THE UNIVERSITY OF ALABAMA IN HUNTSVILLE

MAE 640 Rocket Propulsion II

Lecture 01A Course Introduction

Description of Syllabus Material

Review of Fundamental Concepts from Chapters 1, 2 and 3

Discussion of Thrust Equation

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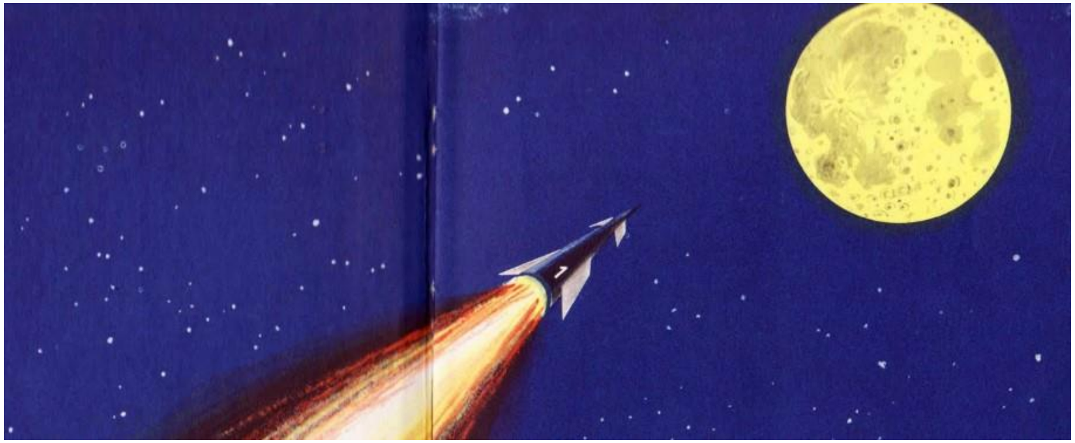
Lecture 01A – Course Introduction



UAH Propulsion Research Center

Course Objectives

Course Description

- Aerothermodynamics of rocket propulsion systems; rocket propellants and combustion; heat transfer and cooling problems. Application to ramjets and hybrid systems. Prerequisite: MAE 540 or permission of instructor.

Course Objectives

- Students will be able to define key rocket propulsion terms.
- Students will be able to calculate component and systems performance using rocket propulsion principles.
- Students will be able to use thermochemcial codes, design equations, and relevant technical literature to design a rocket combustor or propulsion system to meet specific design objectives.

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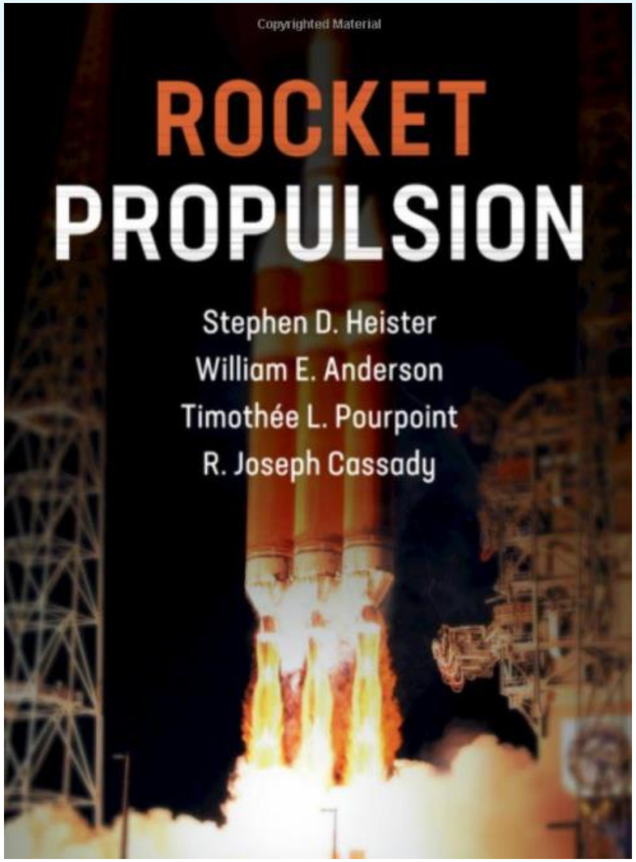
Required Text/Readings

Required Text/Readings

This book was selected because it gives students up to date and practical engineering material on rocket propulsion in a manner consistent with college-level instruction. The book can be purchased as a hardback or an online version.

- Heister, S. D., Anderson, W.E., Pourpoint, T. L., and Cassady, R.J. <u>Rocket Propulsion</u>, Cambridge Aerospace Series, 2019, Hardback, ISBN: 9781108422277

- Heister, S. D., Anderson, W.E., Pourpoint, T. L., and Cassady, R.J. <u>Rocket Propulsion</u>, Cambridge Aerospace Series, 2019, Online, ISBN: 9781108422277, FORMAT: Adobe eBook Reader, ISBN: 9781108397100



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Chapters Covered from the Book

- Chapter 1 - Classification of Prop. Sys. & Historical Perspectives
- Chapter 2 - Mission Analysis Fundamentals
- Chapter 3 - Trajectory Analysis and Rocket Design
- Chapter 4 - Rocket Nozzle Performance
- Chapter 5 - Combustion and Thermochemistry
- Chapter 6 - Heat Transfer in Chemical Rockets
- Chapter 7 – Solid Rocket Motors
- Chapter 8 - Liquid Rocket Engines
- Chapter 9 - Liquid Rocket Propellants
- Chapter 10 - Rocket Turbomachinery Fundamentals
- Chapter 11 - Hybrid Rocket Engines
- Chapter 12 - Combustion Instability

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Approach

- Module 1 - Fundamental Concepts (Book Chapter 1, 2,3 and 4)
- Module 2 - Hybrid Rocket Engines (Book Chapter 11)
- Module 3 - Combustion and Thermochemistry (Book Chapter 5)
- Module 4 - Heat Transfer in Chemical Rockets (Book Chapter 6)
- Module 5 - Liquid Rocket Engines (Book Chapter 8)
- Module 6 - Liquid Rocket Propellants (Book Chapter 9)
- Module 7 - - Turbomachinery and Combustion Instability (Book Chapters 10 and 12)
- Module 8 - Class Project (Material Provided)

Module Learning Objectives - Example

Module 01 – Fundamental Concepts

- Students will be able to demonstrate basic knowledge of propulsion terminology and the results of the last class project
- Students will be able to calculate the performance of an over-expanded nozzle that has separated flow
- Students will be able to derive the thrust and exit velocity equations for a converging-diverging nozzle from the conservation of momentum and conservation of energy equations.

