Design Consideration for Aquilla launch

Alex Fausett

AIAA-92-3588 The Commercial Aquila Launch Vehicle

Third stage propulsion system

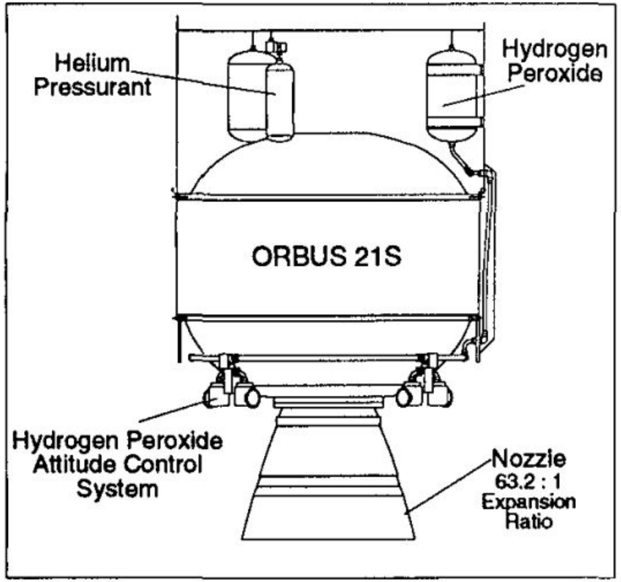


Figure 5. Third Stage ORBUS®21S SRM

The Aquila third stage motor is an ORBUS 21s solid rocket motor.

It has a **Kevlar/epoxy motor case** and a **carbon-phenolic exit cone**.

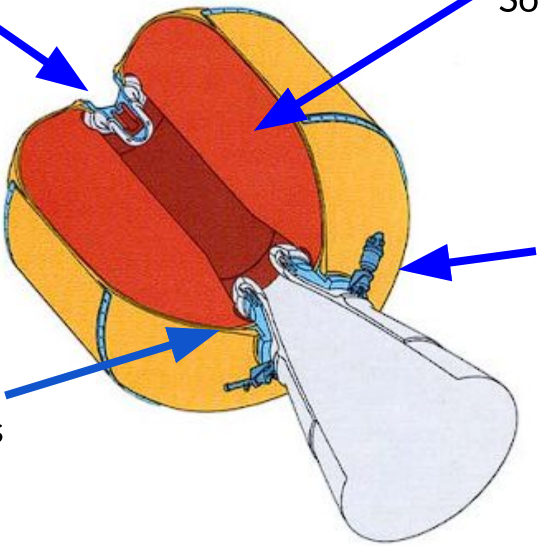
Pitch, yaw, and roll control are provided by hydrogen peroxide **Attitude Control System** (ACS).

Liquid oxygen used for thrust vectoring

The Orbus 21

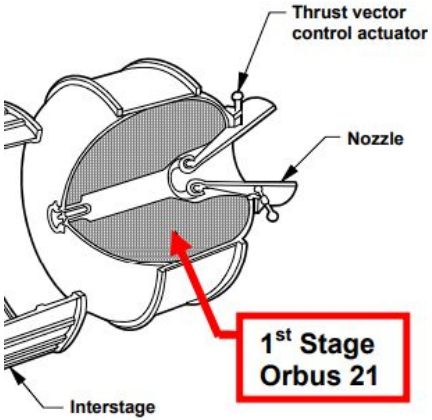
Burn time (145-sec at 60ºF)

Both stages incorporated the world's lowest torque movable nozzle system Seal.



