A reappraisal of the Space Shuttle programme

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The conventional wisdom holds that the Space Shuttle programme has been a 'policy failure' because NASA compromised its original concept in the face of weak political commitment and inadequate funding. However, a detailed reappraisal of the history shows that this reasoning is ambiguous, counterfactual and contrary to experience. Congressional and presidential support for the Shuttle has consistently been generous despite flawed and shifting justifications for the programme advanced by NASA. Among the lessons to be learned are the need for more rigorous congressional oversight and the development of smaller, quicker and independent civil space programmes.

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In January 1972 President Nixon approved the Space Shuttle programme which became NASA's major manned spaceflight effort in the post-Apollo civil space programme. The Shuttle's first orbital mission, in April 1981, was the first US manned mission since Apollo–Soyuz in July 1975, and only the fifth since the last Moon landing in 1972. NASA declared the programme 'operational' four test missions and 18 months later. Up to the *Challenger* accident the Shuttle had successfully completed 20 'operational' missions. No launches occurred until 32 months after the accident.

As the Shuttle programme enters its third decade of existence and its second decade of operations, it is prudent to prepare for the many decisions that will have to be made about how often, and for what purposes, to fly the Shuttle, and its role in the future civil space programme. These decisions may be made under such contingencies as loss of another orbiter, termination of the Space Station, and changing political and budgetary conditions. They are thus best grounded in a realistic reappraisal of the programme's experience to date. Assumptions about the past and hopes for the future are not enough.

A reappraisal is warranted because the most influential appraisals are flawed. Several policy analysts have asserted that the Shuttle programme is a 'policy failure' because NASA compromised its original concept in the political process.[1] This argument constitutes the conventional wisdom, the generally accepted assumptions that continue to frame policy debate and decision on the Shuttle programme. The problem is that conventional wisdom provides a misleading basis for future debate and decision.

This article employs a logical framework to apply a critique of conventional wisdom and structure a reappraisal. A systematic and logically complete appraisal examines performance with respect to criteria (often policy goals or justifications) in order to clarify policy successes and failures, and to clarify responsibility for those successes and failures. Judgements of responsibility guide changes in policy to improve future performance with respect to goals. This article offers a critique of the conventional wisdom and summarizes the successes and failures of the Shuttle programme. It then completes the reappraisal

[1]Three examples of this school of thought are: J. Logsdon, 'The space shuttle: a policy failure?', *Science*, Vol 232, 1986, pp 1099–1105; H.E. McCurdy, *The Space Station Decision: Incremental Politics and Technological Choice*, Johns Hopkins University Press, Baltimore, MD, 1990, Ch 2, pp 22–34; and H. Mark, *The Space Station: A Personal Journey*, Duke University Press, Durham, NC, 1987.

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with assessments of responsibility for the observed performance shortfall, and considers implications for future policy decisions.

Conventional wisdom

Conventional wisdom on the Shuttle was repeated in the *Report of the Advisory Committee on the Future of the US Space Program*, better known as the Augustine Committee:

> To continue manned space flight [after Apollo], the reusable Space Shuttle development program was initiated in 1972, the two principal goals being increased access to space and a substantial reduction in the cost of orbital flight. Unfortunately, budget cuts, technical problems and continuing stretch-outs forced design compromises that led to performance shortfalls.[2]

Members of the Committee were selected for their extensive and diverse experience in or around the civil space programmes. The fact that they accepted this interpretation of the Shuttle is evidence for the claim that it represents conventional wisdom.

The best-known and most influential statement of the conventional wisdom was published in *Science* in 1986.[3] The argument is summarized as follows:

> In order to get approval for shuttle development, NASA during 1971 and 1972 made a series of budget-driven design changes that have turned out to be major sources of the program's troubles in meeting its policy goals. The implications of these trade-offs for program success were not sufficiently examined before the decision to proceed was made despite warnings from White House budget and technical advisors. The decision was a close call, and was not accompanied by enough of a political or budgetary commitment to ensure program success as problems emerged . . . the decision to develop it was made through the 'normal' political process of bargaining, compromise, and coalition-building, not on the basis of presidential leadership. Too much attention was paid to the short term, while longer range implications were inadequately considered. For all these reasons, the shuttle decision stands as a powerful example of how not to make a national commitment to an undertaking on which many other significant projects depend.[4]

The appraisal criterion is understood to be 'meeting [the programme's] policy goals', and the Shuttle's primary policy goals are understood to be 'easy and inexpensive access to low earth orbit and to replace all existing expendable launch vehicles' that existed in the early 1970s, when the Shuttle was initially approved.[5] The argument asserts that 'the shuttle program must be assessed as a policy failure, at least in terms of meeting the objectives that have been its articulated rationale since 1972'.[6] It is implied that there are other relevant criteria for appraising the programme, but they go unstated. In any case, the claim that the Shuttle was a policy failure is not in dispute here.[7]

However, the three explanations for the policy failure are in dispute. The first explanation is that 'budget-driven design changes' made by NASA are the 'major sources of the program's trouble in meeting its policy goals'.[8] (Throughout this article the term 'design' refers to the Shuttle's technical design, while 'concept' refers to requirements to be met by the design, such as partial reusability.) The current NASA historian understood the logical limitations of this claim:

> [T]he argument that the Shuttle would have been a more successful space vehicle had NASA had its way in its development is an implicitly counterfactual

[2] *Report of the Advisory Committee on the Future of the US Space Program*, US GPO, Washington, DC, 1990, p 14.

[3] Other examples of the conventional wisdom include: J. Logsdon, 'The decision to develop the Space Shuttle', *Space Policy*, Vol 2, No 2, May 1986, pp 103–119; and P. Schulman, 'Nonincremental policy making: notes toward an alternative paradigm', *American Political Science Review*, Vol 69, December 1975, pp 1354–1370. Some notable exceptions to the conventional wisdom literature include: S. Pace, 'Engineering design and political choice: the Space Shuttle 1969–1972', Master's Thesis, Massachusetts Institute of Technology, May 1982; A. Roland, 'The Space Shuttle: triumph or turkey', *Discover*, November 1985, pp 29–49; A. Roland, 'Priorities in space for the USA', *Space Policy*, Vol 3, No 2, May 1987, pp 104–114; J. Logsdon, 'Shall we build the Space Shuttle?', *Technology Review*, October/November 1971, pp 49–57; R.D. Launius, 'The development of the Space Shuttle, 1967–1972: technological innovation and governmental politics', unpublished manuscript, NASA History Division, Washington, DC, 1991; and D. Collingsridge, 'Technology organizations and incrementalism: the Space Shuttle', *Technology Analysis and Strategic Management*, Vol 2, No 2, 1990, pp 181–200.

[4] Logsdon, *op cit*, Ref 1, p 1099.

[5] *Ibid.*

[6] *Ibid.*

[7] An alternative to conventional wisdom that is not considered here is that the Shuttle is a technical success. See for example J.C. Fletcher, 'Space Shuttle development', letter to *Science*, Vol 233, 1986, p 263. Technical goals were not the primary basis for approval of the Shuttle.

[8] Logsdon, *op cit*, Ref 1.

argument . . . The argument that the Shuttle would have been successful had it been built under a sweeping mandate from government officials similar to that given to Project Apollo, backed up by sufficient funding to accomplish all that NASA had originally proposed, cannot be proven.[9]

While the counterfactual cannot be proven or disproven, it does suggest a thought experiment. Suppose that NASA's original design for the Shuttle had met the programme's policy goals. Suppose further that subsequent design changes were 'budget-driven' in the sense that they were not justified under engineering criteria. Then it should have been incumbent upon NASA to realign policy goals with the expected performance of the modified design in order to give the elected representatives of the people a dependable basis for decision. Instead, in the effort to promote the programme, NASA held policy goals constant to inflate the programme's apparent benefits while the design was compromised. The US Constitution subordinates the plans and designs of agencies, including NASA, to judgements by the elected representatives of the public. Conventional wisdom inappropriately assumes that NASA's design should have remained uncompromised.

The second explanation is that the Shuttle 'decision was a close call, and was not accompanied by enough of a political or budgetary commitment to ensure program success as problems emerged'.[10] 'Strength of commitment' is ambiguous and requires clarification. Strength of commitment is apparently defined as the resources required to achieve the programme's policy goals. For example, it is argued from the Shuttle experience that

> Decisions to make capital investments in major facilities or capabilities require more than an initial approval. To be effective, they must be accompanied by a *political commitment to provide the resources required over the lifetime of the program* on a timely basis. Further, it makes little sense to invest in a capability intended to enable a wide range of scientific and technological activities if adequate support for those activities is not also provided.[11]

But the argument contains no standard of 'resources required' to achieve the programme's policy goals, other than failure to meet those goals. Hence the argument is circular: There was a weak commitment because the programme failed to meet its policy goals, and it failed to meet its policy goals because of a weak commitment.

An alternative standard of 'resources required' is the amount of funding deemed necessary by programme advocates to achieve policy goals at the time of initial programme approval. This standard is logically independent of the programme's failures: If the resources deemed necessary at the time of project approval were in fact provided on a timely basis, then the policy failures cannot be attributed to a weak commitment. Contrary to conventional wisdom, the data documented below indicate that the commitment to the Shuttle was, and still is, exceptionally strong. In short, depending on how it is interpreted, the explanation that the Shuttle programme lacked a strong commitment is either logically circular or empirically incorrect.

The third explanation is that 'too much attention was paid to the short term, while the longer range implications were inadequately considered'.[12] This aspect of the argument is not developed beyond recognizing the trade-offs between short-term development and long-term operating costs. Again, insofar as trade-offs affected expected performance, NASA should have adjusted policy goals to reflect design

[9]Launius, *op cit*, Ref 3, p 2.
[10]Logsdon, *op cit*, Ref 1.
[11]*Ibid* (emphasis added).
[12]*Ibid.*

changes in order to give the elected representatives of the people a dependable basis for decision.

All three explanations are consistent with the argument, developed elsewhere, that incremental politics are responsible for the failures of large space programmes.[13] In general, the argument holds that NASA's next-logical-steps have been undermined by incremental politics in the post-Apollo era. The solution, the argument continues, is to grant such projects sweeping mandates, free from annual budgetary fluctuations.

These arguments are part of an Apollo paradigm that frames most analyses of the post-Apollo civil space programme.[14] In this paradigm President Kennedy's dramatic announcement of the Apollo programme, and its subsequent funding, are taken as the model of a clear goal and strong commitment to a civil space programme. Moreover, a clear goal and strong commitment are considered necessary and sufficient conditions for the success of the next-logical-steps towards human exploration of the Solar System. Therefore within this paradigm any departure from the Apollo model becomes an obvious explanation for performance shortfalls. Generally, departures from the model are due to incremental politics.