Module Components - Example

Module 01 - Fundamental Concepts

- **Module Checklist**
  - ☐ Attend (and or view) Lectures 1A and 1B
  - ☐ Review Course Syllabus
  - ☐ Review textbook chapter 1, 2, 3 and 4
  - ☐ Complete Quiz 1
  - ☐ Attend or Review Office Hours/Help Session
  - ☐ Complete Homework 01 (01HW)

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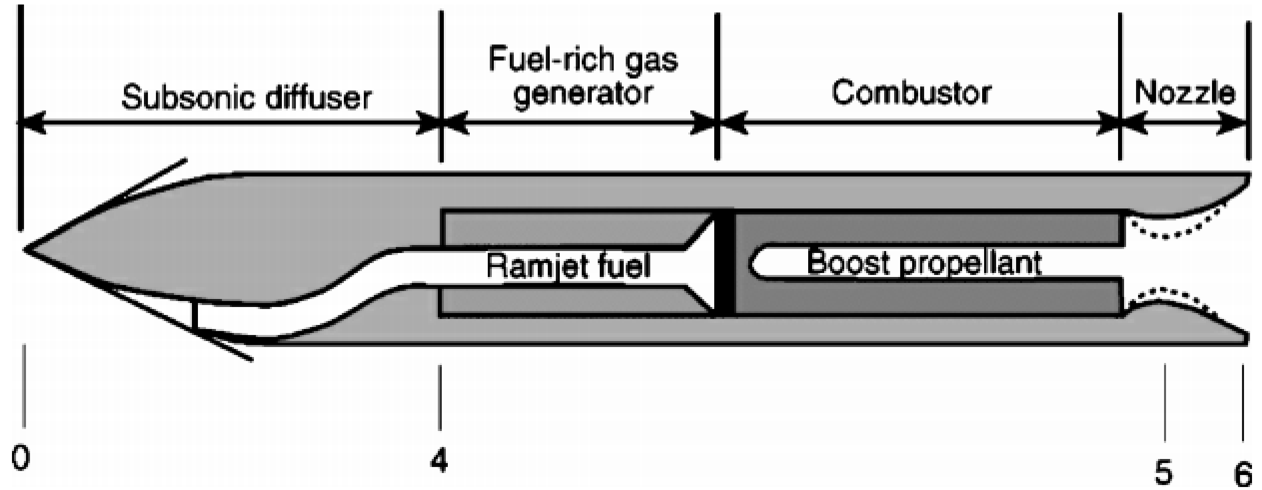
Course Project

Solid Fuel Ramjet Booster/Combustor Design

The course project for the spring 2023 class will use the principles of solid rockets, hybrid rockets to compare designs among: [A] pure solid propulsion, [B] hybrid, and a [C] solid boost/ramjet combustor design for a supersonic mission to achieve the greatest range. The instructor provides additional instructional material and students research supplementary technical papers on the ramjet component of this project that are not contained in the textbook. The instructor provides a Project Requirement Document that describes the mission requirements, guidelines and assumptions, and a list of technical symbols for the project



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Assignment Descriptions

Assignment Types	What to Expect	%
Quizzes	The Quizzes assess the knowledge that you have acquired in a particular module. They are generally facts from the textbook or assigned outside reading. They can also have short calculation problems to assess execution of a concept. There are up to 20 quizzes in this course. There may be some in lecture quizzes that are used to assess the students current skills and level of participation in lecture.	15% (drop 2)
Homework	The Homework assesses your ability to calculate propulsion component and system performance using rocket propulsion principles. It is submitted in a 9-Step format (detailed and illustrated in a later sections) unless otherwise stipulated in the assignment instructions in writing.	20% (drop 1)
Project Assignments	The Project Assignments establish team plans, verify new software routines, integrate algorithms, and promote teamwork skills for the success of your final project report. You and your assigned project partner will complete each Project Assignment together and make joint submissions.	5% (joint grade)
Exam 1	Exam 1 will cover Modules 1, 2, and 3. The exam will include quiz questions and 2 or 3 longer problems worked in the homework format and uploaded. All students will take Exam 1 online.	20%
Exam 2	Exam 2 will cover Modules 4, 5, and 6. Students should expect to use skills from the previous modules for Exam 2. Exam 2 will include quiz questions and 2 or 3 longer problems worked in the the homework format and uploaded. All students take Exam 2 online.	20%
Final Exam	The Final Exam consists of the Class Project Report (you and your project partner receive one grade). Each team will also make a brief oral summary of their project report during the final exam period.	20% (joint grade)

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Basis of Grade

Assignment	Percentage of Grade
Quizzes	15%
Homework	20%
Project Assignments	5%
Exams	40%
Final Exam	20%
Total	100%

Course Average	Letter Grade
90.00 and above	A
80.00 to 89.99	B
70.00 to 79.99	C
60.00 to 69.99	D
0 to 59.99	F

