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# Space Propulsion Education

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# SPACE PROPULSION EDUCATION

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## Abstract

This paper describes the development of a new technical book, *Space Propulsion Analysis and Design* (SPAD), being developed at the US Air Force Academy (USAFA) with sponsorship and guidance from several government, industry, and academic organizations. The philosophy of the book is to present rocket technology to the advanced engineering student and the practicing engineer from the viewpoint of conceptual or preliminary design. The major emphasis is on the design process, with particular emphasis given to space mission requirements, developing specific propulsion system requirements, and generating a preliminary design. Preliminary design includes propulsion system configuration, mass, and performance estimates. Technical discussion is presented in a format that enables direct implementation of the design process. We also present many practical design details.


## Introduction

The United States Air Force Academy is developing a series of technical works on the design of various spacecraft systems. The first book in the series, *Space Mission Analysis and Design* (SMAD), presently in its second edition, discusses the top level, preliminary design of an entire space mission and includes all of the primary systems. This paper discusses an additional book, *Space Propulsion Analysis and Design* (SPAD), that focuses specifically on designing spacecraft and rocket propulsion systems.

Consider the current interaction between academia, government, and industry within the context of the aerospace community. Our universities are among the finest and produce some of the best engineers in the world. However, this accomplishment by no means implies we cannot do better. Two important areas for improvement are engineering design, and preparing graduates for the rigors of an increasingly competitive industry environment. Government, on the other hand, continues to define the missions and provide the funding for the majority of new programs and technologies. Industry uses the product from our universities to respond to these governmentally directed programs and attempts to fulfill those needs competitively and profitably. The desired outcome of this complex interaction is to design and build intelligent, efficient, and reliable spacecraft and launch vehicles for the lowest cost and to fulfill mission needs in the most robust fashion possible. Doing this successfully is the key to remaining competitive in an increasingly more hostile economic and political environment. To this end, we need aerospace engineers who can comfortably and effectively function in a design environment and understand and communicate the impact of their engineering specialty upon the rest of the launch vehicle or spacecraft. We need to produce the best systems engineers that we can!

Our experience has shown that space propulsion education is addressed at the university level through several isolated courses within the aerospace curriculum. It is rare to find spacecraft and rocket propulsion curriculum as well developed as its air breathing counterpart. The engineers we are graduating typically possess more than adequate technical depth, but lack the breadth to function effectively (at least initially) in both government and industry. In addition, they often times know the theory behind their technical discipline, but lack the practical insight to make them as effective as they need to be.

*Space Propulsion Analysis and Design* follows in the footsteps of its highly successful parent *Space Mission Analysis and Design,* in attempting fill a critical need within the space propulsion engineering discipline. Numerous very good texts and references have been written on the subject. Many present in-depth technical details that are focused on one or several technologies (typically liquid or solid rocket propulsion). However, none have attempted to demonstrate how general overall mission requirements flow down to specific propulsion system level requirements, and then provide the data, process, and equations that allow you to design a propulsion system to best meet those requirements. We feel that this next step, will significantly contribute to producing better aerospace engineers from our universities, more technically consistent programs funded by government, and a better product from industry.

## Philosophy

The purpose of the SPAD book, is to present rocket propulsion technology from the point of view of the system designer or the propulsion systems engineer. Our primary goal is to present the "process" of going from requirements for a space mission, through the development of propulsion system specific requirements, *and then come up with a* preliminary/conceptual propulsion system design that allows us to estimate system configuration, mass, and performance. This design template dictates the structure, content, and scope of SPAD. Figure 1 outlines this top level process.

We begin with mission needs and requirements and immediately demonstrate how a set of mission concepts are evolved. For each concept, a set of propulsion requirements are generated for each mission application (earth to orbit, orbital transfer, orbital maneuver and maintenance, and attitude control) as they may apply. Next, a $\Delta V$ budget can be produced for each mission application embedded within a specific mission concept.

From this point, thrust and total impulse requirements are generated to allow the engineer to select appropriate propulsion technologies (liquid, solid, hybrid, nuclear, electric) which in turn supply the data necessary to generate propulsion system requirements for a specific technology option. The Mission Scenario chapter demonstrates this process for an Earth to Geostationary Orbit mission. This chapter draws on all of the information previously introduced within the book. Chapter 1, Introduction, will introduce the process described, and provide the necessary data to perform the propulsion technology selection. Chapter 2 Mission Analysis, provides the details on how to come up with an acceptable $\Delta V$ budget for each mission application. Technology Chapters 5 - 9, take these requirements and provide the process, data, equations, and algorithms necessary to generate a complete conceptual design ( including size, mass, configuration, and performance).

