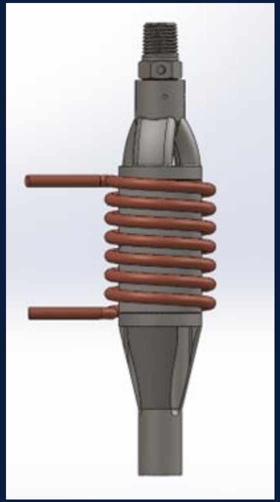
Electrothermal Thruster

Aleksander Angel Aleman

FIU Mechanical Engineering Student
Student Apprentice/Expert
Engineering Deans Office
aalem025@fiu.edu
786-877-5493

Electrothermal Thruster

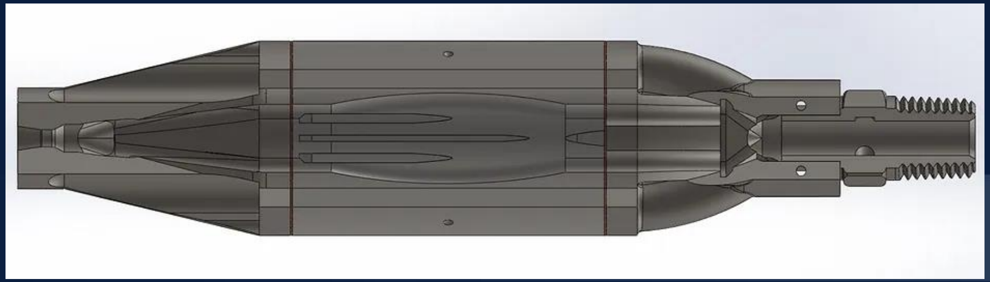
Purpose



Design Purpose:

The electrothermal thruster is designed to decelerate falling payloads for a controlled and survivable landing

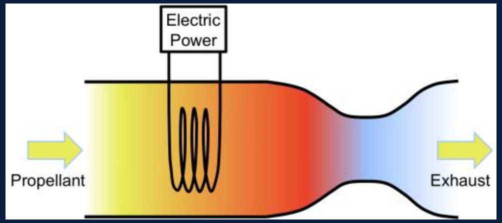
This will be used on a retrievable weather balloon payload and Upcoming lunar lander project

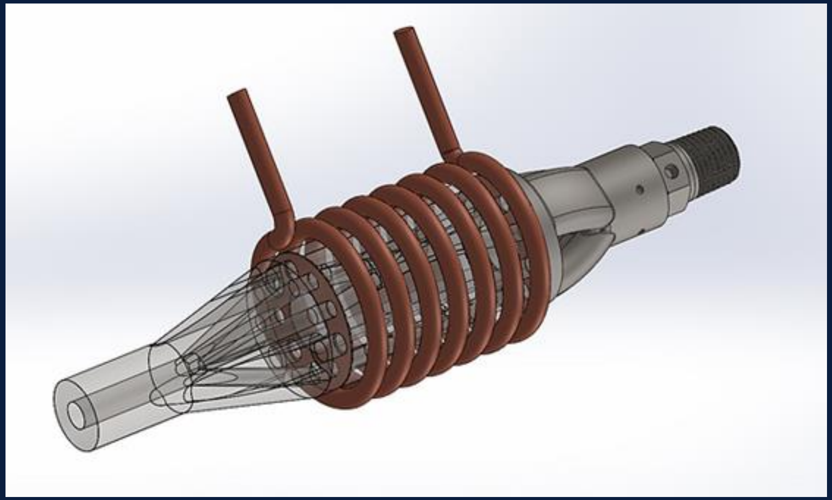


FLORIDA INTERNATIONAL UNIVERSITY

Electrothermal Thruster

Overview





Overview:

Why supercritical CO_2, CO_2 in super critical state is more conducive to consistent flow, technique devised by NASA, using super critical states instead of compressed gases.