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Course Schedule

Date	Class	Module	Book Sections	Quiz #	Q Due	HW	HW Due
1/9	1	Module 1 - Fundamental Concepts	Chapter 1,2,3,4	1	1/14	HW01	1/18
1/11	2	Module 1 - Fundamental Concepts	Chapter 1,2,3,4				
1/16		No Class					
1/18	3	Module 2 - Hybrid Rocket Engines	Chapter 11.1 - 3	2A	1/21	HW02A	1/24
1/23	4	Module 2 - Hybrid Rocket Engines	Chapter 11.4 - 7	2B	1/28	HW2B	1/31
1/25	5	Module 2 - Hybrid Rocket Engines	Examples				
1/30	6	Module 3 - Combustion and Thermodynamics	5.1, 5.2, 5.3	3A	2/4	HW03A	2/7
2/1	7	Module 3 - Combustion and Thermodynamics	5.4				
2/6	8	Module 3 - Combustion and Thermodynamics	5.5, 5.6	3B	2/11	HW03B	2/14
2/8	9	Module 3 - Combustion and Thermodynamics	Examples				
2/13	10	Module 4 - Heat Transfer in Chemical Rockets	6.1, 6.2, 6.3	4A	2/18	HW04	2/28
2/15	11	Module 4 - Heat Transfer in Chemical Rockets	6.4, 6.5				
2/20	12	EXAM 1 - Modules 1, 2, 3		8A	2/25	PR-A	2/28

Course Schedule

Date	Class	Module	Book Sections	Quiz #	Q Due	HW	HW Due
2/22	13	Exam Review and Introduction of Project					
2/27	14	Module 5 - Liquid Rocket Engines	8.1 - 4	5	3/4	HW05	3/7
3/1	15	Module 5 - Liquid Rocket Engines	8.5 - .9				
3/6	16	Module 6 - Liquid Rocket Propellants	9.1 - 9.4	6	3/11	HW06	3/21
3/8	17	Module 6 - Liquid Rocket Propellants	9.5 - 9.8				
3/13		Spring Break					
3/15		Spring Break					
3/20	18	Module 8 - Class Project	Material Provided	8B	3/25	PR-B	3/29
3/22	19	Module 8 - Class Project	Material Provided				
3/27	20	EXAM 2 - Modules 4,5, 6					
3/29	21	Exam Review and Project Discussion				PR-C	4/4
4/3	22	Module 8 - Class Project	Material Provided				
4/5	23	Module 8 - Class Project	Material Provided				
4/10	24	Module 7 Turbomachinery and Comb. Instab.	Chapter 10	7	4/18	PR-D	4/11
4/12	25	Module 7 Turbomachinery and Comb. Instab.	Chapter 11				
4/17	26	Module 8 - Class Project//Course Summary	Material Provided				
4/19	27	Module 8 - Class Project	Material Provided				
4/26		Final Exam - Oral Presentation - 8:00 - 10:30					

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Homework Assignments

Module	Book Problems	Special Problems
1	2.6, 3.8, 4.24, 4.30	SP01
2A	11.3, 11.7	SP02A
2B	11.4, 11.5, 11.6	SP02B
3A	5.4, 5.16	SP03A
3B	5.9, 5.11	SP03B
4	6.4, 6.7	SP04
5	8.2, 8.13, 8.14	SP05
6	None	SP06
7	None	SP07
8	None	PR01, PR02, PR03, PR04

Required Homework Format

9-Step Homework Format Requirement

Required Homework Format (See Example at end of this Syllabus)
In the solution of problems, you are required to:

1. **Name:** Provide name of the student.
2. **Given**: State briefly and concisely (in your own words) the information provided.
3. **Find:** State the information that you have to find.
4. **Schematic**: Draw a schematic representation of the system and control volume if applicable.
5. **Assumptions:** List the simplifying assumptions that are appropriate to the problem and implied by the equations used.
6. **Basic Equations**: Outline the basic equations needed to do the analysis. Use the proper symbol from the book where applicable.
7. **Analysis:** Manipulate the basic equations to the point where it is appropriate to substitute numerical values. Substitute numerical values (using a consistent set of units) to obtain a numerical answer. Include appropriate units in calculations. If multiple repetitive calculations are done on a spreadsheet for example, show at least one example calculation in detail, including all units. The significant figures in the answer should be consistent with the given data. Check the answer and the assumptions made in effecting the solution to make sure they are reasonable.
8. **Answer**. Label the answer(s) with a box and an arrow from the right-hand margin.
9. **Comment**: Write a comment at the end of the homework that reflects on the limitations of the solution, the reasonableness of the solution, or something that you learned by doing the problem.

All nine formatting elements must be specifically shown in Each HW to receive full credit unless otherwise specified.

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Online Items

- Have Good Computer Connection/Camera/Microphone
- Scan Homework Assignments into One Document
- Email Instructor Through CANVAS and expect response within 24-48 hours.
- Homework will be graded within one week of submission
- Exams will be given online
- Review the “Getting Started: Items on CANVAS Website.
- Discussion

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MAE 640 Rocket Propulsion II

Lecture 01A – Fundamental Concepts

1.3 Classification of Rocket Propulsion Systems
2.1 Classification of Rocket Propulsion Systems
3.1 Vertical Trajectories, Example Problem (Mentioned)

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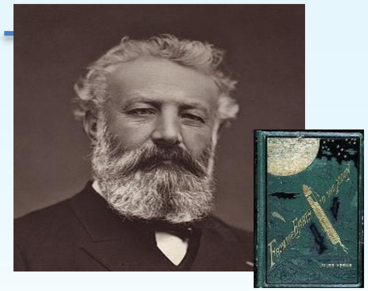
1.2 A Brief History of Rocketry

Whose Inspiration brought UAH to Huntsville, Alabama?

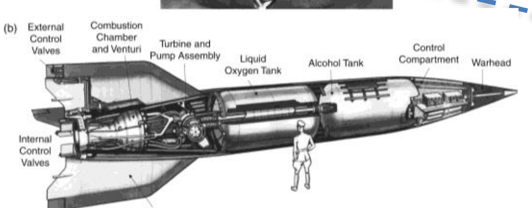
Jules Verne



"From Earth to the Moon" 1863

Herman Oberth

Dr. Wernher Von Braun



UAH Research Institute Groundbreaking

Major General Francis Morrow, Dr. Wernher von Braun, and Alabama Governor John Patterson
December 20, 1962