The best options from each applicable technology area are traded against one another until the best solution is selected as the propulsion specific baseline solution. Reflect for a moment upon what this does. We begin with a set of general mission needs/requirements and demonstrate a process which generates the optimum propulsion solution to those requirements, allowing one to trace that solution directly back to its genesis.

## SPAD Content Description

*Space Propulsion Analysis and Design* has 12 chapters, designed to lead the student or engineer through the development of space propulsion systems:

Chapter 1 : Introduction (Gary Henry, US Air Force Academy) - This chapter has a dual purpose. First, we present a top level discussion of the various engine technologies and some of the key performance and design parameters associated with each technology. Second, we present the mission design process and show how this process flows into the definition of propulsion system requirements.

Chapter 2 : Mission Analysis (J. Horsewood, ADA Soft, J. Erickson, General Dynamics) The purpose of this chapter is to demonstrate how $\Delta$Vs are calculated for different mission applications to include Earth to Orbit (ETO) ascent, Earth orbit maneuvers, Lunar trajectories, interplanetary trajectories, orbit maintenance, attitude control, and low thrust trajectories.

Chapter 3 : Thermodynamics and Mechanics of Fluid Flow (Gary Wirsig, US Air Force Academy) - The basis of all rocket system performance prediction is thermodynamics. This chapter starts off by discussing the classical thermodynamic topics and then extends these into the particular problems associated with propulsion system design.

Chapter 4 : Thermochemistry (Ron Furstenau, US Air Force Academy) - The primary focus of rocket systems in the past and for the foreseeable future is in chemical propulsion. This chapter discusses how chemical reactions/combustion fits into this picture and specifically, how to analyze chemical performance. We demonstrate the process of performing chemical equilibrium analysis and enhance the discussion with the copious thermochemical data required to do design work.

Chapter 5 : Liquid Rocket Propulsion Systems (R. Sackheim, TRW, A. Martinez, Rocketdyne) - This is the first of five technology chapters. The design of liquid rockets is discussed and the key technologies are presented. A single design process is applied to the development of both pressure and pump fed liquid systems with thrust levels ranging from hundredths to millions of newtons.

Chapter 6 : Solid Rocket Propulsion Systems (Stephen Heister, Purdue University) - This chapter discusses the preliminary design of solid rockets. We include an extensive discussion on performance prediction. This includes propellant regression rate modeling as well as lumped and finite element approaches to system performance. We also include a good deal of data useful for the preliminary design of the system hardware such as cases, nozzles, etc.

Chapter 7 : Hybrid Rocket Propulsion Systems - Interest in hybrid rockets has been increasing in recent years. This chapter presents the preliminary design process as well as discussion on performance prediction. The principle technology problem is the combustion process. We present the state of the understanding of this process and apply this to problems such as scaling.

Chapter 8 : Nuclear Thermal Propulsion Systems (P. Sager, General Dynamics) - Nuclear thermal propulsion has been described as an enabling technology for interplanetary missions. In this chapter we discuss the technological problems ranging from fission reactor design to overall system integration into a vehicle.

Chapter 9 : Electric Propulsion Systems (Peter Turchi, Ohio State University) - Electrical propulsion offers tremendously high efficiencies but unfortunately, state of the art thrust magnitudes limit applicability. We discuss the trades necessary to determine system feasibility in addition to the physics of operation and the design process.

Chapter 10 : Mission Scenario (Kyle Shepard, General Dynamics) - This chapter demonstrates the design process. We start off with a typical mission, to geosynchronous orbit and apply the design process from initial mission requirements all the way through preliminary/conceptual design.

Chapter 11 : Propulsion System Testing (David Thompson, US Air Force) - This chapter discusses the process of preparing and conducting propulsion systems tests. We discuss some of the key instruments and processes required in addition to the topic of test design.

Chapter 12 : Advanced Propulsion Systems (Robert Forward, Forward Unlimited) - This chapter discusses various propulsion technologies that are not considered in the mainstream of the space propulsion community. Topics range from air augmented rockets, through anti-matter rockets and tether propulsion.

