Cost Effective Return to the Moon, Advanced performance Rocket Engines*

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Abstract

Advanced performance rocket engines should be developed before returning to the Moon. The RS-68 engine is too inefficient to be used for this mission. The result will be a lesser payload delivered at greater cost. A losing proposition for the expenditure of public money.

Introduction

The administration has prematurely mandated that NASA return to the Moon.
It is premature because we do not have efficient advanced performance rocket engines necessary to perform this mission. This is not a trivial matter. The public deserves to have public funds spent in a most economical way, and in a manner which is environmentally benign. The present approach does neither.

There are reasons why we have not produced advanced performance rocket engines. We have operated under a fallacy since circa 1958. The fallacy is that fuel rich mixture ratios are somehow optimum for rocket engines. The misinformed have routinely quoted this misinformation as a reason not to develop advanced performance rocket engines. If we had developed advanced performance rocket engines, we would now be using them to power a much more efficient Space Shuttle vehicle. The more efficient rocket engines would use less fuel. This would allow a smaller, lighter weight, less expensive, external tank. A tank with a common bulkhead and smaller diameter. The smaller diameter tank would have less drag. All of these improvements would allow the Space Shuttle to carry a greater payload at lesser cost. Instead we are throwing away the public investment in the un-evolved Space Shuttle and developing an even less efficient replacement, Ares I & V vehicles, to even less efficiently return us to the Moon, and continue supplying the Space Station.

Why is the Ares vehicle less efficient? It is less efficient because Ares I uses the J-2 rocket engine, which is less efficient than the SSME/RS-25, and the Ares V uses the RS-68 rocket engine which is significantly less efficient than even the J-2X.

Specific impulse defines an efficient rocket engine. How are specific impulses for rocket engines calculated?

Specific Impulse

Specific impulse is calculated based on the general energy equation of thermodynamics.[1] The general energy equation relates the theoretical rocket exhaust gas velocity (kinetic energy) to the enthalpy of the mixture (potential energy):

$$V_e^2 = (2 J h_m g)$$

The enthalpy of a mixture of hydrogen and oxygen (steam) depends on the energy released when oxygen and hydrogen are combined, an exothermic reaction, 43 thousand British Thermal Units (BTU) per pound of hydrogen which combines. This energy is only obtained if the hydrogen combines with oxygen. No energy is obtained if there is excess hydrogen, which does not combine with oxygen. Thus the fallacy; fuel rich mixture ratios cannot be optimum because no energy is obtained from uncombined hydrogen. Since oxygen combines with hydrogen to form steam at mixture ratio of eight, the enthalpy of the mixture is 43 thousand BTU per pound of hydrogen combined, i.e.,:

$$h = 43.000\ MR / 8$$

The greatest enthalpy occurs when the mixture ratio is at the stoichiometric ratio of eight. The energy obtained must then be distributed over all the mixture:

$$h_m = h / (MR + 1).$$

Using this information, Figure 1 shows the relation between specific impulse and mixture ratio. This figure shows the efficiency which can be achieved by development of the advanced performance rocket engine, RM-8, and illustrates the in-efficiency of the RS-68 rocket in relation to the other rocket systems.

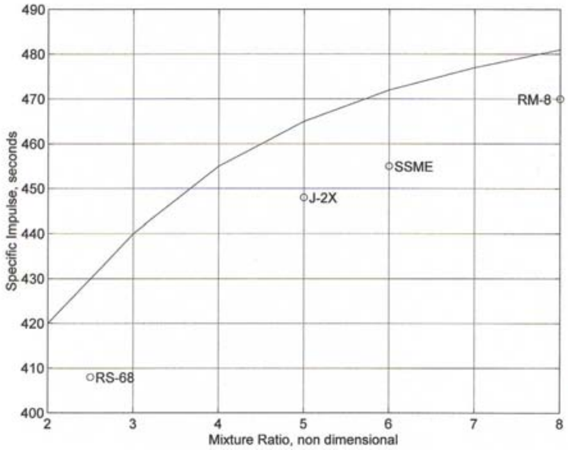

Figure 1 Impulse vs. Mixture Ratio

Table 1 shows this relation for various mixture ratios, along with the combustion chamber temperatures expected at sea level conditions. The sea level combustion temperature is critical because it is the maximum combustion chamber temperature.