Apollo was a policy success in that it fulfilled its Cold War goal of demonstrating the technological prowess of the free world, and it met its performance goals with respect to cost, schedule and capabilities, or came close to them. However, the Apollo paradigm is a myth in important respects. For example, within a few years of the dramatic announcement the programme came under attack in Congress and experienced budget cuts. Also, the myth fails to recognize that the programme was a symbolic weapon of the Cold War, and not primarily a human exploration mission. Like other myths, the Apollo paradigm makes it easier to live with recurring problems than to solve them.[15] It suggests that the problems that plague the civil space programme can be solved by a clear goal and strong commitment from the political system – even though the unique conditions of the Apollo era are unlikely to be repeated. It is even less likely that the political system will be reformed to meet the expectations of the Apollo paradigm. The recurring problems of the post-Apollo space programme would be more easily solved by adapting the space programme to the system of incremental politics established under the US Constitution.

In summary, conventional wisdom fails to withstand critical analysis. Its logic is ambiguous, counterfactual and contrary to experience. Its implications are contrary to the generally expected norms of government. To the extent that decisions are being based on conventional wisdom, a reappraisal of the Shuttle programme is worthwhile and can contribute to better policy. The next section begins a reappraisal of the Shuttle experience.

Successes and failures

The criteria for this reappraisal are based on the following expectations formed at the time of programme approval: (1) level of commitment, and (2) programme performance with respect to original promises in terms of cost, schedule and capability. These criteria are appropriate because they can be used to hold Congress and the administration on the one hand, and NASA on the other, accountable for their initial commitments. Mechanisms of accountability are entirely appropriate

[13]McCurdy, *op cit*, Ref 2, p 32.
[14]On the Apollo paradigm see R. Byerly, ed, *Space Policy Reconsidered*, Westview Press, Boulder, CO, 1989, Introduction, pp 1–7.
[15]An enlightened view of the space programme and its myths can be found in P. Limerick, 'Imagined frontiers: westward expansion and the future of the space program', in R. Byerly, ed, *Space Policy Alternatives*, Westview Press, Boulder, CO, 1992, Ch 15.

when efficient use of public resources is expected, as is the case with NASA programmes. In order that accountability be enforced, standards of accountability are needed. Thus these criteria allow for an examination of the Shuttle experience focused on improving current and future policy decisions in the civil space programme, and more generally, efficiency in the use of resources.

Assessing level of commitment and measuring performance

Funding with respect to original programme cost estimates is the standard chosen for assessing the level of commitment. While it is certainly true that elected officials cannot commit their successors to support programmes previously approved, and initial approval is just that – initial – measuring resource allocation over time provides a reasonable barometer for assessing what is and is not a strong commitment. Thus the estimated total cost of the Shuttle programme agreed by NASA, Congress and the administration at the time of programme approval is the baseline against which allegations of weak or strong commitment are measured. The historical record provides the necessary data for this measurement. If, over the development of the programme, the Shuttle was not funded commensurate with estimates, then allegations of a weak commitment to the programme would have merit. However, if the Shuttle was funded at or above the level of initial estimates, then allegations of a weak commitment are unwarranted.

The historical record suggests that the commitment to the Shuttle programme was very strong during development, and continues to be so today. At approval NASA estimated the cost of Shuttle development during the period 1972 through 1980 to be $6.45 billion in 1971 dollars.[16] In 1980 NASA's estimate had risen to $7.61 billion in 1971 dollars, a cost growth of about 18%, while capability had been reduced.[17] Congress accepted the cost growth in the sense that there were no attempts to terminate the programme either in committee or on the floor due to the increased costs or reduced capabilities. In fact Congress voted overwhelmingly to appropriate supplementary funds in 1979 and 1980 to cover the rising costs of the programme.

Furthermore, Figure 1 shows that during development Congress never cut the administration's request for the Shuttle programme. The Office of Management and Budget (OMB) did cut NASA's initial programme requests in 1974, 1975, 1976 and 1977. NASA estimated, however, that the 1975 and 1977 cuts would only add $70 million, or about 1%, to the original estimates. The FY 1974 and 1976 cuts would not affect the cost commitment.[18] The sum of final appropriations to the programme during development was almost 20% greater than that which was estimated to be necessary in 1972.

Thus this suggests that allegations of a weak commitment, at least in terms of providing the agreed necessary resources, are unfounded. Furthermore, in the years since the programme has deviated significantly from the initial operating plans, the level of funding given to the programme further supports the thesis that the commitment has been very strong. Funding during the 10 years since 1981 has averaged over $4 billion annually.

The second criterion is performance as promised. Performance is defined in terms of cost, schedule and capability. At programme approval these factors were established as goals that the programme would be expected to meet, providing a baseline against which actual

[16]Level of commitment is most easily measured using development costs as NASA provided Congress with the programme's annual cost growth in these terms. The figures used here are found in US House of Representatives, Committee on Science and Technology Report, *Space Shuttle: 1980*, US GPO, 1980, pp 42–43.

[17]For example, the Space Tug, an integral part of the original programme, was no longer part of the programme in 1980.

[18]'Oversight: Space Shuttle Cost, Performance, and Schedule Review', hearing before the House Subcommittee on Space Science and Applications, 28 June 1979, p 146. NASA sometimes added the $70 million cost growth attributed to OMB cuts to the original $5.15 billion DDTE (design, develop, test and evaluate) estimate. This explains why NASA sometimes prudently referred to the original DDTE estimate as $5.22 billion, including the cost growth attributed to OMB cuts to the original request. For example, $5.22 billion is used in a letter restating the commitment from NASA Administrator James Fletcher to the Chairman of the Subcommittee on Space Science and Applications, Don Fuqua, dated 29 March 1977. Adding $70 million to the original commitment does not affect the analysis in this article.

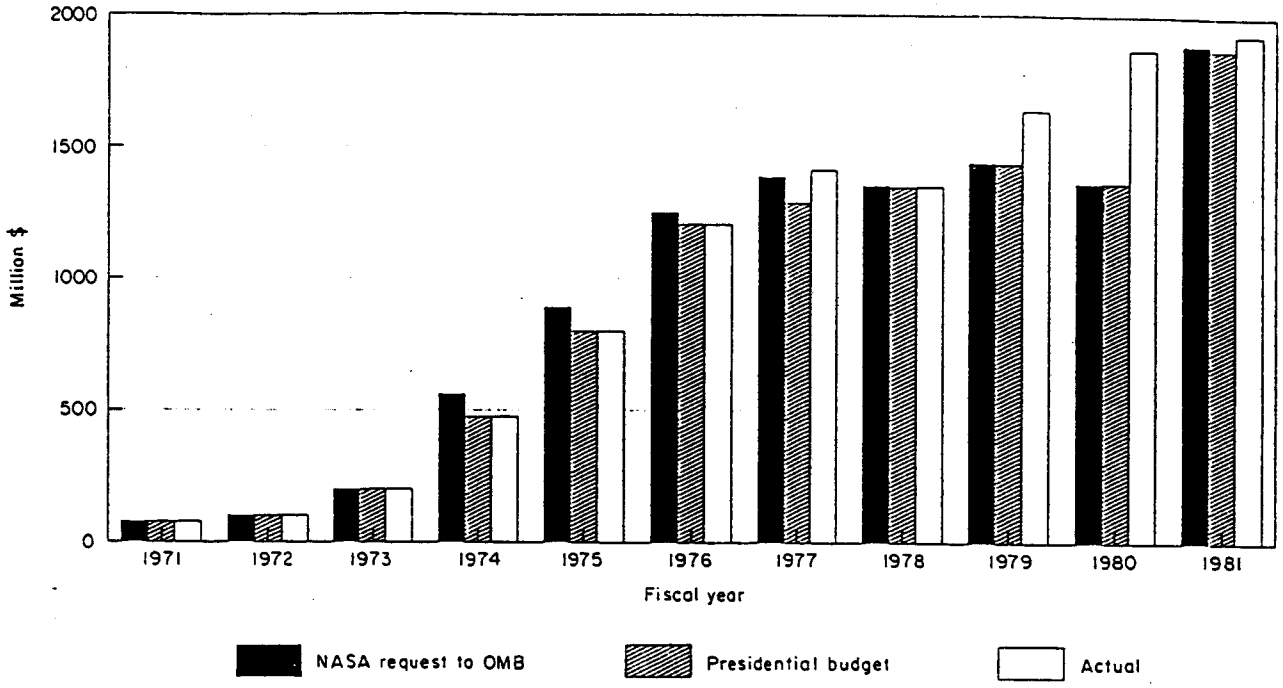

Figure 1. Space Shuttle programme, 1971–81: development and production funding.
Source: Cohen and Noll, NASA, 1991.

[19]A detailed accounting of the methodologies used and justifications supporting the performance evaluation on which this article is based can be found in R.A. Pielke, Jr, and R. Byerly, 'The Space Shuttle program: performance versus promise', in R. Byerly, ed, *Space Policy Alternatives*, Westview Press, Boulder, CO, 1992, Ch 14.

[20]Another measure of capability (not found in Pielke and Byerly, *ibid*) is reliability. According to OTA, NASA originally intended each orbiter to have a per-flight

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performance may be measured. Perhaps more importantly, the programme's initial promises were an agreement between NASA, Congress and the administration.[19]

Table 1 summarizes the evaluation of Shuttle performance with respect to the promises made at initial programme approval.[20] Egregious failures occurred with respect to cost per flight, annual flight rate, total flights and vehicle reliability. The performance evaluation clearly shows that the Shuttle programme experienced a performance shortfall with respect to its original goals. These data suggest that to understand why this performance shortfall occurred, we must look beyond allegations of a weak commitment to the programme.

Table 1. Summary comparison of goals and achievements for the Shuttle programme through 1990.

Goal	Promise	Performance	Difference
First flight	1978	1981	3 years
Total cost	$51 billion	$65 billion	$14 billion
Average cost per flight			
Including development	$88 million	$1.7 billion	$1.612 billion/flt
Excluding development	$14 million	$1.1 billion	$1.084 billion/flt
Flight rate			
Annual average	48	4	44 flights/year
Total	580	37	543 flight
Reliability[a]	0.9997 (3333:1)	0.966 (30:1)	2 orders of magnitude
Cumulative reliability[b]	2311 flights	21 flights	2290 flights
Payload mass	65 000 lb	49 000 lb	16 000 lb/flt
Manned capability	Yes	Yes	–
Reusable	Yes	Yes	–

[a] Reliability is the probability of losing an orbiter on any single flight. The difference is expressed in terms of odds against failure.
[b] Cumulative reliability is expressed in terms of the number of flights required before the likelihood of an accident becomes greater than 0.50.

