NASA, Post-Apollo and the Rise of the Space Shuttle: A Glance at the Definition of a Launch Vehicle.

Brian Woods

SATSU Working Paper N27 2003

This is a preprint draft.
Citation should conform to normal academic standards. Please use either the 'SATSU Working Paper' number and date. Or, where a paper has entered into print elsewhere, use normal journal/book citation conventions.

Acknowledgements
Thanks go to NASA and Lockheed Missiles & Space Company for permission to reproduce the images.

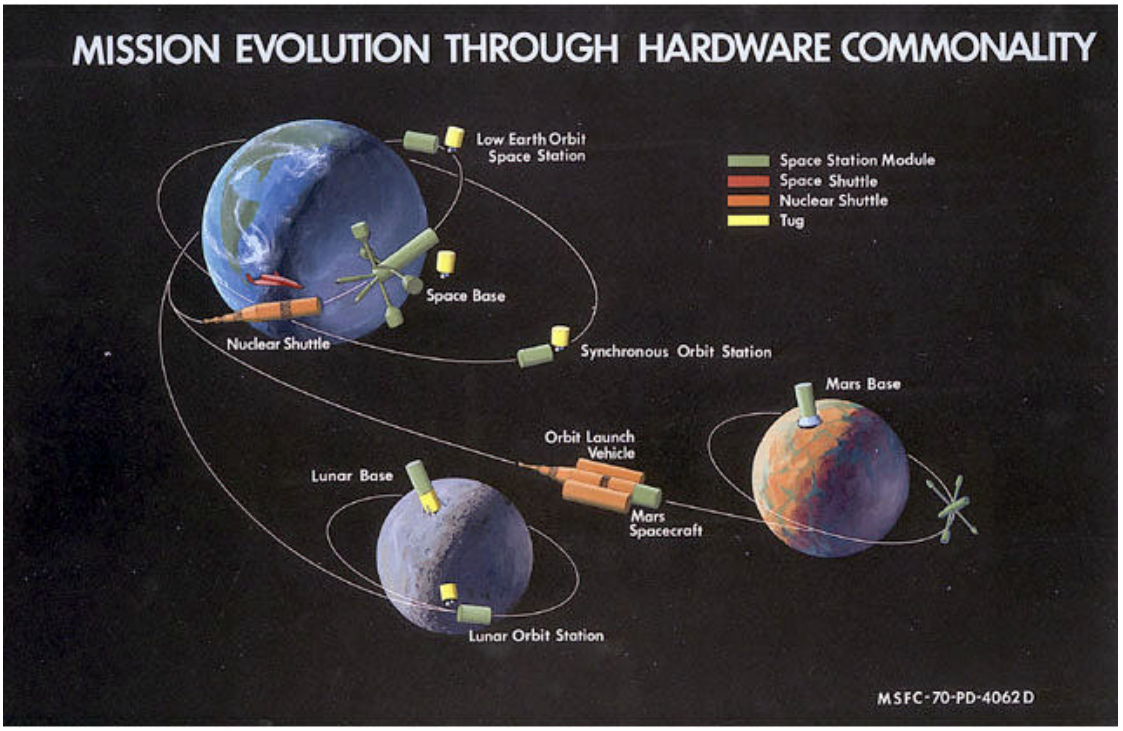
A discreet announcement to an audience of the British Interplanetary Society in early 1968 marked the first public acknowledgement by the NASA (National Aeronautic and Space Administration) Office of Manned Space Flight that it intended to develop a reusable launch vehicle.[1] The announcement came as Apollo, NASA's grand mission to land an American on the Moon, approached its conclusion. NASA had not fully resolved the issue of what to do next, but the disclosure did marked a consolidation of thinking within organisation's upper echelons on future programmes, objectives and direction.