## Hybrid Rocket Example

To illustrate our approach, we will discuss the contents of chapter 7 on hybrid rockets. Figure 2 shows a schematic representation of a hybrid rocket, similar to that appearing in the book. Figure 3 shows the top level preliminary/conceptual design process. The following is a list and description of the chapter 7 contents, this is representative of all of the technology chapters :

1.) History - This section contains a short outline of hybrid rocket development history to put the subject into perspective.

2.) Design Process - This section discusses the design process depicted in Figure 3. Each section is discussed and more detailed design charts are included.

3.) Performance Prediction - The major problem involved with any propulsion *system is performance prediction.* This section discusses the theoretical aspects of the solid/liquid combustion process as well as the algorithms used for preliminary performance prediction. In addition, we present sufficient regression rate and thermochemical data to allow for analysis by *the reader.*

4.) Hardware Design - This section discusses many of the aspects of preliminary component design to a level which will allow preliminary configuration and mass estimates. In addition, sufficient discussion is included so that the reader can understand the technology and the issues involved in a more detailed design.

5.) *Case Study - This is an example of the* design process. Starting from specific basic mission requirements, we illustrate how the process works and include a representative preliminary system design.

## Concluding Remarks

In this paper, we have attempted to describe a new textbook concerning the design of spacecraft propulsion systems. We feel that it will be an asset to both industry and academia. We invite any discussion concerning the book.