Assessing responsibility

The context of Shuttle decisions

Manned space advocates share a grand vision – the colonization of space. As with many visions, this vision is set on improving the human condition. The vision holds that through human colonization of space the immense resources available in the Solar System can be used to ensure that everyone has enough of everything – food, shelter, etc. This vision can be traced from its early beginnings through present policy. The seminal definition of the vision of manned space flight was written in 1952 by Wernher von Braun. His vision is centred on a manned space station that would be permanently occupied in orbit around the Earth. Complementing the space station is a reusable vehicle that would ferry people to and from the station. The station would serve as a transfer point for exploratory missions into the Solar System.[21]

The current Shuttle, Station and the proposed Strategic Exploration Initiative, culminating in a manned mission to Mars, mirror aspects of Von Braun's vision. However, the vision did not always exist as sequential 'next logical steps'. The means to achieve the vision were first construed as an interdependent whole. The following two subsections look at the vision at two points in time: (1) immediately preceding the initial Shuttle decision when the means to achieve the vision shifted from an interdependent whole to sequential steps, and (2) currently, when the distinction between goals and means in pursuit of the vision has become increasingly unclear.

The vision: 1969. The Apollo programme was not part of Von Braun's vision. Rather, it was a political response to the perceived Soviet technological threat[22] which left no infrastructure in orbit that could be used to colonize the Solar System. (Von Braun had in fact argued for a lunar programme strategy that would require creating a space station, an integral part of his vision.) Thus no bridging infrastructure existed from the Apollo to the post-Apollo manned space programme. Therefore the programme was integrated into the vision *post hoc* as the 'first logical step'.[23] However, prior to pursuing the vision as logical steps, NASA, through the Space Task Group (STG), first proposed the entire Von Braun vision.

On 13 February 1969 newly elected President Nixon directed Vice President Agnew to recommend by 1 September 1969 'the direction which the US space program should take in the post-Apollo period'.[24] The recommendation was to include programme and budget options. The STG reported back to the President that a 'balanced' space programme would consist of five programme objectives that should be pursued in any post-Apollo programme.[25] These objectives included: (1) space technology applications, eg communications, (2) military space operations, (3) unmanned ground-based and planetary missions, (4) a space station, space shuttle, space tug and nuclear rocket stage, and (5) international cooperation.

In addition, the STG recommended three programme options 'that would cover a range of future resource levels and be consistent with the goals and objectives recommended by the Task Group'.[26] The three options were simply one goal pursued on three different time scales: a mission to Mars, a mission to Mars soon, or a mission to Mars very soon. The levels of resources estimated to be required for each option

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reliability of 0.9997 (Office of Technology Assessment, *Round Trip to Orbit: Human Spaceflight Alternatives – Special Report*, OTA-ISC-419, US GPO, Washington, DC, 1989). For 50 flights with 49 successes the observed success rate is 49/50 or 0.98. This corresponds to a lower bound of the 0.50 confidence interval of 0.966. That is, statistically, the actual reliability has a probability of 0.50 of being greater than this number under these observations (49/50). Similarly, the lower bound of the 0.95 confidence interval is 0.941. Some such number should be used for Shuttle reliability when making policy because it reflects experience without bias. The observed reliability and the 0.50 and 0.95 lower confidence bounds for single-flight reliability correspond to a greater than 50% chance of at least one accident in 34, 21 and 12 flights respectively. For example, a single-flight reliability of 0.966 suggests that the Shuttle has a greater than 50% chance for at least one failure within 21 flights.

[21] W. von Braun, 'Crossing the last frontier', *Collier's*, 22 March 1952, p 24.

[22] This thesis is documented in W. McDougall, ... *the Heavens and the Earth: A Political History of the Space Age*, Basic Books, New York, 1985.

[23] It is an interesting question whether the choice of means to conduct the Apollo programme made a significant difference to the post-Apollo programme. Had NASA chosen Earth-orbit-rendezvous (EOR) rather than lunar-orbit-rendezvous (LOR) to get to the Moon and back, there would have been bridging infrastructure from Apollo to post-Apollo. However, it is uncertain what policy makers would have done with it. This observation has been made several times since the Apollo era. For example, see Christopher B. Roberts, 'NASA and the loss of space policy leadership', *Technology in Society*, Vol 12, 1990, pp 139–155, esp p 143.

[24] *The Post-Apollo Space Program: Directions for the Future*, Space Task Group Report to the President, September 1969, p 27.

[25] *Ibid*, pp 12–15.

[26] *Ibid*, p 19.

ranged from slightly less than that required during the Apollo programme's peak, to almost twice that number. The STG report defines the post-Apollo vision in terms of both objectives and means.

With hindsight it is obvious that the range of options presented by the STG did not realistically reflect the political and fiscal environment of the post-Apollo period as neither Congress nor the President selected from the recommended options. However, NASA did not abandon pursuit of its vision, but rather changed to a more politically palatable strategy.

Instead of the space station being the centrepiece of the post-Apollo plan, as it was in the STG report, NASA chose the space shuttle.[27] This was both logically and politically necessary. The proposed space station programme was estimated to cost much more than the space shuttle. Thus the shuttle was more politically palatable in an era of declining or constant budgets. Furthermore, the space station could not exist without some means to get to it; logically, having a space station meant having a shuttle. Therefore NASA decided to pursue the vision in a series of 'logical steps', of which the shuttle was step one.[28]

Thus the transition from Apollo to post-Apollo set the context for the Shuttle decision. Several factors from this period bear remembering. First, from NASA's perspective the vision of manned space flight emerged intact, but with increased emphasis on the means necessary to pursue the vision. The space shuttle, space station and possible missions to Mars were to be pursued serially, rather than in parallel as recommended by the STG. Second, from the perspective of Congress and the administration the vision in the form of the shuttle, station and mission to Mars had been soundly rejected in the political process as unreasonable at that time. To gain approval, a shuttle had to be justified as worthwhile in and of itself. Thus the manned space element within NASA found itself in the paradoxical position of pursuing a vision that had been rejected in the political process. This asymmetry of expectations between Congress and the administration on the one hand and NASA on the other set the stage for the misjustification of the programme in terms of cost effectiveness, and ultimately the programme's poor performance with respect to that justification.

The current vision. In 1986 the presidentially appointed National Commission on Space issued a report which updated and restated the vision, and means through which it would be achieved. The report opens: 'Our vision: the Solar System as the home of humanity'.[29] The report recommends three primary goals for the space programme: science, manned exploration, and stimulating economic benefits to be achieved through advancing technology and providing low-cost access to space.[30] The report also recommends six types of technological milestones: establishing a permanent orbiting base, developing lower-cost transportation back and forth from low-Earth orbit, developing vehicles for transportation in Earth orbit, developing nuclear transportation to the outer planets, developing lunar infrastructure, and developing Martian infrastructure.[31] The context has changed, but the vision – in terms of both objectives and means – as defined by Von Braun and adapted to the post-Apollo period had remained essentially the same.

A more recent invocation of the vision indicates that the post-Apollo vision may be changing:

The Space Exploration Initiative is a vision for the 21st century. It is a vision of

[27]There are several possible reasons which explain why NASA did not choose to advocate using Apollo hardware more in the post-Apollo period. First, decreasing budgets would have limited what could have been done, eg a permanently manned station as opposed to the man-tended Skylab would have required keeping the Saturn rocket line open, at that time considered expensive. Second, and perhaps more importantly, the Apollo hardware was not part of the vision of manned space flight, and hence the full significance of its availability was not recognized until too late.

[28]According to a white paper prepared for the *Challenger* investigation by J.P. Loftus, Jr, S.M. Andrich, M.G. Goodhart and R.C. Kennedy entitled 'Evolution of the Space Shuttle design', 'As studies of the Station and a fully reusable Shuttle were pursued, it became clear that concurrent development would require more than a doubling of NASA's budget, unrealistic at any time and particularly so in the light of increasing military expenditures in Southeast Asia . . . In April, 1970, during Congressional review of the FY 1971 budget, NASA Comptroller W. Lilly indicated that the Shuttle must precede the Station because if they could not be developed concurrently, the Shuttle in extended sortie, could act as a surrogate station and the long term future of space flight lay in reducing the cost of all operations, but foremost in the cost of delivery to low Earth orbit.'

[29]*Pioneering the Space Frontier*, Bantam Books, New York, 1986, p 3.

[30]*Ibid*, p 5.

[31]*Ibid*, summarized pp 17–18, detailed pp 93–142.

America reaching beyond itself, and onward, beyond the very bounds of this planet to an entirely new world. On the way there, we will reap the real, tangible benefits of space exploration. Space is clearly our most challenging frontier. Enroute to Mars we will explore the Moon, advance Earth sciences, and develop new innovative technologies. We will tap lunar, Martian, and solar energy resources as we explore the heights of human talent and ability. Along the way, America's drive, initiative, ingenuity and technology – all those things that have made our nation the most successful society on Earth – will propel us toward a future of peace, strength, and prosperity.[32]

In this version of the vision the Space Station, once the keystone of the vision, is de-emphasized. This may signify adaptation of the vision to changing fiscal and political conditions.

To summarize, the vision of manned space flight is a critical factor in the course of events which led to NASA's pursuit of the Space Shuttle programme. In particular, how the vision was initially proposed through the STG and subsequently rejected in the political process shaped NASA's decision to justify the programme in terms of cost effectiveness and to promise more than the programme could deliver. The analysis now turns to initial programme approval and the subsequent development period.

The initial decision: 1969–72

Events leading up to the decision to build the Space Shuttle are well documented. However, a policy appraisal of the programme based only on the decision and its preceding events is necessarily flawed as most experience and many decisions have occurred since. Thus the period analysed in this section constitutes only one part of the assessment of responsibility for the programme's poor performance. While it is true that no amount of analysis can make the 1972 decision better, an understanding of why the decision led to a performance shortfall can serve to help decision makers avoid making similar mistakes in the future.

The 1972 presidential announcement of support for the Shuttle programme was the result of several years of planning, compromise and debate between several government agencies, the Office of Management and Budget, the administration and private interest groups – not unlike most major policy decisions. The performance shortfall which followed the decision suggests that the decision process which culminated in the Shuttle was flawed, and that lessons can be learned from that experience.