Super critical CO_2 system, is in a higher energy state then compressed liquid CO_2, This system will have higher potential energy.

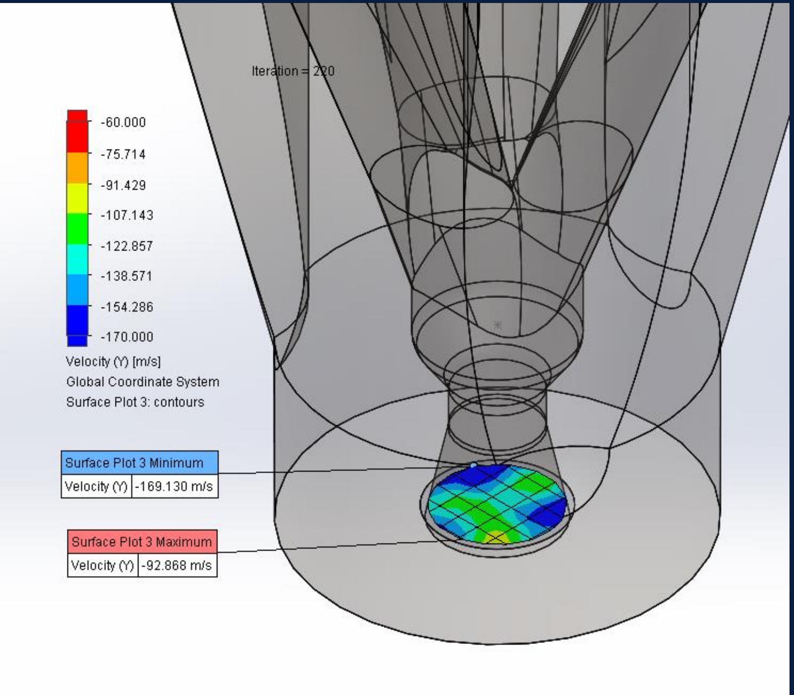
CO_2 is also less hazardous than other propellants (hydrazine, high test peroxide, etc), more in line with environmental requirements for space habitat.

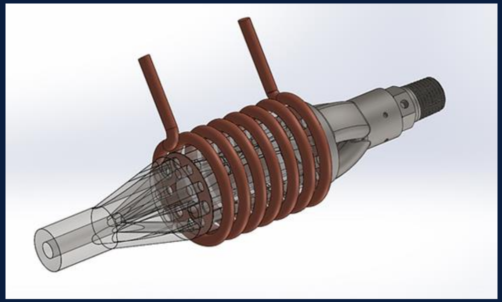
CO_2 can be seen as a byproduct in space habitat's that can be re-purposed.

FLORIDA INTERNATIONAL UNIVERSITY

Electrothermal Thruster

Nozzle Overview





Overview:

nozzle throat → expanded → exhausted

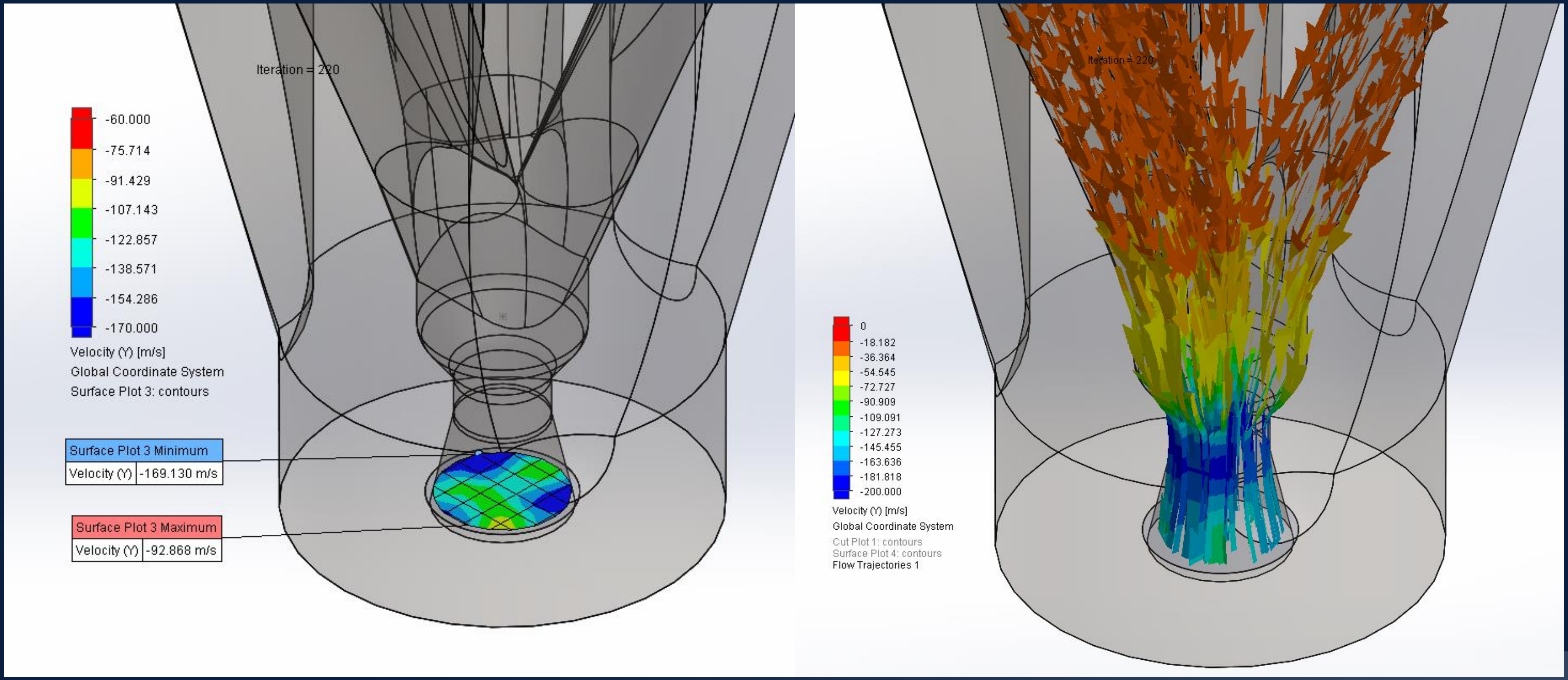
The thruster uses induction heating to transfer energy to supercritical CO_2 at 50°C. The heated CO_2 is then compressed at the nozzle throat, expanding and accelerating as it exits, producing thrust.

