Space, the Final Frontier?

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The space age has had more than its fair share of ups and downs in its brief, 45-year history. Three key questions are:

- Why did our vision of space exploration fade so rapidly after the *Apollo* programme to the Moon?
- Should space activities be regarded as a rather special way of making money, or of viewing the Earth and the Universe beyond?
- Do astronauts and cosmonauts do a much better job than robots in space, and so justify the much greater expense involved?

People with different backgrounds will give different answers to these questions.

A DRAMATIC BEGINNING

Conventionally the space age began on October 4, 1957, when the first artificial satellite of the Earth, *Sputnik 1*, a small spherical object with a mass of 83.6 kg, was launched by the Soviet Union. Up to that day it seemed that only a relatively few people were interested in whether man could learn how to travel in space, while most people were either disinterested or doubtful about its actual feasibility. Pioneers such as Goddard, Tsiolkovsky, Oberth and von Braun anticipated space travel. They worked hard to make their dreams come true, often encountering scepticism and criticism on the way.

In 1926 a British scientist, A.W. Bickerton, wrote:

> This foolish idea of shooting at the moon is an example of the absurd length to which vicious specialisation will carry scientists.

> To escape Earth's gravitation a projectile needs a velocity of 7 miles per second. The thermal energy at this speed is 15,180 calories [per gram]. Hence the proposition appears to be basically impossible.

Space travel seemed to belong more to fiction, particularly to science fiction, than to science or technology. Many men of letters were much interested in it: as an example, the Italian writer Carlo Emilio Gadda wrote in 1952 about the exploration of the Moon, Venus and Mars, defining these celestial bodies as the *New Indies*, a definition which implies not only exploration but also colonisation.

On October 4, 1957, the whole picture suddenly changed. What had previously been considered with scepticism or regarded as impossible turned out to be within the range of human capabilities, and new hopes emerged. In the Western World, however, these were accompanied by the fear of losing the technological supremacy on which its very survival seemed to rest – that Cold War atmosphere might, at any moment, degenerate into actual war. These feelings became stronger when, on November 3, 1957, the Soviet Union repeated its success, launching an even larger satellite. It had a mass of 508 kg and carried an animal, a dog named Laika. The demonstration that life was possible aboard a satellite in orbit around the Earth was there for all the world to see.

It was such a shock that there were some who could not believe these facts, arguing that it was all a form of propaganda. Within about three years notable achievements were recorded by the Soviet Union and by the USA – the first Moon probe (*Luna 2*, 1959), the first images of the other side of the Moon (*Luna 3*, 1959), the first weather satellite (*Tiros*, 1960), the first probe to Venus (*Venera 1*, 1961, and *Mariner 2*, 1962), and the first man to make an orbital flight (Yuri Gagarin, on *Vostok 1*, April 12, 1961, Figure 1.1).

President John Kennedy, in his famous speech of May 25, 1961, declared formally that the United States would land a man on the surface of the Moon and return him safely to Earth before the end

Figure 1.1. The first two astronauts: on the left Yuri Gagarin, who travelled once around the Earth in the spacecraft *Vostok 1* on April 12, 1961; on the right Alan Shepard, who performed a suborbital flight on the spacecraft *Mercury Freedom 7* on May 5, 1961 (the picture refers to the *Apollo 14* mission, during which Shepard walked on the Moon).

of the decade. This goal was spectacularly achieved.[1] Such an ambitious programme had never before been attempted and has never again been matched. The old NACA (National Advisory Committee for Aeronautics) was transformed[2] in 1958 into NASA (National Aeronautics and Space Administration), with powers and funding far greater than before.