Orbus-21: IUS 1st Stage

Diameter = 92-in
Wp = 21,400-lb



https://gobluechase.files.wordpress.com/2014/08/pioneers-in-propulsion-final.pdf

Fourth stage propulsion

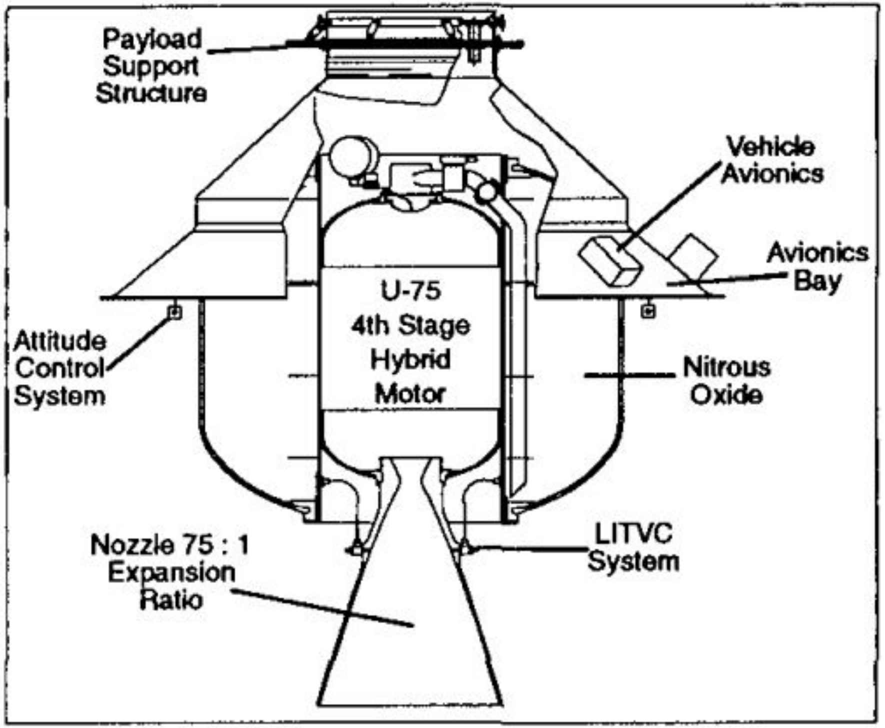


Figure 6. 4th Stage AMROC U-75 Hybrid Motor

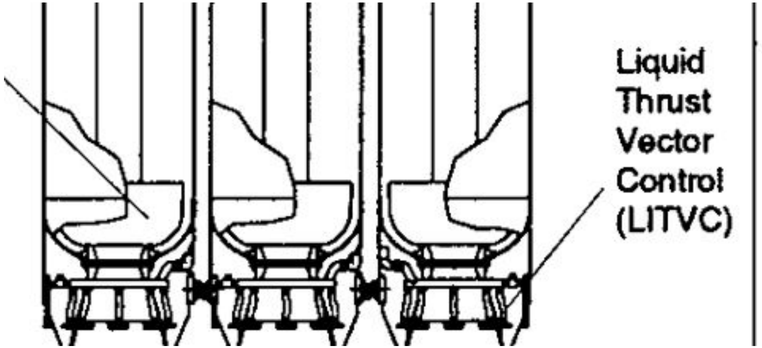
Nitrous oxide is storable at room temperature and preloaded in the stage.

Nozzle is equipped with an LITVC system that uses oxidizer supplied from the main tank.

Thrust axis a maximum of 2" using four redundant, digitally proportional valves.

Pitch, yaw and roll control is furnished by six N,O cold gas thrusters fed from the vapor side of the main oxidizer tank.

Thrust vectoring system



The H-1800 injector provides an even distribution of liquid oxygen to the motor. The injector is a centrally located, multiple element, showerhead-type injector.

The H-1800 motor is ignited by a reliable pyrophoric liquid ignition system. Triethylaluminum (TEAl) is injected coaxially with the liquid oxygen through the motor injector to initiate ignition.

The H-1800 oxidizer tank is the storage vessel for the LOx used by the hybrid motor and the LITVC system. The tank is made of a light-weight aluminum alloy. Its internal operating pressure is held to approximately 60 psi.

HYDROGEN PEROXIDE ATTITUDE CONTROL SYSTEMS

https://www.sciencedirect.com/science/article/pii/0032063361901313 look into further

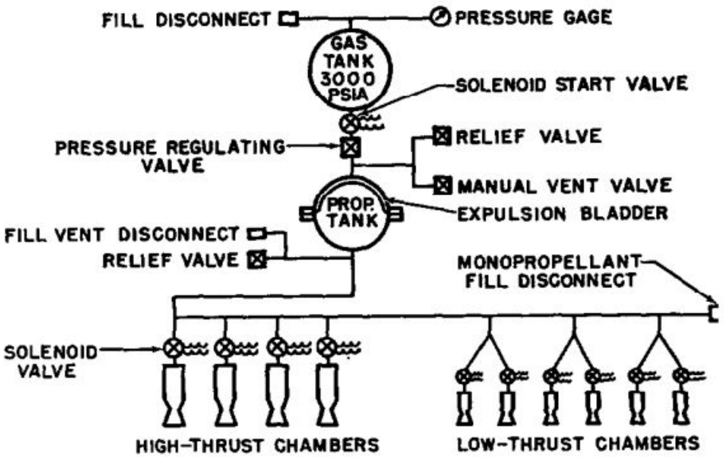


Fig. 2. Schematic of hydrogen peroxide attitude control system.

