2019 MDSGC Student Research Symposium

Feasibility Study of the Liquid Propellant Rocket Engine

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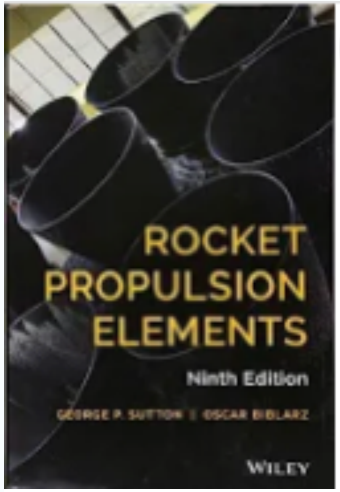
How to Design A Liquid Propellant Rocket Engine

Purpose: Explore the properties of liquid propellants used in rocket engines and determine design factors for optimal engine performance.

Objectives:

- Analyze and Compare Different Types of Liquid Propellants
- Design the Prototype Rocket Engine with Case Study Data
- Compare NASA CEA Analysis to Theoretical Calculations of Engine Performance

Research & Methodology



- Read Articles, Books, and Databases on Rocket Science, Design, and Relevant Thermochemical Processes
- Perform Calculations to Establish Design Parameters
- Utilize Case Study & Computer Simulations to Validate Preliminary Design

Propellant Options

	RP-1	Methane	Ethanol	Hydrogen	Hydrazine	Oxygen	Fluorine	Nitric Acid	Di-nitrogen Tetroxide
Boiling point, K	420	112	351	20	386	90	85	356	294
Melting point, K	222	92	159	14	200	54	53	232	264
Density, g/ml	.820	.423	.790	.071	.793	1.142	1.500	1.510	1.440
Molecular Weight, g/mol	175	16	46	2	60	32	38	63	92
Critical Pressure, MPa	2.17	4.6	6.39	1.35	8.2	5.01	5.58	8.06	7.01
Combustion Enthalpy, KJ/mol	7768	891	1367	286	1975	0	0	N/A	N/A
Handling Properties	Storable	Cryogenic	Storable	Cryogenic	Storable	Cryogenic	Storable	Storable	Storable
Toxicity	Nontoxic	Nontoxic	Nontoxic	Nontoxic	Toxic	Nontoxic	Toxic	Toxic	Toxic

COMBUSTION & HYPERGOLIC REACTIONS

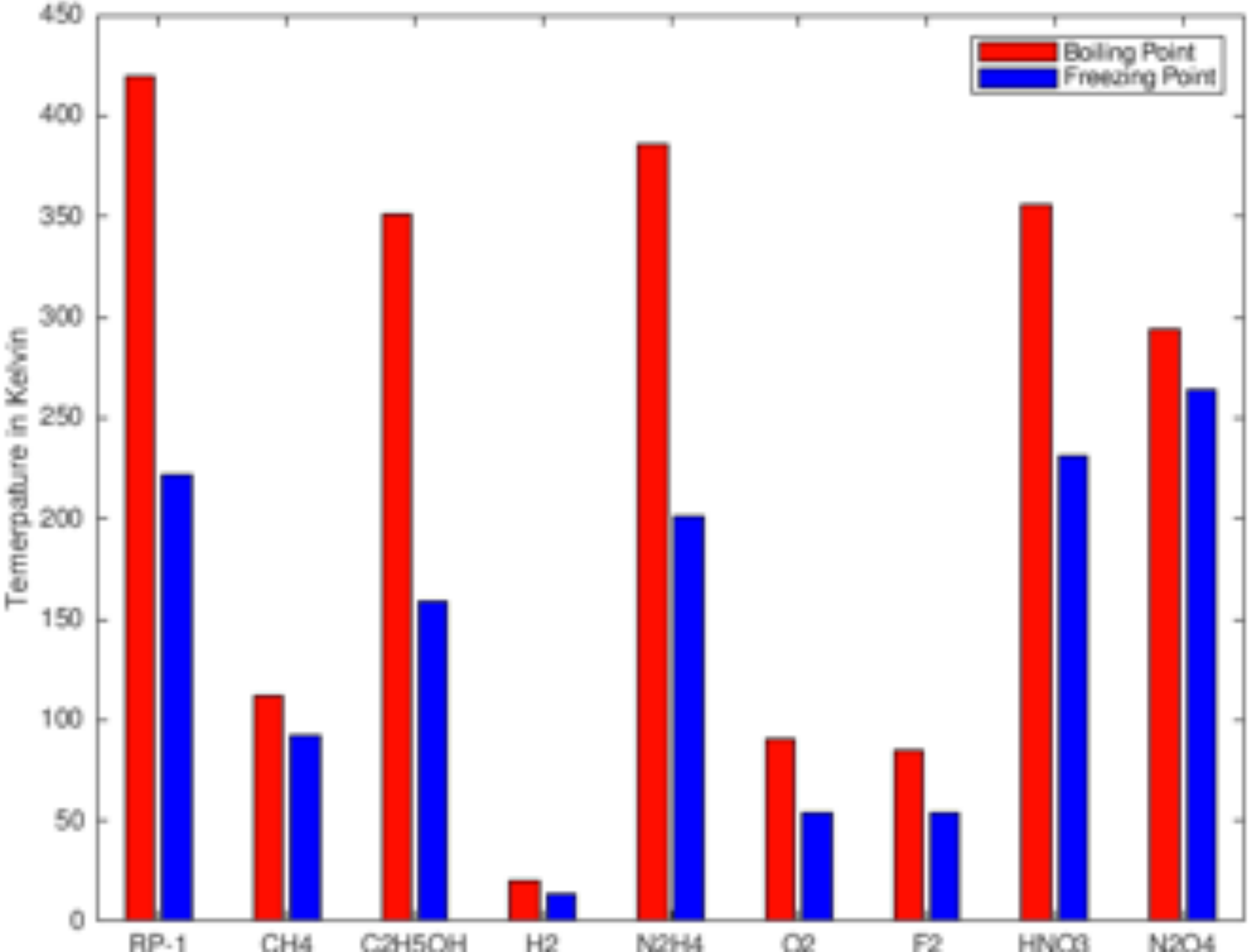
$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