Their gargantuan efforts enabled the United States to reduce the large lead which the Soviet Union had in the space race.[3] Not only

[1] W.E. Burrows, *This New Ocean: the Story of the First Space Age*, Modern Library, New York, 1999.
[2] R.E. Bilsten, *Orders of Magnitude: A History of NACA and NASA, 1915–1990*, NASA, Washington, DC, 1989, including works of art from NASA's collection; see R.D. Laurins and B. Ulrich, *NASA & the Exploration of Space*, Stewart, Tabori and Chang, New York, 1998.
[3] M. Collins, *Space Race: The US–USSR Competition to Reach the Moon*, Pomegranate, San Francisco, California, 1999.

were astronauts sent to the Moon, but also a number of other goals, such as new rocket launch vehicles, satellites of all types and robotic exploration of the whole solar system, were met in the 1960s and into the early 1970s.

UNFULFILLED PROMISES

Everything seemed possible in the enthusiastic atmosphere of that time, even if a few voices were starting to object to human expansion into space as summarised in the Preface. But who could cast doubts on the technical feasibility if such an unbelievable enterprise as landing a man on the Moon and bringing him safely back to Earth could be performed in just eight years? A few might have said that it was not worth going to Mars or reaching any of the other proposed goals. But they did not say that such goals were beyond the reach of humans, and in a short time too. Several ambitious projects started to take shape.

As a prerequisite a fleet of 'aeroplanes' capable of reaching low Earth orbit was needed. Many design projects were carried out and it was predicted that such flying machines could be operational by the end of the 1970s. This schedule was essentially met, but with severe limitations. The Space Shuttle (Figure 1.2), flight tested in 1981, is a reusable launcher which lands like an aeroplane. However, severe compromises had to be made on its complete reusability – it has two external solid fuel boosters which are recovered from the ocean and a large non-reusable external fuel tank. The Space Shuttle's operational costs are enormous and its performance characteristics not as good as had been hoped for. That routine access to space, of which its promoters were dreaming, was not realised.

A second huge project was that for a space station. The designs of the 1950s anticipated a very large space station, possibly like a wheel (Figure 1.3), slowly rotating about its axis to obviate the lack of gravity with the centrifugal acceleration due to its rotation. It was anticipated that, by the end of the 1970s, several crew members would live, more or less permanently, in space. They would work in the various sections

Figure 1.2. Landing of flight STS 67, the Space Shuttle *Endeavour*, on March 18, 1995 (NASA photo).

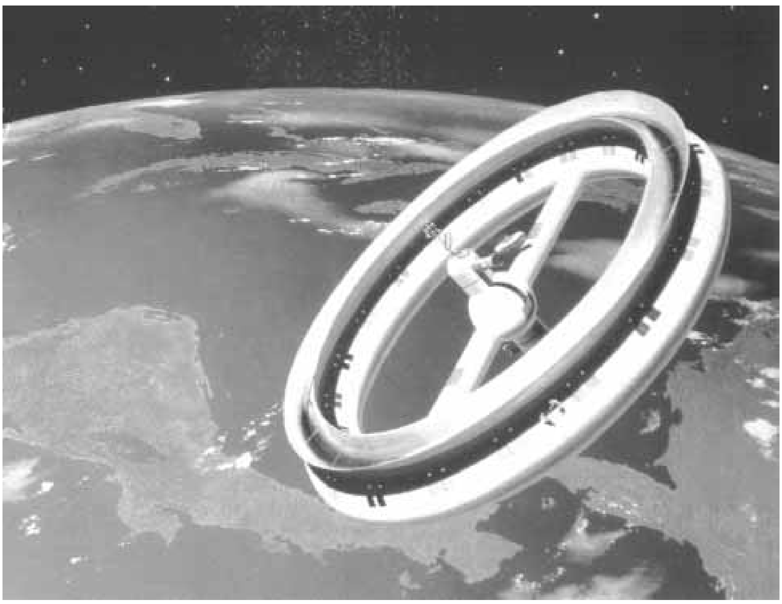

Figure 1.3. A space station in the shape of a wheel, as it was dreamt of by space pioneers and such as appeared in movies like *2001, A Space Odyssey*.

of the space station including scientific laboratories, factories, a spaceport and even a hotel. These predictions turned out to be wrong, and not only as far as the timing is concerned. The construction of the *International Space Station* started at the end of 1998; large as it is, it will be smaller and simpler than the space station originally conceived. It will be a step forward in the direction of the colonisation of space. Thanks to its modularity, it may be enlarged following a possible future redefinition of needs to be a staging post in space. However, it will always fall far short of the expectations of the 1960s and 1970s.

