Spaceflight Challenges for proposed Crew Exploration Vehicle and next generation spacecraft

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Abstract

This brief article demonstrates some of the fundamental problems regarding present spaceflight in general. It is also demonstrated that a single space vehicle capable of flight to multiple destinations would require a major paradigm shift in current engineering design parameters, possibly even beyond the capabilities of present science.

1 Introduction

During January 2004, U.S. President George W. Bush introduced a new vision for the future direction of the National Aeronautics and Space Adminstration (NASA) in regards to human spaceflight [1]. The presidential space adminstration package request the development of an yet unspecified spacecraft known as the Crew Exploration Vehicle (CEV) in order to facilitate the human exploration of the Moon and possibly Mars, as well as to pave the way for further interplanetary explorations. The best description of the CEV in fact comes from unofficial sources, the Wikipedia website defines the CEV as follows [2]: "The CEV will launch on an expendable launch system and carry crew to low Earth orbit, the moon, Mars, and other destinations." Presently there are two conceptually proposed CEVs put fourth by the *Boeing* [3] and *Lockheed-Martin* [4] aerospace corporations. The *Lockheed-Martin* proposal is nothing more than an orbital space plane intended to replace the Space Shuttle for flights to the International Space Station (ISS) and possibly other future outpost, and as such it should be considered a transportation vehicle and not an exploration vehicle. The *Boeing* proposal on the other hand demonstrates the possibility for the existence of CEV as required by the Wikipedia definition of a CEV, although its interchangeable design parameters would be more costly than a single vehicle distend for one route (which is required by the limitation of present rocket science and not *Boeing*!).

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What should be made immediately clear to the general public is that the engineering requirements of a multipurpose long term space vehicle such as the CEV is perhaps far more complex than what many people are aware, and from a physical perspective may be highly questionable as realistic spacecraft design useable for human spaceflight. There are a number of limiting factors well agreed upon in the aerospace literature that puts strict limitations onto the mass of a spacecraft, their speed, life support systems, propellent load, etc. The purpose of this article is to show the shear scale of the requirements necessary for interplanetary travel, and what this translates to on recognizable human scales.

For those who push for the reality of peopled space exploration, only a few of them see the requirements of travel durations as a problem for those engaging interplanetary flight. Travel durations however should be taken as a real concern as it is a large physical and engineering problem that must be conquered to achieve spaceflight, but it often glossed over for the consumption of the general public. To illustrate the problem at hand, it is widely known that with conventional liquid propellent a trip to the Moon can be made within a few days, and a trip to Mars can be accomplished within a two year period. However the hidden looming problem behind the CEV is that arriving to a preselected destination is only half the battle of spaceflight, the how part often gets over looked. When looking at rocket science in general the existence of a spacecraft capable of both lunar and martian exploration is neither ergonomical nor economically feasible without the invention of a new type of propulsion system outside of rocketry. From the stand point of Newtonian physics a larger spacecraft would be required to travel to Mars rather than the Moon. Further Newton's second law of motion requires that spacecraft travelling at increasing distances from their point of origin would require greater loads to support crew members, to protect crews from space hazards, and to return home which would also exponentially increase the amount of propellent required to transverse such interplanetary destinations.

To illustrate some of the problems and challenges with rocket propulsion this article discusses the performance of the well known Saturn V rocket which provided the means for humankind to set foot on the first celestial body outside of the Earth. It is also argued that the only way a lunar-martian CEV can even be entertained is by the development of a Field Drive Propulsion (FDP) system which could allow for persistent periods of constant acceleration as well to open up the prospects of shorter spaceflight durations. In general it is concluded that peopled exploration of the interplanetary space environment would require a tremendous investment in space infrastructure on the national level, or to simply rethink how interplanetary travel can be accomplished.

2 The Moon and the Saturn V Rocket

In this work System International (SI) units used while the older English units will only be given sporadically in prentices, or in normal text when the original data sources used English units. The purpose of this section is to demonstrate to the reader the scale of the problems associated with rocket propulsion for interplanetary travel. We do so by first reexamining a well known trip to Earth's closest celestial body located at an average distance of $3.84 \times 10^5 km$ ($6.22{\times}10^5$ mi) from the Earth, as performed by NASA's Apollo 11 spacecraft in 1969.