$V_{Average\ (Y)} = 114.5$ m/s

FIU FLORIDA INTERNATIONAL UNIVERSITY

Electrothermal Thruster

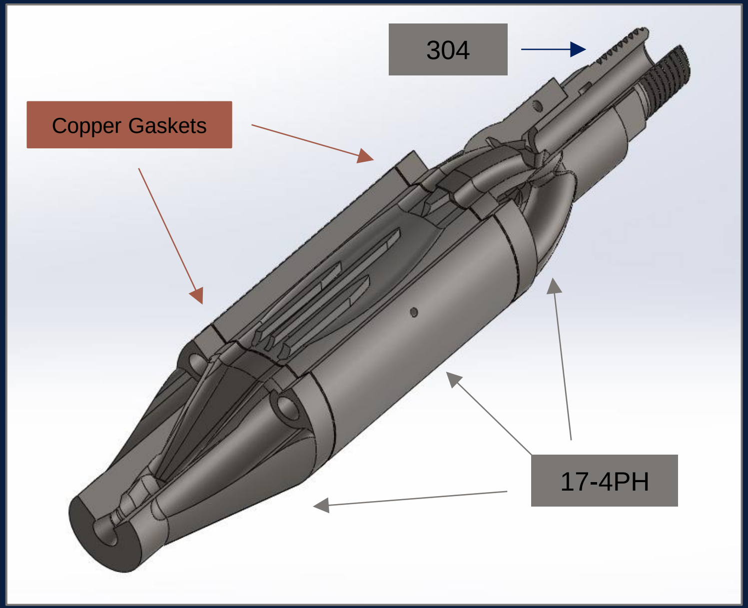
Nozzle Simulation



FIU
FLORIDA INTERNATIONAL UNIVERSITY

Electrothermal Thruster

Revision One Material Selection



Non-Sinter parts

Copper Gasket

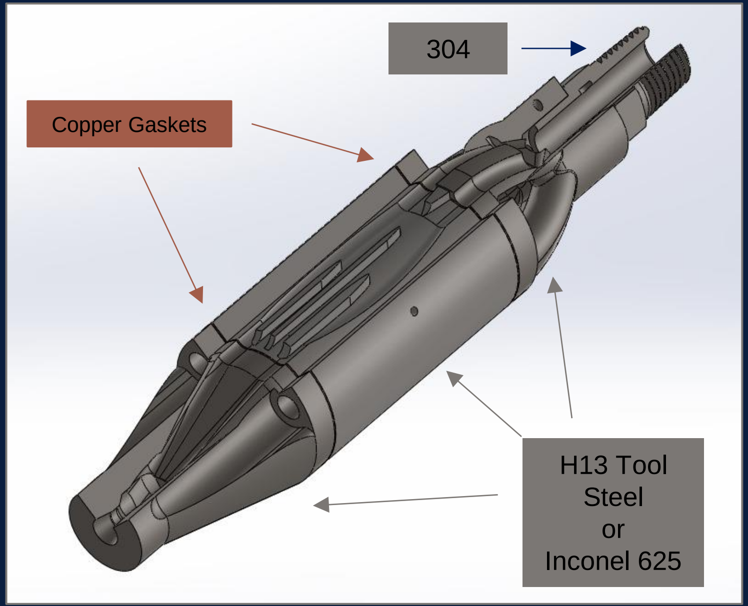
Markforged 17-4PH Stainless Steel

https://markforged.com/materials/metals/17-4-ph-stainless-steel

FLORIDA INTERNATIONAL UNIVERSITY

Electrothermal Thruster

Future Revision Material Selection



Future materials

Even though 17–4 PH stainless steel was selected for the first iteration, it is not the optimal material

The material was selected because of cost. It was the cheaper alternative and met the minimum requirements

Workaround for the lower performing material is to simply decrease the opening from the tank to the thruster assembly, Lowering mass flow rate and pressure

With material that is more capable of standing higher pressures the thruster will have higher exit velocity thus increased thrust

Markforged Steel

https://markforged.com/materials/metals/625-inconel
https://markforged.com/materials/metals/h13-tool-steel

FLORIDA INTERNATIONAL UNIVERSITY

Electrothermal Thruster

Future Revision Material Selection

Future materials

Any material choices would need to be verified through dog bone pull testing with MTS (with furnace)

Markforged does not publish UTS with heating

Markforged Inconel 625 material has 27% less UTS then standard Inconel 625

Material	UTS (Mpa)	Cost ($/cc)
Inconel 625	765	1.65
H13	1540	1.15
17-4PH	1050	0.65