UAH Propulsion Research Center

Dr. Hugh Coleman
Dr. Clark W. Hawk
Dr. Robert Frederick
August, 1991

UAH
MAE 440/540
Rocket
Propulsion I
130 Students - 2022

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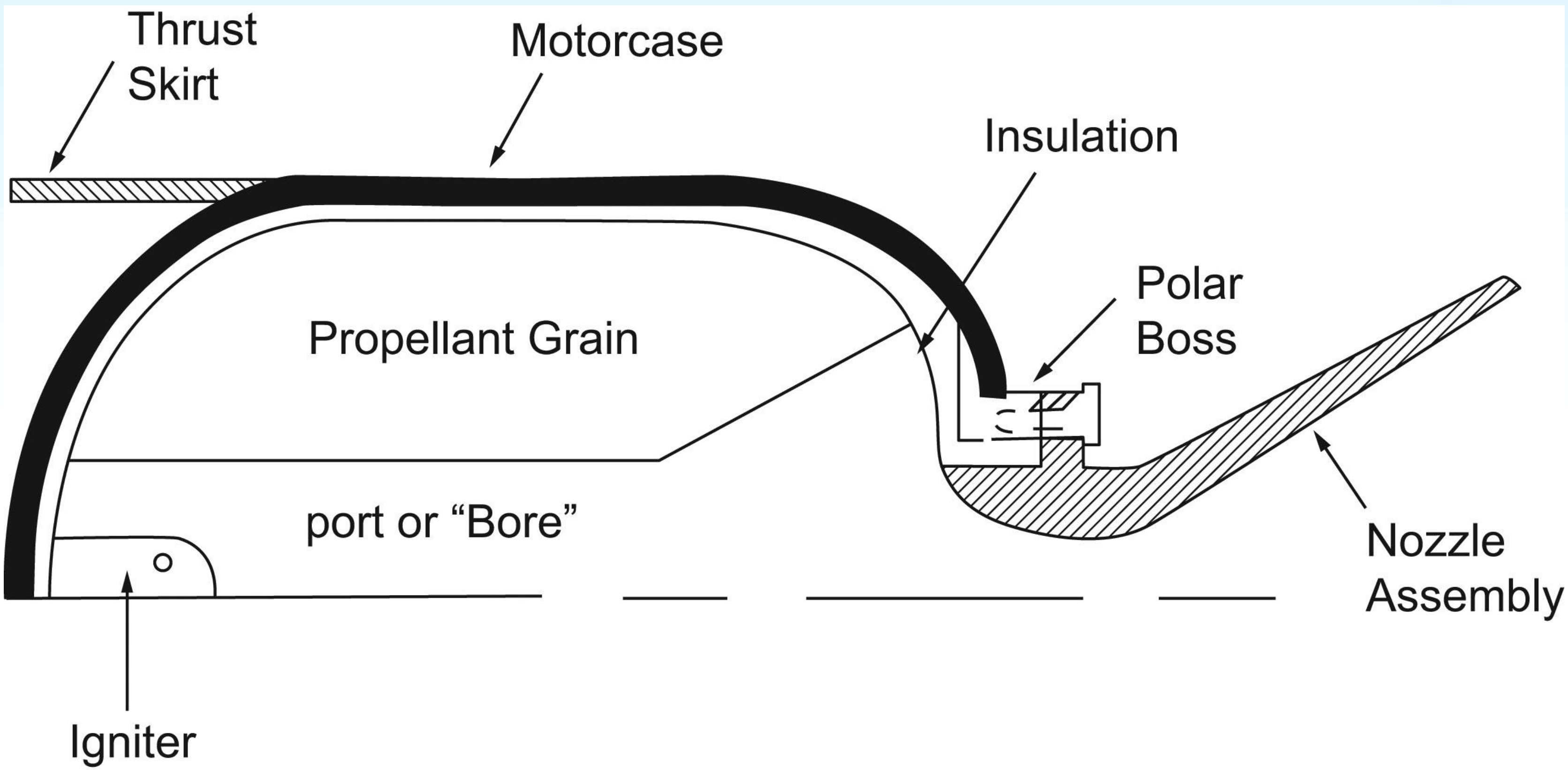
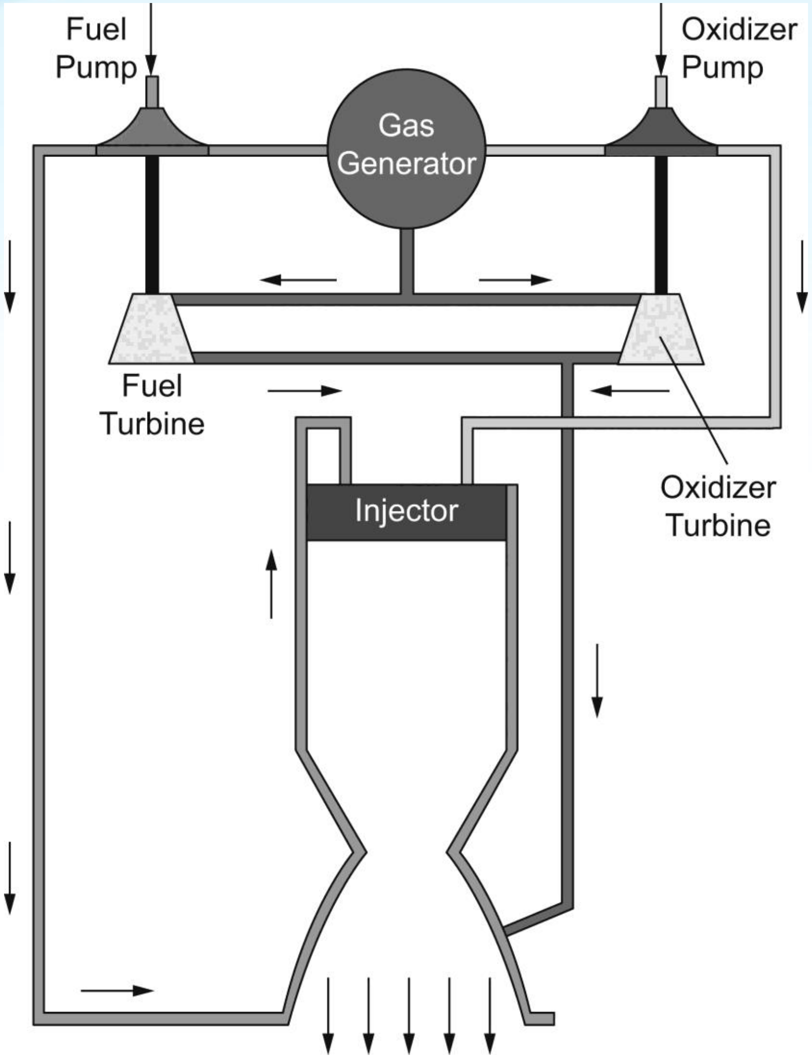
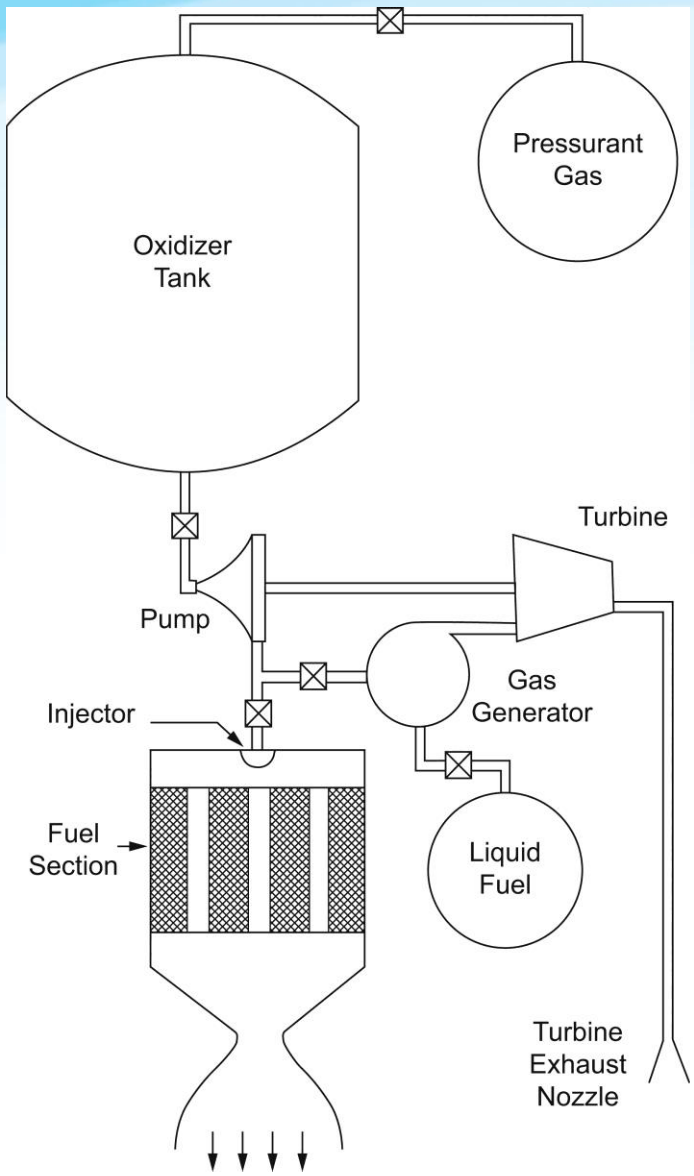
1.3.1 The Solid Rocket Motor (SRM)