When planning journeys to the Moon there was the idea that humans would go there to live. Many other missions, longer and more complex, could have followed the first *Apollo* landings, until a permanent outpost was built, perhaps in the 1990s.

A short summary of the predictions of the 1960s cannot avoid including a human landing on Mars, which was assumed to have taken place, without doubt, in the early 1980s. Optimistic forecasts were made in the 1960s, when all seemed possible and when the time between any one achievement and the next, more ambitious one was incredibly short. But the entire history of space exploration is packed with unfulfilled promises and erroneous forecasts. At the end of 1988, in one of the darkest periods of space exploration, and following the recommendations of a Working Group chaired by the astronaut Sally Ride, after the *Challenger* disaster, NASA recommended, among other goals, the following:

- a permanent base on the Moon,
- a manned expedition to Phobos, one of the satellites of Mars, in 2003,
- a manned expedition to Mars, in 2007.

Needless to say all these goals are very far from being achieved.

Often a mission with very ambitious goals is proposed and the budget initially put forward seems to be adequate. Then, when the initial study (phase A study, in aerospace jargon) proceeds, the costs rise and the funding is relatively reduced, forcing the mission goals to be less ambitious. With the subsequent design (phase B), development (i.e. construction, phase C) and implementation (phase D) stages, further reductions of the objectives often take place in such a way that the actual mission is but a pale imitation of the initial one.

Most important missions since the mid 1970s have been either downsized or cancelled altogether. Even successful missions, such as the US *Galileo* probe to the planet Jupiter, had been rethought, redesigned, delayed and even risked being cancelled. Another example is the *Rosetta* mission, an initial objective of which included the retrieval of samples from a comet: it has been simplified, and now will just land on the nucleus of a comet.

The consequences of this failure to meet expectations are great. The general public has lost much of its initial interest in space exploration, and the effects on many specialists have been devastating. To cancel a space programme, or to make budgetary cuts to a project which has already started, often means reducing the number of personnel employed in research centres or in divisions of the space industry. Hundreds of space specialists have been dismissed or moved to less-creative jobs within the same industries working for space agencies. Apart from these human problems, it is a waste of human resources, both of highly qualified individuals and of the huge investment of time and effort in creating effective teams. However, some positive aspects can be found even in this process, as some specialists who found new jobs in other sectors brought to the latter the valuable experiences which they acquired in the space field; performing technology transfer in this way is, nevertheless, extremely inefficient.

There is a worse, and more subtle, problem. Those who have worked on programmes which are cancelled are demotivated, and may develop an attitude towards their work which is bureaucratic. If it is likely that a mission will never 'fly' in space, what matters most is not the mission itself but the number of formal duties, meetings, progress reports, assessments and other paperwork by which the financing agency justifies payment for the work performed.

All those who work on a space programme need to be sure that the programme will be completed, even if this means that the choice of missions to be financed must be made with more severe – and realistic – criteria.

CRISIS OF GROWTH?

The crisis of space activities started exactly when space was experiencing its greatest triumph. When the *Apollo* programme was at the point of taking a man to the Moon, the political situation was very different from that at the beginning of the 1960s. The Vietnam war was attracting the attention of public opinion and there were strong protests in many countries, especially the United States, against the American administration. The enthusiasm of the Kennedy era for the 'new frontier' was being substituted by duller national politics and the credibility of US and other institutions was decreasing. Anti-technological movements, with their ecological aspects but also with their sheer irrationalism, were gaining ground. The primacy of politics, preached by the movements of 1968, put all other activities in a shadow of suspicion or contempt.