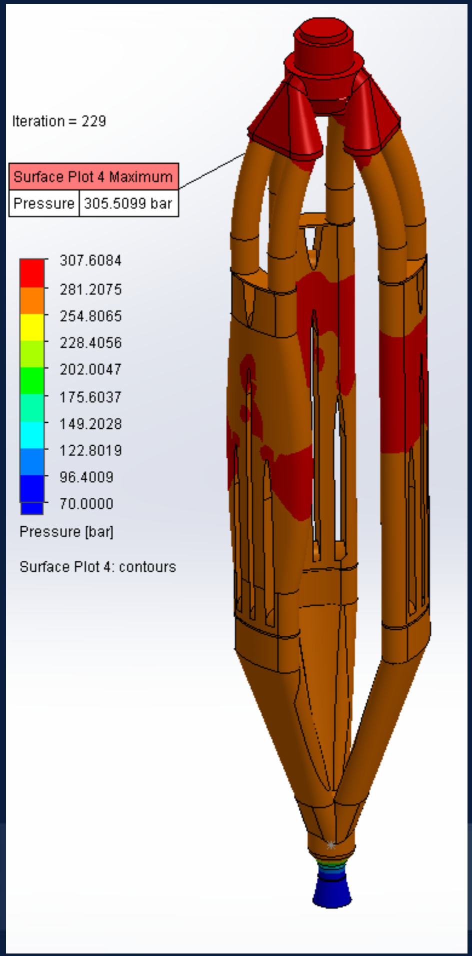
FIU
FLORIDA INTERNATIONAL UNIVERSITY

Electrothermal Thruster

Simulation Pressure (bar)

(1/4 opening)

Max Pressure: 305 bar



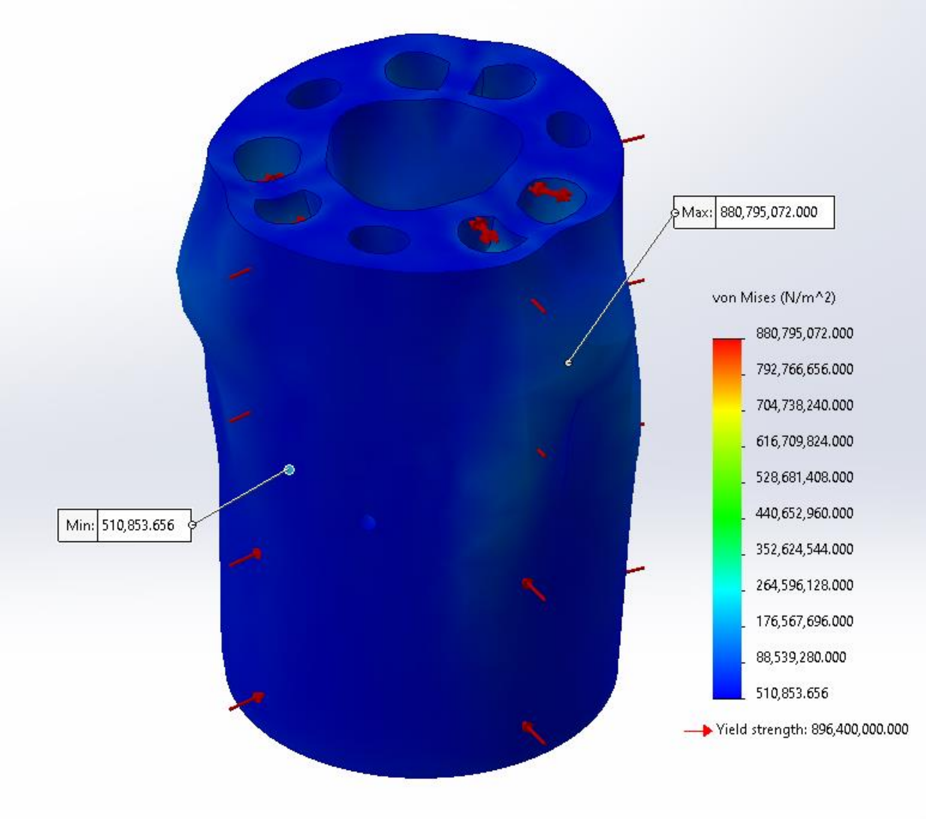
FLORIDA INTERNATIONAL UNIVERSITY

Electrothermal Thruster

Simulation Stress (vonMises)

(1/4 opening)

Max Stress: 8.80x10^8 (N/m^2)