NASA's funding had peaked in1966 and 1967 marked the transition from expansion to retrenchment.[2] Various groups within NASA's space divisions thus began to mobilise in 1968 with the aim of strengthen their positions by re-defining the shape of space activity. Those that advocated the development of a space shuttle represented only one of a variety of movements that sought to control over a seemingly burgeoning future in space. The NASA Centers devoted to space science saw their hopes ready to expand now that Apollo was nearing completion. In the eyes of many space scientists, the Moon landing programme had curtailed the scientific endeavour. The rise of another large, human centred programme sent a wave of consternation through the space science community as once again their goals looked in danger of being submerged.[3] James Van Allen, discoverer of the vast radiation belts that bear his name, was one of the most outspoken, claiming that non-human space programmes could best serve scientific purposes.[4]

Nonetheless, in its 1969 report, *America's Next Decade in Space*, NASA's upper management gave a prominent and permanent position to the human element of the national space programme. Outlined was a quixotic inventory of projects to take the "space age" into the next century, which included: three Earth orbiting space stations and one space station in Lunar orbit – a fleet of reusable shuttles that would link the Earth with the three Earth orbiting space stations – a nuclear powered shuttle that would form a link between the Earth space stations and the Moon – a Lunar base equipped with a Lunar Module that would link the ground base with the Lunar orbiting station – and a human expedition to Mars, which would also conduct a fly by of Venus on its journey back to Earth.[5] In the politics of post-Apollo, NASA's higher echelons sought to fortify the organization's position through an expansion of the space enterprise and the creation of a vast new space infrastructure.

Central to the NASA Office of Manned Space Flight was the permanent Earth orbiting space station and a fleet of reusable shuttles. The concept of a permanent human-inhabited space station had been 'a gleam in the eye of numerous NASA engineers' since the agency was founded. Indeed, the original planning for Apollo incorporated an Earth orbiting rendezvous method, which, NASA planners hoped, would eventually lead to an Earth-orbiting space station by 1967.[6] Nevertheless, pressure to complete Apollo within the time frame set by President John Kennedy in 1961, to land an American on the Moon by the end of the decade, forced NASA to adopt a Lunar orbit rendezvous method. What this effectively meant to some NASA officials was that the agency would have no productive technology with which to

establish extensive near Earth orbit operations.[7] Many in NASA, therefore, perceived Apollo as imparting no logical legacy upon which to build a space infrastructure.[8]



This artist's concept from 1970 shows propulsion concepts such as the Nuclear Shuttle and Space Tug in conjunction with other proposed spacecraft. Because of the recommendations from President Nixon's Space Task Group for more commonality and integration in the American space program, Marshall Space Flight Engineers studied many of the spacecraft depicted here.

