UPPSALA UNIVERSITET

Supersonic Flow Model for a CubeSat MEMS Thruster

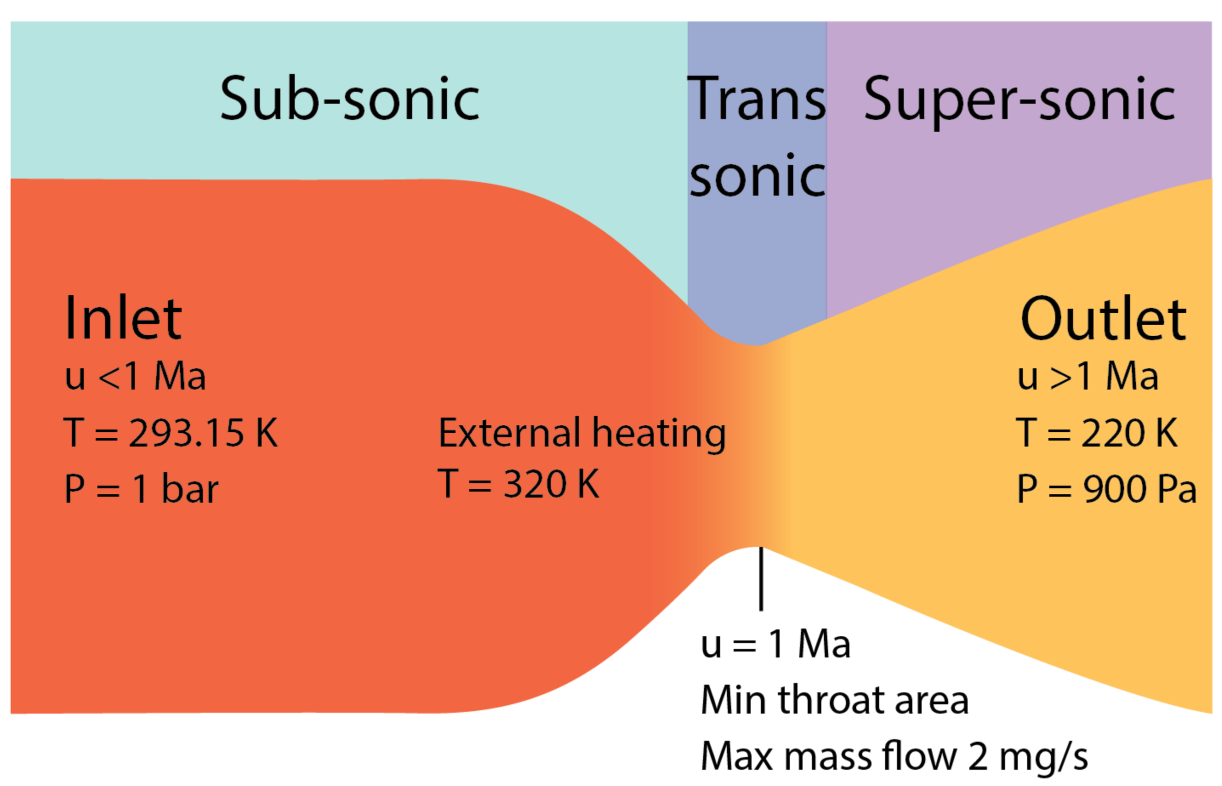
INTRODUCTION

GomSpace Sweden manufactures propulsion systems for CubeSats, small nanosatellites made up of cubic modules. Their MEMS (Micro Electro Mechanical Systems) thrusters are small silicon chip with dimensions 10 x 20 x 0.35 mm. The design includes a gas inlet, a larger chamber, and a Converging-Diverging nozzle. High pressure butane gas flows from the inlet and through the throat of the nozzle after which it rapidly expands and reaches supersonic speeds. Because no combustion is present in the flow, thrust only depends on the mass flow at the outlet.

AIMS

The task in this project was to model the MEMS thruster in different materials and perform a high Mach number flow simulation in COMSOL. The solutions would reveal how each material affects the temperature, pressure and velocity of the flow. The project was conducted under the supervision of GomSpace Sweden.

Converging Diverging Nozzle



SIMULATION

COMSOL Multiphysics is a software tool for simulating coupled physics problems. It uses FEM and a broad range of numerical solvers.

The study is stationary and has 500 000 DOF which is created manually with boundary layers and a sweep mesh option to yield sufficient accuracy for the thin geometry. The iterative GMRES solver is used with a geometric multigrid method with SOR pre-smoother and post-smoother, and a coarse solver using MUMPS. The nonlinear solver is based on newtons method.