The engineering specifications for the third and final stage of the Apollo spacecraft Saturn V rocket, for the single J-2 engine was that it could burn a liquid Hydrogen-Oxygen fuel for a period of 480 seconds with a maximum thrust of 225,000 lbs, which had a store of 228,000 lbs of propellent [5]. One pound of thrust is equal to $1\text{lb}_{thrust} = (0.45kg \cdot 9.8m/s^2) = 4.45N$, so that in SI units the Saturn V was capable of producing 102,600 N of thrusting force.

The first physics issue that must be encountered to launch a rocket is to over come the downward pull of Earth's gravity. To over come the force of Earth's gravity a rocket would have to accelerate beyond $1g = 9.8m/s^2$ ($32ft/s^2$), which would require a rocket to accelerate beyond 1g until an orbital velocity can be achieved. The velocity required to maintain an orbital velocity is given in terms of a mass of a body and the distance from it, expressed as

$$v = \sqrt{\frac{GM_\oplus}{r}} \tag{1}$$

which at an altitude of 292 km (150 mi) gives a velocity of 27,359 km/h (17,000 mi/h). The afore mentioned orbital velocity was what the purpose behind the lower stages (3 and 2) of the Saturn V. Which required over half the mass of the Apollo spacecraft to be jettisoned just to reach Low Earth Orbit.

The next challenge that was overcome to arrive in Lunar Orbit was leaving Earth Orbit which requires an orbital escape velocity of

$$v_{esc} = \sqrt{\frac{2GM_\oplus}{r_\oplus}} = 11.18km/s. \tag{2}$$

Since we now know the escape velocity for Earth we must factor in an acceleration of the second burn of the stage 1 assembly, which lasted 240 seconds. The acceleration required to leave Earth Orbit from rest is

$$a_{roc} = \frac{v_{esc}}{240s} = 46.58m/s^2 \tag{3}$$

or on the order of 4.75 g accelerations. Now one must calculate how much propellent must have be expelled a second if such an acceleration was possible

$$m_{pro}\frac{102,600N}{g \cdot 46.58m/s^2} = 220.70kg \tag{4}$$

in that case then over the 240 second burn period 140,360 kg should have been expelled. Since the liquid propellent carried by the Saturn V was 227,955 kg (228,000 lbs), it indicates that about half of its fuel was expelled on its second burn. In loose terms the acceleration of a chemically propelled rocket is given in terms of Newton's Second Law of motion where $a = F/m$, that is the acceleration and rate of travel for a rocket is confined by the limited fuel it contains. There are also further limitations on a rocket's rate of acceleration, such as the amount of kinetic energy required to regulate thrust, which happens to be directly tied to the chemical bonds of the propellent in question.

From Equations 3 and 4, the amount of work done by such an acceleration is

$$W_{roc} = m_{pro}a_{roc}1s \cdot 1.118 \times 10^4 m = 11.49 \times 10^7 j \cdot s \tag{5}$$

and where the kinetic energy of the thrust is

$$KE_{roc} = \frac{1}{2}m_{pro}v_{esc}^2 = 13.79 \times 10^9 j. \tag{6}$$

To the observant what should have been noticed missing in equation 5 in respect to equation 6, was that the potential energy shouldn't have been less then kinetic energy as $mv^2/2 = mgh$. This is because equation 5 is given in terms of impulse force so that total work impulse over the engine burn is $W_{tot} = W_{roc} \cdot 240s = 27.58 \times 10^9 j \cdot s$. In short it is the gravitational force which determines at what accelerations and paths a spacecraft must take to its destination, and chemical propellent restrains what these constraints can be.