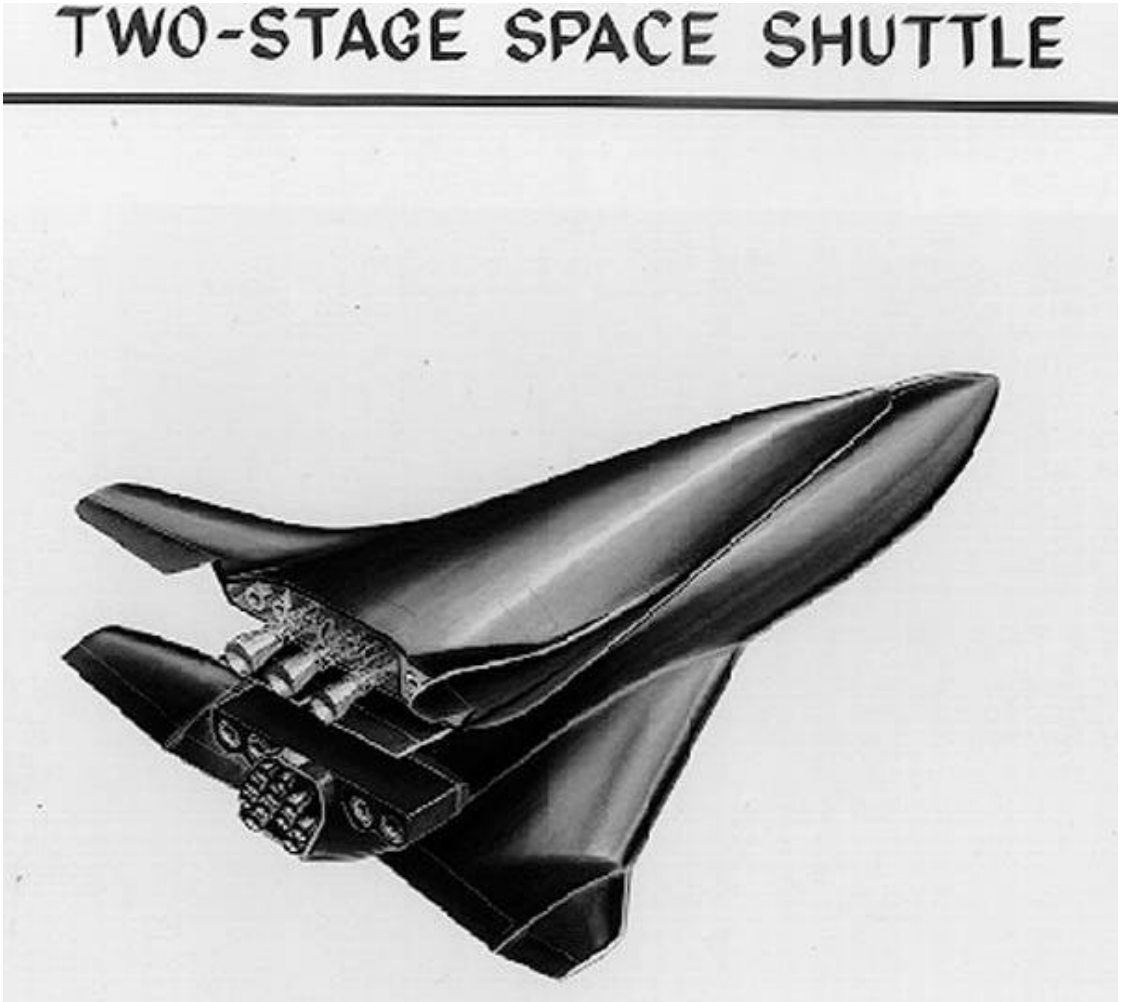
The large Saturn boosters and the Apollo spacecraft were single mission technologies, built to carry people and machines to the lunar surface. Expansion of the space enterprise, according to NASA, had to rest on operations in near Earth orbit. If space was to be colonised then according to NASA, the US needed a stepping-stone in near Earth orbit. Rapid growth could only be encouraged by means of a revolution in launch vehicle and spacecraft technology; a revolution in the means would provide a

revolution in the ends. A growing contingent, therefore, converged around the idea of developing an entirely new launch vehicle for Earth orbit logistics.[9] Ultimately, this orientation towards leapfrog innovation rather than incremental innovation became dominant because of NASA's penchant for the development of advanced technology. Ideas to move in an incremental fashion and modify both the Saturn or Titan boosters and the Apollo or Gemini spacecraft were quickly silenced.

By the end of 1968 project planning was well under way and by early 1969 the Office of Manned Space Flight had established two task groups, during a reorganization of its management structure; one to take responsibility for the proposed space station and the other to take responsibility for the shuttle. The Office of Manned Space Flight delegated the task of evaluating the diverse technical issues of Phase A to the Space Shuttle Task Group, headed by Apollo Test Director LeRoy Day. Labelled advanced studies, Phase-A was the first part of an anticipated four-phase shuttle development process, including Phase-B, project definition, Phase-C, actual vehicle design and Phase-D, production and operations.[10]