Mixture Ratio	Specific Impulse, ideal, seconds	Specific Impulse, rated, seconds	Combustion Chamber Temperature, ^{O}F*
2	420	410, RS-68	2690
3	440		2760
4	455		2850
5	465	448, J-2	2980
6	470	455, SSME	3060
7	475		3140
8	481	470, RM-8	3210

*estimated combustion temperature for expansion to sea level pressures

Table 1 Combustion Chamber Temperature vs. Mixture Ratio

Development of combustion chambers which could handle the combustion chamber temperatures at sea level for mixture ratios at eight, is the research the NASA should have accomplished, but apparently has not.

Consequence of Fuel Rich Mixture Ratios

The consequence of fuel rich mixture ratios is that unused fuel is carried aloft rather than payload. As a "*rule of thumb,*" a half pound of payload may be added for every pound less fuel which is carried. Also, excess fuel requires a larger structure to carry the excess fuel. The larger vehicle has more aerodynamic drag which further reduces the amount of payload which can be carried. The larger structure is more expensive and the excess hydrogen fuel costs more. These are not trivial costs. Lithium-Aluminum alloy costs five times the cost of aluminum, but it is used because of its' strength to weight ratio which improves the mass fraction ratio, i.e., the ratio of fuel weight to structure weight. Also, a gallon of hydrogen costs 20 times the price of a gallon of gasoline[2]. The 230,000 pounds of hydrogen fuel for a Space Shuttle flight, at $75 per gallon, costs in excess of $28 million.

Table 2 shows the estimated cost of fuel, the size of the tank, and the increase or decrease in aerodynamic drag for a Space Shuttle vehicle if it were powered by any of the various engines, RS-68, J-2X, SSME, & RM-8.

Rocket Engine	Tank Volume, cubic feet	Fuel Cost, Dollars#, millions	Relative Cost of Tank	Aero. Drag Ratio
RS-68	123,000	69.0	1.55	2.4
J-2X	61,500	34.5	1.10	1.2
SSME	51,300	28.7	1	1
RM-8	38,400	21.6	0.87	0.75

Table 2 Rocket Engine Comparison*

*Referenced to Space Shuttle external tank for 3 engines. # @ $75 per gallon

Notice the Ares V vehicle will be twice as large and cost twice as much because it is currently planned to use six engines.

In addition, hydrogen is polluting in its manufacture process called "steam reforming" which converts steam and methane gas into carbon dioxide and hydrogen gas.[2] The carbon dioxide is released into the atmosphere.[2] Furthermore, the superheated excess hydrogen released into the atmosphere, from the rocket exhaust nozzle, has potential to form nitric acid, HNO_3 which is harmful to plant and animal life. This is because the atmosphere contains 20 percent oxygen, including ozone, O_3, and 80 percent nitrogen, N. Further heating of the already superheated hydrogen when it combines with ozone is likely to cause, at least, some of the nitrogen to combine.

The RS-68 rocket engine planned for use on the Ares vehicle has a specific impulse 408-414 seconds. This corresponds to a mixture ratio of about two and a half. The excess (unused) hydrogen approaches sixty nine percent. The volume required to carry a pound of hydrogen is 4.5 pounds per cubic foot of space. The vehicle, to carry this excess fuel, is exorbitantly large, has excessive aerodynamic drag, carries, therefore, a smaller payload, and costs significantly more. Lesser payload at greater cost is a losing proposition for the expenditure of public funds. What are the benefits of an advanced performance rocket engine?

Advanced Performance Rocket Engine

An advanced performance rocket engine would carry no excess fuel. The specific impulse would be about 470 seconds; a more efficient engine than either the SSME at 455 seconds or the J-2 engines at 448 seconds. The lesser fuel carried would cost less. The smaller vehicle would have less aerodynamic drag, and cost less.

The vehicle is smaller and carries less fuel, but it puts a greater payload in orbit. This is a winning proposition for the expenditure of public funds. A picture of an advanced performance rocket engine is shown in Figure 2.