The first two landings on the Moon (*Apollo 11* and *Apollo 12*) attracted considerable attention for a short time and brought the earlier enthusiasm to a climax (Figure 1.4). But with *Apollo 13* nearly ending in tragedy, criticisms were voiced and requests to cancel the *Apollo* programme gained momentum. And this was so notwithstanding the fact that *Apollo 13* dramatically demonstrated that human beings were able to work in space, reacting to unpredictable events and showing a surprising ability to improvise in order to master the worst of situations.

Only the success of the *Apollo 14* mission could save the programme, which had already been downsized – it enabled the last three *Apollo* missions, *15*, *16* (Figure 1.5) and *17* to proceed. And even *Apollo 14* came very close to failure; the docking of the command module to the lunar excursion module, a manoeuvre which was essential to transfer the crew for the Moon landing, almost failed. It was

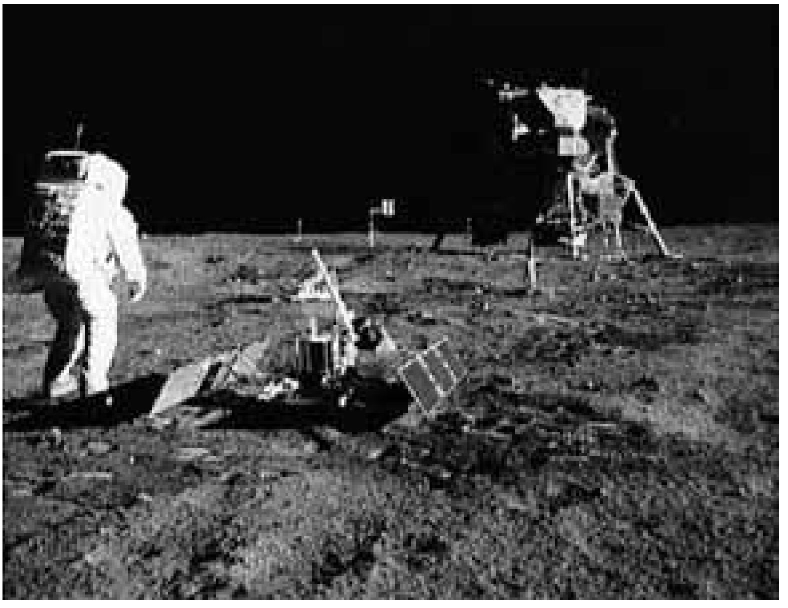

Figure 1.4. Picture of Edwin 'Buzz' Aldrin, lunar module pilot, on the Moon taken by the mission commander Neil Armstrong; he had just deployed some scientific instruments, visible in the foreground (NASA photo).

attempted five times without success; it was only when the pilot of the command module tried to force the secondary locking device by ramming the two spaceships together at a speed greater than anticipated that the docking was successful. Later, it was discovered that the mechanism had been jammed by an ice crystal. In retrospect it is amazing to contemplate that the future of a multi-billion dollar programme and four of the most important *Apollo* missions had been jeopardised by a relatively simple mechanical device and by an insignificant ice crystal. Lunar missions ended with *Apollo 17* (Figure 1.6). Many thought that all the goals of the entire space adventure had been reached, but in a somewhat disappointing way. Some thought that the lunar missions were only a 'space show', an effort to impress public opinion rather than to attain scientific goals or to open the space frontier to further projects with crews. The result of this approach could