Standard set up for a LITVC system.

A typical H,O, attitude control system schematic is presented in Fig. 2. A gas pressurization circuit includes a tank, fill disconnect, pressure regulating valve, relief and solenoid start valves.

HYDROGEN PEROXIDE ATTITUDE CONTROL SYSTEMS

https://www.sciencedirect.com/science/article/pii/0032063361901313?fr=RR-2&ref=pdf_download&rr=8152cad16d02508b

Table I. Estimated Thrust Chamber Data

50 and 1 Pound Thrust Chambers for Attitude Control Systems

	Nitrogen	Hydrogen Peroxide 90%	Hydrogen Peroxide 99%	Hydrazine	IRFNA-UDMH
Chamber pressure, psia	250	250	250	250	250
Nozzle exit area ratio	12	15	18	20	20
Characteristic velocity	1322	3040	3380	4265	—
Approximate chamber temperature, °F	0	1360	1820	1610	1900
Approximate chamber characteristic length	10	30*	30*	200	40
Specific impulse (∞ altitude)	68	160	180	220	200
Ignition power requirements, watts (per chamber)	0	0	0	100	0

* Includes catalyst bed

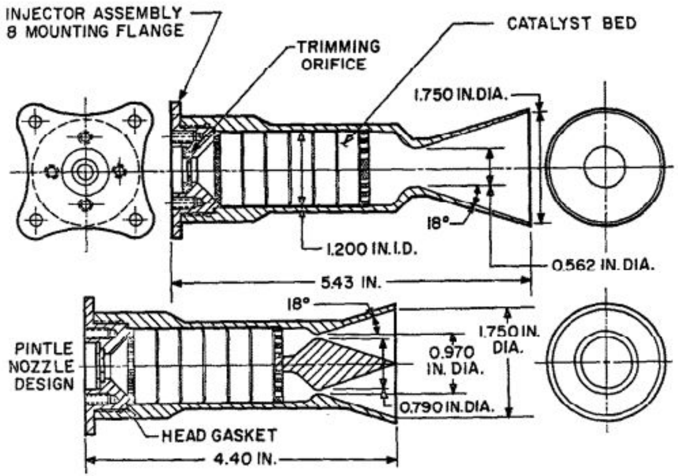


Fig. 3. 50 lb thrust chambers. Nozzle exit area ratio = 9·7.

Hydrogen peroxide altitude systems

Using hydrogen peroxide for thrust vectoring:

https://www.sciencedirect.com/science/article/pii/0032063361901313?fr=RR-2&ref=pdf_download&rr=8152cad16d02508b

Table 2. Physical Properties of 90 per cent H_2O_2[3]

Density at 68°F	1·39 g/cm^3 11·62 lb/gal
Viscosity at 64·4°F	1·30 centipoises
Vapor pressure at 86°F	5 mm Hg
Freezing point (Note: When frozen solid contracts by 11% of liquid volume)	12°F
Normal boiling point	284°F
Heat of vaporization	590 B.t.u./lb
Heat capacity, 0–18·5°C	0·58 cal/g–°C
Surface tension at 64·4°F	75·53 dynes/cm

AIAA-91-2046 The Commercial Aquila Launch Vehicle

Premise

Vehicle attitude control and guidance steering will be provided by either Liquid Injection Thrust Vector Control (LITVC) or cold gas attitude control