$$2H_2 + O_2 \rightarrow 2H_2O$$

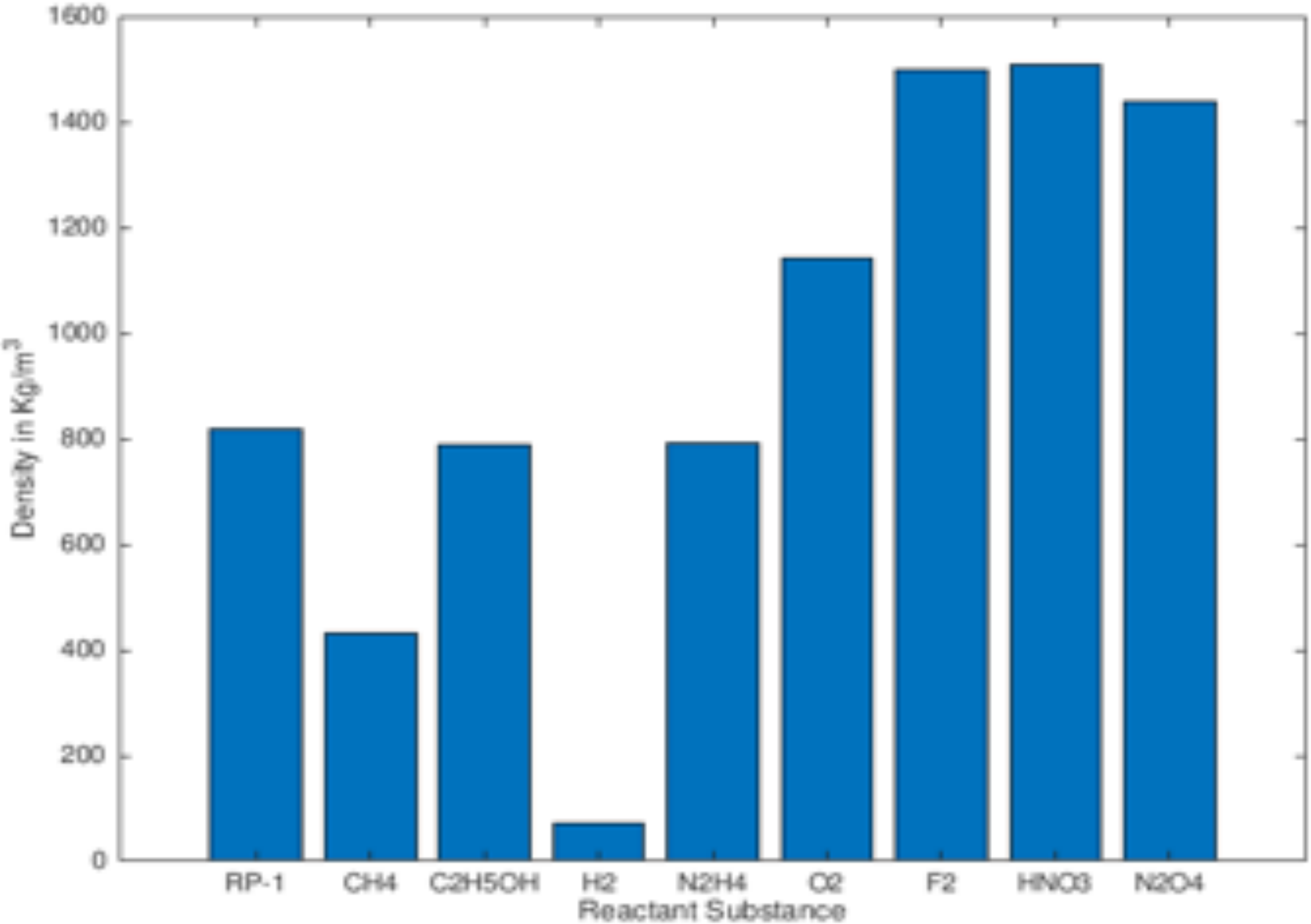
$$C_{12}H_{24} + 18O_2 \rightarrow 12CO_2 + 12H_2O$$

