LIMITED BY COST: THE CASE AGAINST HUMANS IN THE SCIENTIFIC EXPLORATION OF SPACE

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Abstract. Human space flight represents a heady mix of bravery and drama which can be inspirational to nations and to humankind but at huge economic cost. Due to the current high launch costs only a handful of people have ventured beyond low Earth orbit and walked on the Moon, propelled by aspirations related more to the Cold War than to science. Problems with reusable launch vehicle development mean that severe launch cost limitations will exist for some time. Meanwhile, cheaper robotic probes have visited all the planets except Pluto, flown by comets, landed on Mars, Venus and an asteroid, have probed Jupiter's atmosphere and studied the Universe beyond our own solar system with telescopes. Using these data we are determining mankind's place in the Universe. Public interest in the historic Eros landing eclipsed a simultaneous space walk at the fledgling International Space Station and the Mars Pathfinder landing generated hundreds of millions of website hits in a few days. Given the fact that hundreds of Mars missions could be flown for the still-escalating cost of the International Space Station, the unsuitability of human bodies for deep space exploration, and the advances in 3-d and virtual reality techniques, we discuss whether human exploration needs a place in a realistic, useful and inspirational space programme.

Keywords: Unmanned spacecraft, manned spacecraft, solar system exploration, International Space Station, Moon, Mars

1. Introduction

When Yuri Gagarin became the first human in space 40 years ago the reason for sending him was clear – national pride. The world was gripped by a Cold War and the Russians had a huge lead in space exploration. They had launched the first satellite and the first dog into Earth orbit and the first probes towards the Moon. It was natural to claim another first, involving incredible bravery and drama, with the West looking on helplessly.

Then Kennedy made his bold pledge to land Americans on the Moon before the end of the 1960s. The US achieved this spectacularly and in a 42-month period sent 12 astronauts to the Moon's surface propelled by Cold War politics rather than science. The budgets were huge at some 5% of the US Federal budget. That type of money has not been available since and, realistically, is unlikely again. Apollo was ahead of its time but science took a back seat. Human space exploration has been limited and dangerous but still hugely expensive since.

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Now, it costs about $10,000 per kilogram to put anything into space on a reusable rocket (e.g., Ariane). For the space shuttle the cost is nearer to $16,000 per kilogram according to NASA cost and cargo statistics. Even the lightest person needs heavy life support equipment and heavy radiation shielding for the region beyond Earth's protective magnetic envelope. No wonder only a few hundred people have been to low Earth orbit and a handful of people have been to the Moon. Human spaceflight represents a heady mix of bravery and drama which can be inspirational to nations and humankind but at huge economic cost and low efficiency in exploration.

In contrast to the meagre explorations by people, unmanned probes have visited all the planets except Pluto, telescopes have scanned the Universe at wavelengths that cannot penetrate our atmosphere, and probes have landed on the Moon, Mars, Venus and an asteroid, and another penetrated Jupiter's atmosphere (see Table I). Unmanned probes, the real tools of exploration, are helping us understand our place in the Universe (see, for example, Lewis (1997) and Beatty et al. (1999)) and this should continue apace. There are many other interesting and exciting targets to explore within our solar system and beyond. Humankind needs to explore the diversity of different planetary environments and perform astronomical observations not possible from the ground in a methodical, scientific space programme. It is not sufficient to tag along with a manned space flight programme with targets limited by the enormous cost.

2. National Pride

So why do we send people into space now the Cold War has ended? National pride still plays a role as the imminent entry of China into the manned space race shows. Tears in Russian eyes recently accompanied the demise of Mir. Russia now plays a pivotal role in the International Space Station. They supply reliable rocket launches, the trusty Progress supply ships and Soyuz crew delivery and lifeboat vehicles. Russian experience and expertise are crucial to this enormous international effort. But to Russians it's not the same as an independent manned presence in space.

The International Space Station started as a US-only $8 billion cold war project to rival Mir. Over the years its political justification has changed from the hawkish pride of nations working on their own to a vehicle for international collaboration. Collaboration is a laudable aim – but the cost has risen during 15 years of redesigns, refocusing and reinvention. And there are less nations collaborating in the ISS than in the unmanned Cassini–Huygens mission to Saturn and Titan. The total cost of the ISS now, according to US House of Representatives reports, is around $100 billion including launches, operations and participation from the USA, Russia, ESA, Japan, Canada, Brazil and others. About 600 unmanned missions to Mars could be built for this cost.

