Re: Heavy Lift Design for Mining/Cargo Propulsion

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The energy applied to a propellant determines how fast it can be made to move.

E = 1/2 m V^2

The rate at which propellant is moved through the system determines the thrust

F = dm/dt * V

The determines the power of the engine

Power = 1/2 * dm/dt * V^2

The pump power is given by the dynamic pressure times mass flow rate

Pump Power = pressure *dm/dt * factor

and dynamic pressure scales with chamber velocity

Dynamic Pressure = 1/2 rho V^2

You can see that the pump power scales with the engine power. So, if you inject propellant under zero pressure (when the engine is off) you save considerable power.

In a continuous rocket these are continuous functions. In a pulse rocket, these occur in pulses, which are averaged over time. This on again off again operation lowers the thrust for a given thrust structure and adds the need to smooth the pulses with some sort of momentum transfer device.

So, why do it?

Because it reduces heat handling problems as well as pump or injector power and weight and cost.

When you pump something against a pressure, that takes power too as shown. Subtracting from the power of your engine. Even if you're shooting ions with an ion beam into a magnetic containment of other ions, speeding those ions up to the speed needed takes energy. Its the same process − and the same energetic relations. I call them all pumps, even if they look more like an ion gun at the back of a CRT display and not a typical centrifugal turbopump.

So, when you get really really high pressures you get really really high pump energy − and that means costly, heavy, complex pumps that do not scale well with increasing performance. Which means at higher energies, it makes sense to dispense with pumps altogether, and put up with heavy thrust structures and momentum transfer structures − while you're working on improved continuous or high frequency versions.

http://en.wikipedia.org/wiki/Pulse_detonation_engine
http://en.wikipedia.org/wiki/Nuclear_pulse_propulsion
http://en.wikipedia.org/wiki/Project_Orion_%28nuclear_propulsion%29

This derives from the dynamic pressure of a highly energetic gas or plasma.

Pulse rocket: (no pump energy)

TNT : 1 ton per ton
4.184 GJ
2.9 km/sec

U235: 3 million tons per ton
12,052,000 GJ
5,022.9 km/sec

Li6D: 60 million tons per ton
251,040,000 GJ
22,463.3 km/sec

Continuous Rocket −
dynamic pressure with plasma density equal to 1 kg/m3

Solid: 2.9 km/sec
4.2 megapascals

U235: 5,022.9 km/sec
12.6 million megapascals

Li6D: 22,464.4 km/sec
252.3 million megapascals

By the way, we can see how much easier it is to contain a useful plasma of uranium or plutonium than it is to contain a useful plasma of fusor material...

Now, to get a ton of thrust from each engine requires

F = dm/dt * V −−−> dm/dt = 9,820 / V

Solid: 3.38 kg/sec
U235: 1.96 grams/sec
Li6D: 0.44 grams/sec

The power of the engine is given by the mass flow rate times gas velocity. So, for our engine that produces one metric ton of thrust we have

P = 1/2 * dm/dt * V^2

Solid: 14.2 megawatts.
U235: 24.7 gigawatts
Li6D: 111.0 gigawatts

In a continuous engine we have to overcome the dynamic pressure for each kg we inject pump or otherwise insert in our engine. For the solid, to make things comparable, we imagine feeding a rod of solid material into the combustion chamber at the burn rate required. Its easy to see that driving this rod forward requires power − even though its not a turbopump it is a sort of solid pump. Similarly, a magnetic containment for U235 that 'leaks' a stream of actinide series products needs new U235 this is easily added by shooting small pellets into the containment with enough speed to overcome the pressure to arrive inside the chamber. Kicking the pellets up to speed requires energy, typically 1% of the energy produced by the engine.

Solid: 142 kilowatts − 'pump' power
U235: 247 megawatts − 'pump' power
Li6D: 1.11 gigawatts −− 'pump' power

Now a 1.11 gigawatt pump is a pretty impressive piece of engineering. The circulating power in a fusion rocket producing just one ton of thrust requires as much energy as a full scale nuclear power plant − which typically weighs far more than a ton.

So, to get reasonable thrust to weights at these high performances with materials and techniques we know how to use today − a pulsed system is recommended. This doesn't mean you don't continue research on continuous systems, but you don't wait on continuous systems either.

The thrust to weight of most chemical engines is about 70 pounds of thrust for each pound of engine. The thrust to weight of a nuclear light bulb engine, or a fusion variation of it, is less than 1 to 1 − due to the weight and power levels needed for the pumps and heat handling.

Pulsed systems don't have much injector or pump energy. That's because they're not working against any chamber pressure. They inject new pulse units when the engine has cleared of the last pulse − or nearly so − and so, these injector systems can be quite modest in their power requirements.

Heat transfer is another problem with high performance engines. Temperature is a measure of energy. The velocity of a plasma which is proportoinal to the exhaust speed of the engine is proportional to the square root of the temp

http://en.wikipedia.org/wiki/Thermodynamic_temperature

This doesn't change. A continuous engine has to handle heat diffusing through it

http://en.wikipedia.org/wiki/Heat_conduction

An intermittent engine can transfer momentum from a hot plasma to a thrust structure (either magnetic, electrostatic or physical) before the plasma cools − or transfers a lot of energy out of the plasma (either by radiation or conduction) to other surfaces. If surfaces get hot the intermittent engine can slow pulse rate to keep them cool. A very robust system.