However, learning the lessons of past mistakes is not always an easy task. In 1986 NASA Administrator James Fletcher wrote of Shuttle programme analyses:

The shuttle decision was made within the realities of 1970–1972 and was specifically based on what was known in 1971. The shuttle was developed within the realities of the decade that followed. With hindsight it is now possible to point to criticisms that have proved to be right, to advocacy statements that have proved to be wrong, and to decisions that might have been different. But it has, nevertheless, brought this nation most of those things for which it was developed.[33]

Fletcher identified a key aspect of improving the policy process, the use of hindsight, but dismissed it as insignificant, concluding that the programme is a technical success. Given that the Shuttle decision was based on what was known in 1971, two important questions need to be

[32] *America at the Threshold: America's Space Exploration Initiative*, Final Report of the Synthesis Group, chaired by Thomas P. Stafford, US GPO, Washington, DC, 1990, p iv. Throughout this report the Space Station's role in the vision is de-emphasized in favour of technologies such as nuclear propulsion.
[33] Fletcher, *op cit*, Ref 7.

asked. Why was it that the critics, whose preliminary appraisal of the programme turned out to be correct, did not emerge as winners in the policy process? And, given that we cannot improve or change the past decision, what lessons can be learned from a less-than-perfect decision that will improve future decisions?

The decision process which culminated in the Shuttle programme is an intricate weave of participants, perspectives, goals and strategies. To help understand this tapestry, three interconnected factors have been chosen for elaboration because they best explain the outcome of the Shuttle decision process and why the programme was ultimately misjustified. These factors are control, compromise and cost.

Control over alternatives. The recommendations of the STG had been left to cool on President Nixon's desk for six months. When Nixon finally did reply in a statement on the future of the space programme on 7 March 1990, his support fell far short of that recommended. His policy statement was more about reining in the space programme than setting a course for the future.

> We must now define new goals which make sense for the seventies. We must build on the successes of the past, always reaching out for new achievements. But we must also recognize that many critical problems here on this planet make high priority demands on our attention and resources. By no means should we allow our space program to stagnate. But – with the entire future and the entire universe before us – we should not try to do everything at once.[34]

The response signified to NASA that a different strategy for pursuing the vision would be necessary: The budget dictated that the parts had to be pursued serially, logic dictated that the Space Shuttle come first.[35]

Fletcher, assuming the priority of the vision, made it clear in his first news conference as Administrator on 10 May 1971 that 'if you have to decide between the shuttle and the space station, you pick the shuttle first because you have to have that for the second'.[36] The Shuttle was assumed, and this assumption was difficult to challenge.

However, the assumption was challenged in some quarters. Donald D. Rice, OMB assistant deputy director during the period of the Shuttle decision, recalled in an interview four years later that 'what sticks in my mind more than anything else was the difficulty of getting any solid attention paid to alternative designs. I don't mean alternative in the technical detail sense, but alternative in terms of mission requirements and why that mattered.'[37] Senator William Proxmire, a Shuttle opponent, had much the same feeling. He stated on the Senate floor that,

> I have written to NASA on a number of occasions to ask whether . . . there is a need for the space shuttle–space station. All NASA has told me in reply is that first, the shuttle would enable us to continue to have an active space program, and second, it would reduce the costs of the space program. But why do we actually need it? What would it help us to accomplish that we could not otherwise accomplish? NASA seemingly has no answers to these questions.[38]

According to the current NASA historian, 'the debate shifted from one of whether or not to build a Shuttle to one of what type of Shuttle should be built during the latter half of 1971'.[39] This implies that any serious discussion of possible Shuttle alternatives would have occurred between mid-1970, when it became apparent that NASA wished to pursue the Shuttle, and mid-1971, when the Shuttle had been generally accepted by Congress and OMB. However, no evidence has been found which

[34] *Public Papers of the Presidents of the United States: Richard Nixon, 1979*, US GPO, Washington, DC, 1971, pp 250–253, quote from p 250.
[35] At this time OMB limited NASA to level budgets, effectively limiting the total that could be spent on Shuttle development.
[36] As transcribed in *Astronautics and Aeronautics: 1971*, pp 127–128.
[37] Donald D. Rice interviewed by John M. Logsdon, 15 November 1975, NASA History Division Reference Collection. His use of 'design' is equivalent to the term 'concept' as used in this article.
[38] *Congressional Record*, 26 May 1971, p S7811-2.
[39] Launius, *op cit*, Ref 3, p 15. Launius also notes: 'NASA and OMB and the White House participated in additional give and take over the Shuttle's configuration, size, and capabilities during the late fall and early winter of 1971 . . . There was not much difference of opinion, however, over whether there would be Shuttle' (p 17).

suggests that alternative concepts to the Shuttle were ever seriously considered.

Controlling the range of alternatives in a policy debate is not unique to this situation. A body of experience and theory suggests that in many situations it is politically expedient to try to limit the scope of alternatives in order to gain acceptance of preferred outcomes. However, rationality requires that a range of alternatives be introduced into the decision process with the purpose of achieving a decision that is most likely to serve formal goals. Democracy requires that a range of alternatives be introduced into the decision process with the purpose of achieving a decision that is acceptable to a wider interest.[40]

While it is true that in many instances NASA cannot be considered to speak with one voice, it is clear that there was little, if any, debate within the agency over whether a Shuttle should be pursued.[41] The debate within NASA was focused on alternative Shuttles rather than Shuttle alternatives. Thus without alternative concepts coming from NASA, which had a virtual monopoly on civil space technology expertise, it was left to the Congress and administration to ensure that alternatives were considered. Perhaps the best opportunity for alternatives to be considered came on 23 April 1970 on the House floor when Joseph E. Karth, Chairman of the House Subcommittee on Space Science and Applications and a NASA supporter, offered an amendment to NASA's FY 1971 appropriations bill that would have deleted funding for the Space Shuttle and Space Station pending consideration of alternative concepts which could achieve the goals of the Shuttle. Karth wanted alternatives considered because he believed that 'The space shuttle station [*sic*] in my judgment is a start, I think an essential start to the manned Mars landing program. I think that it is the first step, because without the space shuttle and without the 100 man space station to assemble the various spacecraft and other paraphernalia to get them to Mars and to the huge space station, no Mars program is possible, and I defy anyone to dispute that.'[42] Others in the House did dispute Karth. While Karth believed that alternatives to the Shuttle should be considered, others were sold on the merits of the Shuttle itself. Rep Richard Roudebush (D–IN) argued that 'I am puzzled by the statement that the shuttle is in some way mixed up with the Mars landing, when nothing is further from the truth . . . the purpose of the space shuttle is simply this; to go out and work on satellites such as communication satellites, to refurbish them, and to take men to and from a space station inner earth orbit'.[43] On this day debate was focused on the nation's need for a Shuttle orbiter and its possible alternatives, ie whether the Shuttle had intrinsic merit, or was just a first step in a Mars programme.

Karth's amendment was defeated 53–53. Had Karth's amendment passed, we cannot be certain that it would have made any difference as its effects could have been reversed at a later date. However, what is certain is that the defeat shaped thinking and outcomes on subsequent Shuttle termination votes, none of which were as close as this one.[44] The House and Senate were thus unable to force NASA to consider alternative concepts.

The significance of the 1971 termination attempts did not go unnoticed by NASA. If supporters of the Shuttle in Congress did not believe the programme to be part of the grand vision of colonization or did not support the vision itself, then NASA could not promote the

[40]E.E. Schattschneider, *The Semi-sovereign People: A Realist's View of Democracy in America*, Dryden Press, Hinsdale, IL, 1975; and J. March, 'Theories of choice and making decisions', *Society*, November/December 1982, pp 29–39.

[41]See W.J. Normyle, 'NASA divided over space shuttle', *Aviation Week and Space Technology*, 13 April 1970, for details on debate on the Shuttle within NASA.

[42]*Congressional Record*, 23 April 1970, V 116, p 12865, debate on Karth's amendment on pp 12864–12869.

[43]*Ibid*, p 12867.

[44]Reinforcing the precedent set by the House vote were two votes on the Senate floor to delete Shuttle funds. Both were offered by Sen Walter Mondale (D–MN) and were defeated by 28–32 and 26–50, on 6 July and 7 December 1970 respectively.

programme on that basis. Thus the Shuttle had to be sold on its own merits. NASA publicly distanced itself from linking the Shuttle to the vision. On 28 January 1971 George Low, Acting Administrator, stated, 'We have in our program today no plans for a manned Mars landing. Our exploration of Mars . . . will over the next many years be carried out with unmanned spacecraft . . . I repeat, we have no plans at this time for manned Mars landing missions.'[45] This was a step towards focusing the justification on the cost effectiveness of the programme.

As the administration had determined that it would support a Shuttle of some type in mid-1971, no consideration of alternatives to the Shuttle originated there. Thus NASA had remained steadfast in its pursuit of the Shuttle, and was allowed to do so without considering alternatives. The resulting political environment dictated the strategies that would be necessary to secure the programme as a fixture in NASA's budget. NASA's control of the scope of alternatives in the post-Apollo period mean that opposition to the Shuttle programme had to argue against the NASA concept. Thus, unable to present a viable option to argue for, the opposition had the deck stacked against them to begin with as approval of some post-Apollo manned programme was almost certain. With hindsight it is clear that the Shuttle opponents overlooked the existing space infrastructure, eg Saturn V hardware, as components of an alternative space programme to argue for.

A compromised design. While the Shuttle concept was firmly established by mid-1971, the actual design and exact capabilities of the vehicle were not. In order to build support for the programme and to meet the fiscal realities of the 1970s, NASA made several major compromises to the Shuttle design. These compromises were a necessary continuation of the compromises which had been made in the STG's post-Apollo plan. The political system was winnowing NASA's requests down to something that was politically acceptable. NASA's initial post-Apollo shuttle had not yet reached that point, and the period leading to the President's decision to support the programme saw progress through compromise to a more politically acceptable programme.

The evolution of Shuttle designs was not a linear process. That is, designs were not always considered serially, moving from one to the next, but often in a parallel process which sought to satisfy the needs of the political system as well as technical constraints. With the advantage of hindsight it is clear that meeting the political constraints was a higher priority than satisfying technical constraints implied by the concept.

For two reasons the argument that if the 'original' design favoured by NASA had been approved technical performance would have better approximated promises is flawed.[46] First, there is no such thing as an 'original' design. The programme's final design was the result of a process of the evolution of many different designs. Instead, what existed was an original concept in terms of the vision that never changed, and original justifications which did. Second, programme goals and objectives are not fixed or off limits for compromise. Performance could have better matched promises if the programme concept had been scaled down to match the evolution of the programme design that was occurring to meet the political realities of the period. Some will claim that this logic presents a Catch-22 for manned space advocates as scaling down promises could have possibly caused programme termination.