$$2N_2H_4 + N_2O_4 \rightarrow 3N_2 + 4H_2O$$

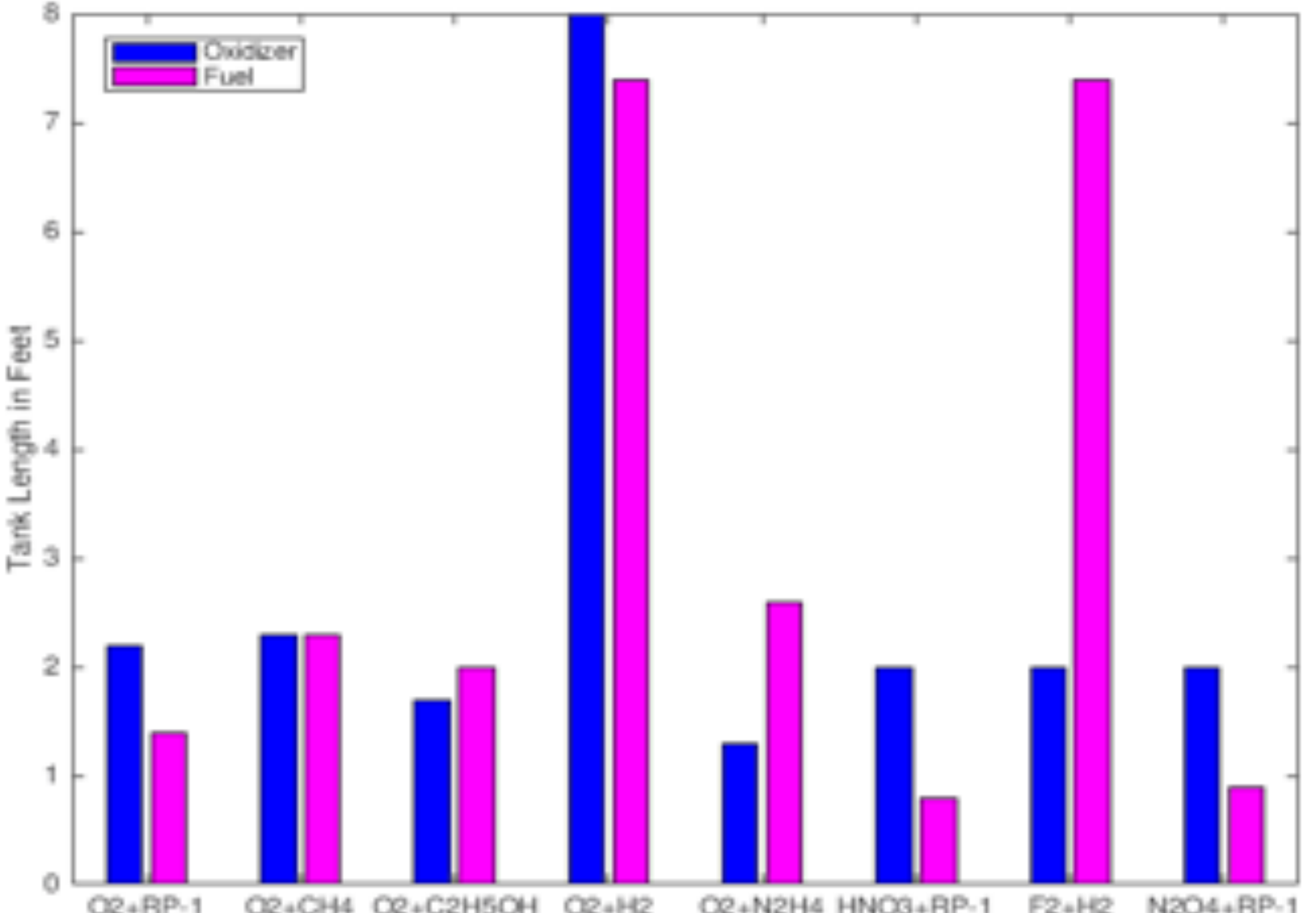
Boiling and Freezing Points



Density


1600
1400
1200
1000
800
600
400
200
0
Density in Kg/m3
RP-1
CH4
C2H5OH
H2
N2H4
O2
F2
HNO3
N2O4
Reactant Substance

Propellant Tank Approximations D= 4.6in.



Ideal Design Factors of Prototype Rocket

- **Efficiency**

High Specific Impulse (Isp)