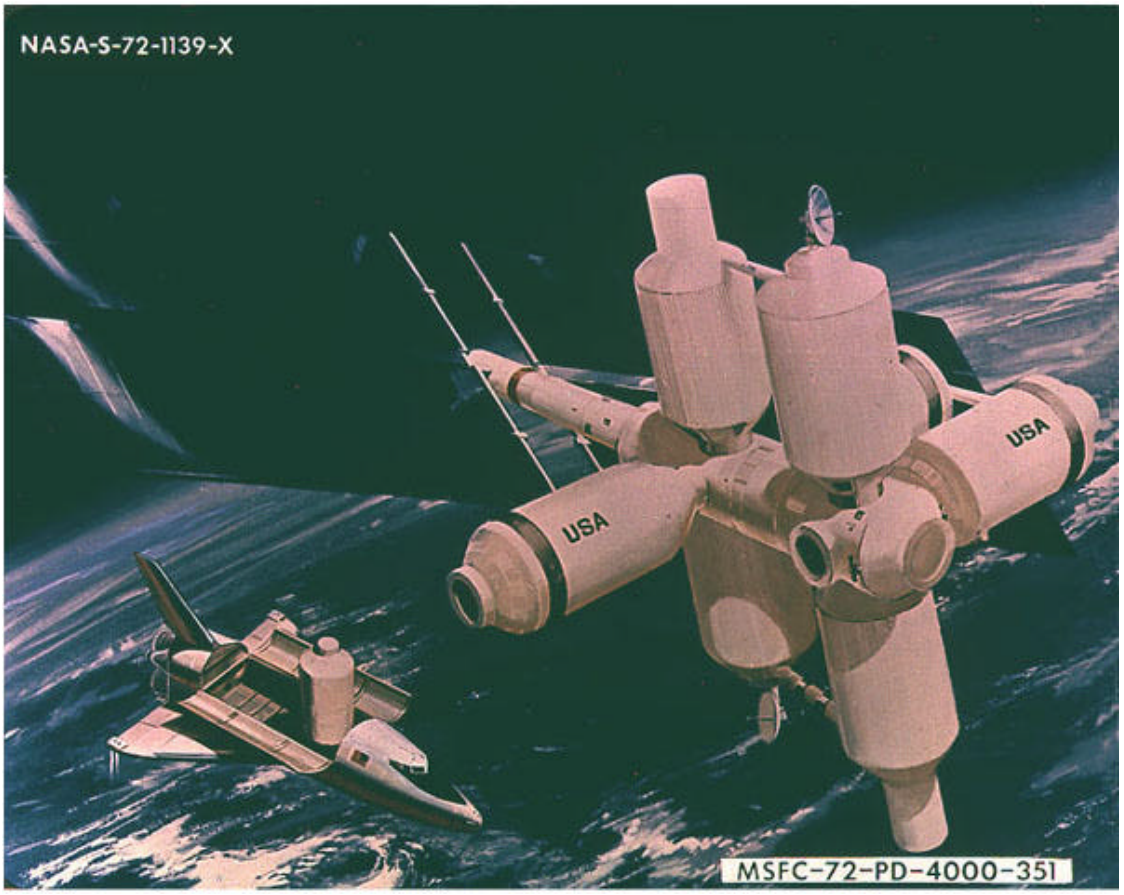
Major sections of the US aerospace industry were involved with NASA's Phase-A shuttle planning studies and as 1969 drew to a close, the contractors put forward a variety of designs. The Office of Manned Space Flight selected a fully reusable, two-stage shuttle design as the most promising concept to go forward into Phase-B. The design comprised of two separate vehicles, a booster, about the size of a Boeing 747 that would provide the thrust to lift the system off the Earths surface and riding piggy-back, an orbiter, about the size of a Boeing 707 that would disengage at

between 10 to 20 miles altitude and go on into orbit on its own. NASA projected a ten-year life cycle for the systems during which time it would have to conduct a minimum of 100 missions before requiring any major refurbishment.[11] The Office of Manned Space Flight envisaged that the shuttle would be operational by the second half of 1977 and capable of conducting 75 flights per year by the end of that decade.[12]



Lockheed's two-stage shuttle design, circa 1970: a Lockheed Missiles & Space Company image.

The configuration of NASA's proposed space station had also taken shape by mid-1969. Earlier plans to launch a small fully constructed space station had been rejected on the grounds that it would be too conservative in size, scope, and potential accomplishments. Instead, NASA opted for a modular design with the intention of constructing the station in orbit rather than on Earth. This would allow development of a platform that could accommodate up to 100 people by 1980.[13]



An artist’s concept of a modular space station circa 1972.

These concepts were both grandiose in design, potential and cost. In 1969, NASA estimated cost of development for the space station at over $10 billion and $5.2 billion to develop the shuttle. By January 1970, the figure for the space shuttle climbed to just under $10 billion[14] and reached $12 billion before the year concluded.[15] Including the space station, NASA was asking for an investment of well over $20 billion from the American taxpayer.