Upper stage propulsion

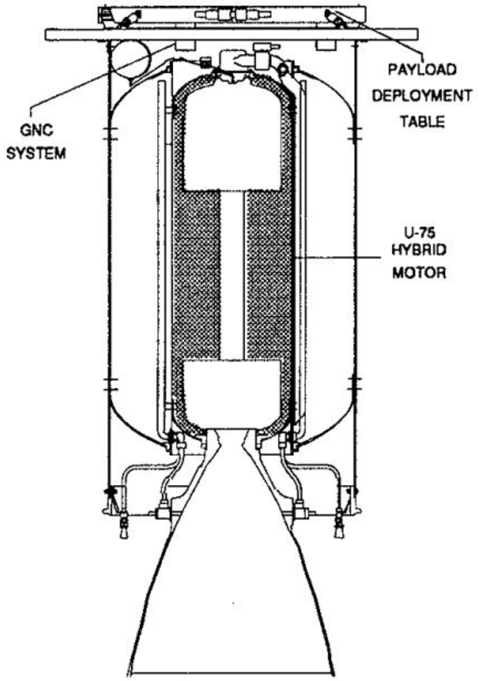


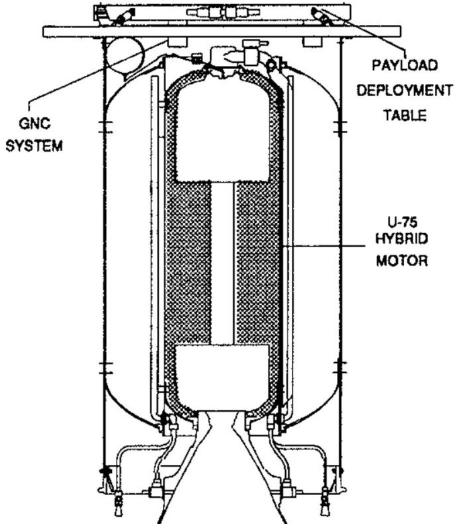
Figure 7 - U-75 Hybrid Upper Stage Propulsion System

In the pressure-fed U-250 and U-75 hybrid systems, the N2O is seif-pressurized by its own vapor pressure, fed through the main N2O valve, and injected through the injector at the head end of the motor and ignited.

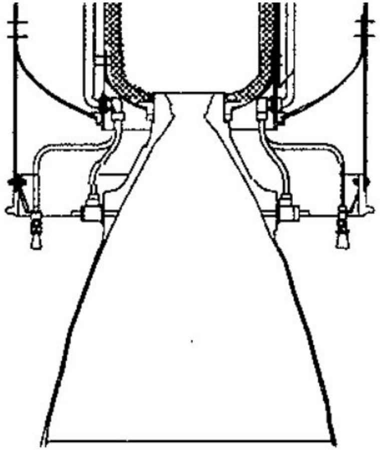
- GNC system (Guidance and control system)
- N20 injected

Interesting features

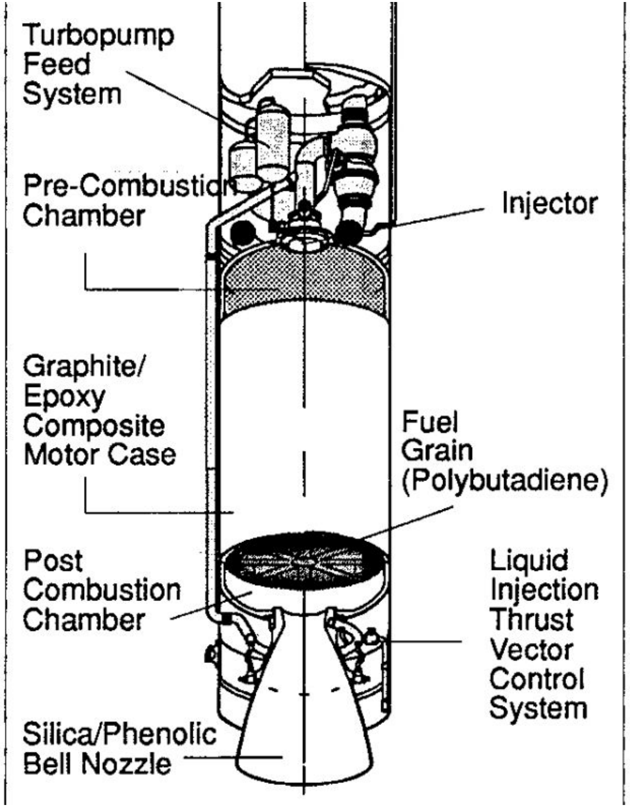
The tank is maintained at a nominal pressure of 60 psia in order to provide the required NPSH at the turbopump inlet



With various valve combinations and mass flow rates, the motor thrust can be deflected up to 6 degrees at discrete nozzle azimuths for pitch, yaw and roll control during the motor operation