- **Simplicity**

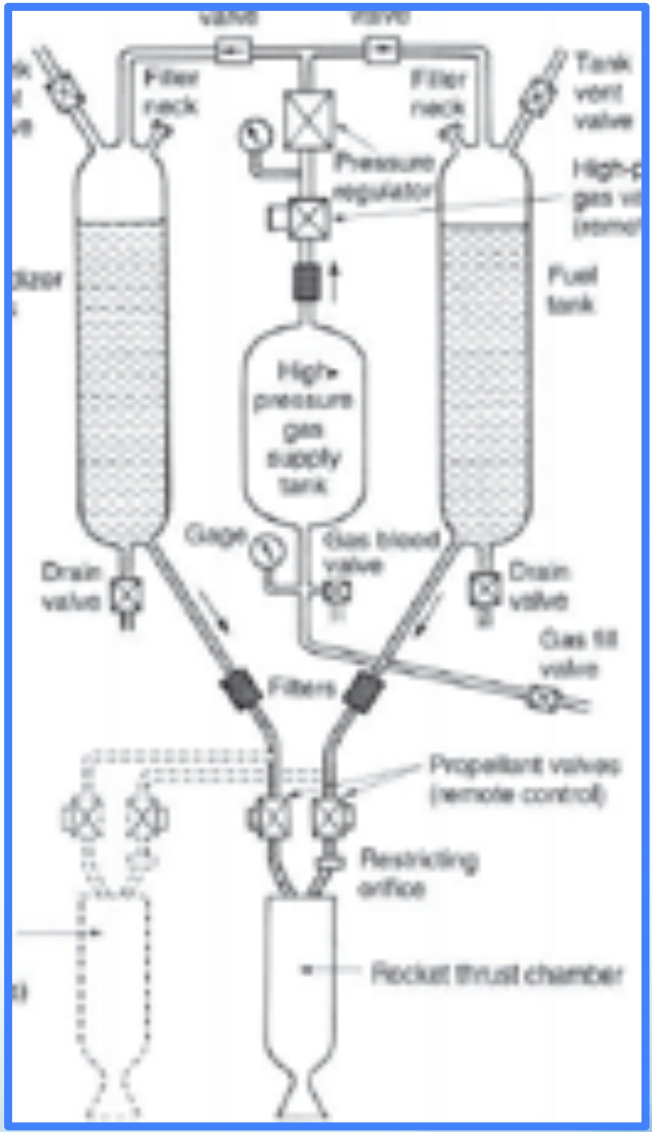
Pressure Fed System

- **Safety**

Minimal Toxic Reactants/ Emissions

- **Reusability**

Non-ablative Cooling System



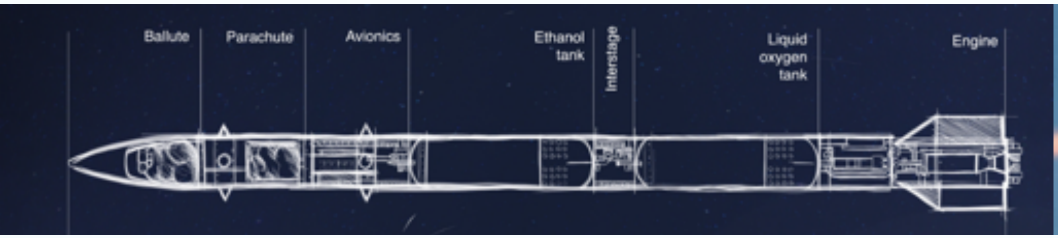
Summary of Case Study

Copenhagen Suborbitals

- NEXO II

UCLA

- ARES



	NEXO II	ARES
O/F	1.3	Data Not Released
Pc	1.6 MPa	Data Not Released
Thrust	5,000 N	3,114 N
Height/ Diameter	22ft/12”	15.2ft/7”
Apogee	46,000 ft.	14,600 ft.

Design Calculations of Prototype Rocket Engine

Desired Specifications	
O/F	1.3
Pc	2.28MPa
Tc	3000K
Thrust	2800N
Height/ Diameter	≈ 12ft / 6.9”
Apogee	13,000 ft.

CONTROL PRESSURE RATIO

$$\frac{p_2}{p_1}, \text{ is } \frac{0.054019}{2.28} = 0.02369$$

$$\frac{A_t}{A_e} = \left(\frac{k+1}{2}\right)^{\frac{1}{(k-1)}} \times \left(\frac{p_2}{p_1}\right)^{\frac{1}{k}} \times \sqrt{\frac{k+1}{k-1} \times \left[1 - \left(\frac{p_2}{p_1}\right)^{\frac{(k-1)}{k}}\right]}$$