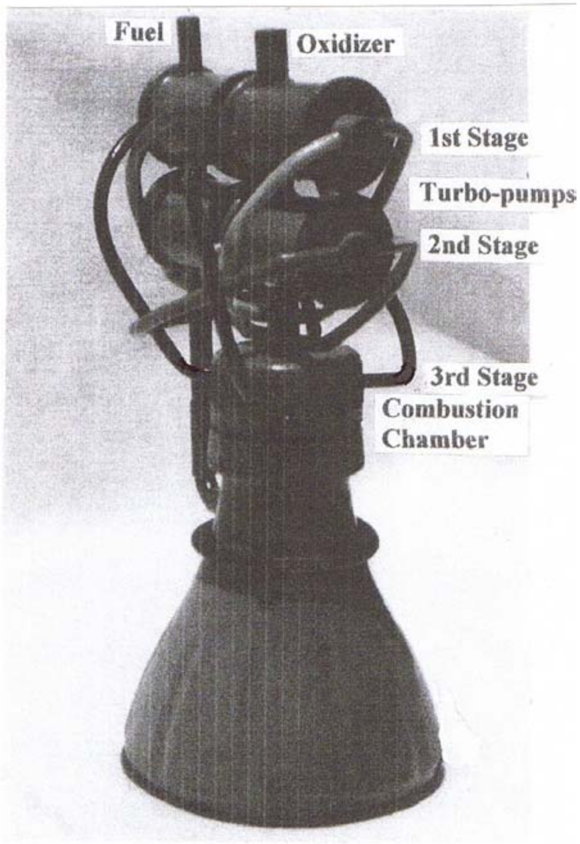

Figure 2a Advanced Performance Rocket Engine

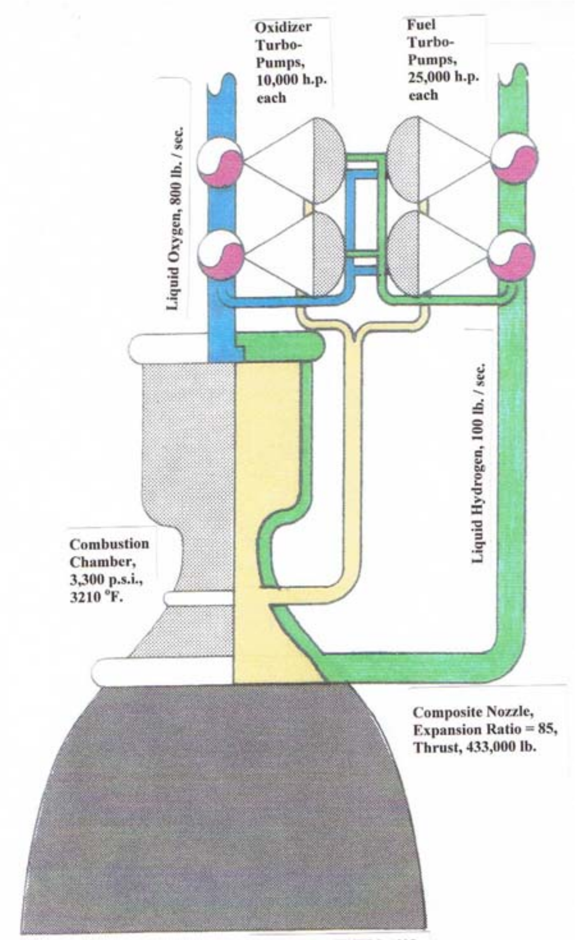

Figure 2b Schematic, Advanced Performance Rocket Engine

The engine would have two input turbine pumps, each for fuel and oxidizer. The two oxidizer pumps would be of equal 10,000 horse power, and the two fuel turbo-pumps would be of equal 25,000 horse power.

This compared with the SSME engines which have very small, 1,500 – 2,400, horse powered first stage pumps and very large, 21,000 – 62,000 horse power main pumps. The equal powered pumps for the RM-8 are a more equitable, and an easier to design and build, arrangement. A carpenter would build two equal steps between two levels, not a small step and then a large step.

Conclusion & Recommendation

The plan to use the RS-68 engine to replace the Space Shuttle will deliver lesser payload at greater cost. It is concluded that advanced performance rocket engines should be developed before returning to the Moon. Advanced performance rocket engines can be developed in about five years time if the NASA is so directed. The APRE will be more economical, and a better investment of public money.

It is recommended that Congress should direct NASA to develop advanced performance rocket engines before we return to the Moon.

In addition, the Space Shuttle vehicle is the perfect vehicle to demonstrate the advanced performance rocket engine.

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References

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