FLORIDA INTERNATIONAL UNIVERSITY

Electrothermal Thruster

Simulation FOS

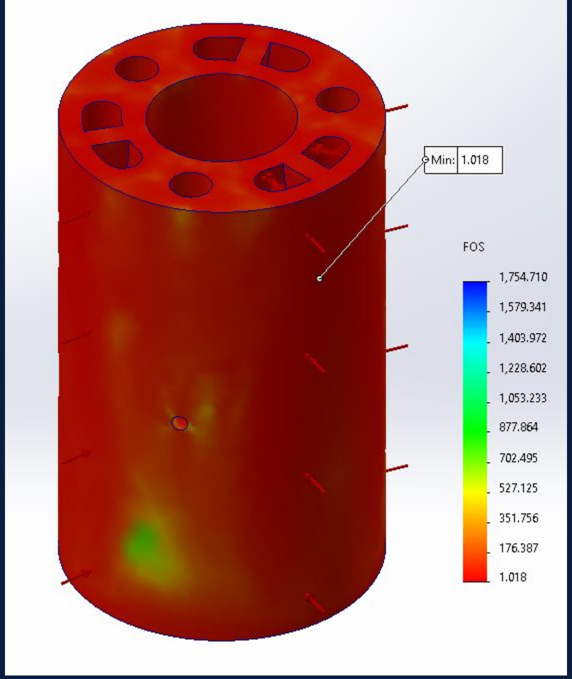
(1/4 opening)

FOS: 1.018

FoS = Ultimate Load / Applied Stress

Typical ranges are between 1.25 and 2.0

The FoS is not ideal, (Workaround slide 7)



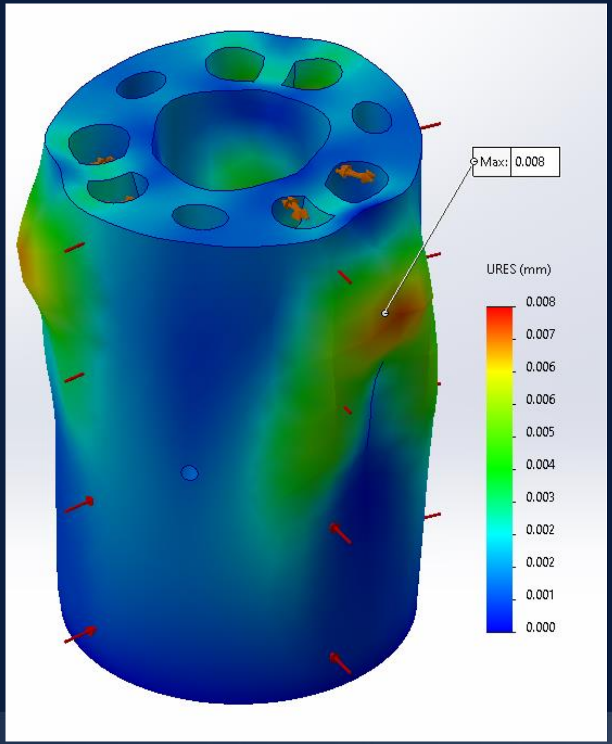
FIU
FLORIDA INTERNATIONAL UNIVERSITY

Electrothermal Thruster

Simulation Deformation (mm)

(1/4 opening)

