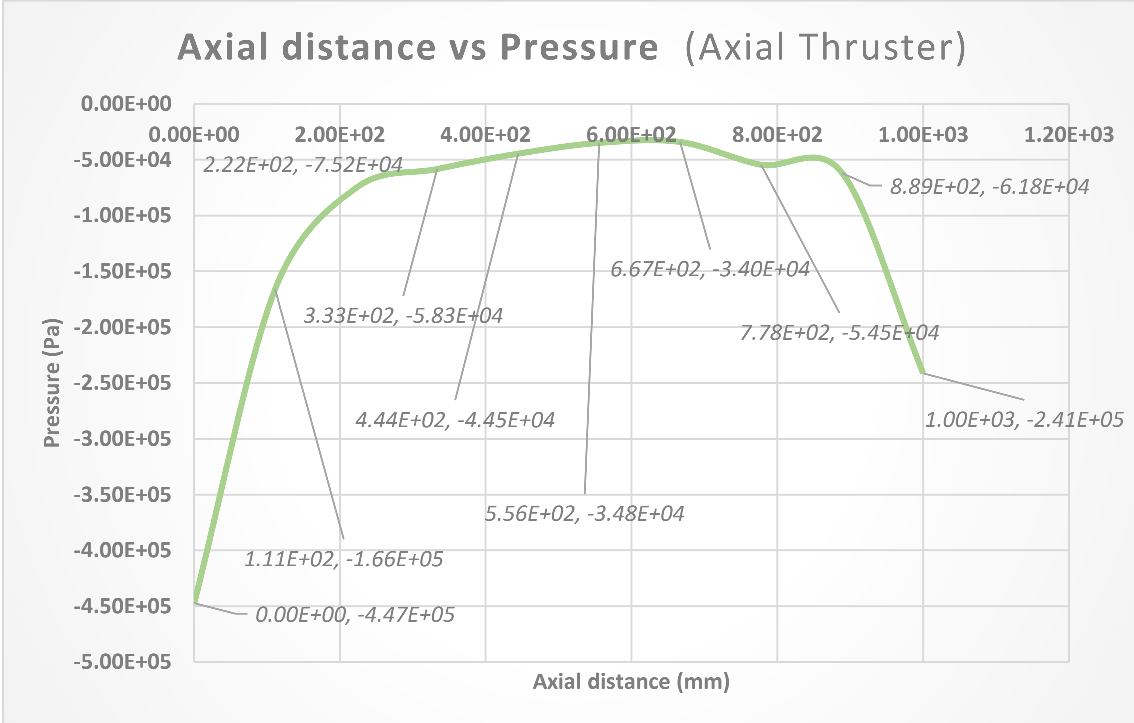
Graph 2: Chamber Pressure vs Force at outlet for Axial thruster



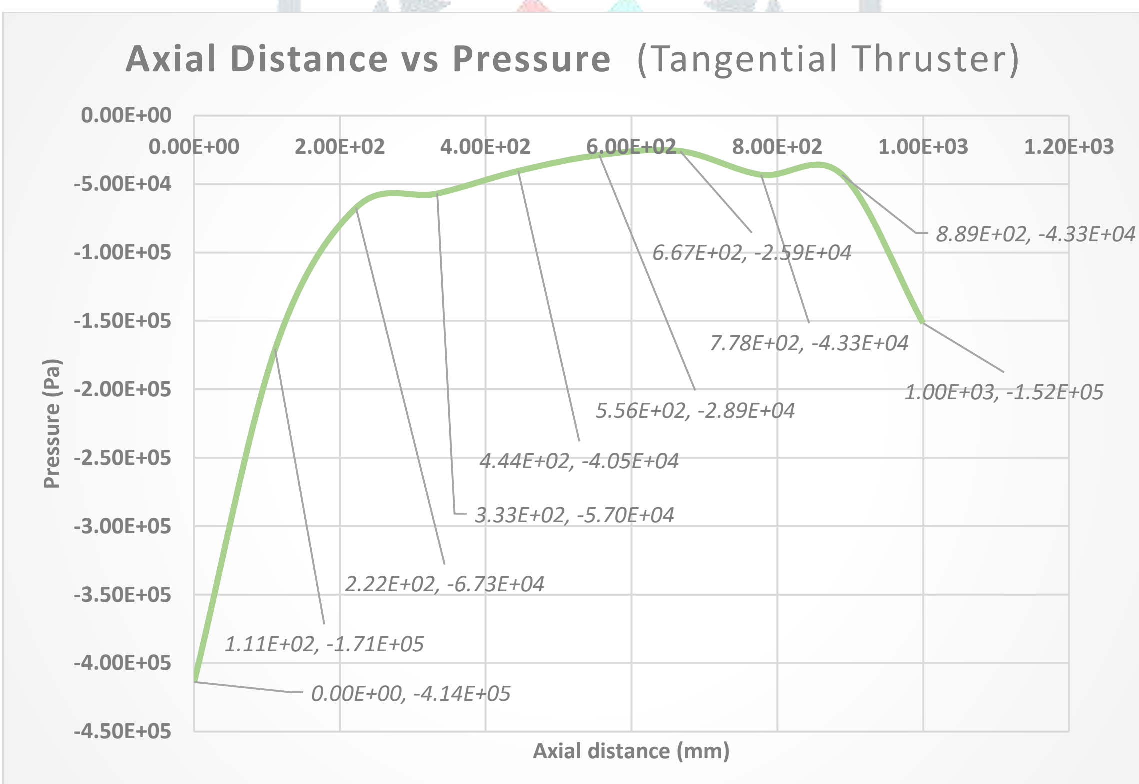
Graph 3: Chamber Pressure vs Force at outlet for Tangential thruster



Graph 4: Chamber Pressure vs Force at outlet for Reverse thruster



Graph 5: Axial distance vs Pressure for Axial thruster



Graph 6: Axial distance vs Pressure for Tangential thruster

5. Discussion

- It is seen from the graphs (1, 2, 3, 4) that as the chamber pressure increases, the force at outlet increases
- It is seen from graphs (5, 6) that with the increase in axial distance, the pressure increases, then fluctuates with almost the same values and sharply drops.

- From the graph and tables, it is observed that as the chamber pressure increases, the force at outlet increases, whereas the velocity decreases.
- The mass flow rate is almost similar, but the velocities of tangential and reverse thrusters are comparatively higher than the main and axial thrusters.

Conflict of Interest

We confirm that there is no conflict of interest to declare for this publication.

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