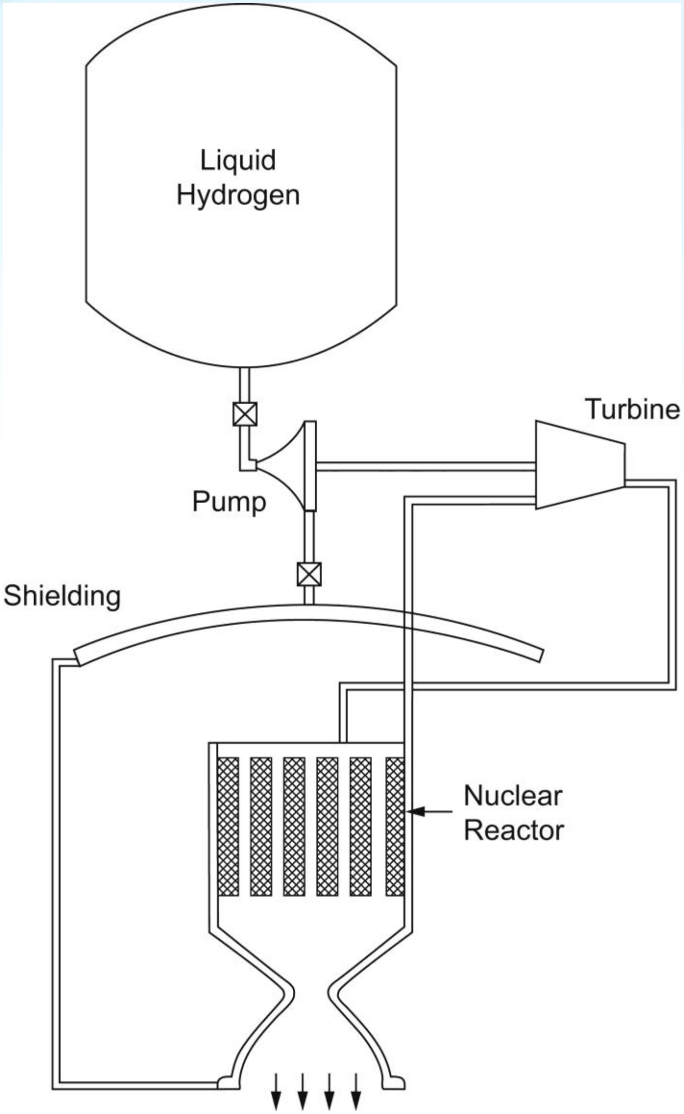
1.3.2 The Liquid Rocket Engine (LRE)