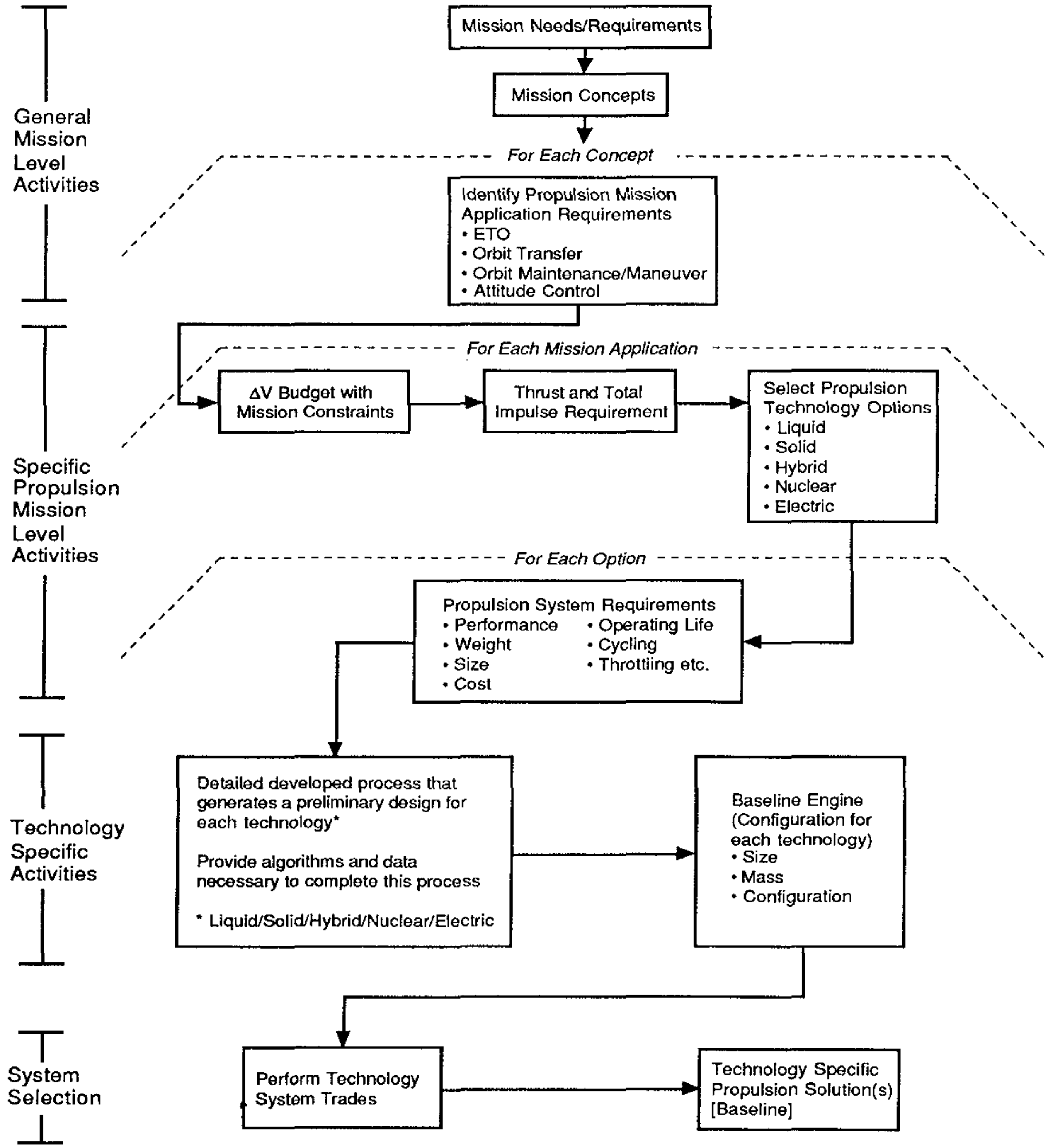


Figure 1. Top Level Design Process.

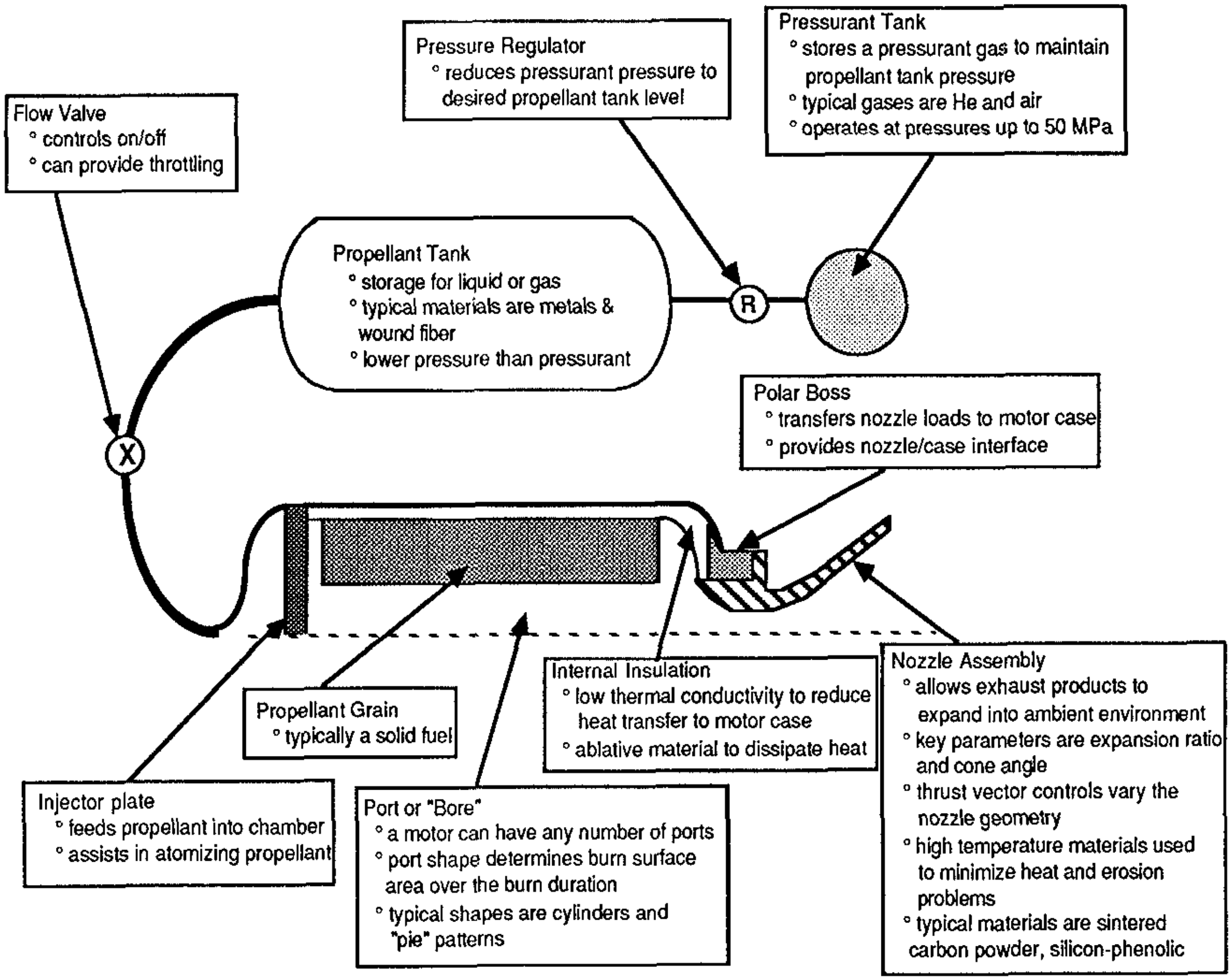


Figure 2. Schematic of a Pressure Fed Hybrid Propulsion System.