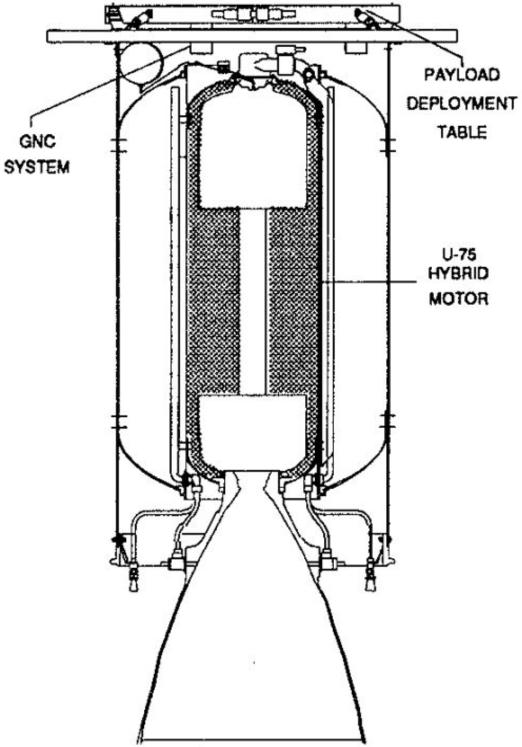


Some interesting points????



- Interesting design points
- Fan blade post combustion chamber
- Liquid injection system

Liquid Injection Thrust Vector Control



In addition to being used as a motor propellant, LOX is also used as the LITVC injectant fluid. LOX is drawn from the LOX tank by the turbopump, fed into the LITVC manifold surrounding the nozzle, and distributed to eight high resolution digital electric LITVC valves equally spaced around the nozzle. During operation, the liquid oxygen is injected into the nozzle approximately 1/3 of the distance between the nozzle throat and the nozzle exit plane. The injected fluid expands upon entering the nozzle, creating a shock wave in the nozzle, and imparting a side force on the nozzle.

Liquid injection thrust vectoring

https://en.wikipedia.org/wiki/Thrust_vectoring

https://www.novamente.net/solid-rocket-thrust-vector/liquid-injection-thrust-vector-control.htm

Liquid injection TVC has provided thrust vector deflections as large as 10°, equivalent to side forces of 17.6 percent of axial force (ref. 46).