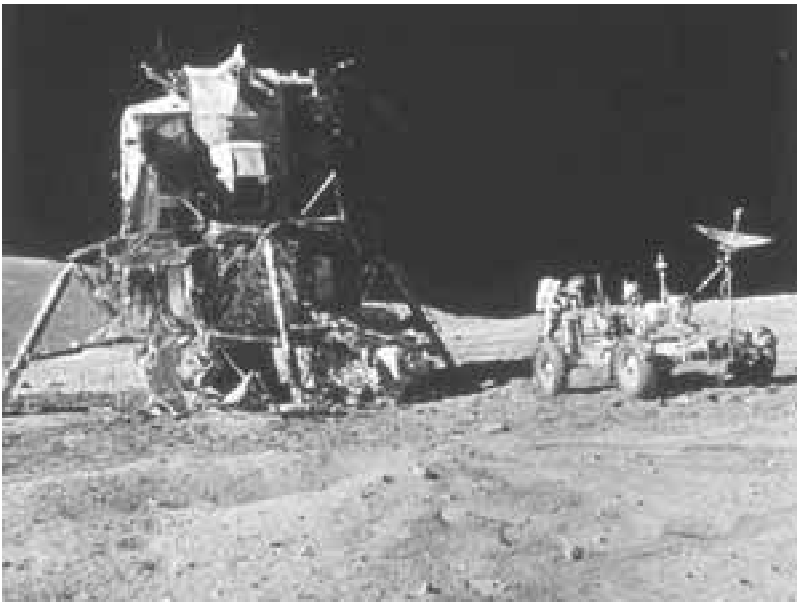

Figure 1.5. The *Apollo 16* Mission; the Lunar Excursion Module is on the surface of the Moon and an astronaut is getting the Lunar Rover ready for travelling (NASA photo).

only be a disappointment, with no continuity in the detailed exploration of the Moon to lead on to the construction of lunar outposts.

Other people noted that the disappointment was unavoidable. The decision to send men to the Moon instead of robotic probes, which was taken against the advice of many members of the space community, was also based on the consideration that it would be easier to obtain the required funding for a mission making a very high impact on public opinion.[4]

But this is highly questionable. The *Apollo* programme was far more than a series of 'flag and footprint' missions; the astronauts carried out top-class scientific research on the Moon, and the results of

[4] A detailed account of the discussions which accompanied the *Apollo* programme and of the scientific, political and military milieu in which they took place can be found in the form of the novel *Space*, by J.A. Michener, Corgi Books, London, 1986. A factual account is given in B. McNamara, *Into the Final Frontier: The Human Exploration of Space*, Harcourt, Orlando, Florida, 2001.

Figure 1.6. An *Apollo 17* astronaut performing geological studies during one of the long-range reconnaissance activities using the Lunar Rover (NASA photo).

the *Apollo* missions shed new light on the origin of the Moon and of the solar system. The ease with which the astronauts learned how to move and how to work in such an unusual environment showed that colonising extraterrestrial bodies is not as difficult as many predicted then and still think now. Advances in the engineering sciences brought about by the *Apollo* programme were outstanding; in retrospect we can say that they changed our lives. Every time we walk on snow, use a computer or travel by plane we use something developed for the Moon adventure or designed using methods introduced for it. And this trend is continuing. Soon we will drive non-polluting cars powered by fuel cells which would never have been developed without the *Apollo* programme.

The *Apollo* programme was also good for business. Costing some US $70 billion (in present-day currency terms) its revenues, in royalties and know how, were several times that. Some economists consider that the unprecedentedly long expansion phase of the American economy which is still going on was founded on the technological effort following John Kennedy's commitment to land a man on the Moon.

The decision to terminate the *Apollo* programme was a political decision taken by Richard Nixon under the influence of current pressures and for short-term economic convenience.[5]

Space Shuttle: instrument of progress, or hindrance?

In fact, NASA was concentrating on the post-Apollo programme, with the Space Shuttle as one of its focal points, but without any general agreement among the specialists as to where space efforts should be focused. On the one hand, there was the widespread opinion that only a launch machine which could dramatically reduce the cost of launching satellites could really open the gateway to space. On the other hand, some thought that concentrating the shrinking resources into a launch vehicle would reduce the funds available for scientific missions. So it was a quarrel between engineers and scientists, between those who wanted to put the emphasis on technology and those who wished to stress science. There was a further disagreement between those who thought that the role of humans in space was essential – the Space Shuttle being a vehicle to carry humans beyond the Earth's atmosphere – and those who promoted the robotic exploration of space. The Space Shuttle was even seen as a plot by the industrial/military complex to use public funds to build a machine whose importance was mainly military.