The governing equations of the simulation are the compressible Navier Stokes equation and the heat equation.

$$\rho(\mathbf{u}\cdot\nabla)\mathbf{u} = \nabla\cdot[-p\mathbf{I}+\mathbf{K}]+\mathbf{F}$$
$$\nabla\cdot(\rho\mathbf{u}) = 0$$
$$\mathbf{K} = \mu\left(\nabla\mathbf{u}+(\nabla\mathbf{u})^{\mathbf{T}}\right)-\frac{2}{3}\mu(\nabla\cdot\mathbf{u})\mathbf{I}$$
$$Q = \rho C_p\mathbf{u}\cdot\nabla\mathbf{T}+\nabla\cdot\mathbf{q}$$
$$\mathbf{q} = -k\nabla T$$

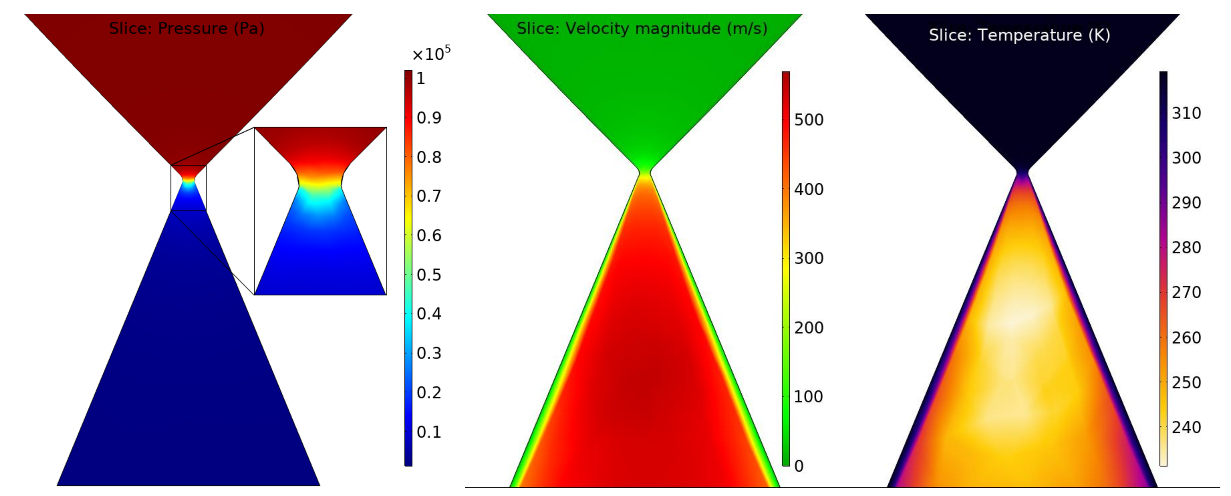
RESULTS

With design parameters provided by GomSpace, the COMSOL simulation produced a solution which came close to the target variables, as seen in table 1.

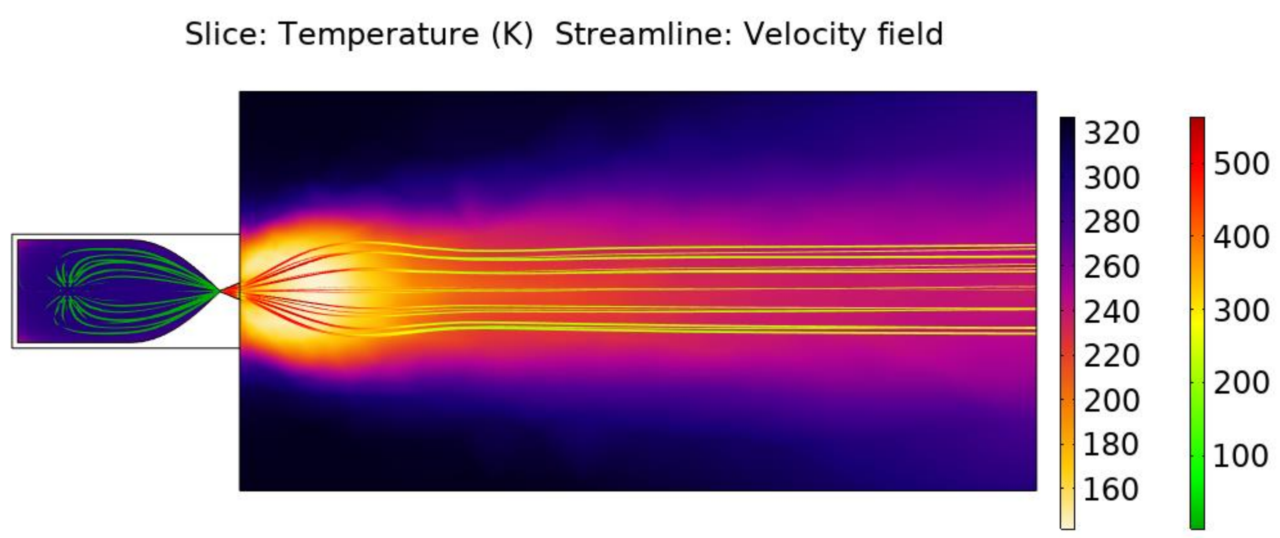
With insufficient drop in pressure, the model fails to reach the outlet velocity target of 3.5 Mach. Using steel or titanium raises the temperature of the gas which is exposed to the heating element before the nozzle. This is explained partly by the increased thermal conductivity of the metals.

Variables	Place	Target	Silicon	Steel	Titanium
Velocity (m/s)	outlet	-	552.03	570.77	575
Mach number	outlet	3.5	2.93	2.92	2.92
Temperature (K)	nozzle	320	319.57	342.82	348.88
Temperature (K)	outlet	220	226.82	243.50	247.32
Pressure (Pa)	outlet	900	1269.2	1283.2	1285.2
Mass flow (mg/s)	nozzle	2	2.27	2.19	2.18

Table 1: *Reached results for different materials of the thruster.*



Velocity, pressure and temperature at the nozzle for silicon thruster



Simulation of the exhaust plume

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COMSOL GOMSPACE

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