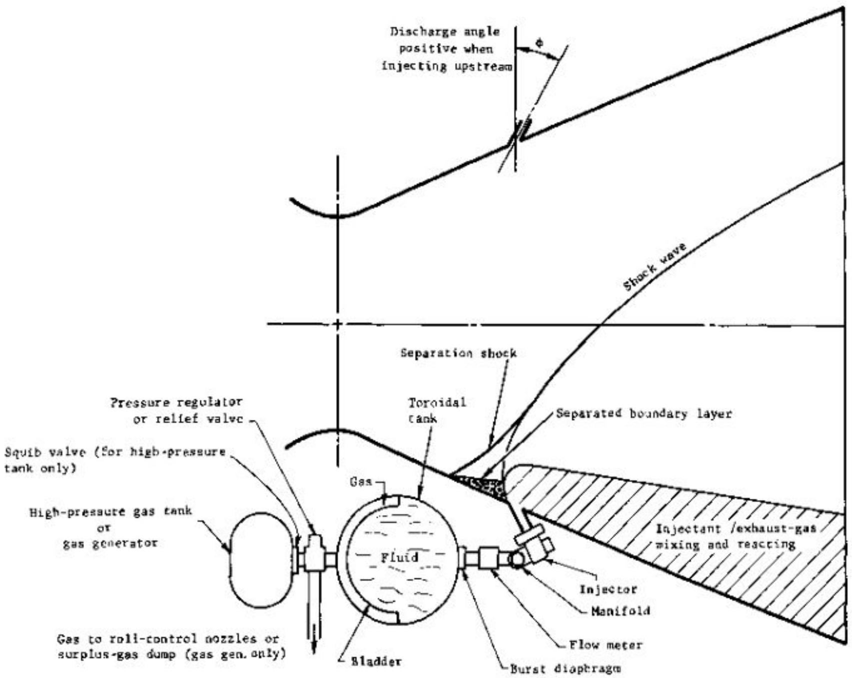
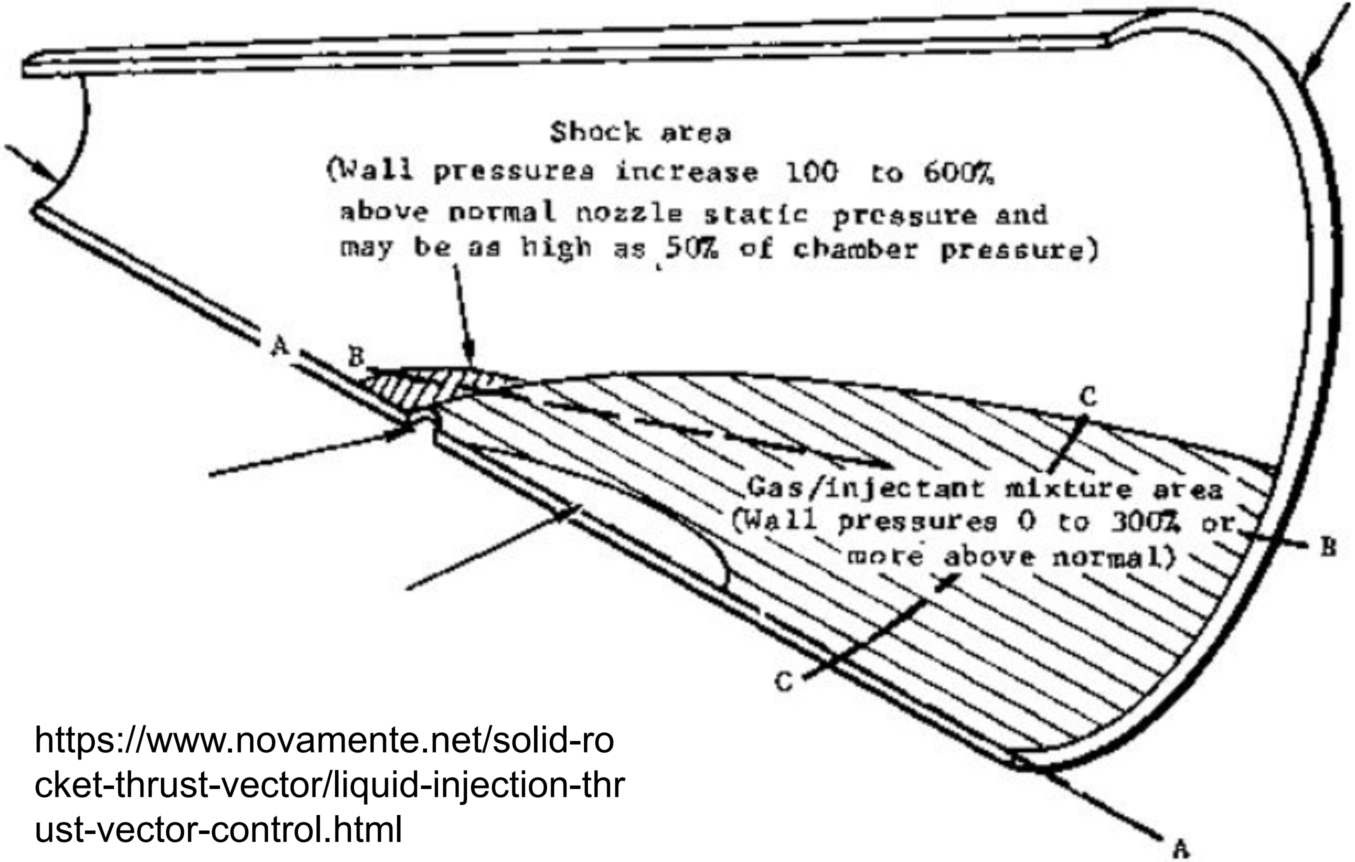


Figure 23. - Schematic of typical liquid injection TVC system and side force phenomena.



https://www.novamente.net/solid-rocket-thrust-vector/liquid-injection-thrust-vector-control.html