$$\frac{A_t}{A_e} = 0.1884733$$

$$\dot{m} = \frac{F}{V_2} \qquad \dot{m} = \frac{2800}{2325.86}$$

$$\dot{m} = 1.203\ kg/sec$$

$$t_b = \frac{m_p}{\dot{m}}$$

$$10 = \frac{m_p}{1.203}$$

$$m_p = 12.03\ kg$$

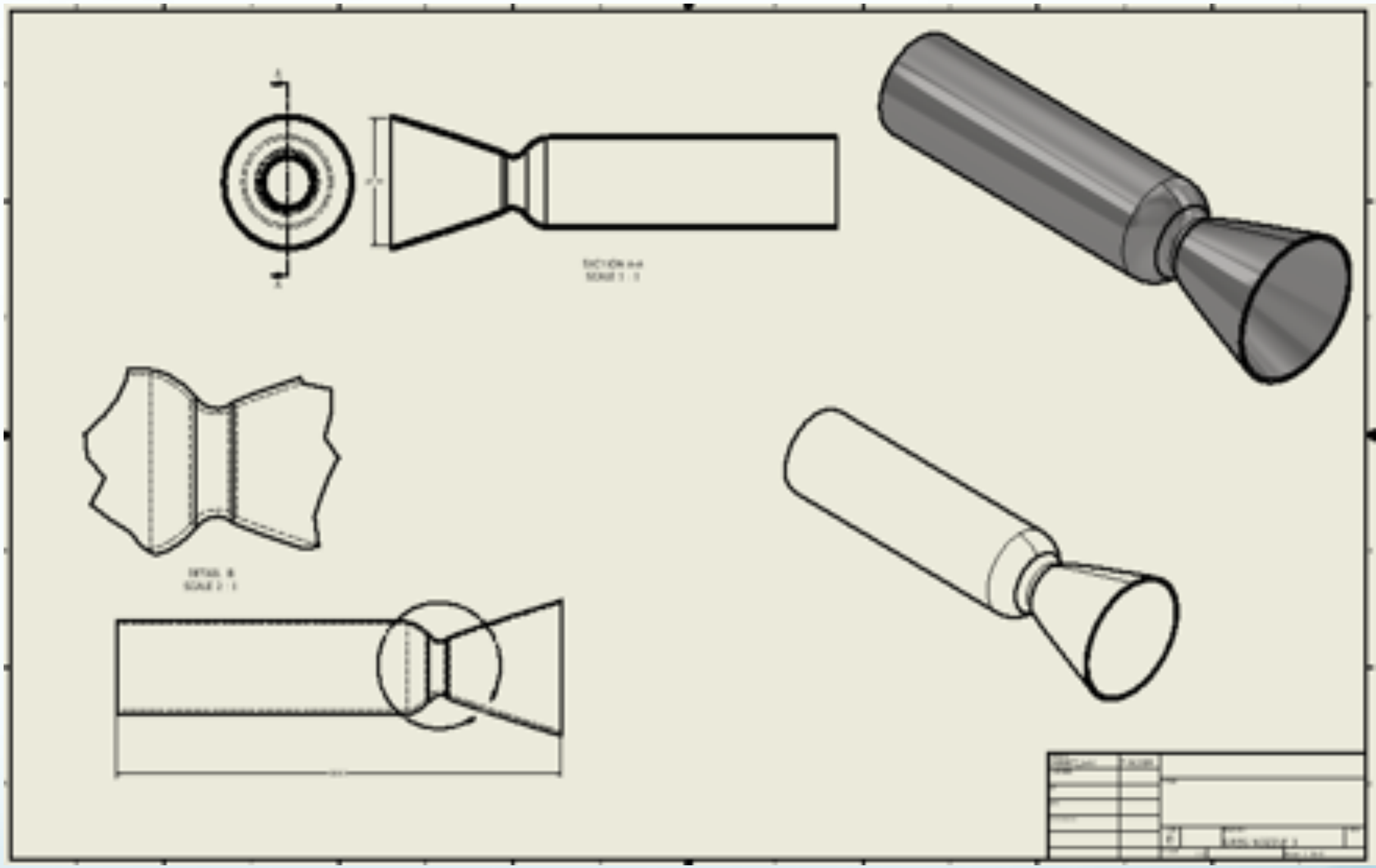
$$D_t = \sqrt{\frac{4(8.22)}{\pi}} \qquad D_t = 3.235cm$$

$$D_e = \sqrt{\frac{4(43.6)}{\pi}} \qquad D_e = 7.45cm$$

$$D_c = \sqrt{\frac{4(24.66)}{\pi}} \qquad D_c = 5.603cm$$

Prototype Rocket Engine Design

Inventor CAD Model



Performance Analysis (NASA CEA)

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O/F=     1.30000   %FUEL= 43.478261   R,EQ.RATIO= 1.4757

                    CHAMBER    THROAT      EXIT       EXIT
Pinf/P               1.0000    1.7231     1.0235     28.689
P, BAR               2.2800    1.3232     2.2277    0.07947
T, K                3189.07   3052.10    3183.07    2391.63
RHO, KG/CU M      1.6518-1  1.0172-1   1.6180-1   8.3142-3
H, KJ/KG           -229.26   -958.44    -261.27   -4114.59
U, KJ/KG          -1609.56  -2259.27   -1638.05   -5070.46
G, KJ/KG          -45301.3  -44094.7   -45248.6   -37916.1
S, KJ/(KG)(K)      14.1333   14.1333    14.1333    14.1333

M, (1/n)            19.210    19.508     19.223     20.803
(dLV/dLP)t        -1.05255  -1.04542   -1.05225   -1.01001
(dLV/dLT)p          2.0050    1.9084     2.0012     1.2511
Cp, KJ/(KG)(K)     10.7011   10.1170    10.6798     4.7976
GAMMAs              1.1236    1.1211     1.1235     1.1369
SON VEL,M/SEC       1245.4    1207.6     1243.7     1042.4
MACH NUMBER          0.000     1.000      0.203      2.674

PERFORMANCE PARAMETERS

Ae/At                          1.0000     3.0000     5.3000
CSTAR, M/SEC                   1856.1     1856.1     1856.1
CF                             0.6506     0.1363     1.5018
Ivac, M/SEC                    2284.8     5693.8     3130.5
Isp, M/SEC                     1207.6      253.1     2787.6