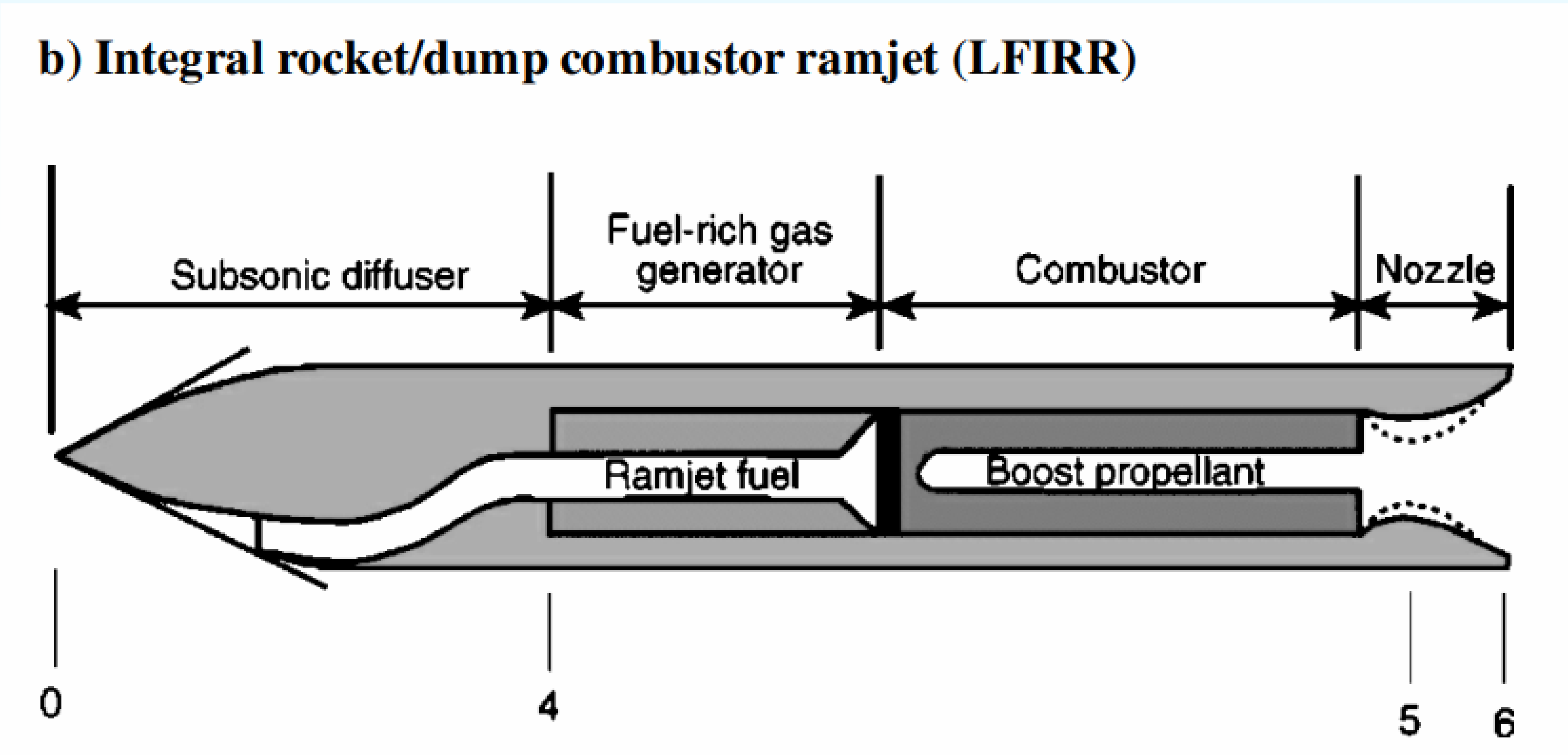
1.3.3 The Hybrid Rocket Engine



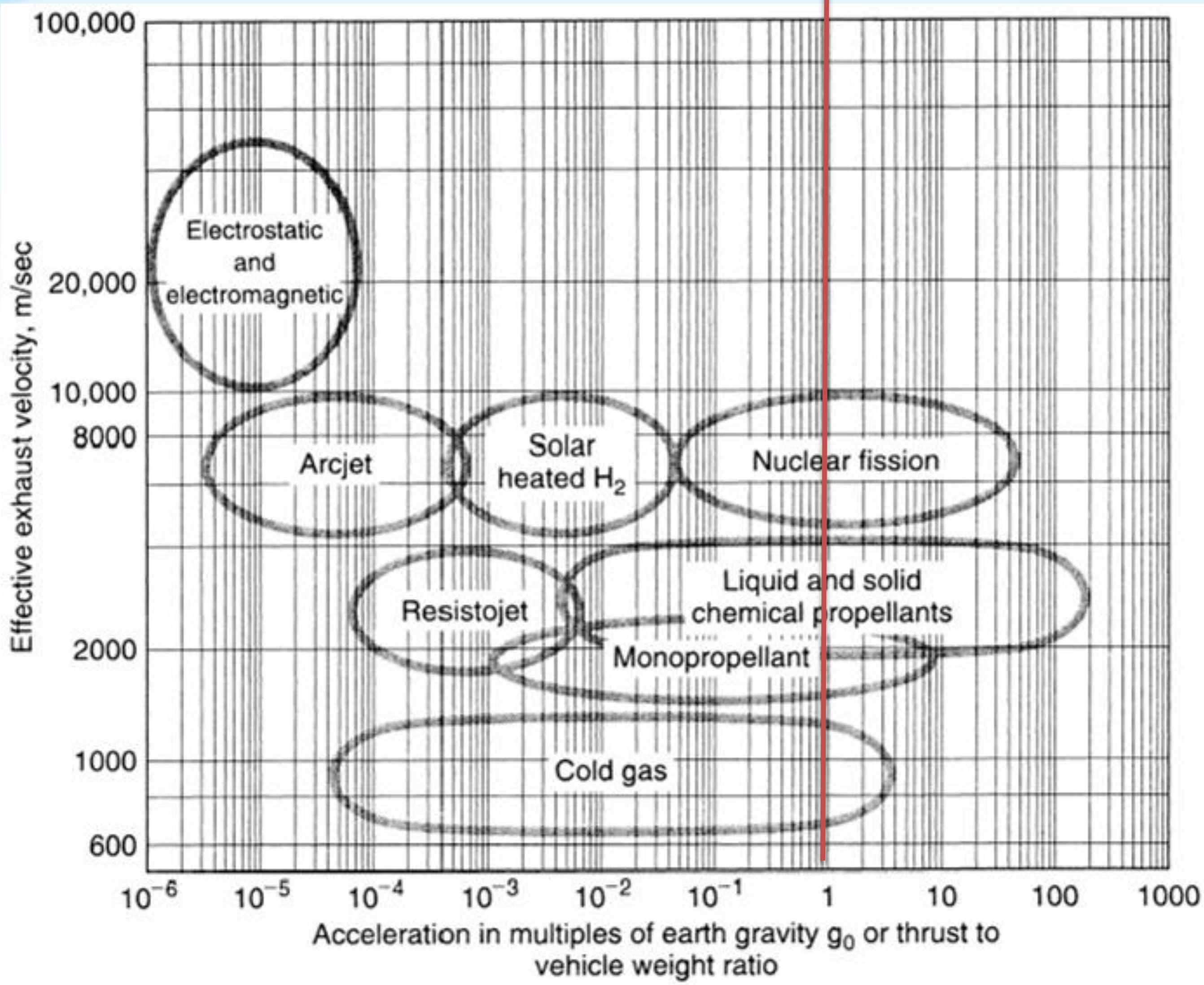
1.3.4 Nuclear Rocket Engines



Integral Rocket/Dump Combustor Ramjet



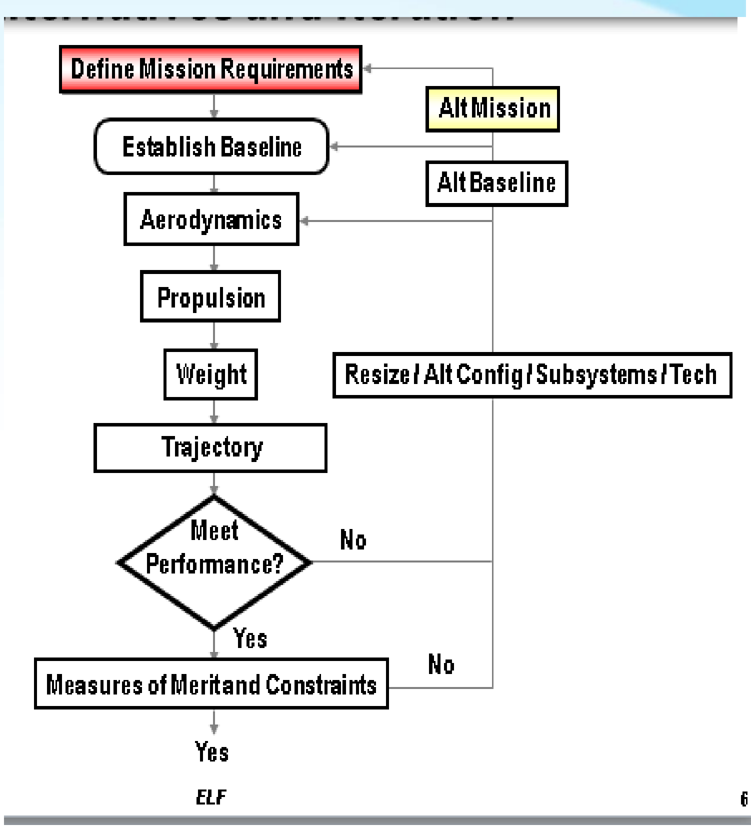
Comparison of Propulsion Systems



$$c = gI_{sp}$$

2.1 General Design Process for Rockets

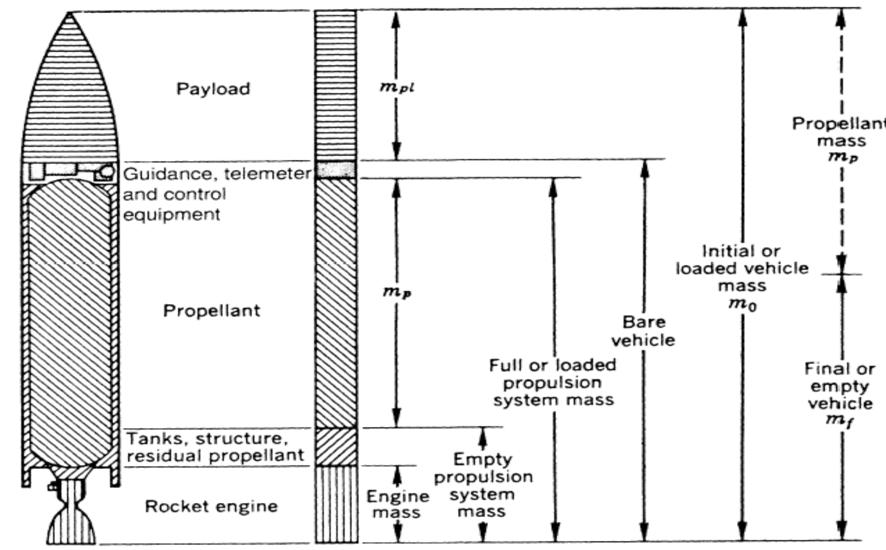
1. Select a Propulsion System
2. Derive the Mission Requirements
3. Preliminary Design and Trade Study
4. Detailed Design and Fabrication
5. Demonstration and Qualification Testing
6. Iteration as Required



From Fleeman

2.1 Vehicle Components

1. Inert Components
2. Propellant
3. Payload Components



λ = propellant mass fraction =

$$\lambda = \frac{m_p}{m_p + m_i}$$

2.1 Driving Factors

1. Specific Impulse

$$I = \text{ total impulse } = \int_0^{t_b} F\,\mathrm{d}t = F t_b \text{ for } F = \text{constant}$$

$$I = \int_0^{t_b} I_{sp}\dot{m}\ g\mathrm{d}t = I_{sp}\int_0^{t_b} \dot{m} g \mathrm{d}t = I_{sp} m_p g$$

$$I_{sp} = F/(\dot{m} g)$$

Using a simplified constant mass assumption and *F = m(d v/dt)*

$$\Delta v = \frac{F}{m} t_b = \frac{I}{m} \qquad \Delta v_{id} = g_e\, I_{sp} \ln(m_o/m_f)$$