Parallels

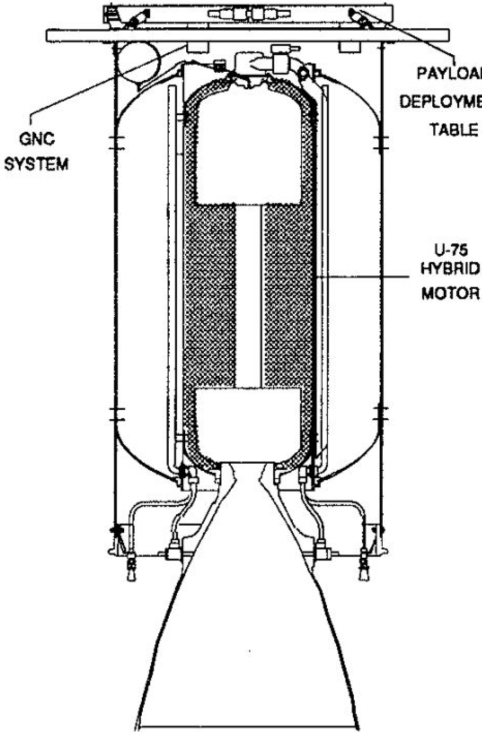
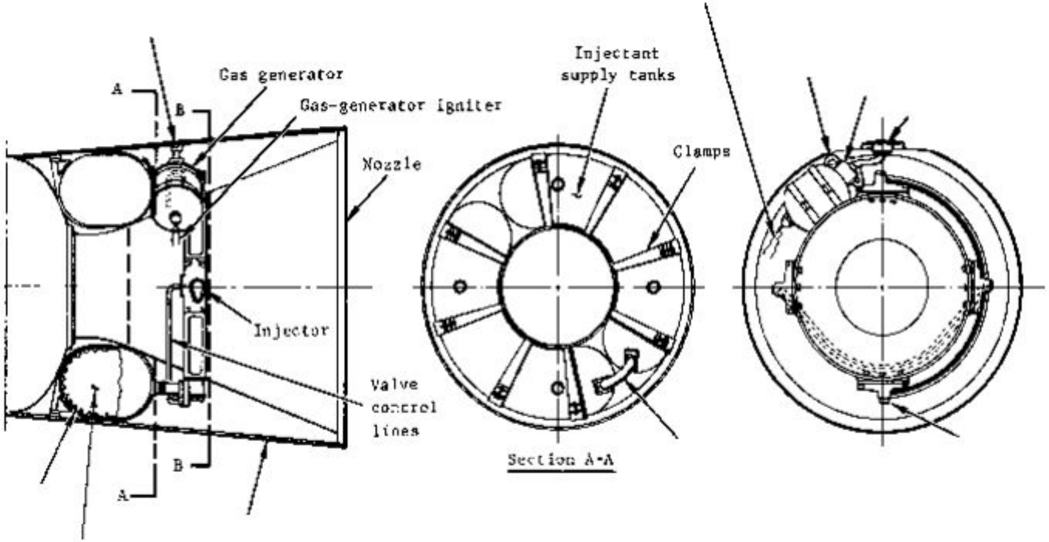
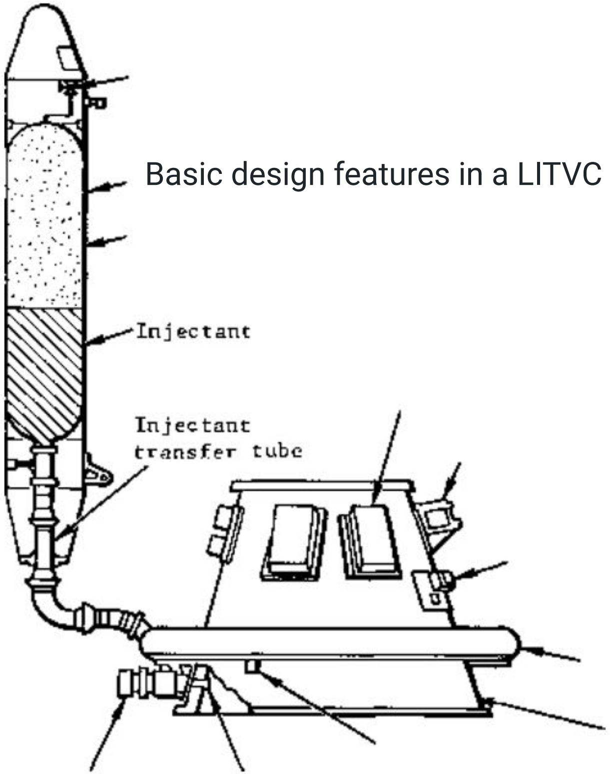