A similar argument, which is in fact still going on, was later initiated by the decision to build a space station. It is likely that such

[5] See H.E. McCurdy, *Inside NASA: High Technology and Organizational Change in the U.S. Space Program*, The Johns Hopkins University Press, Baltimore, Maryland, 1993, and R.D. Launius, *NASA: A History of the U.S. Civil Space Program*, Krieger Publishing Company, Malabar, Florida, 1994.

debates will follow future decisions regarding the construction of a lunar base, the landing of men on Mars, or future ambitious projects in space.

Both sides had good reasons to support their viewpoints, and the main problem was basically one of politics and economics. In a situation of shrinking budgets it was difficult to cope with the operating costs of the Space Shuttle, which were found to be much higher than expected. And now the Space Shuttle is ageing. Technology has made much progress since the Space Shuttle was designed and built, above all in electronics and computer science, but also in materials science and design techniques. The current research programmes, such as NASA's X-33 programme[6] to build a second generation shuttle, must proceed rapidly, since the pressure to reduce launch costs is increasing. The current NASA maxim of 'faster, better, cheaper' can be applied, to a certain extent, to launch vehicles, satellites and spacecraft.

It is also very important not to entrust all space activities to a single type of launcher, but to have some elements of competition between launch manufacturers. The very existence of the Space Shuttle and the necessity to justify its enormous and escalating costs led to the construction of large non-reusable rockets being stopped in the United States. A launch system based on a single class of vehicles is extremely vulnerable to a 'single-point failure'. Only four Space Shuttles were built, and such a failure occurred with the *Challenger* tragedy of January 28, 1986. The grounding of all Space Shuttles after the *Challenger* disaster paralysed American space activities for several years. The lesson to be learned is that the different needs of the various space missions planned require some choice between several different launch vehicles.

The fate of the *Galileo* probe, to study Jupiter and its satellites, is a good example of the problems associated with the use of the Space Shuttle. Initially, the launch of that probe was scheduled for 1981. It should have left Earth orbit aiming directly at Jupiter under the thrust of a chemical rocket, after having been put into low Earth orbit

[6] The X-33 programme is now cancelled, but other programmes are replacing it.

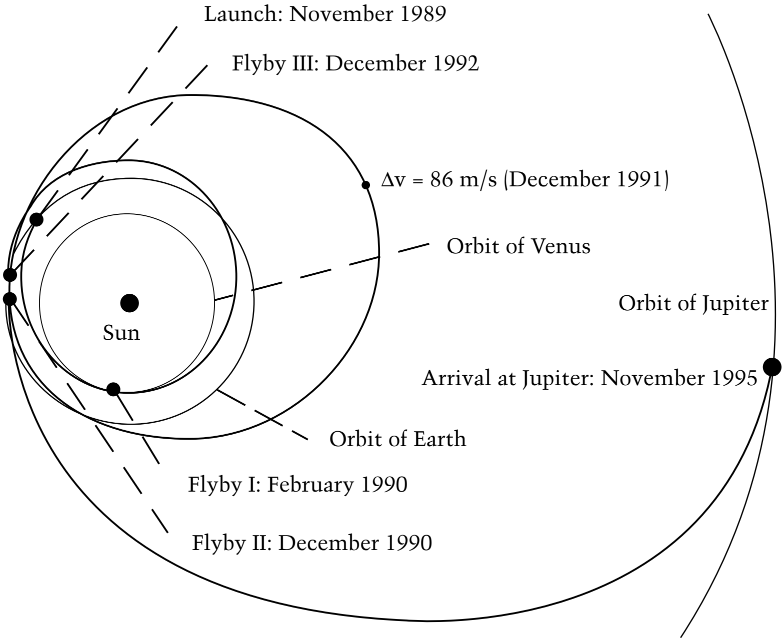

Figure 1.7. Trajectory of the *Galileo* probe, with the flybys shown and also the trajectory correction, a boost giving a velocity increment Δv of 86 m/s (see Appendix B).