So delta V is proportional to the total impulse

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Driving Factors

1. Specific Impulse

$$I = \text{ total impulse } = \int_0^{t_b} F dt = F t_b \text{ for } F = \text{constant}$$

$$I = \int_0^{t_b} I_{sp} \dot{m} \; g dt = I_{sp} \int_0^{t_b} \dot{m} g dt = I_{sp} m_p g$$

$$I_{sp} = F/(\dot{m} g)$$

Using a simplified constant mass assumption and *F = m(d v/dt)*

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$$\Delta v_{id} = g_e I_{sp} \ln(m_o/m_f)$$

So delta V is proportional to the total impulse

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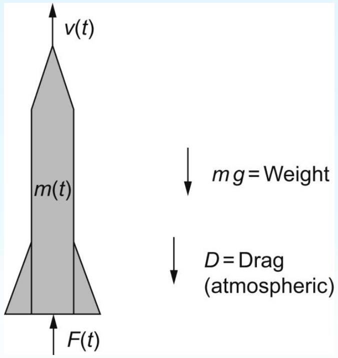
3.1 Vertical Trajectories

$$\Sigma \text{ forces} = m \frac{dv}{dt}$$



$$-mg - D + \dot{m} g I_{sp} = m \frac{dv}{dt}$$

$$dv = -g I_{sp} \frac{dm}{m} - \frac{D}{m} dt - g\, dt$$

$$v(t) = -g_e I_{sp} \ln(m(t)/m_o) - g_e t$$

$$\Delta v_D = \int_0^{t_b} (D/m)\, dt$$

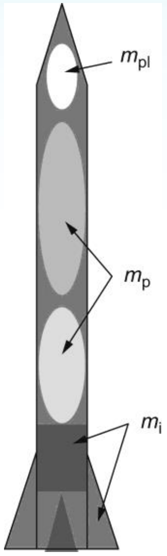
3.1 Vertical Trajectories

$$\lambda = \frac{m_p}{m_p + m_i}$$

$$MR = \frac{m_o}{m_f} = \frac{m_{pl} + m_p + m_i}{m_{pl} + m_i} = \frac{\lambda m_{pl} + m_p}{\lambda m_{pl} + m_p(1-\lambda)}$$

$$\Delta v_{id} = g_e\, I_{sp} \ln(m_o/m_f)$$

$$MR = e^{\Delta v_{id}/(g_e I_{sp})}$$



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3.2 Burning Time and Accel. Effects

$$I_{sp} = F/(\dot{m}g)$$

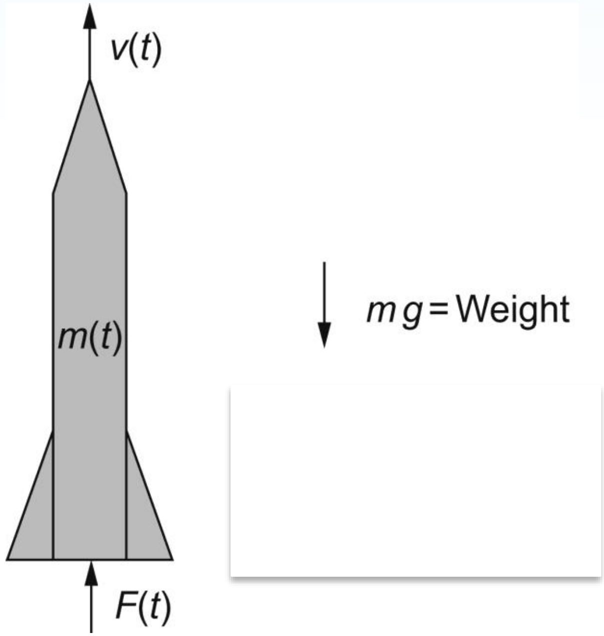
$$v(t) = -g_e I_{sp} \ln(m(t)/m_o) - g_e t$$

$$h_{bo} = g_e I_{sp} t_b \left(\frac{m_f}{m_o - m_f} \ln(m_f/m_o) + 1 \right) - \frac{g_e}{2} t_b^2$$

$$h_c = \frac{1}{2} v_{bo}^2 / g_e$$

$$\eta_0 = F/(m_o g_e) > 1$$

$$t_b = m_p/\dot{m} = m_p I_{sp}/F$$



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01 Homework Assignment

- Textbook Problems

  2.6, 3.8, 4.24, 4.30
- Special Problems

  SP01A Annotated Bibliography

  Berg, P., Loeblich, W., and Frederick, R., "Using CEQUEL for Thermochemistry Calculations in a Graduate Rocket Propulsion Course at UAH," 2023 AIAA SciTech, January 26, 2023.

  SP01B Derive Basic Thrust Equation

  SP01C Derive Basic Exit Velocity Equation

Remember to upload you entire assignment in one file. If you work by hand and do not have a scanner, there are phone aps that you can use to take picture and pdf the pictures into one file. We just need to be able to clearly see all the requested homework in one file.

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Required Homework Format

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Homework 01 - Problem 2.6

1. Name : Instructor
2. Given:

A small interceptor is launched horizontally from an aircraft flying at $M = 0.8$ at an altitude of 40,000 ft. The rocket motor operates over a one second duration after release from the aircraft. The missile velocity history during this time is given by

$$V = V_o\left(1 + 2\sin\left(\pi \, t/2\right)\right) \qquad 0 \le t \le 1$$

where V_o is the aircraft velocity at the time of release. Guidance experts indicate that the missile will have adequate agilty to intercept its moving target as long as its velocity is at least 1000 f/s. Assume that we can neglect drag during the brief boost phase. During the coast pahse, assume the following:

Missile Mass = 300 lb.

3. Find:

a) The range at the end of the boost phase.

b) The total range of the missile.

Discussion of Thrust Equation

Discussion of Thrust Equation

Discussion of Thrust Equation

Discussion of Thrust Equation

Discussion of Thrust Equation

Discussion of Thrust Equation

Discussion of Thrust Equation