Forces of Resistance

Such an outlook was overly optimistic and out of line with the political and economic conditions of the time: 1968 had been a watershed year on many fronts. Incipient contradictions in the consensus politics promoted by both the Kennedy and Johnson Administrations had surfaced by 1967. Riots swept through American cities exposing the fragility of the solutions offered by liberal democracy to the problems of civil rights and social exclusion and destabilizing Johnson's Great Society programme. Opposition to the Vietnam War had also intensified as it escalated. Economic crisis threatened in the spring of 1968 as inflation reached an unprecedented 4.7 per cent and the federal deficit crept towards $25 billion, far more than in any other post war year. Although unemployment remained relatively stable, sections of organized labour, not least in the public services, were showing signs of discontent.[16]

Each of these factors impinged upon NASA's future planning. The most decisive was the collapse of the Democratic hegemony. President Johnson had announced that he would not be seeking re-nomination for another term; and in an

election fought in 1968 over the Vietnam War, support for Republican, Richard Nixon grew in strength.[17] Prior to and during his presidency, Johnson's politicking had been crucial to NASA.[18] When the Soviet Union launched Sputnik I in October 1957, he interpreted it as the second Pearl Harbour, an invasion of US skies.[19] The then Republican President, Dwight Eisenhower attempted to play down the significance of the Soviet Union's entry into space, but under political and public pressure during the post-Sputnik paranoia agreed to remodel the National Advisory Committee for Aeronautics to take charge of a new civilian space programme.[20] As Vice President, Johnson convinced the newly elected President Kennedy to recruit NASA in their campaign against a perceived Soviet threat by engaging in the lengthiest battle, en route to the Moon.[21] When Johnson himself became president in 1964, NASA received almost unqualified support from his administration despite political opposition and programmatic friction between Apollo, the Vietnam War, and the Great Society programme. The Johnson Administration regarded a victorious outcome for the US in the space race as so important that NASA was in a position to continue with its project no matter what the cost. Even the deaths of three astronauts in the Apollo fire of 1967 did not deter NASA or the government from persisting with its main objective: to beat the Soviets to the Moon.[22] It is clear then, that Johnson's departure from office had an important bearing on the political support NASA would receive for its post-Apollo planning. Its immediate consequence however, was to influence the departure of another significant individual, James Webb.

Lambright describes NASA Administrator James Webb as the power behind Apollo.[23] His management skills and political sophistication were well recognized within NASA.[24] Indeed, Webb's leadership unquestionably led to the location of the Manned Spacecraft Center in Texas and the building of the southern crescent: a political manoeuvre which assured NASA powerful congressional support.[25] By locating NASA facilities right across the south at a time when these areas were trying to get out from an agricultural based economy, Webb managed to make powerful members of the Congress 'stakeholders in Apollo'.[26] After Johnson's announcement of departure, Webb became concerned that the agency's leadership would become a political issue. If he remained NASA Administrator after the election political conflict would be inevitable. Vice President Hubert Humphery, the Democratic favourite, and Webb had had tensions and if Nixon succeeded then it was likely that Webb would be removed. Webb felt that his removal would also cut deeper into NASA's leadership, with Nixon excising those that he regarded to be loyal to Webb or Johnson. After a meeting with Johnson on September 17, 1968, Webb announced his retirement and Thomas Paine, NASA's Deputy Administrator, took up the reins.[27] In November 1968, Nixon won the presidential election and the new administration took office in January 1969.

President Richard M. Nixon announcing the appointment of Dr. Thomas O. Paine as Administrator for the National Aeronautics and Space Administration. From left to right: President Richard M. Nixon NASA Administrator Dr. Thomas O. Paine Vice President Spiro T. Agnew.

Over 1.5 billion people around the globe witnessed the planting of Old Glory at Tranquillity Base,[28] assuring Neil Armstrong's place in history as the first man to walk on the Moon on July 20 1969.[29] In the public's eyes, NASA had reached the zenith of the "space age". Over ten years of planning, research, development, and production accomplished what Francis Hoban called, the 'greatest engineering feat of all time.'[30] The Apollo euphoria was short lived nonetheless. Rather than a mechanism for uniting a nation, Apollo reflected its divisions. Not missing the potential of good publicity, the

newly elected President Richard Nixon, had declared July 20, 1969 a 'National Day of Participation'. But the events of the day were not universally shared. Although exemplified as the embodiment of the "frontier spirit" of America, Apollo remained at odds with everyday life.[31] Discontent quickly spilled over into the space programme. Student groups from Boston and New York disrupted meetings of the American Association for the Advancement of Science, and formed picket lines at a NASA exhibition of Lunar rock brought back from Apollo XI.[32] Hans Mark, then director of NASA's Ames Center, recalled a formal dinner, hosted by the President, to celebrate the return of the Apollo XI astronauts. He described the atmosphere inside the Century Plaza Hotel, Los Angeles, as both 'festive and patriotic'.[33] Outside a large demonstration had amassed. Its message, a brusque reply to Vice President Spiro Agnew's proposition that America's next venture in space should be a 'manned flight to Mars by the end of this century.'[34]

