

COMMENT

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NASA



Launch of the first shuttle, *Columbia*, in 1981. Will NASA have a future to rival its past?

DENNIS BUSHNELL Revolutionize research

*Chief scientist at NASA Langley
Research Center*

To achieve revolutionary goals, such as sending humans to explore the Solar System, NASA needs to develop revolutionary technologies. Because it is extremely difficult to pick winners in advance, research and development is required in several areas simultaneously.

Transporting humans to low-Earth orbit — such as the International Space Station — and beyond are two very different missions. But they both depend on the same metrics: safety and cost.

Humans have been travelling to and from low-Earth orbit for some 50 years, mostly on what were once military rockets. Today's commercial rockets use similar expendable technologies. The development firm Space Exploration Technologies (SpaceX) in Hawthorne, California, achieved notable success last year with rocket launches at quite low cost. Thus, with due attention to safety, commercial transportation of humans to low-Earth orbit should be feasible.

Transport of humans outside low-Earth orbit, especially to the Moon, Mars and beyond, is a wholly different challenge. Aside from Apollo, which 'only' went to the Moon, we have almost no experience to draw on. Also, such expeditions become exceedingly costly with existing rocket technology if they are to guarantee that crew members will remain healthy during long missions.

Revolutionary technologies should be targeted at: reducing the mass of the vehicle; novel launch and propulsion systems (including alternative fuels, such as positrons, energy beaming and in-orbit refuelling); and intelligent architecture and systems for more affordable life-support and radiation protection. Several of these technologies could be truly game-changing. The use of nanotubes in spacecraft construction, for example, could reduce the 'dry mass' — the amount to be launched, excluding ►

NASA: what now?

This month marks 50 years since Yuri Gagarin first ventured into space in the Vostok 1 mission, and 30 years since NASA's first shuttle flight. As the shuttle *Endeavour* prepares for its final flight, seven experts outline what NASA's priorities need to be.

► fuel — by three to five times, if we can create structural materials with the same strength properties as individual nanotubes.

A final alternative to sending humans to the toxic environment of Mars would be to develop space exploration for everyone using immersive virtual reality and remote planetary sensors, with autonomous robotics to supply the data. This could offer a better-than-being-there experience at much reduced cost and risk.

MARC GARNEAU

Get us to Mars

First Canadian in space and now a Member of Parliament

I believe there is a specific challenge that can galvanize us all: sending humans to Mars. A clearly defined objective can seize the imagination. Neil Armstrong understood this when he criticized his country's decision to take a broader approach to space exploration rather than giving itself something with a specific end point, if not an end date.

Last year, President Barack Obama cancelled the Constellation programme intended to return astronauts to the Moon. As a result, the road map for human space exploration is no longer as clear as it was. NASA and other space agencies are about daring and inspiration. But while their engineers and scientists develop new technologies and make new discoveries, it is the public who must be mobilized to support human spaceflight. This happened with Apollo when there was a race to win, and money was no object then.

Today, there is no clear race to win and money is very much a limiting factor — but that doesn't mean there is no reason to once again attempt what seems impossible. For me, that should be an international human mission to Mars led by the United States. With the completion of the International Space Station, we have proved that many countries can work together and share both the cost and the development of new technologies.

JOHN M. LOGSDON

Build a case for humans in space

Professor emeritus at George Washington University

NASA will probably continue to muddle along once the shuttle retires. Over the past 20 years the United States has spent more than \$20 billion on developing an alternative way to take humans into space. None even reached

the flight-test stage. The 2003 *Columbia Accident Investigation Board Report* (of which I was an author) called the lack of a replacement for the shuttle “a failure of national leadership”. That failure continues.

Eight years later, there is still no replacement in sight, just the hope that together, the private sector and NASA can develop ways to carry astronauts to the International Space Station (ISS) and replace NASA's embarrassing dependence on Russian rockets. Since the Columbia accident, NASA has used expendable vehicles to launch its science missions, so the end of the shuttle programme will have little impact on space science.

The biggest uncertainty is whether the United States will even have a human-spaceflight programme once the ISS is retired in 2020. In 2009, the Augustine Commission called for a spaceflight programme that is “worthy of a great nation”. In the commission's view, that meant human exploration at increasingly greater distances from Earth. Since then, there has been a confused and confusing debate among the White House, US Congress, NASA and the non-government space community over the best way to get started. No compelling proposal has emerged. The case has not yet been made for going back to the Moon, visiting a near-Earth asteroid or sending humans to Mars. Until it is, the US leadership is unlikely to commit the country to human spaceflight “worthy of a great nation”.

ROALD SAGDEEV

Send more robots

Former director of the Russian Space Research Institute and adviser to former President Mikhail Gorbachev

The closing down of NASA's space-shuttle programme leaves the Russian Soyuz rockets as the only spacecraft capable of delivering manned vehicles to the International Space Station (ISS). With the right political will, however, there is no reason why NASA cannot regain self-sufficiency in the next few years, even on a more modest budget.

In the interim, NASA has a genuine historic opportunity to rethink its goals once the ISS discontinues operations. An earlier vision to return astronauts to the Moon is off the agenda of the administration of President Barack Obama (and perhaps for the foreseeable future). A mission to Mars, a dream of spaceflight pioneers, in an environment of global multidimensional (not simply economic) crisis, will probably remain a dream for decades to come.