[45]As quoted in Pace, *op cit*, Ref 3, p 26.
[46]Recall that the original concept, the Earth-to-space station vehicle, had not been approved as Nixon had rejected the recommendations of the STG. However, NASA sought to maintain many capabilities entailed by the original concept, and simply changed the justification of the programme to meet the test of political acceptability.

This begs the question: Is doing something poorly better than not doing it at all?

The Shuttle programme was not exclusively a product of the late 1960s.[47] Rather, its roots can be traced back at least 25 years. Pace argues that 'as a result of numerous studies, some going back to World War II, [design] concepts involving horizontal take-off, vertical landing, nuclear propulsion, single-stage-to-orbit, three stage systems, and expendable spacecraft had been eliminated . . . Design selection started from the premise of some sort of two-stage, vertically-launched, horizontal land-landing, reusable or partially reusable system.'[48] These constraints, while many, left much room for consideration of alternative designs to meet a spectrum of concepts.

At least early in the design process a single design never existed. In September 1966 a joint DoD–NASA group, the Aeronautics and Astronautic Coordinating Board, issued a report on shuttle design. A subpanel of the board 'could not identify *one single [design] concept* capable of satisfying both the future needs of NASA and the needs of DoD, and thus the subpanel summarized a variety of proposed systems'.[49] Further research suggests that the evolution of the Shuttle design in the late 1960s did not occur in any ordered manner, but in haphazard fashion in response to the political and fiscal environment in which NASA operated.

The argument could be made that the Phase A contracts issued by NASA to study the Integrated Launch and Re-entry Vehicle (ILRV) are candidates for the 'original' design.[50] However, 'both MSC and MSFC emphasized that the RFP [Request for Proposals] would not necessarily result in an actual development program'.[51] Hence labelling any of the ILRVs the original design is problematic. Many configurations were examined between the initial Phase A ILRV studies and the end of primary Phase B period, January 1971.[52] During this period NASA continued to study fully reusable designs, but began to accept partially reusable designs as more realistic in a constrained fiscal environment.

Jumping forward in time past literally hundreds of different designs, in August 1971, near the end of the Phase B extension studies, NASA had a design from which the final design would directly evolve.[53] This design was the result of compromises to satisfy payload size and weight, and crossrange capabilities of the DoD in exchange for their support of the programme.[54] According to Hallion, 'In brief, the Air Force was willing to support the Shuttle in Congressional hearings providing it had utility for the defense community. For its part, NASA considered such support vital if the STS [Space Transportation System] were to withstand the attacks of Congressional critics from both parties questioning the space program's need and rationale.'[55] In a common bureaucratic practice NASA traded utility for support. The problem associated with compromise then lies with not adjusting the programme concept to reflect the constraints of the compromised design – not with having to compromise at all.

The lesson of the design compromise is the following. When programme design was compromised to garner support, the concept was not correspondingly compromised. This gave the programme little chance from the outset to meet its stated goals. Before dismissing the argument that design changes caused the performance failure we might suppose that the design compromises were not made, and assume that an

[47]This section is only a rough history of the evolution of the Shuttle design. For a more complete story consult Pace, *op cit*, Ref 3, and the thorough research done by Hallion, from which much of the detail here is drawn: Richard P. Hallion, *The Hypersonic Revolution, Vol II: From Scramjet to the National Aerospace Plane, 1964–1986*, Wright-Patterson Airforce Base, Dayton, OH, 1987, Case VIII: Chapter I, 'The path to the Space Shuttle', pp 947–1174.

[48]Pace, *op cit*, Ref 3, pp 58–59.

[49]Hallion, *op cit*, Ref 47, p 964 (emphasis added).

[50]Phased contracts is NASA terminology for project planning: Phase A = advanced studies and preliminary analysis, Phase B = project definition, Phase C = design, Phase D = development and operations. Pace, *op cit*, Ref 3, pp 60–64; Hallion, *op cit*, Ref 47, pp 995–1036.

[51]Hallion, *op cit*, Ref 47, p 995.

[52]Hallion reproduces designs of about 30 of these, including an odd 'Blue Goose', *ibid*, pp 998–1035, Figures 30–59b.

[53]*Ibid*, p 1051. The design was labelled the 040, and the final design that would evolve was called the 040C.

[54]Pace (*op cit*, Ref 3) details extensively the technical trade-offs that were made in securing programme approval.

[55]Hallion, *op cit*, Ref 47, p 1041. Hallion observes also that 'as the 1970s progressed, however, congressional opposition to space in general and Shuttle in particular gradually withered, freeing NASA to proceed with Shuttle development unimpeded by significant Congressional opposition'.

'original' concept could be found. There is little reason to believe that a more complicated, eg fully reusable, design would have performed better with respect to promises than the current one, and even less reason to believe that it would have been approved. Furthermore, the argument that additional resources should have been provided to build a more complicated design is a question of commitment rather than compromise and was addressed above. As will be seen next, failure to readjust the concept exacerbated the policy failure caused by misjustifying the programme in terms of cost effectiveness.

Cost effectiveness: a misjustification. Prior to Nixon's announcement of support for the programme, costs had played an increasing role in the programme's public justification. In May 1971 NASA contractor Mathematica, of Princeton, New Jersey, released a report which examined the costs and savings that would be realized from the Shuttle programme.[56] The report concluded that the fully reusable Shuttle would approximately break even by flying 600 missions between 1978 and 1990 while incurring $12.9 billion in non-recurring costs.[57] These figures helped NASA, but were unlikely to sell the programme to Congress because breaking even meant that the decision hinged on factors other than cost. NASA wanted the decision to have obvious general benefits as perceived in Congress, eg providing the country with net savings.

NASA abandoned the fully reusable Shuttle in search of one which could be proven to be more cost effective. In the words of one NASA veteran, 'Since the political support for the space program was at a low ebb in the early 1970s, Fletcher and his staff were driven to make economic justification – something that was new to NASA since these were not necessary during the Apollo program . . . *Fletcher asked [Mathematica analyst] Heiss to calculate under what circumstances the shuttle could be operated less expensively than conventional launch vehicles.*'[58] What emerged from the search were requirements for a design that could be proven by Mathematica using economic analysis based on planned capability to be cost effective under the fiscal constraints that had been placed on the programme. The design would break even at between 300 and 360 flights over the 1979–90 period.[59] A second Mathematica analysis was completed prior to Nixon's decision.[60]

One point that should be made clear here is that the Shuttle programme was dependent upon the Space Tug to achieve the cost savings that were projected.[61] However, almost immediately after programme approval the Space Tug was deferred for fiscal reasons. What was to have served in its stead until the Tug could be completed was the initial upper stage (IUS). The IUS flew on the Shuttle once – unsuccessfully – and was barred from further use after the *Challenger* accident due to the technical risk. It was possible to recognize that the programme would have little chance of performing as promised as early as 1973, when the Tug was deferred, but the significance of this was overlooked.[62]

Almost immediately after Nixon's announcement of support critics of the programme focused on the cost argument. In the *Chicago Sun-Times* on 12 January 1972 one columnist commented,

> What the President offered last week was not a completely reusable workhorse aerospace plane at all, but a scaled-down hodgepodge of obsolete, current and avant garde technology that cannot possibly meet the stated goal of $100-a-

[56]Mathematica, Inc, 'Economic analysis of new space transportation systems', 31 May 1971.
[57]See Pace, *op cit*, Ref 3, pp 30–31 for discussion.
[58]Mark, *op cit*, Ref 1, p 49 (emphasis added).
[59]Pace, *op cit*, Ref 3, p 39.
[60]Klaus Heiss and Oskar Morgenstern, 'Factors for a decision on a new reusable space transportation system', memorandum to NASA Administrator Fletcher, 28 October 1971, cited in Pace, *ibid*.
[61]This observation is made by Banks, 'The Space Shuttle', in Cohen and Noll, *The Technology Pork-Barrel*, Brookings Institution, Washington, DC, 1991, pp 185–186.
[62]See *US Civilian Space Programs: 1958–1978*, Committee Report, US House of Representatives, Committee on Science, Space, and Technology, US GPO, Washington, DC, 1981, Vol 1, pp 505–515 for details on the history of the IUS, and pp 515–516 for details on the history of the Space Tug.

pound payloads in 1980. The sad truth is that the original shuttle couldn't, either, once it became apparent that development costs would approximate $13 billion rather than the $5.2 billion estimated in 1969. As backers of the defunct supersonic transport finally had to admit, when you markedly alter the development cost of a flight system, you alter its economics also.[63]

Another analyst was more blunt: 'The proposed space shuttle can be likened to building a goldplated limousine to deliver small bundles; once built, its existence becomes the justification for delivering lots of bundles.'[64] Other critics of the programme emerged in the months following, most taking aim at the costs of the programme.[65] Despite the criticism the programme sailed through Congress without much resistance. At least one member of the House, Charles A. Vanik (D–OH), recognized the logic behind the economic argument: 'If we pass the [Shuttle] authorization we will be placing ourselves in the difficult position of spending money to save [money].'[66]

The programme can be said to be misjustified for three reasons. First, assuming that the programme could be successfully operated at a rate of about 48 flights per year with a 65 000 lb payload as promised, this amounts to over 3.1 million lb that could be launched into orbit annually. However, at the height of the Apollo programme the maximum payload weight launched into orbit in any year was about 470 000 lb.[67] There was no apparent justification for the need to increase the ability to launch mass into orbit by a factor of about 6.5 over that required at the height of Apollo. Second, related to the mass argument is the fact that there were not enough payloads planned to meet the planned capability; as it was the Shuttle had to launch all planned payloads, obviating the need for other launch vehicles and creating a single failure point in US launch capabilities.[68] Finally, the justification was made to meet the political constraint of cost effectiveness. This cost-to-design policy is exactly the opposite of how effective policy should have been made. Effective policy would have designed the programme to the level of resources determined to be available, ie design to cost.

Why did a concept which, with hindsight, failed so dramatically to meet its promises pass through Congress (and continue to do so year after year) when credible experts were accurately appraising the programme's chances for success? Like most decision process analyses there is no simple answer (despite the wishes of the analyst), but four factors can be pulled from the tapestry of the Shuttle decision to help explain the decision.