Max Deformation: 0.008mm



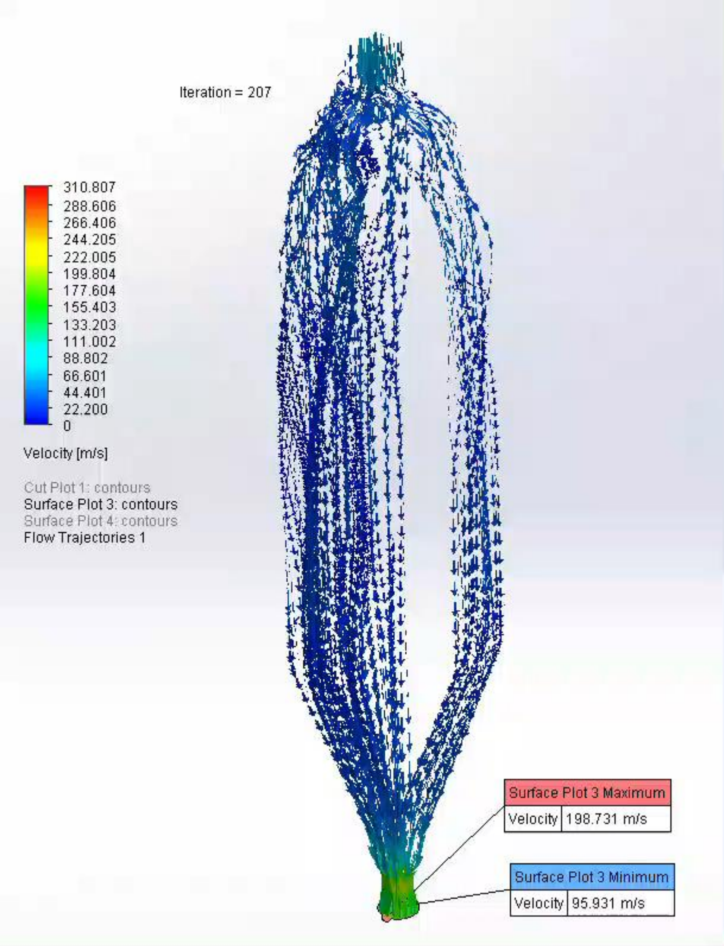
FLORIDA INTERNATIONAL UNIVERSITY

Electrothermal Thruster

Flow

(1/4 opening)

Max Velocity: 198.7 m/s



FIU
FLORIDA INTERNATIONAL UNIVERSITY

Electrothermal Thruster

System Energy Equation & Thrust Equation

(1/4 opening)

Body Equation

M=5kg

Vo =5 m/s

(Time (s) when $V_o = 0$)

$$t = d/g$$

$$t = \frac{3m}{9.8} m/s^2$$

$$t = \sqrt{0.3061s^2}$$

t=0.553s

Thrust Equation

$$M_{eDOT} = 2.018kg/s$$

$$V_e = 141m/s$$

$$(P_e - P_0) = 5205525N/m^2$$

$$F_T = M_{eDOT}V_e + (P_e - P_0)A_e$$

$$F_T = 417.9N$$

Electrothermal Thruster

System Energy Equation & Thrust Equation

Body Equation

(Falling Velocity)

$$v = v_o + gt$$

$$v = 5\frac{m}{s} + (9.8m/s\text{^}2)(0.533s)$$

$$v = 10.422\ m/s$$

(Acceleration)

$$a = {}^{\Delta v}/_{t}$$

$$t = {}^{\mathrm{d}}/_{v}$$

$$t = {}^{3\mathrm{m}}\Big/_{10.422(\frac{m}{s})}$$

$$t = 0.287s$$

$$a = \frac{10.422(\frac{m}{s})}{0.287s}$$

$$a = 36.313(\frac{m}{s^2})$$

(Fall Body)