Perhaps the most import equation regarding rocket flight is simply known as the rocket equation

$$\frac{m_i}{m_f} = e^{\Delta v_{roc}/v_{exh}} \tag{7}$$

Where the power associated with expelled thrust is often given in terms of specific impulse

$$I_{spc} = \frac{v_{exh}}{g}. \tag{8}$$

From which it is seen that specific impulse acts to translate differences between a spacecraft's momentum and its exhaust which yields a specific acceleration rate for the engine in question. More specifically what is shown is that a change in mass from spent chemical fuel is responsible for differences in the original momentum of a spacecraft. When the spent chemical propellent is measured in units of a second (for impulse force) and compared to another source of acceleration (such as a gravitational field), one can measure forward momentum in terms of gravitational acceleration, this terminology for acceleration is simply what layman term as g forces. Simply stated the acceleration and motion of a rocket propelled spacecraft is strictly limited to how much of its mass it can change through ejection. Simple physics clearly demonstrates that a craft designed for Earth orbit is not reasonable for lunar or nor for possible martian spaceflights. The reason the Saturn V even got to the Moon was the fact that it was designed to, the reason the gemini spacecraft remained in Earth Orbit was because they were designed to, present technology simply does exist to allow a single all purpose spaceflight vehicle (unless you happen to have a negative mass spacecraft), if there were such a vehicle it would require side stepping Newton's cherished laws of physics!

2.1 lunar path

Noting the distance between the Moon and Earth being $3.84 \times 10^5 km$, one can do a linear calculation of the time it would take for that trip. For the acceleration rate of the Saturn V there the final burn velocity is given by 11.18 km/s, so the travel time to reach the Moon would be

$$\frac{3.84 \times 10^5\, km}{11.18\, km/s} = 34347.04 s = 9.54\, hr \tag{9}$$

so one may be mistakenly led to believe that a trip to Moon onboard a Saturn V would only take 10 hours, sorry this does not prove that the lunar missions were hoaxed as claimed by a small minority (the math in fact proves that the Saturn V did what historical records say it did!), so why did the Apollo 11 spacecraft take over three days to reach the Moon? The answer is again the gravitational force, remember the main stages of the Saturn V were used to get to Earth Orbit and not to travel to the Moon so only an initial 27,359 km/h velocity was required, and the 11.18 km/s was only needed to leave Earth Orbit. The Apollo spacecraft also had to fire retro rockets at a latter time to slow their velocity to be captured by the Moon's gravitational influence which is much weaker than the Earth's.

The Saturn V also would encounter another rather interesting problem on route to the Moon as its acceleration toward earth would decrease. And the Moon's decreased gravity also introduces a slower acceleration rate, the problem is that from the rocket's point of view its velocity begins to change

$$v_{roc} = I_{spc} \int_{g_{ear}}^{g_{lun}} r dt \tag{10}$$

were going to stop here as now we are getting into calculus and the very high complexity of rocket propulsion. Needless to say a spacecraft must have an available store of propellent to at the very least make gravitational course corrections in order to arrive at a desired location (which puts further constraints on the design of a spacecraft). The problem of rocket propelled spaceflight can be further illustrated by considering the fact that celestial bodies are always in motion, so further course corrections are required to take into account the motion of these bodies.

3 distance magnitudes

Mars is located on the average a distance of $7.83 \times 10^7 km$ (12.68 $\times 10^5$ mi) from the Earth, or about 200 times as distant as the Moon. From that simple analogy it is evident that an impulse similar to a Saturn V rocket would take about 90 days to reach martian orbit. What often goes unnoticed to the untrained is the scale of these distances, most often they are given in relative terms such as astronomical units ($1Au = 1.495 \times 10^8 km$), however for an engineer relative numbers are useless as you have to use a real amount of fuel to get from point

A to point B. To put into more human understandable units, take the speed of a vehicle along a typical US highway at 89 km/h (55 mi/h), at that speed it would take 4,319 hrs. (or roughly $6\frac{1}{2}$ months of travel) to arrive in lunar orbit. To reach Mars travelling at typical highway speeds would require a staggering 107 year trip (even travelling at that speed would require 11 days to make a trip around the globe), needless to say its a long ways from home should something go wrong.