The President. First, it should be recognized that individual perspectives and beliefs do make a difference in policy outcomes. In this case Nixon's commitment to the programme aided in the promotional process. As will be suggested below, some manned civil space programme would have almost assuredly been approved by Nixon. In this case presidential support helped the Shuttle programme favoured by NASA gain enough support to win congressional approval. According to Launius, Nixon's own predispositions contributed to his giving support to the programme: 'Nixon was friendly toward the space program, believed it important, and that it was a rallying point for the nation at a time when there did not seem to be many around. He especially thought of the astronauts as heroes, people very important for America to look up to as the nation dealt with Vietnam, racial violence, and economic difficulties.'[69] Furth-

[63]W. Hines, *Chicago Sun-Times*, 12 January 1972, p 16, as quoted in *Astronautics and Aeronautics 1972*, p 16.
[64]D.S. Greenberg, *Science and Government Report*, Washington, DC, 1 June 1972, p 1.
[65]For examples of the type of criticisms raised over Shuttle programme costs see R.E. Lapp, 'Cost of the Space Shuttle', letter to *Science*, 3 March 1972, p 944; and B.T. O'Leary, letter to the *New York Times*, 16 May 1972, p 40.
[66]Quoted in *Congressional Quarterly Almanac*, 1973, p 880.
[67]*US Civilian Space Programs: 1958–1978, op cit*, Ref 62, Vol I, Appendix G, 'Master log of US space flights', pp 1247–1339.
[68]Additionally, even if enough payloads could be generated to fill the manifest, it is unlikely that resources would have been made available to pay for them. OTA has estimated that mission payloads launched between 1963 and 1978 cost about $200 000–800 000 per lb. With several million pounds of launch capability the payload costs become large quickly, even with free launches. Thanks to Ray Williamson for this observation. See US Congress, Office of Technology Assessment, *Affordable Spacecraft: Design and Launch Alternatives Background Paper*, OTA-BP-ISC-60, US GPO, Washington, DC, January 1990.
[69]Launius, *op cit*, Ref 3, p 16.

ermore, Nixon was preparing for a re-election campaign. According to John Erlichman, Nixon's domestic advisor, 'When you look at employment [for the aerospace industry], and you key them to the battleground states, the space program has an importance out of proportion with its budget . . . So you must not underemphasize that element, the employment element in Nixon's decision on the whole manned space program.'[70] Thus the President's predispositions and perspectives were an integral factor in the Shuttle programme gaining initial approval despite the warnings of a vocal minority of credible critics. With his endorsement, the President can enlist a significant amount of partisan support for the programme. This was a necessary, but not sufficient, condition for the programme to gain first approval, and continue to have strong support through development.

Pork-barrel politics. Another factor which contributed to the programme gaining enough support to win initial approval and carry it through the 1970s was that many congressional delegations benefited economically from the programme's existence. As with the other factors which contributed to building support for the programme, the district benefits probably did not have enough influence to carry the programme alone. NASA sought to maximize the scope of sending dollars to districts so that the programme had the greatest chance for political success.

NASA was no stranger to the importance of satisfying the needs of those in Congress. *Newsweek* magazine editorialized that the 'two greatest resources' that influenced NASA to locate the Manned Space Center (now the Johnson Space Center) in Houston, Texas, were then Vice-President Lyndon B. Johnson and Representative Albert Thomas (D) of Houston. Furthermore, Senator John Sparkman (D–AL) publicly took credit for the Marshall Space Center being located in Huntsville, Alabama.[71]

One aspect of the pork-barrel politics involved locating the Shuttle launch and landing sites. In April 1970 NASA established a 14-member Space Shuttle facilities group that was to recommend where the programme should be located. The group was open to any and all suggestions, giving the impression that any site could be chosen. The group 'quickly selected 35 to 40 locations for serious consideration', covering about 10% of all congressional districts.[72] In December 1970 the *Wall Street Journal* ran an editorial which took issue with the strategy taken by NASA to help gain support for the programme: 'There's a lot to be learned from the space shuttle, we have no doubt. The scientific results will be greatest, though, if NASA manages to locate the project where it can be managed most efficiently – and not merely where local Congressmen are most adept at gathering spoils.'[73]

The strategy, despite its detractors, was a contributing factor in gaining support for the programme.[74] The selection was to have been made in October 1971, about the time that the President was to decide whether or not to support the programme. However, when the President's decision was put off for several months that October, prior to site selection, NASA announced that selection of launch and landing sites would be delayed for six months as well.[75] This kept all contenders in the running when support had to be maximized.

Pork-barrel politics was a necessary, but not sufficient, factor in the programme gaining initial approval despite the warnings of experts that the promises made by NASA were unrealistic and certain not to be met.

[70] *Ibid*, quote from p 17.

[71] Information and *Newsweek* quote in this paragraph from Claude E. Barfield, 'Space report/NASA feels pressures in deciding on location for its space shuttle base', *National Journal*, 24 April 1971, pp 869–876.

[72] Barfield, *ibid*.

[73] *Wall Street Journal* editorial of 7 December 1970, as reported in *Astronautics and Aeronautics: 1970*, p 391.

[74] Consider Governor Dewey J. Bartlett of Oklahoma who told state legislators that Oklahoma could become the launch site for the Space Shuttle: *Daily Oklahoman*, 6 January 1971.

[75] The delay in site selection was characterized in terms of development problems, not political problems: *Astronautics and Aeronautics: 1971*, p 281.

Expertise and accountability. The third factor is more protean. It deals with the role of the 'expert' in a democracy. Experts may be thought of as individuals with a particular area of substantive knowledge. Thus bankers, lawyers, politicians, doctors and scientists are all examples of experts. Democracy depends on bringing disagreements among experts to the population as a whole for compromise and resolution. However, a problem arises when the experts do not disagree and policies which are consistent with their special interest, as opposed to the common interest, are pursued.[76] The Space Shuttle decision may be an example of this problem.

As detailed above, NASA and its contractors (the space experts) had a vested interested in controlling the scope of alternatives considered in the Shuttle decision process to give the vision of next-logical-steps a greater chance for gaining political approval. Also detailed above, many politicians (the decision process experts) had a vested interest in seeing the programme approved as it provided benefits for their constituents. Thus, with conflict confined to NASA's preferred concept the search for solutions to the problem presented by the post-Apollo space programme was short-circuited, and the common interest was not served as well as it might have been.

While an examination of the problem presented by expertise goes beyond the scope of this article, it is an important subject for discussion, and the Shuttle programme can be a case study to be taken for consideration.[77] Certainly, the agreement of the experts in a close debate was a factor in the programme gaining initial approval, and continuing to be strongly supported through the 1970s and 1980s.

A final factor is the role of accountability in the democratic process. If incentives do not exist for programmes to perform as promised, then there is little reason to believe that they will. Certainly the political and bureaucratic environment surrounding the Shuttle decision did not emphasize accountability. Expectations must be created that performance will be compared to promises, and that commensurate sanctions will be enforced by Congress acting on behalf of the people when performance does not meet promises. Performance as promised is a hollow prescription if accountability to the general welfare does not exist.[78]

To summarize, the period leading up to Nixon's decision to approve the Shuttle is part of the assessment of responsibility for the programme's performance shortfall. NASA's control of consideration of alternative concepts, and subsequent decisions not to alter the concept when the design was compromised, gave the programme little chance of meeting its stated promises. Furthermore, misjustifying the programme in terms of cost effectiveness made the chances for performance as promised even less likely. However, despite a vocal minority of critics, programme approval may be understood through consideration of the President's support, pork-barrel benefits, collusion of experts and an expectation of non-accountability. The next section examines the post-decision period leading to Shuttle operations.

Post-decision development: 1972–81

The post-decision development period was marked by a strong commitment, technical problems and delays, and the reassessment of goals and objectives for the programme.

[76]Common interests, at the level of the space programme, might be thought of as the efficient use of resources towards attaining some perceived national goal or objective that is publicly recognized. This may be contrasted to satisfying special interests which target a goal that is not widely shared.

[77]Such a case study might begin by examining J. Dewey, *The Public and its Problems*, Gateway Books, Chicago, IL, 1946, esp pp 123–127 and 203–109; H.J. Laski, 'The limitations of the expert', *Harper's Magazine*, Vol 162, 1930, pp 101–110; and H.D. Lasswell, 'Must science serve political power?', *American Psychologist*, Vol 25, February 1970, pp 117–123.

[78]Thanks to Donald P. Hearth for this observation.

Funding: a strong commitment. One misinterpretation of the Shuttle programme experience is that the programme's troubles were largely the result of congressional budget cuts stemming from a weak commitment to the programme. This argument was dismissed above at a general level, but is worth revisiting in greater detail. NASA contributed to this misreading of the historical record. In a January 1980 report on Space Shuttle management NASA stated that 'the program was underfunded at the start and, viewed with investigative hind sight, has been underfunded since'.[79] This claim of inadequate funding is not clearly associated with any standard of measurement. The question is, 'Underfunded with respect to what?' It is assumed that both the initial commitment and subsequent annual appropriations are the focus of the statement.

However, recall that throughout the period 1971–81 Congress funded Shuttle development at or above the President's budget request each year, and that the cuts OMB placed on the programme had a minimal effect. Moreover, NASA received about 110% of the total money it estimated would be necessary for development of the Shuttle at the programme's outset.[80] Congress also passed supplementary appropriations bills in fiscal years 1979 and 1980 which channelled additional funds for the programme when problems occurred near the end of development.

Furthermore, during development Shuttle budgets rose through four presidents and their administrations, and five different congresses. After Bella S. Abzug's (D–NY) unsuccessful termination attempt on the House floor in 1973, the programme was not threatened by a congressional termination attempt through the development period.[81] This evidence indicates that strong support for the programme existed in Congress and the administration, as development of the programme was funded above the level at which the programme was originally sold. This point is difficult to dispute given that NASA received more than it had said would be necessary in 1972 for development of the programme. In addition, after development the programme has been carried out under a very strong commitment. This commitment is perhaps best exemplified by the decision to replace the *Challenger* after its destruction in 1986. Congress overwhelmingly voted to appropriate funds to replace the lost orbiter in a single appropriation.

Thus any realistic claim of underfunding would have to be traced at least to the initial estimates for programme costs. This would imply that NASA proposed a programme in which performance could not be delivered for the amount agreed to. NASA was either egregiously wrong or deliberately misleading in its original estimates of projected cost, schedule and capability.[82]

Thus a close examination of the historical record allows for no conclusion other than that claims of a weak commitment to the programme are completely unfounded. Responsibility for this false view becoming part of conventional wisdom must be shared by NASA, which misjustified the programme and then claimed the programme was underfunded, and by analysts who neglected the period after development, which is crucial to understanding the actual level of commitment.

Why the commitment has lasted. In the previous subsection the significance of pork-barrel benefits was examined as a factor which contributed to the programme gaining first approval. Certainly if the promise

[79] 'Report on space transportation system management actions', a report to the President, reproduced in *Space Shuttle: 1980*, Status Report for the Committee on Science and Technology, US House of Representatives, Serial AA, US GPO, Washington, DC, January 1980, pp 573–577, quote from p 573.