At the same time, the unmanned space programme is developing with tremendous

success and is costing much less. Robotic missions have vastly enriched our knowledge of the Solar System, and of Earth in particular, and have put numerous new-generation telescopes into space. These developments challenge the need for a costly human presence in space. Yes, astronomers are thankful to NASA's shuttle astronauts for prolonging the life of the Hubble telescope, thereby making it so successful. And in its last flight on 19 April, the *Endeavour* shuttle will deliver to the ISS an alpha-magnetic spectrometer — the most advanced high-energy experiment yet to be deployed in space.

But if such ventures remain isolated episodes, the expensive game of human spaceflight risks degenerating into ‘space tourism’ paid for by taxpayers.

ED LU

Deflect risky asteroids

Physicist, entrepreneur and former shuttle astronaut

The reason for human spaceflight is to protect human civilization. That means preventing direct threats such as asteroid impacts on Earth, as well as opening up the Solar System to human activity, including commerce, science, exploration and, some day, settlement.

NASA should survey and catalogue the orbits of potentially threatening asteroids, and show that humans can alter the Solar System (if ever so slightly) by deflecting a non-threatening asteroid using a robotic spacecraft. Such a focus would tie together the human-spaceflight programme with the robotic planetary-exploration programme in a common purpose.

Most importantly, NASA must move faster. The agency moved so slowly on some recent major programmes that they have been cancelled for lack of progress. Its plans for a heavy-lift rocket should therefore also be scrapped: it is too expensive, and meaningful progress will not be made until the 2020s.

Instead, NASA should find ways to solve the fuel problem: the fact that most of the mass of any spacecraft leaving Earth is taken up by fuel. NASA should develop a fuel depot in low-Earth orbit that can be used to refuel missions to deep space. Commercial firms could be paid to deliver fuel to the depot. Routine operations of this sort will bring down the overall costs and free NASA up to develop its deep-space missions. The agency would then be able to make progress in extending the reach of humanity into the Solar System.

The author declares competing financial interests: details accompany the full-text HTML version of the paper at go.nature.com/wx4vlv.

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NASA



MIDDLE: NASA, TOP: AP PHOTO

SPACE X



The highs and lows of human spaceflight. In 1961, Yuri Gagarin was the first man in space (top left). The shuttle first took flight 30 years ago (bottom left). Shuttle astronauts helped repair the Hubble Space Telescope in the 1990s (middle). The *Columbia* shuttle exploded after launch in 2003 (top right). Last year, a private company successfully launched a reusable space capsule (bottom right).

MATT MOUNTAIN Find a united purpose

Director of NASA's Space Telescope Science Institute and scientist at the James Webb Space Telescope

Human spaceflight will be at its best when NASA can demonstrate that the whole is greater than the sum of its individual parts.

In the 1990s, NASA's ambitious shuttle missions to repair and upgrade the Hubble Space Telescope ensured that Hubble remained the most scientifically productive telescope in history, and uniquely captured the public's imagination. What stood these missions apart from other NASA human-spaceflight activities was that the whole agency was committed to a coherent purpose — a partnership between science and human spaceflight to explore the Universe — something that only NASA has done.

Now imagine a NASA committed to lead an international spaceflight endeavour to search for habitable worlds, and to extend humanity's reach to Mars and beyond — I suspect there would be a collective sigh of relief among the world's space agencies. It would give immediate focus and relevance to the International Space Station as a platform for understanding how to sustain a long-term

human presence in space. For Mars, the focus should be not on rockets that hark back to the Apollo era — but on developing truly novel propulsion systems that allow humans to explore the entire Solar System.

In the medium term, NASA's astronauts could help to assemble and service giant space telescopes capable of searching for life around another star. The discovery of extra-terrestrial life would have as profound an impact on the twenty-first century as Neil Armstrong's Moon walk had on the twentieth.

NEAL STEPHENSON Ditch the rockets

Science-fiction author and space enthusiast

NASA should throw itself into developing radically cheaper ways of getting into space: a task that only it can do, and that would help to restore the lustre and *esprit de corps* of a legendary organization.

Rockets got as good as they are ever going to get four decades ago. Measured in terms of specific impulse — the momentum imparted to the vehicle per unit of fuel, and the only factor that matters as far as the laws of physics are concerned — no game-changing advances have been made since the Apollo programme. The technologies pioneered by the Soviet Union and the United States have

been endlessly cannibalized by NASA and parroted by many other countries.

The only way to fundamentally change humanity's relationship with space is to develop radically new launch systems, a challenge that no private company is likely to undertake. This is a job for NASA if ever there was one. The only catch is that it has to be NASA at its best — the NASA that many of us idolized in our youth — and not the grab-bag of aerospace-industry support programmes that the agency has become in the decades since the last Moon landings.

Scientists and engineers have been proposing alternative launch technologies since the 1950s, including laser- and microwave-powered propulsion, large gun-like devices, orbital tethers, space elevators, airplane- and balloon-assisted mechanisms and scramjets. None of these has taken hold, not because they are crazy (although some might be) but because the unbelievable amounts of taxpayers' money collected during the cold war and ploughed into old-school launch systems gave rockets a technological lead, and a privileged legal, regulatory and political position, unassailable by mere free enterprise.

Budget shortfalls provide an opportunity for NASA to eliminate many programmes that in happier economic times would be politically untouchable. NASA should make the most of this opportunity, and then rededicate itself to striving for the sorts of radical advances that, 50 years ago, had the power to awe the world.