> A major feature of the demonstration was a huge sign with the legend "Fuck Mars" printed on it in large letters that the demonstrators had somehow been able to hang along the upper floors of one of the office buildings across the street from the Century Plaza. The same message was clearly repeated on signs that some of the demonstrators carried.[35]

Political activists were not however, alone. The very success of the Moon landing led to a general public disinterest in space.[36] Leaders within the agency feared that NASA's decline would be sharp without continued public support. Television had become an important medium for NASA, beaming their achievements back to a captivated audience on Earth. Soon after Armstrong's historic footsteps, NASA's TV ratings

dropped rapidly. George Low, NASA Deputy Administrator, put together a group of very senior NASA officials to address this problem. Nicknamed the Think Group, discussions centred on efforts to create a TV extravaganza during Apollo's next visits to the Moon.[37] All of their endeavours failed and public curiosity continued to drop, and was only briefly rekindled during the abortive flight of Apollo XIII.

Political support for Apollo was also decidedly weak. The Lunar landing signalled a turning point. With the space race won, many in the political arena believed that the programme should be terminated.[38] Apollo was to include nine further visits to the Moon after the initial landing, but pressure on NASA's fiscal year (FY) 1971 budget forced the agency to phase out production of the Saturn rocket and cancel the final two Lunar landings.[39] NASA astronauts visited the Moon on December 11, 1972 for the last time, and have not returned since.

Congress had severely downsized NASA's Apollo Applications programme in the politics of 1967 and 1968 and the agency had no mission objectives beyond the mid-1970s. The newly formed Nixon Administration did not place civilian space activity very high on its agenda and instead of making any immediate announcement decided to establish a Space Task Group to examine the issue. Chaired by Vice President Spiro Agnew, the Space Task Group consisted of a variety of actors, including the new NASA Administrator, Thomas Paine[40] and was in charge of providing a 'definitive recommendation on the direction the US space program should take in the post-Apollo period'.[41] In addition to the Space Task Group, several other planning activities were also under-way. The President's Science Advisory Committee

had established the Branscomb committee, headed by Lewis Branscomb, then director of the National Bureau of Standards; and within NASA, George Mueller, Associate Administrator for Manned Space Flight, had expanded the Office of Manned Space Flight's management committee.

The Space Task Group reported at the end of 1969 and provided a selection of spending options that ranged between a *maximum pace*, where the limits were set by technology, not available funding; and a *low level pace*, which did not include any human missions for the 1970s. Paine and Agnew, both endorsed a human expedition to Mars as the next logical step in space exploration. The Office of Manned Space Flight, however, were still pushing hard for the development of the space shuttle and the space station. Whereas the President's Science Advisory Committee's followed its earlier position, and recommended that NASA should concentrate its efforts on only developing a reusable transportation system for the 1970s.[42] Moreover, the President's Science Advisory Committee suggested that automated equipment should conduct planetary exploration and NASA should adopt a slow pace development of a space station; examining its viability during the 1970s and progressing to full development in the 1980s.