What is rather misleading from the above is that a vehicle capable of lunar travel seems also to be capable of martian travel, it would just take a longer time. From a physics perspective this is perfectly acceptable, until you consider the implications of a crewed vehicle such as the proposed CEV. One would have to include life support systems to help keep a crew alive, food, atmosphere, liquid, power, etc. which would increase the mass of a craft, requiring more propellent and stronger impulse forces to arrive at the destination in question, and this is not even including the additional resources required to get back home! The problem with a space vehicle that is designed to explore the many frontiers of outer space (similar in principle to an aircraft), is that it can not explore more than on area with the methodologies possible within the current field of rocket science. With present rocket science one must rearrange the design of such a craft for each trip it makes, as demonstrated by *Boeing's* proposal [3].

4 the problem of acceleration

A wrong way to attempt to solve the problems associated with a spacecraft transversing multiple destinations, is to increase its rate of acceleration. By increasing acceleration only a short impulse is required for travel to close destinations, while slightly longer impulses for longer destinations. To break things down simpler increasing the reaction rates of a propellent would act to increase the rate of change in momentum of the system, so one would be led to believe that less fuel is being burnt. However increasing acceleration simply acts to increase the rate at which mass is expelled, that is the amount of fuel needed to reach a certain velocity remains a constant for the space vehicle in question as seen by equation 7. By increasing the acceleration rate of the propellent in question only reduces the travel time to the destination desired, this in itself could be a good thing as it would reduce a crafts mass as less life support systems would be required. In fact that is the major motivation behind the use of nuclear propelled rocket engines for martian trips, that is to reduce the travel time and the spacecraft mass in question. In short the performance of a spacecraft to explore the space environment is strictly limited to the amount of propellent it carries along with its rates of impulse and when using Newtonian Mechanics there is no way around this problem.

5 hypothetical requirements for a usable CEV

The only applicable method of altering acceleration rates of spacecraft without a massive loss of propellent is though theoretical constructs of FDP. A simple example of what can be done through FDP is that it would be possible to have a spacecraft capable of constant acceleration through its entire journey, as such its constant velocity increase would greatly reduce travel times. A spacecraft that accelerated at one Earth value for g, on its way to Mars would only take ten days and the crew would not have to deal with the effects of weightless while in motion, none the less while the concept is intriguing it is well beyond the bounds of modern rocket science.

At present the best description of a FDP method might be taken as the following illustrative example. Imagine fluidic metallic motion generating a strong magnetic field to the rear of a spacecraft (similar in principle to how the Earth derives its magnetic field), and this field pushes against an external field to the craft. This in principle could be achieved by means of an artificial floating metallic structure being electrically attracted to the spacecraft, but having the magnetic poles diametrically aligned with the spacecraft as to magnetically propulse the spacecraft in question. At this stage chemical propellent becomes irrelevant to the design of the spacecraft itself, thus maintaining the field drive system would be the primary function of the spacecraft, as such the performance of the spacecraft increases exponentially.

The quintessential problem with the development of a CEV is that according to present technology such a spacecraft would be severely restricted by the amount of fuel it carries and its reaction process. Thus with present aerospace technology a CEV would be limited to exploration on a one flight per destination basis, expanded exploration is simply not feasible with standard reactionary technologies. However from a purely theoretical perspective a CEV should be possible providing that a method of interplanetary travel could be engineered based on present theoretical FDP systems. The relevant question however is are we capable of performing such advanced propulsion feats today, the short answer is no, there are great number challenges to be overcome for next generation space exploration vehicles. However a usable CEV is possible in theory, it would just require major paradigm changes in both engineering and the incorporation of 21st Century physical theories into are well behaved and limited 20th Century technologies. What is more troublesome is that the CEV at present doesn't seem capable of Crew Exploration as seen from current conceptual aerospace designs [3], [4]. As such while Boeing's CEV is possible with present technology with interlocking design parameters [3], it would be far more costly to maintain than a one purpose vehicle. In short presently a CEV can only be entertained with large amounts of funding required to arrive at a selected new destination and to support the design parameters of an interchangeable CEV. So the existence of an operational CEV vehicle can be accomplished one of two ways, a) present technology with exponential funding, or b) by funding research into incorporating 21st century science into our 20th Century technology, the route to be taken has yet to be decided but caution is merited.

References

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