[80] Banks, *op cit*, Ref 61, p 194. The figure used is all non-recurring costs. If only DDTE (Design, Development, Test and Evaluate) costs are considered then the percentage is about 130% of that promised at the programme's outset.

[81] Also in 1973 Senator James Abourezk (D–SD) offered an amendment during Senate Aeronautical and Space Sciences Committee mark-up of the NASA appropriations bill which would have diverted $131 million of the $475 million proposed for the Shuttle to other space programmes. This measure was defeated 2–10.

[82] Some advocates of manned space flight will argue that the only manner that the programmes which they support can be approved is to 'buy-in' with or 'low-ball' their cost estimates. Once the nation sees the benefits of space colonization, the argument continues, the higher cost will be accepted. However, the implications of this line of thinking are a subversion of the democratic process, no matter how well intentioned.

of pork-barrel benefits was a factor in getting the programme started, the performance of pork-barrel politics would have an even greater influence in keeping the programme going as members would have a direct economic reason to support the programme. One reason why the programme had strong support throughout development was the benefits members of Congress ascribed to the programme. In 1975 NASA announced that there were approximately 31 000 contractor personnel in 47 states working on the development of the Space Shuttle.[83] This implies that business-as-usual was in favour of keeping the programme going. During development principal contractors for the Shuttle programme were distributed across 16 states and 37 congressional districts.[84] Included were the California, New York and Texas congressional delegations which alone comprised about a quarter of the House.

In a statistical analysis of political support of the Space Shuttle programme in the development phase one analyst finds that:

> Pork barrel support for the space shuttle program shows up clearly in the regression results . . . Once the Shuttle program was under way and the contractors were selected, the program picked up political steam as the relevant constituencies became enfranchised and the contract benefits of the program began to accrue. These political constituencies then were sufficient to keep the shuttle program going, when, in the late 1970s, the economic rationale initially offered for the shuttle was in jeopardy.[85]

Thus, aside from the factors which contributed to the Shuttle gaining initial approval, ie control, compromise and cost, pork-barrel benefits are an additional factor that helps explain why the commitment to the programme has lasted.

Technical problems. In February 1977 the first Shuttle, *Enterprise*, began atmospheric test flights. The programme appeared to be running smoothly and on schedule. However, at the same time NASA was experiencing serious problems with the Space Shuttle main engines. In five tests of the main engines in 1978 'four different engines and one turbopump were damaged, resulting in four months of downtime and $21 million in repairs and modifications'.[86] The problems with the main engines were not the only serious technical problems threatening the programme. The external tiles were perhaps the most widely publicized problem. The tiles serve to protect the orbiter from extreme heat associated with re-entry. Putting tiles on *Columbia*, the first fully functional orbiter, took approximately 670 000 hours, or 355 man-years.[87]

NASA dealt with the technical problems through supplementary appropriations and by trading investments in the future for up-front cost savings.[88] This caused unknown damage to other NASA programmes, as funding the Shuttle assumed the highest priority within NASA. According to James Van Allen, one of the critics of the Shuttle programme in 1972, 'In the summer of 1981, faced with serious delays and major cost overruns on the shuttle, NASA decided that development of the Shuttle must proceed, come what might to other ongoing projects. The result was a "slaughter of the innocents": massive cuts, postponements and cancellations of dozens of programs, many of which were already in advanced states.'[89] According to Van Allen at least 17 other programmes were severely affected during this period. While many of the programmes which suffered setbacks due to NASA's decision were put back in the budget in some form at a later date,

[83]NASA release 75-63, as reported in *Astronautics and Aeronautics: 1975*, p 43.
[84]Banks, *op cit*, Ref 61, p 208.
[85]*Ibid*, quote from pp 211, 214.
[86]A. Roland, 'The Space Shuttle: triumph or turkey', *Discover*, November 1985, pp 29–49.
[87]*Ibid*.
[88]Banks, *op cit*, Ref 61, p 187.
[89]James Van Allen, 'Space science, space technology, and the Space Station', *Scientific American*, Vol 254, No 1, January 1985, pp 32–39.

schedule delays, cost and capability cutbacks were inevitable. The range of actions taken by NASA to preserve the Shuttle are an indication of how important preserving the means to achieve the vision of manned space flight is to the agency.

One wonders what magnitude of cost overruns and schedule slips would have occurred if a more technically sophisticated programme had been approved in 1972. As it was, the programme proved to be much more technically difficult than originally envisaged. At least one NASA official felt that the political process which had forced the programme to accept a more technically realistic design was beneficial: 'In retrospect, I think, "Thank God we didn't have to build that [more complicated] design."'[90] NASA was able to overcome the technical problems and the first Shuttle flight occurred on 12 April 1981.

Goal reassessment. During the promotional period prior to approval the Shuttle programme was justified in terms of lowering costs associated with transportation to low-Earth orbit. NASA claimed the Shuttle to be worthwhile on this basis alone. Often overlooked is that this justification existed at only one period in time. Both before and after the decision NASA took efforts to recharacterize the Shuttle in terms of the vision of the colonization of space – as a resupply vehicle to a manned space station.

In 1971 Walter Mondale (D–MN) noted the shift in justification for the programme prior to its approval:

> Last year, the shuttle and station were presented by NASA as a joint project – the basis of what NASA called a new epoch in manned space flight. The agency justified the shuttle primarily as a reusable 'logistical truck' for carrying men and supplies to a permanent space station in earth orbit . . . This year – in defending its authorization for fiscal year 1972 – NASA now argues that the shuttle is no longer related to development of the station and that it can be justified on its own merits.[91]

NASA concurred with this assessment. According to one official in NASA's Space Shuttle office in 1971, 'This does represent a reversal of priorities. Initially, we thought of the shuttle only in terms of the station; now the shuttle is to the fore alone.'[92] However, soon after approval NASA began attempting to alter the programme's justification. Less than two years after Nixon's endorsement of the programme NASA officials, before the House Committee on Science and Astronautics Subcommittee on Manned Space Flight, once again did an about-face on the programme's justification: 'NASA believes that the results of our cost benefit analyses are important and valid elements supporting the decision to develop the Space Shuttle, *even though the principal justification for the Space Shuttle is the new capabilities it will provide.*'[93]

The change in the justification became expedient as the programme moved towards operations in the 1970s and it became apparent that it would not perform close to promises. Promises were adjusted to meet expected performance. Congress was lax in its oversight duties, and the programme continued despite the lack of a formal justification. The effective justification for the programme was in terms of payloads that were designed specifically for, and thus completely dependent on, the Shuttle, eg the Large Space Telescope (now called Hubble), and especially Defense Department missions. After the *Challenger* accident NASA completely abandoned justifying the programme in terms of cost effectiveness.

[90] Charles Donlan, director of NASA Space Shuttle office in the early 1970s, as quoted in Launius, *op cit*, Ref 3, p 2.

[91] *Congressional Record – Senate*, 28 June 1971, p 22372.

[92] Statement of Carl H. Dry, executive assistant in NASA's Space Shuttle office in 1971, as quoted in Claude E. Barfield, 'Space report/NASA gambles its funds, future on reusable space shuttle program', *National Journal*, 13 March 1971.

[93] Statement of NASA Deputy Associate Administrator Willis H. Shapely before House Committee on Science and Astronautics Subcommittee on Manned Space Flight hearing on GAO report on Space Shuttle cost estimates, as reported in *Astronautics and Aeronautics 1973*, p 196 (emphasis added). Here 'capabilities' are interpreted as those necessary to fulfil the requirements of the vision.

In the early 1980s, following a change in the White House and in NASA's administration, NASA resumed actively seeking support for a space station programme, still the keystone of the vision. This time it was successful in gaining presidential approval of the programme. Today the Shuttle programme is once again justified in terms of taking people and materials to and from a manned space station. The justification for the Shuttle programme has come full circle back to what NASA had originally proposed at the start of the initial post-Apollo era. However, it must be a bittersweet accomplishment as neither programme currently performs to the degree necessary to make much progress towards fulfilling the vision.

To summarize, the development period of the Space Shuttle can be best characterized in three ways. First, the period was one of a strong and sustained commitment to the programme. The commitment was strengthened by political support in the form of a wide distribution of the programme throughout the nation. Second, the programme began experiencing technical problems which indicated flaws in the argument on which the programme was sold. Finally, as a result of more pessimistic performance estimates and a desire to return to the vision of colonization, after approval the programme's justification evolved from economies to the missions that the programme was to serve, and at last back to building and resupplying an orbiting space station. All of this has occurred despite the oversight responsibilities of Congress and the administration.

Lessons

If this reappraisal of the Space Shuttle programme experience is accurate, then the probable future will see a continuation of the trends in the programme over the last 10 years of operations. This implies that the programme will continue to fail to meet schedule goals until the flight rate is reduced to a reasonable amount, ie less than 10, and most likely less than eight. Furthermore, annual costs of the programme will continue to be at least $4 billion (in 1990 dollars). In addition, the programme will probably lose another orbiter, causing major disruptions in most of NASA's activities. Table 1 summarizes the likely constraints under which experience suggests that the Shuttle must operate.

Lessons of the Shuttle programme

As the Shuttle programme enters its third decade of existence and second decade of operations in 1992, many policy decisions will have to be made which presume an adequate appraisal of the Shuttle programme experience. Some of these interdependent decisions were listed at the beginning of this article. They fall into the following three categories:

- the future of the Shuttle programme;
- the Shuttle's role in the future space programme;
- decision points which will be reached under programme contingencies.

The lessons of the Shuttle experience are presented in the context of the three decision areas.

Conserve the Shuttle. With only four orbiters the Shuttle is a scarce resource – the only US means to transport humans into space. Operational evidence suggests a significant probability exists that another orbiter may be lost within the next 20–35 flights. Thus there is justification to lower the flight rate below the maximum annual number of flights that it is reasonable to expect to extend the useful life of the programme. The exact number of annual flights should be determined based on actual performance and meeting programme goals. As suggested above, the programme currently meets neither criterion.

Provide margins or accept risk. If present policies are continued the programme will continue to fail to meet performance goals. The current manifest schedules up to nine flights per year,[94] which is near the limit that experience and theory suggest it is reasonable to expect.[95] If the programme does fail to meet performance goals, then payloads will be delayed or cancelled, and resources will be diverted to fund programmes that should have been completed. For example, in the current manifest 58 flights are planned to occur from June 1992 through fiscal year 1998. Schedule delays that reduce the number of total flights would imply that the payloads that cannot be launched in that time period either be cancelled or be launched on the Shuttle at a later date. These options imply disruption and cost to the civil space programme.