Figure 7 - U-75 Hybrid Upper Stage Propulsion System

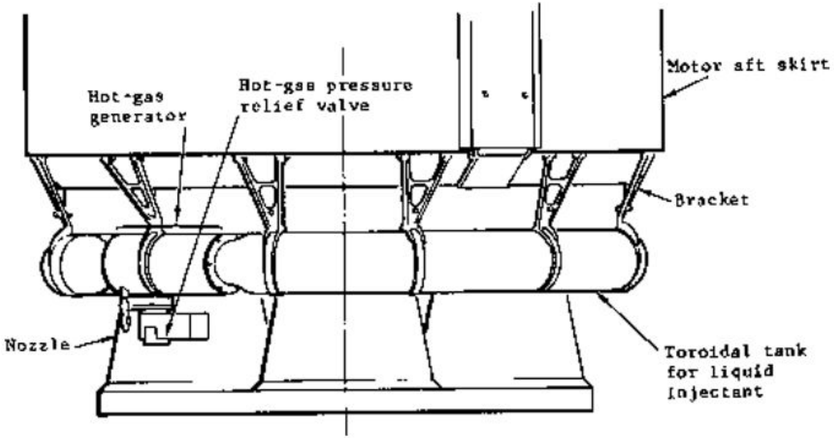


Here you can see the parallels between the designs

Other interesting images



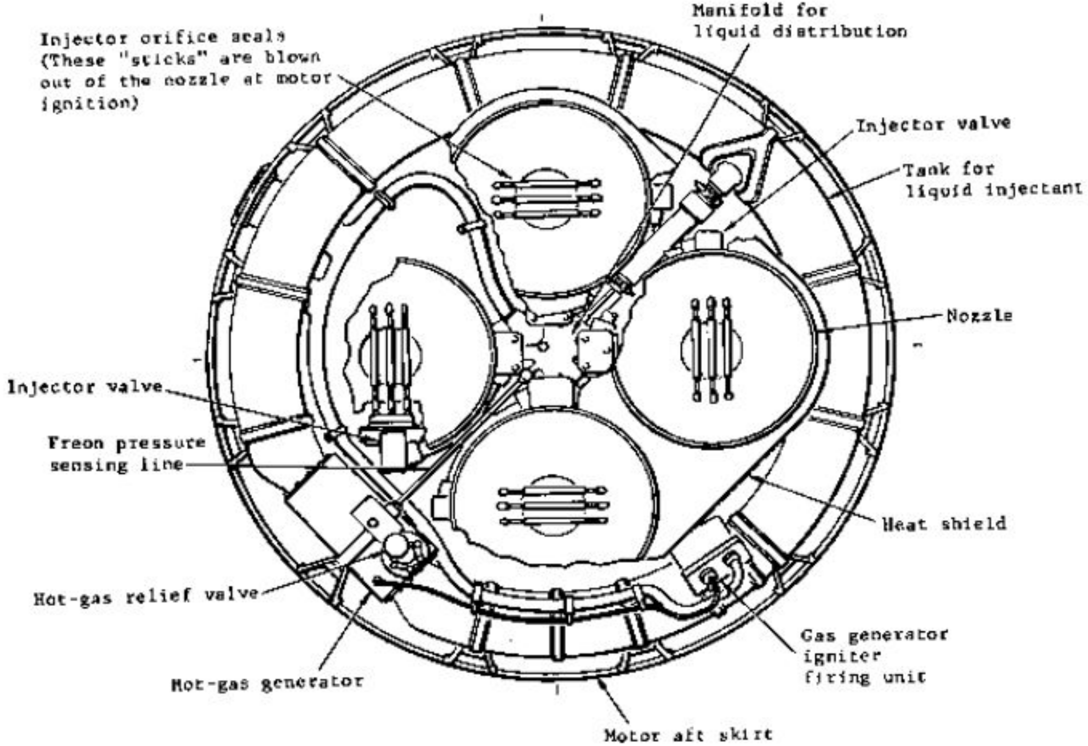
Basic design features in a LITVC system.



- Schematic of Titan III ullage-blowdown LITVC system.

Figure 28. - LITVC system for Polaris A3 second stage.

(a) Side view



Another example of LITVC system except this time on the Polaris A3

https://www.jstor.org/stable/40393648

Interesting design tool to investigate

SRM 2023.XLS - spreadsheet design tool

[(1014) How to Design A Solid Rocket Nozzle - YouTube]

[Richard Nakka's Experimental Rocketry Site (nakka-rocketry.net)]

SRM 2023.XLS
Solid Rocket Motor Performance

Written by:	Richard A.Nakka
Version:	2023 (for free distribution). Supercedes SRM_2014.XLS version 1.1 (2014)
Date:	23-Mar-23

Instructions for use: Enter required data in the blue-outlined cells (with blue text)
Note that some data cells have drop-down lists
Then click on the Solve buttons (1-3)

Introduction

Changes incorporated into SRM 2023 version

KNPSB and KNFR have been added to the choice of propellants. All propellant properties have been tweaked based on revised two-phase flow analysis. The value of "k" is corrected to a single value. The overall effect of these updated property values is a small reduction in predicted performance (thrust, total impulse & specific impulse) compared to SRM_2014. Motor performance up to "V" class is now supported.

This spreadsheet was created in order to predict the performance of a **Solid Rocket Motor** (SRM). Although there are many factors which make a precise prediction of actual performance difficult, it was felt that a reasonably close approximation to expected performance would be attainable, and be very useful for design purposes.