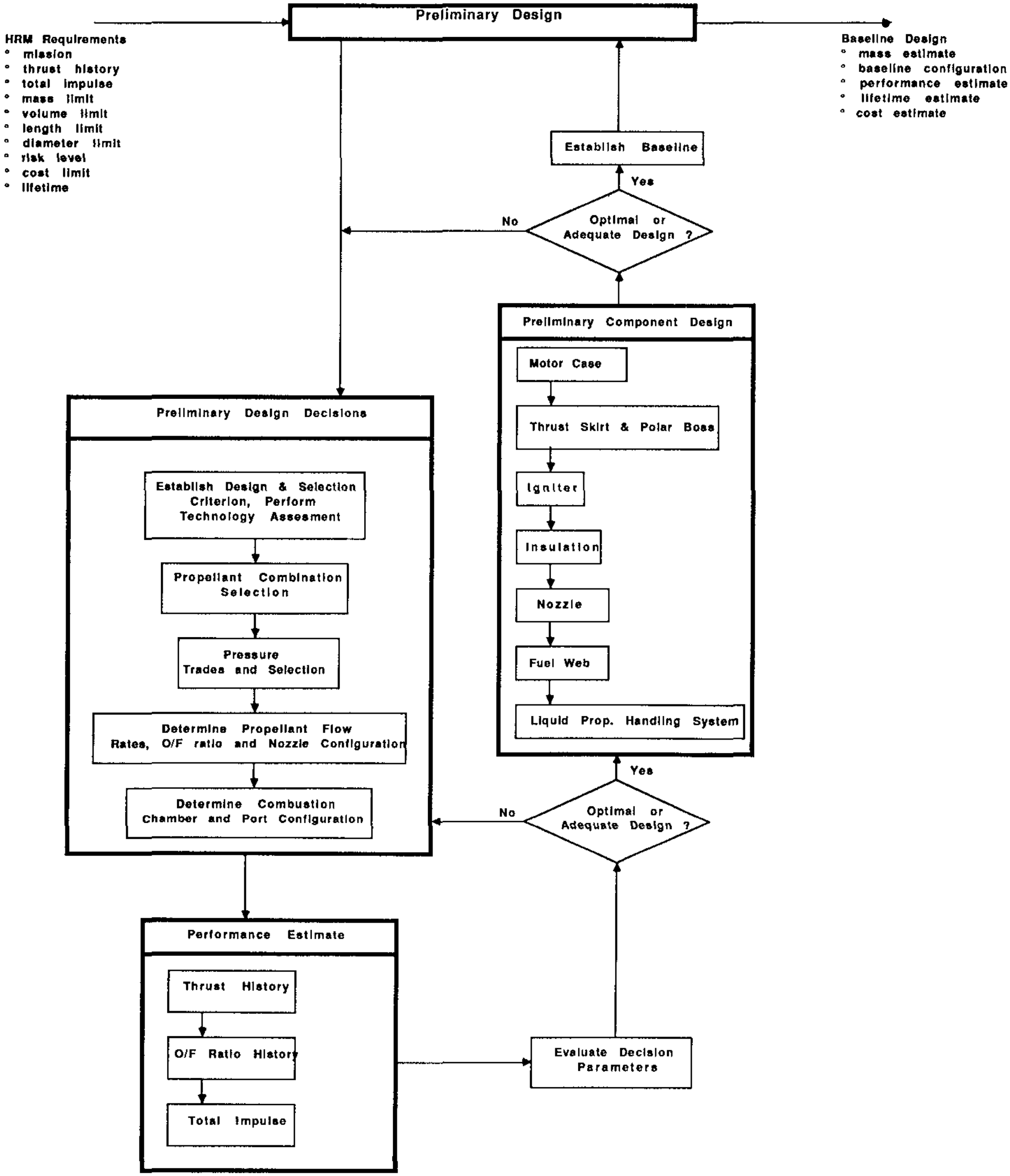


Figure 3. Hybrid Rocket Propulsion System Preliminary Design Process.