MASS FRACTIONS

*CO                0.41818   0.41002    0.41783    0.37166
*CO2               0.17365   0.18647    0.17420    0.24675
*H                 0.00376   0.00328    0.00374    0.00107
HO2                0.00003   0.00002    0.00003    0.00000
*H2                0.01643   0.01611    0.01641    0.01592
H2O                0.30139   0.31290    0.30190    0.35352
*O                 0.01272   0.00966    0.01258    0.00068
*OH                0.05341   0.04499    0.05304    0.00900
*O2                0.02042   0.01655    0.02026    0.00141

 * THERMODYNAMIC PROPERTIES FITTED TO 20000.K
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Input:

Pc = 2.28 MPa

Fuel = C_2H_5OH(L)

Oxidizer = O_2(L)

Mix Ratio = 1.3

Ac/At = 3

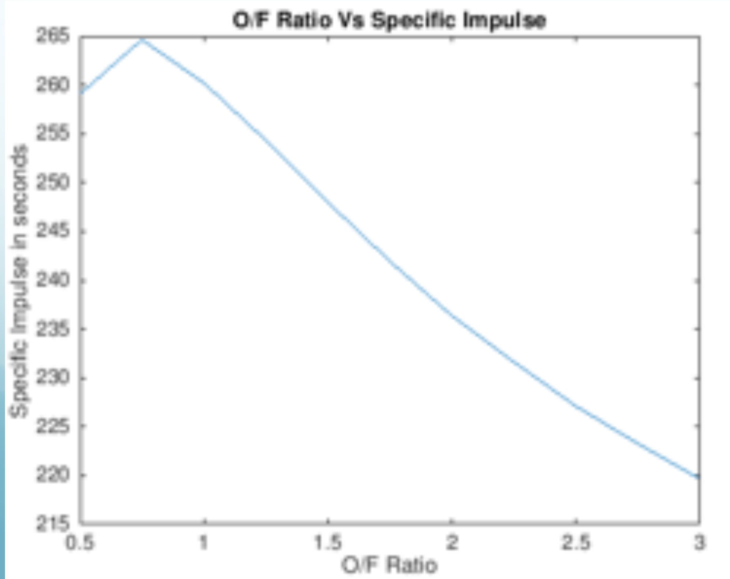
Ae/At = 5.3

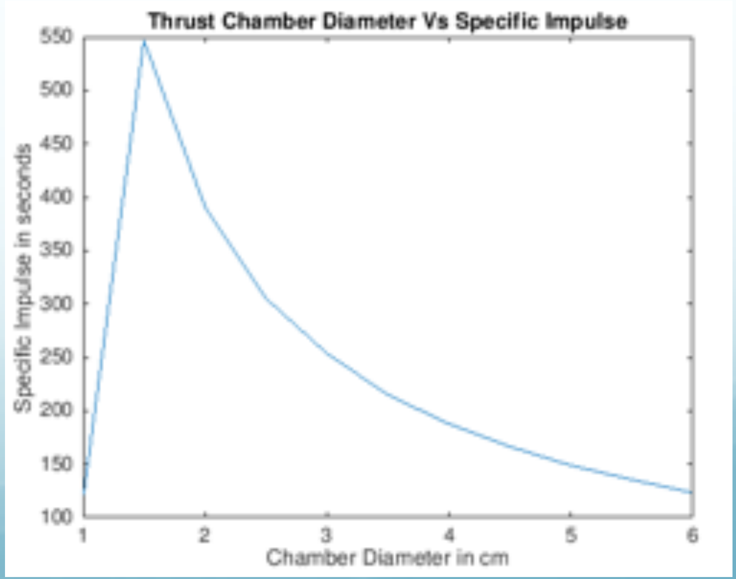
Comparison of Theoretical Calculation & CEA Simulation

The insight provided by the literature and the case study resulted in a series of design calculations that produced a liquid propellant engine system that has the following performance characteristics:

	Theoretical	CEA	%Difference
Isp., s	237.5	253.1	6%
Tc, K	3000	3189	6%
C*, m/sec	1557.45	1856.1	16%
CF	1.49	1.5	0.66%

Trends in Variation of Design:





Conclusion

Ethanol is a great fuel choice

- Storable at room temperature ✔
- Nontoxic ✔
- Practical Tank Size ✔

Literature and Case Study were effective

- Enabled Enlightened Systems Choices ✔
- Calculations produced an ideal engine design ✔
- Design could successfully be modeled in 2D & 3D ✔

Comparison validated Calculations

- Theoretical performance matched CEA analysis ✔

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Thanks and Q&A