TABLE I

In situ solar system exploration. Scientific mission stages: 1 = initial reconnaissance by flyby, 2 = detailed study by orbiter, 3 = direct measurement of atmosphere or surface by entry probe, 4 = sample return

Object	Past missions	Present stage	Future missions (approved)
Mercury	Mariner 10	1	Messenger, BepiColombo
Venus	Mariner, Pioneer Venus, Venera, Vega, Magellan	3	Venus (Japan) Venus Express (ESA)?
Earth	Many	N/a	Many
Moon	Luna, Ranger, Surveyor, Zond, Apollo, Clementine, Lunar Prospector	4	Lunar-A, Selene, SMART-1
Mars	Mars, Mariner, Viking, Phobos, Pathfinder, Global Surveyor	3	Mars Odyssey 01, Nozomi, Mars Express and Beagle2 03, Mars Exploration Rovers 03, Mars Reconnaisance Orbiter 05
Jupiter	Pioneer, Voyager, Galileo, Ulysses, Cassini	3	Europa Orbiter?
Saturn	Pioneer, Voyager	1	Cassini-Huygens
Uranus	Voyager	1	–
Neptune	Voyager	1	–
Pluto	–	0	Pluto-Kuiper Mission?
Asteroids	Galileo, DS1, NEAR	2	Muses-C
Comets	ICE, Sakigake, Suisei, VEGA, Giotto	1	DS1, Stardust, Rosetta, CONTOUR, Deep Impact
Sun + i/p medium	WIND, ACE, ISEE, AMPTE SMM, Yohkoh, SOHO, TRACE, IMAGE, Cluster	N/a	Genesis, Solar-B, STEREO, Solar Orbiter, Solar Sentinels, Solar Dynamics Observatory, Radiation Belt Mappers, Magnetospheric Multi Scale, Constellation?

3. Why Humans in Space?

So what are supporters' other arguments for ISS and manned space flight, and are they valid? First, a large international project like ISS needs good coordination, management and engineering. Second, the idea of nations working together in space is an inspirational goal. These points have already been important in countless unmanned programmes and indeed are the very raison d'être for the European

Space Agency. Third, we might want to use a space station as a stepping-stone for human exploration of the Moon and planets. But, realistically, the political will and economic means to do this are lacking.

The fourth reason from ISS supporters is that some useful science will emerge. This is controversial because most ISS science is only useful if we are really going to embark on long duration space travel. Materials processing, crystal growth and micro-gravity research were all promised as the benefits well before Mir started 15 years ago. In 2001 we are still awaiting those benefits. Of course, something useful may emerge but use of ISS is neither cost effective nor necessary. Nor is the ISS exploration as it involves sending scores more people just a few hundred kilometres above our heads. Related to this is the desirable but unrealistic idea that science could tag along as part of a big manned planetary exploration programme, and that involving people on the spot improves decision making capability. These are counterbalanced by cost, logistics and the likelihood of human error and such a programme is unrealistic at present.

Manned space flight supporters believe that science can be advanced by manned missions, even though science is not the driver. In an expensive manned programme, such as Apollo, some important science can certainly be achieved (see Lewis, 1997, Beatty et al., 1999, and references therein). During the Apollo manned Lunar missions, 382 kg of lunar material was brought back to Earth for detailed study, from a variety of landing sites but biased towards the lunar equator for logistical reasons. In addition, about 300g of regolith were returned to Earth by unmanned Soviet spacecraft. Proponents of unmanned sample return missions at present point out that all regolith samples, however small, contain a well-mixed set of samples of many rock types on a planetary body such as the Moon or Mars, due to regolith transport. The larger rocks brought back by Apollo contain more information about specific locations but the collection points were a biased set of points on the surface. All of these samples have unquestionably advanced lunar science, as would unmanned or manned sample return missions to other bodies. The point here is that with cheaper unmanned missions one can cover a wider range of sites on a particular body, and indeed sample more diverse locations on different bodies, than would be available from manned missions. For example, a manned return to the Moon with all the encumbrances of heavy spacecraft and heavy life support systems would provide some science but with much worse value for money than unmanned missions. Many unmanned missions to different bodies allows much more complete science.

A fifth cited reason for human space flight is that it draws youngsters into science and engineering. Again the aim is laudable but the attraction for a youngster is associated with bravery and high drama, and with what it is like to be away from our planet, rather than the questionable reasons for doing it. We can share the thrill of unmanned exploration of different environments with similar effect.