For example, the first assembly flight of the Space Station is scheduled for the first quarter of 1996. Furthermore, 17 of 25 flights from fiscal year 1996 to 1998 are dedicated solely to the Space Station. If the Space Station flights have priority during this period, then a minimum of about six flights per year will be necessary for payloads other than the Station to be launched. Under this scenario, if the Shuttle schedule is disrupted such that annual flight rates drop below six, then non-Station payloads would suffer the most. Needless to say, if an orbiter is lost, then the Space Station and the civil space programme will have to be restructured, as three orbiters cannot meet the current schedule demands.

Reduce dependence on the Shuttle. The Augustine Committee asserted that the Shuttle 'would seem to be the weak link of the civil space program – unpleasant to recognize, involving all the uncertainties of statistics, and difficult to resolve'.[96] Data in this article indicate that the Shuttle is indeed a weak link. Therefore rational policy would not be completely dependent upon the Shuttle. Depending less on the Shuttle would imply that operating plans are scaled down to meet the test of experience, and that contingency plans are made. Given its constraints, policy goals would be adapted to meet considerations of realism, worth and practicality. For example, one option would be to dedicate (part of) the Shuttle fleet to long-duration flights. This would serve the objective of lowering the flight rate, while providing knowledge on the effects of long-term space flight. Contingency plans should be formulated that would structure recovery from the loss of an orbiter. Not only would this provide for a coordinated response to the loss of an orbiter, it would also focus attention on how dependent the space programme is on the Shuttle.

The Shuttle is expensive, and likely to stay so. The period of Shuttle operations suggests that it would be difficult for NASA to significantly

[94] *Payload Flight Assignments: NASA Mixed Fleet*, NASA Headquarters, Washington, DC, January 1992.
[95] See also *Space Shuttle: NASA Faces Challenges in Its Attempt to Achieve Planned Flight Rates*, GAO/NSIAD-92-32, General Accounting Office, Washington, DC, December 1991, which comes to much the same conclusions.
[96] *Report of the Advisory Committee on the Future of the US Space Program*, *op cit*, Ref 2.
[97] It is likely that annual cost would be significantly reduced near programme termination when research into upgrades has stopped and production lines are closed down.

reduce the annual costs of the programme under sustainable conditions.[97] For example, during the period of grounding of the fleet after *Challenger* annual cost did not deviate significantly from years in which orbiters flew. This, when considered in the context of the flight rate, implies that the cost per flight will continue to be very high. These are important factors to consider when determining what types of missions the Shuttle should fly.

Within the larger context of the space programme the lessons of the Shuttle experience may be more broadly applied. However, these lessons are meaningless if performance does not matter. They are put forth with the hope that it does.

Scrutinize the promises made by advocates of new programmes. Is there reason to believe that performance will approximate promises? And if it does not, are there sanctions in place, eg termination? Congress should establish the expectation that NASA will be held accountable for the promises made in securing programme approval. To facilitate accountability project-specific measures of progress with respect to goals are needed. Cost, schedule and capability as used in this article are one way to track programme performance.

Do not abandon the capabilities before a replacement has been proven to perform at least as well. This lesson applies to the Shuttle as well as other space programmes. The decision to depend completely on the Shuttle for the nation's launch needs was clearly a mistake. However, to avoid making the same mistake when the decision to replace the Shuttle is made, a new programme should demonstrate the ability to replace the capabilities that the Shuttle currently provides. In a constrained budgetary environment this gives additional impetus to assuring that promises reflect actual performance.

Develop quick, smaller and independent programmes.[98] The Shuttle programme has been conducted within a policy that is long term, large scale, and interwoven with many other aspects of the civil space programme. The performance shortfall that marks the programme suggests that alternative policies be considered.

Long-term projects assume that goals and objectives are static. This is not often the case. The Shuttle programme's goals have changed several times, from serving a space station to cost effectiveness to mission requirements and back to serving a space station. These changes were in response to evolving goals and the diminished expectations of performance.[99] However, goal evolution was constrained by the capabilities provided by the Shuttle. Rational policy matches capabilities to goals, rather than goals to capabilities. Projects carried out over shorter terms can be optimized to a specific goal, giving policy makers more control over the direction of the civil space programme.

The Space Shuttle is also an example of a large-scale project. In large-scale projects performance shortfalls necessarily have correspondingly large impacts on the civil space programme. These impacts can be in the form of cost overruns, schedule slips or capability cutbacks, all of which can severely disrupt other programmes. Small-scale programmes, on the other hand, minimize the amount of resources being bet on the success of any one project. Rather than attempt to design one programme with no failures, it may be more efficient to design many small

[98]There is a growing body of support for these types of strategies, but not yet enough to supplant current policies. See for example R.D. Brunner, 'Performance as promised', *Space Policy*, Vol 8, No 2, May 1992, pp 116–136; M.D. Griffith, 'Management of the Space Exploration Initiative', unpublished paper, NASA Office of Exploration, 1 June 1991; and R. Byerly, Jr, ed, *Space Policy Alternatives*, Westview Press, Boulder, CO, 1992.

[99]R. Brunner and R. Byerly, Jr, 'Long-term goals and commitments in US space policy', unpublished paper, Center for Space and Geosciences Policy, Boulder, CO, 19 June 1989.

programmes each focused on a specific objective, and then implement those features which work in future designs and abandon those which do not. Small-scale programmes, taken in parallel and in series, can possibly achieve policy goals better than single long-term, large-scale programmes.

Civil space programmes should also be independent to the greatest degree possible. This is so that failures do not propagate through the entire civil space flight programme. Several times, Shuttle performance failures caused major disruptions to the civil space programme. Programmes which fail and are short term, small scale and relatively independent will have little or no effect on the balance of the space programme. Independence allows for more efficient use of resources in the pursuit of ever-changing goals as programmes can be optimized to the specific function that they are to serve. Furthermore, programmes that do not perform can be terminated with minimal loss of resources and little effect on other programmes if they are relatively independent.

The Shuttle experience suggests that large-scale, long-term and interdependent programmes are not the best policy for achieving our goals in space. An alternative is a policy of smaller, quicker and independent civil space programmes. Determining exactly what is meant by smaller, quicker and independent can be a task for policy makers and analysts alike. Then it should be left to the genius of scientists and engineers to design programmes to meet these constraints in the effort to fulfil policy goals. This process is consistent with and lends itself to efficiency in the use of resources as well as democratic accountability.

Contingencies

For several reasons the present time may present an opportunity to re-examine Shuttle policy. First, in recent years Congress has contemplated terminating or severely changing the Space Station programme. Termination would provide an opportunity to reassess the role of the Shuttle in civil policy. Without the Station, the Shuttle would have to be formally rejustified. Second, the data presented in this article suggest that most likely the Shuttle cannot perform the duties for which it is currently intended. If this is indeed the case, then it would be in the interests of NASA, Congress and the US public to reformulate the Shuttle's role before the programme contributes to another series of performance shortfalls.[100]

Reformulating Shuttle policy could occur under NASA's, congressional or administrative guidance. Possible actors include NASA's House and Senate Authorizing and Appropriating Committees in Congress, and the White House, OMB or National Space Council in the administration. Whoever makes the first steps towards better policy could have a defining role in shaping the future of civil space policy. However, if no one takes these steps, then civil space policy will continue to struggle to achieve its grand goals. This would be damaging politically to congressional and bureaucratic defenders of the programme, as well as to the image of NASA from the public's viewpoint. The public was quick to support the programme after *Challenger*. However, it is unlikely that in the aftermath of a second accident the space programme would be as strongly supported.[101]

Changing Shuttle policies would require that the conventional wisdom of the programme be rejected. However, simply rejecting conven-

[100]The Space Station programme has already egregiously failed to perform as promised. Continued reliance on the Shuttle could exacerbate the poor performance of the Station programme, as well as the civil space programme as a whole. See R. Brunner and R. Byerly, Jr, 'The Space Station programme: defining the problem', *Space Policy*, Vol 6, No 2, May 1990, pp 131–145.

[101]J.D. Miller, 'The *Challenger* accident and public opinion', *Space Policy*, Vol 3, No 2, May 1987, pp 122–140.

tional wisdom is not sufficient for change to occur. This appraisal suggests that there has existed and still exists a strong commitment to the Shuttle, and therefore the manned space programme. The problem of poor performance in the civil space programme is more a matter of inefficiency in use of the resources being provided than a lack of resources required.

The end of the Cold War, and the fiscal constraints that have resulted from fighting that war, may also provide an impetus for constructive change in the civil space programme. Change may at first be difficult, but done sooner rather than later it would have a greater probability of obviating the need to change under more difficult circumstances, such as the unexpected loss of an orbiter or continued fiscal constraints. The institution that brought us into the space age should be not only a leader in technology, but also able to lead the country in new ways of conducting public policy. This requires careful attention to the lessons of experience, and not being afraid to change when current practices are ineffective. NASA will eventually change; the only question is whether they will instigate that change, or events will force change upon them.

The following statement from William Lenoir, former Associate Administrator for Space Flight, is reason for both optimism and recognition that change is not yet upon us: optimism because there are signs that conventional wisdom with respect to the Shuttle is weakening; recognition that change is not yet upon us because the lessons of the past are yet to be linked with policies of the present and future.

> The space station is our link to the future. The next step needs to be taken and needs to be taken now or else we are going to admittedly be in a going-out-of-business posture . . . In many ways we've put all our eggs in this [the Station] basket . . . We don't have any contingencies that say 'Well, if it's lost, here's what we will do.' We'd have to come to grips with accepting something that's not quite as good. We did not adequately plan our post-Apollo period and it's taken us almost two decades to fully recover technologically from having gone blindly over that cliff . . . We flew Apollo and quit. We went out of business while we took a decade off to build a space shuttle.[102]

While Lenoir's remarks suggest that reappraisals of the Shuttle programme may find some support, it would be a hollow accomplishment if the lessons of the past are not linked to formulating current and future policy. Learning the lessons of the Shuttle programme experience means making a break from the business-as-usual policy of 'logical steps' to smaller steps that are consistent with experience and capable of adapting quickly to the lessons of future experience. The country has learned much from the technical successes and policy failures of the Shuttle programme. Much more can be learned if for the remainder of its existence the Shuttle is operated with the lessons of experience in mind. The point of reappraisal is to free us from dogmatic adherence to old visions in order that the Shuttle's capabilities are well used for the remainder of the programme, and that future programmes do not suffer from the same mistakes.

[102]Quoted in H.F. Rosenthal, 'Killing Space Station could set back US space program a decade', Associated Press, 21 May 1991.