by the Space Shuttle. The *Challenger* disaster delayed the launch for some years and new safety regulations prevented the liquid propellant Centaur rocket from being carried aboard the Space Shuttle. Then the Centaur programme was cancelled and it seemed that the *Galileo* mission would have to be abandoned. Considering the impossibility of a direct launch, a complete redesign of the mission was undertaken. The trajectory eventually chosen was for a launch toward Venus, with a close flyby to use 'gravity assist' due to that planet[7] to obtain a first increase of speed.

The very complicated trajectory later included two flybys of Earth to aim the spacecraft towards Jupiter (Figure 1.7). The total travel time was greatly increased, from 2 to 6 years, and so were the chances

[7] A flyby with gravity assist is a manoeuvre in which a spacecraft exploits the gravitational field of a planet to change its trajectory and to increase its speed *en route* to its destination (see Appendix B).

of an accidental malfunction or of an error in the trajectory correction. A secondary antenna had to be fitted to the probe, to allow the primary one (which could not withstand the heat from the Sun during the initial part of the flight in the inner solar system, near the orbit of Venus) to be folded initially. All this increased the complexity of the mission considerably.

Galileo was eventually launched on October 18, 1989 by the Space Shuttle *Atlantis*. The trajectory proved to be feasible and, after passing close to Venus in February 1990, to the Earth in December 1990 (see Figure 1.8), to the asteroid Gaspra in October 1991 (Figure 1.9) and again to the Earth in December 1992, *Galileo* began

Figure 1.8. South America and Antarctica as observed by the *Galileo* probe during a flyby of the Earth (NASA photo).

Figure 1.9. Picture of the Gaspra asteroid taken by the *Galileo* probe from a distance of about 16,000 km on October 29, 1991. Gaspra is 17 km long and 10 km wide (NASA photo).

to travel towards Jupiter. When the main antenna failed to open, this malfunction seemed likely to lead to the total loss of the mission. But with the probe homing in on Jupiter and its main antenna inoperative, the programming of the on-board computer was changed to include recently developed image compression techniques. In this way images were broadcast, although at a far slower rate than planned originally, using the secondary antenna (Figure 1.10).

The mission was finally a success; the atmospheric entry module was released in December 1995, while the orbiter continued its observational work around the planet. The arrival at Jupiter had been delayed by 12 years, more than the time which elapsed between President Kennedy's speech and the actual landing on the Moon! On

Figure 1.10. Image of Jupiter's moon Io taken by the *Galileo* orbiter during its ninth orbit around Jupiter. An enormous volcanic plume is clearly visible (NASA photo).

the positive side, however, was further confirmation that the gravitational fields of planetary bodies can be used to change a space probe's direction and speed just as old-time sailors exploited the winds and ocean currents. It also demonstrated that a mission which seems to be doomed to failure can be saved.

Space bureaucracy

In the 1960s NASA had an almost perfect reputation and considerable popularity; it looked as if nothing was impossible. The Americans were achieving success after success – they were regaining the technological supremacy which, at the end of the 1950s, they seemed to have lost.

Then came budget cuts, and downsizing become the 'in' word. Many of those involved in the space triumphs became disillusioned; some looked for more interesting jobs, others were made redundant or retired, and some died. Among the latter was Werner von Braun, who died in 1977. As often happens, the decline of enthusiasm and of the *esprit de corps* led many to concentrate on the daily routine and the space agency became more and more like any other government bureaucracy. T.R. McDonough[8] notes that the rules of the civil service – under which most NASA centres operate – make it very difficult to sack the incompetent or lazy, and that the 'rocket scientists' and engineers were replaced by administrators more accustomed to 'flying a desk than a rocket, more adept at handling paperwork and office politics than nuts and bolts engineering'.