4. Why No Humans in Space?

There are at least three powerful arguments against manned space flight. The first showstopper is the enormous cost. Until launch costs can be reduced by one or two orders of magnitude it is simply makes no economic sense to consider serious space travel by humans. This is reflected in the poor performance of manned space flight for exploration so far. Problems with the technology needed for cheap, re-usable space transport keeps mankind grounded for the foreseeable future. A return to the Moon or new exploration of Mars would cost at least as much as the hundreds of billions of dollars Apollo cost Americans: surely unpalatable at present.

The second potential showstopper is that our bodies are unsuitable for prolonged space exploration. Work on Mir has shown that with exercise the tendency for bone thinning can be ameliorated. But the worst problem is radiation. During the 9 month each way trip to Mars, and on the surface of Mars or the Moon, there is no magnetic protection from the solar radiation storms and cosmic rays. To protect against these a thick walled spacecraft or ground shelter would be needed, increasing the launch mass and cost again. However brave the explorers they should not be exposed to radiation which would be fatal sooner or later.

The third argument is that, given the improvements in computer technology and virtual reality techniques, why do we need to go at all? Humankind's natural need for exploration can be met by an imaginative and exciting programme of robotic exploration which can reach more diverse locations, make more measurements and are much more versatile than manned missions will ever be.

5. Conclusion

The balance of all the arguments leads us to keep our feet on the ground and make better use of the money. We need to explore the inner and outer planets, their moons and primitive solar system bodies. Table I illustrates how much exploration there is to do even within our own solar system. In addition we need to look for solar systems around other stars and attack the problems of astrophysics and cosmology. We need to do these using unmanned spacecraft. We do not need to send humans for the sake of it. We can have a wonderfully realistic, useful and inspirational space programme without humans.

Clearly at present the most effective exploration, in both scientific and cost terms, of the solar system and the Universe must use unmanned robotic probes. These should be used for serious scientific exploration beyond low Earth orbit until much cheaper access to space is possible. If that is ever achieved it is conceivable that, in the distant future, we may have the need, will and means to explore further in person. The driver then would not be the Cold War or indeed science. Ultimately it may be the survival of the human race.

References

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Discussion

Mr. William Marshall (University of Oxford): You spoke about the reasons for manned space exploration, including national pride, international collaboration, etc., but I think you overlooked the most important two points: (1) technological spin-offs, and the fact that these are driven by the most exciting missions (e.g., the microprocessor during the Apollo era); and (2) the fact that one day humans may have to leave Earth for safety reasons (i.e., getting all our eggs out of one basket). The latter is the most important reason, and transcends the issue of cost, which is your major argument against human spaceflight, because if we are not alive then we can't do any science!

Dr. Coates: Well, of course you do need to develop a lot of stuff to do manned spaceflight, and certainly there would be spin-offs – I can't argue with that at all. Whether we need to escape or not I think is another question beyond the scope of this symposium. Nevertheless, it is an important one, and maybe there will be a situation where we will need to escape and the technology will need to be developed, but fortunately we are not in that position at the moment.

Professor Mark Bailey (Armagh Observatory): In fact, the cost argument is not overwhelming. The actuarial cost of impacts for the UK alone is more than 100 million pounds per year; and is in fact very much greater than this figure (i.e., it is unbounded). Recognizing that in the long term humans will have to leave this planet in order to survive, surely cost is not the major problem?

Dr. Coates: Perhaps we need to start thinking about this in the long term, yes, but for the moment I don't think the arguments are there.

Dr. Kevin Fong (UCL): Successive UK governments have operated a successful strategy of 'divide and conquer' with respect to the life and physical science components of the space programme. Instead of asking whether humans or machines deserve the greater share of public funds, should we not be working together as a united space community to demand further investment in space science as a whole?

Dr. Coates: Well, yes, I agree that it would be better to have better funding for science in general, and that if wedges are being driven in then that is certainly a bad thing. But in terms of justification, I think that the exploration of the planets

with people fails on two "show-stopping" grounds: the cost, and the effects on the human body (especially radiation from solar flares). That's why I have difficulty supporting manned spaceflight. However, considering the ISS, we know it's going to be there anyway, so we may as well use it to the extent that makes sense, for example for life sciences and [astronomical] X-ray detectors. If they have good science cases then we should certainly try and push government to support them, I agree.

Professor David Hughes (University of Sheffield): Why don't you accept the inevitable? We have the capability of living permanently on the Moon, and as soon as we have two superpowers on Earth again we will be off like a shot!

Dr. Coates: Yes, you are probably right. Cold war propulsion certainly worked well in the 1960s, and I guess there's no reason why it shouldn't when China gets into space. . . .