$$f = ma$$

$$f = 5kg * 36.313(\frac{m}{s^2})$$

$$f_B = 181.565N$$

$F_T = 417.9N > 181.565N = f_B$

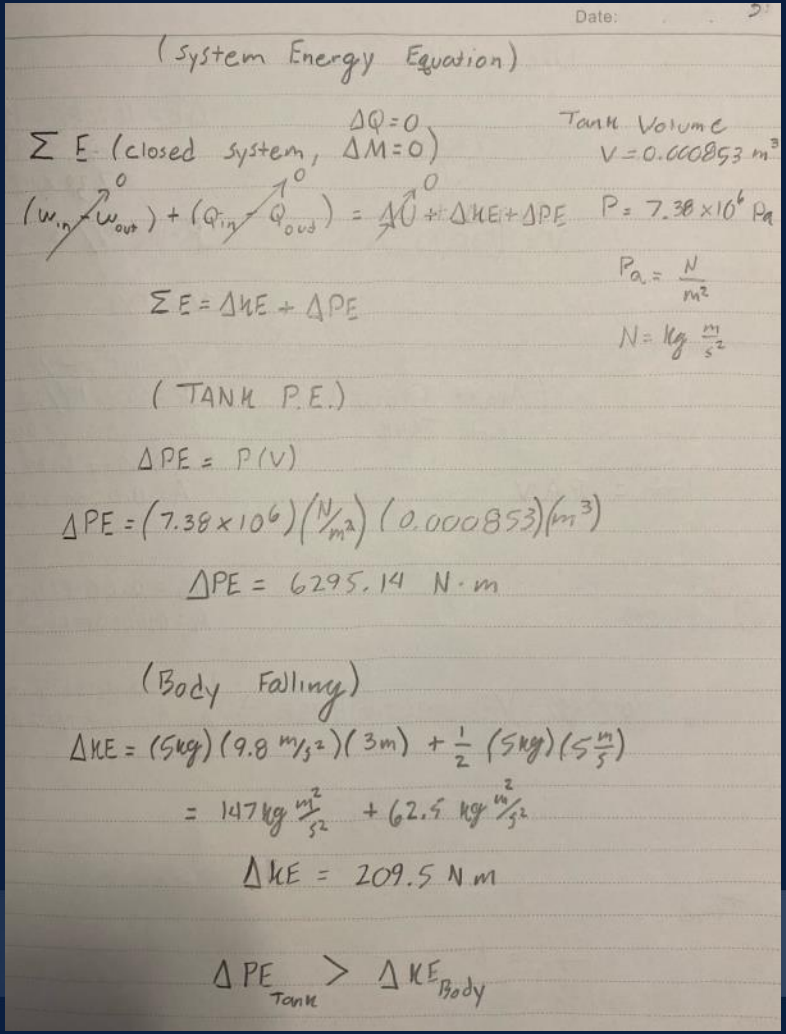
Force of thruster is greater than Freefalling Body

Electrothermal Thruster

System Energy Equation

$$\Delta PE_T = 6295.14Nm > 209.5Nm = \Delta KE_B$$

PE of tank is greater than KE Freefalling Body


Date:

(System Energy Equation)

ΣE (closed system, $\Delta Q = 0$, $\Delta M = 0$)

Tank Volume $V = 0.000853\ m^3$

$(W_{in} - W_{out}) + (Q_{in} - Q_{out}) = \Delta U + \Delta KE + \Delta PE$

$P = 7.38 \times 10^6\ Pa$

$Pa = \frac{N}{m^2}$

$\Sigma E = \Delta KE + \Delta PE$

$N = kg\ \frac{m}{s^2}$

(TANK P.E.)

$\Delta PE = P(V)$

$\Delta PE = (7.38 \times 10^6)(N/m^2)(0.000853)(m^3)$

$\Delta PE = 6295.14\ N \cdot m$

(Body Falling)

$\Delta KE = (5kg)(9.8\ m/s^2)(3m) + \frac{1}{2}(5kg)(5\frac{m}{s})^2$

$= 147\ kg\ \frac{m^2}{s^2} + 62.5\ kg\ m^2/s^2$

$\Delta KE = 209.5\ N.m$

$\Delta PE_{Tank} > \Delta KE_{Body}$

FIU FLORIDA INTERNATIONAL UNIVERSITY

Electrothermal Thruster

Summary

Based on simple calculations and simulations, this is a valid design. Energy equation show that the PE in the tank is greater than the KE from the freefalling body. The force generated by the thruster is greater than the force generated by the body coming to rest.

(Future improvements)

Revision 2 requires different materials with higher ultimate tensile strength and optimization for unlocking potential increases in velocity. Embedding of sensors is also in the works and protective Coatings.

(Future branches of this project)

- Cold Spray unit
- Miniaturized Cold Spray

FIU
FLORIDA INTERNATIONAL UNIVERSITY