The Presidential Commission investigating the *Challenger* disaster included the Nobel laureate Richard Feynman, the astronaut Neil Armstrong and the test pilot Chuck Yeager. With the care typical of American Commissions at difficult times, they revealed the attitudes of complacency and overconfidence that led to that tragedy. The solid fuel booster blew up due to the failure of a small rubber seal between two of its segments. The examination of some boosters used in previous flights, which were recovered from the Atlantic Ocean,

[8] T.R. McDonough, *Space, The Next Twenty-five Years*, Wiley, New York, 1989.

had already suggested that possible problem. The engineers of the firm responsible for the boosters, Thiokol Corporation, had warned NASA not to launch the *Challenger* that day as the previous night's freezing temperatures could have damaged the seals. But those responsible for the launch continued, without even informing the doomed astronauts aboard of this. Whilst such a structural failure was the specific cause of this disaster, the actual cause was pressure exerted on NASA to keep up the schedule of frequent Space Shuttle launches, following the decision to launch all American satellites using this vehicle.

What applies to NASA bureaucracy could also hold for the European Space Agency (ESA), with added problems associated with the subtle rules for the division of the costs and benefits among its member states – namely the principle of *juste retour* – and of the overgrown and bureaucratic structures of the European Community.

Among the solutions to such problems is a reduction of the obstacles for private organisations to put payloads into orbit. Thus a privatised launch industry can be started; launch vehicles can not only be built, but also operated, applying the criteria of commercial enterprises. This could enable space agencies to concentrate on scientific missions and on those infrastructures which cannot be operated by private organisations but which, if correctly run, can be good investments.

A new, business-like approach will also cut costs. As Robert Zubrin notes in his book *Entering Space: Creating a Spacefaring Civilization*,[9] one of the causes of the very high costs of American space hardware can be traced back to the so-called 'cost-plus' system. Its aim is to prevent private enterprises from making too large a profit from a government contract. Instead of fixing a price in advance, as in private business, the companies supplying goods and services to the government agency must document all expenses and internal costs and then apply a limited profit (in the 10% range). In this way there

[9] Robert Zubrin, *Entering Space: Creating a Spacefaring Civilization*, Tarcher/Putnam, New York, 1999.

is an incentive to make every product cost as much as possible and, even worse, all investments on innovation are discouraged.

For the USA, the protectionist policy of using only American launchers for government-funded spacecraft has the effect of discouraging research aimed at reducing launch costs or improving the performance of rockets. A similar situation also affects Europe, with the additional fact that many aerospace companies are state-owned and, like most industries of this type, their efficiency is not very high.

Continuity of funding

In the *Bible* a well known parable of the New Testament asks the question: 'for which of you, desiring to build a tower doth not first sit down and count the cost whether he have wherewith to complete it?...'.[10] That is common sense, but it does not necessarily seem to be in agreement with the rules of modern society, where public funding is concerned. NASA must submit its annual budget to the Congress, who must approve the various line items and re-examine its projects every year; the other space agencies face the same, or similar, financial situations.

The problem stems from the fact that all space programmes, by their very nature, must last for several years. The tendency, at least for major space projects nowadays, is to go on for more than a decade. Nobody can guarantee that a programme, which has been duly approved and funded for a certain number of years, may not later be cancelled, perhaps when it is near to reaching its goals. Then the result is suddenly to nullify all the efforts made up to that point, with a tremendous waste of resources. Resources of all types, both human and material, will then be dissipated. The most striking aspect, a half-finished space vehicle rusting in a warehouse, is just the tip of the iceberg.

This does not mean that space activities must be removed from the control of the representatives of those who pay the bill. The choice of which space projects are to be funded and of their relative priorities

[10] St. Luke's gospel, chapter 14, verse 28, Revised Version.