It was clear that a schism was beginning to develop between the ideas that the Office of Manned Space Flight generated and the ideas that other actors were considering. The Office of Manned Space Flight placed the highest priority on the creation of new technologies to operate in space. What they would actually do with these technologies was secondary in importance. In contrast, the Space Task Group, the

President's Science Advisory Committee and other areas of NASA concentrated on mission objectives. They saw technology as something that would have to be created in order to execute the missions that were being proposed.[43] Notwithstanding this rift, the Office of Manned Space Flight was successful in translating its interests into the interests of the other groups. By advancing the idea that the shuttle and the space station represented steppingstones in space, the Office of Manned Space Flight managed to persuade each of the groups to include at least one or the other in their proposals. This strategy was particularly effective with the Space Task Group who incorporated the shuttle in three out of four of its options.[44]

In the immediate politics of post-Apollo, NASA's higher echelons sought allegiance with the White House through the chair of the Space Task Group, Vice President Spiro Agnew, in the expectation that his approval would result in a new mandate. Initially this strategy appeared to work. Agnew endorsed NASA's grand plans and the agency had partial success in influencing the direction of the other groups involved in the post-Apollo planning. NASA soon found however, that it had few friends in the White House and was entering a new world of post-Apollo with no real identity.[45]

Richard Nixon monitored political reaction to the post-Apollo planning reports before delivering his space policy message in March 1970. The message was considerably less ambitious than even the third option offered by the Space Task Group. It did not include any commitment to a space station, a shuttle, or an expedition to Mars. Instead, Nixon expressed the need for a *balanced space programme*, which

would combine all the elements of exploration, accumulation of scientific knowledge, and practical applications. Nixon indicated that studies into the development of a space station and a shuttle were proposed, but he detailed no new projects. Nixon's submission of NASA's Fiscal Year (FY) 1971 budget to the Congress remained well below the $4 billion minimum needed if NASA were to begin its programme in that fiscal year.[46]

NASA's budget had been on a steady decline from its peak of 0.9 per cent of GNP in FY 1966, to 0.47 per cent of GNP in FY 1969. The primary objective pursued by NASA Administrator, Thomas Paine, was to reverse this trend and push for an investment commitment of 1 per cent of GNP.[47] Agnew gave his patronage to a venture on the scale of Apollo, but the shapers of space policy were vastly out of step with the shapers of macro-economic policy. Fiscal and monetary constraint were the primary tools advocated by the Council of Economic Advisors, to stave off the threat of economic crisis, perceived because of the growing federal deficit, a slow down in economic growth, high inflation and signs of rising unemployment. Hence, the dictation of economic policy was to maintain a federal budget in which expenditures matched revenues.[48] Policy implementation was under the control of the newly formed Office of Management and Budget and they were showing a growing concern over NASA's lack of justifications for its expensive programmes.[49]

Sceptical of NASA's development cost estimates, the Office of Management and Budget directed the agency to conduct a cost-benefit analysis of its proposed shuttle design. At the end of this study, NASA projected development costs of between

$6.4 and $9.6 billion for its fully reusable, two-stage shuttle system.[50] Unconvinced, the Office of Management and Budget made an extraordinary manoeuvre and demanded that NASA contract an outside evaluation of shuttle development costs. NASA's upper management were reluctant to conduct such a study, fearing that it would raise the whole issue of what constituted a *good* space programme. Nevertheless, given the political climate, NASA bowed to White House pressure and contracted Aerospace Corporation and Lockheed Corporation to assess the impact of the shuttle on reducing payload and launch costs; and Mathematica Incorporated, to provide an overall economic analysis.[51]

The Office of Management and Budget were not the only White House agency seeking control over NASA's activities. The Office of Science and Technology and the President's Science Advisory Committee also demonstrated apprehension over both the costs and the technological risks associated with the agency's proposals. In the summer of 1971, the Presidents Science Advisory Committee established a high level scientific panel to examine NASA's post-Apollo plans. Chaired by Alexandria Flax, President of the Institute for Defense Analysis, the Flax panel worked closely with the Office of Science and Technology and the Office of Management and Budget to curtail NASA's ambitious plans. Critical of NASA's programme cost estimates, the Flax panel concluded that cost overruns could be in the region of 30 to 50 per cent. Armed with an open mandate, the Flax panel also focused attention on technological matters. In an effort to reduce research and development costs, but retain a national space programme, the panel expended a lot of energy on proposing alternatives to NASA's

baseline shuttle design. While making no single recommendation, the panel did outline three alternative options: (i) defer the decision on new technology until a later data; (ii) develop a new expendable ballistic launch vehicle; or (iii) develop a small partially reusable launch vehicle.[52]