As I've mentioned elsewhere, I am doing a detailed engineering and numerical analysis for a fission free Li6D with D+T trigger − and HF frangible laser initiator − using a 'magnetic blanket' design with multiple−detonation chambers, all venting to a common magnetic exhaust. The resulting spacecraft is a spherical design with a super magnet just below the equator, and a plug sticking out of the south pole of the ball. There are 8 detonation channels feeding into the common thrust chamber. Eight chambers and a single magnetic nozzle to collimate the resulting plasma stream smooths out thrust without excessive mass dedicated to momentum transfer. The rotating magnetic field created by the plasma containment field changes, conserves containment energy, and tapping the current flow between containment fields charging and discharging, provides a simple source of AC power while the engine is running.

The smallest version is 12 m in diameter and produces 1,100 metric tons of thrust, masses 165 metric tons empty, carries 200 metric tons of propellant, and up to 200 metric tons of payload. I modeled this design on the Aires 1b moon shuttle, though the propulsion system is far superior than that imagined for the movie 2001.

Exhaust speed exceeds 20,000 km/sec. At one gee thrust − generating 565 metric tons of thrust (5.55 MN)− the engine consumes 0.28 kg/sec of propellant. Thrust is adjusted by adjusting pulse rate. Top speed is 8,738 km/sec − divide by 4 to obtain a four boost distance at constant gee. (2,184.6 km/sec per boost) This is maintained by injecting 4.6 gram pulse units into the engine at a rate of 60 per second − with each chamber cleared in less than 125 milliseconds. 450 pulse units are injected per minute into each chamber − with a 1/60th second lag between adjacent chambers.

Thrust at one gee to reach the speed limit imposed by the propellant takes 2.57 days or 61.7 hours − that distance is 242 million km per leg 484 million km total distance.

This is a velocity limited system, so the relations between distance and gee force are pretty simple.

Distances shorter than 484 million km distant, mean shorter boost times, and the ship has legs for that. The Earth Moon system for example has two planets separated by 0.38 million km − and this ship takes less than 3.5 hours to jump from one body to the other at 1 gee. The ship can carry out 35 flights between these bodies before refueling.

Mars varies from 58 million km distant to 378 million km distant. So, again, the system described here can tool around the inner solar system at one gee no problem.

The dwarf planet Ceres varies in distance from Earth from 264.7 million km to 564.7 million km. So, we're going beyond the range of the vehicle at one gee.

No problem, lowering gee level in flight reduces propellant consumption, and increases range, at the cost of lengthening trip time.

The Jovian system for example varies in distance from the Earth in the range 628.5 million km to 928.5 million km. Even so, the constant gee system can get to Jupiter by reducing acceleration.

Say the acceleration is cut in half − that means it takes twice as long to achieve a given velocity maximum at half way to have enough fuel to return.

V = a * t = 2,184,600 m/sec = 4.91 m/sec/sec * t

t = 444,928.7 seconds = 5.15 days

this increases distance to reach this velocity

D = 1/2 * a * t^2
= 1/2 * 4.91 m/s/s * 444,928.7 ^ 2
= 485,995,600,545.4 meters
= 486 million km

Double this distance is 972 million km − which reaches Jupiter. Bring provisions for 22 days plus however long you're going to stay in the

Jovian system.

What about a visit using this ship to Eris and its moon Dysmonia?
(although I like planet Xena − aka planet X)

It varies a distance from 14,355 million kilometers to 14,655 million kilometers from Earth over the course of a year.

http://en.wikipedia.org/wiki/Eris_%28dwarf_planet%29
http://en.wikipedia.org/wiki/Kuiper_belt_objects

Can this ship make it there?

Sure! At lower gees. Lets say on a given day the half−way point between Earth and Eris is 7,250 million km. Our top speed is still 2,184.6 km/sec per boost. So, we can figure out what are gee force has to be to give us that distance

D = v^2 / (2a) −−>
a = V^2 / (2D)
= (2,184,600)^2 / (2*7,250,000,000,000)
= 0.329 m/s/s

About 1/30th gee...

It will take 76.85 days to reach the half way point at this acceleration, and another 76.85 days to arrive at Eris. It will take 153.7 days to return − about 10 months round trip. Less time than it takes to fly to Mars and back with a chemical rocket system.

With a crew of 16 − 10 passengers in five staterooms − and 4 pilots − with 2 stewards − sharing flight quarters up front − and a main deck between the two − this flight will take 32 tons of consumables − 200 tons of propellant − and can carry 18 tons of personal effects − and 150 tons of scientific gear.

Again, a nuclear pulse fusion rocket built along the lines described − even as small at a 12 m diameter ball (40 ft) carrying between 16 and 180 people, or up to 200 tons of cargo − would be what both Heinlein and Clarke have described as the DC−3 of space!

A single ship tasked to Luna would transfer 400 tons of cargo and 180 people EVERY DAY to the moon. A single ship tasked to Mars would transfer 200 tons of cargo and 90 people EVERY WEEK to Mars. A single ship tasked to explore the outer solar system could do a significant exploration EVERY YEAR OR LESS − to any object we can see from Earth in our planetary system.

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