The major difference between NASA and the White House on the type of space transportation system required revolved around a trade-off between operational costs and development costs. The shuttle designs that had emerged from the Phase-B studies reflected NASA's vision of a future of “mass space transportation.” Development costs were, therefore, a secondary consideration to a system designed around reducing operational costs.[53] The White House however, wanted to disembark from a heavy funding curve. Consequently, many of NASA's debates in Washington related to the annual funding of its proposed programmes, as Space Shuttle Programme Manager, Robert Thompson, recalled:

> A lot of our debates in Washington had to do with what the annual funding in support of the program would be. And I know lots of times up there the meetings would kind of come to the bottom and say, we don't care what you build, but we don't want the annual funding to get over $1 billion a year.[54]

In the fragile politics of post-Apollo, NASA discovered that many members in both houses of Congress had also developed a negative response to the costly and seemingly intangible proposals coming from the agency. Opponents in the Congress to funding large technological programmes had steadily mushroomed as social, political and economic conditions declined.

Within the House of Representatives, two main issues dominated the space policy debate during 1970 and 1971: whether to support NASA's proposals for human space flight and whether space programmes should receive such a large slice of the national budget. Some members of the subcommittee on Space Science and Applications and the subcommittee on Advanced Research and Technology positioned themselves against the quixotic visions of a post-Apollo age. In an address to the American Institute of Aeronautics and Astronautics, Space Science and Applications subcommittee chairman, Joseph Karth (Democrat, Minnesota), condemned the Space Task Group's report as 'totally unrealistic'.[55] It was the decision by NASA to delay several space science and applications projects to make room for the space station and the shuttle as budget items that led the Space Science and Applications subcommittee to campaign against both programmes.[56]

When the debates unfolded on the House floor, it was evident where the battle line had been drawn. The Manned Space Flight subcommittee jostled to increase NASA's budget for human space flight and the Space Science and Applications subcommittee, sought to fix the human space flight budgets under the Office of Management and Budget's recommendations. A continuing rise in unemployment during 1970, however, spurred many within the House to increase public spending; and John Wydler (Republican, New York), expressed a common sentiment in 1971 when he told the House during a shuttle authorization debate:

> I have been going along with these cuts year to year. I really feel we have reached a point where we should stand up and say "enough." ... I

> think we had better start redirecting the public's attention to the fact they ... [are spending public money] ... to hire American people, to do American productive work.[57]

Nevertheless, opposition to the shuttle and the space station was at its height in 1970 and both failed to get development approval.

In the years between 1968 and 1970, neither strong advocates nor influential opponents of the civilian space programme successfully dictated the political agenda. Public and political support for any new space programme on a similar scale to Apollo was, at best, indifferent. Those that exhorted the development of the space station and shuttle were successful only in negotiating for further research into the possibilities. Although NASA had secured funding for the Apollo applications programme, which would utilize the remaining Apollo hardware in near-earth orbit, the prospects for NASA's space station and shuttle were bleak.

Internal Dissidents

The plans of the Office of Manned Space Flight were not only frustrated by external factors. Internal obstacles also appeared as factions within NASA mobilized their forces in an attempt to capture control of the shuttle programme's resources.[58] At the end of 1969, no firm consensus existed between, or within, the NASA Centers about a shuttle design. Supporters for partially, or completely recoverable versions of the Saturn rocket and some minor patronage for a single stage to orbit vehicle could still be found.[59] Advocates for further development of lifting body technology could also be

found at the Flight Research Center and the Office of Advanced Research and Technology.[60] The greatest pressure though, came from the Johnson Space Center.[61]

Max Faget, the Mercury capsule designer, was leading a group of engineers in an attempt to influence the Office of Manned Space Flight to develop a small interim shuttle to test the concept of a logistics system. Known as the DC-3 because of its relative simplicity, the design was much smaller than those under consideration by the Office of Manned Space Flight.[62] But despite his efforts Faget did not find much support for his ideas.[63] The Office of Manned Space Flight favoured building a large-scale shuttle that would qualify immediately as an operational system.[64] Nevertheless, a realization that the White House would not restore NASA's to the heights of Apollo slowly filtered through the organization. NASA Administrator, Thomas Paine, thus agreed to establish a separate Phase-A effort in the event that budget limitations forced NASA into a redesign.[65]

Proponents of the large fully reusable two-stage shuttle also began to seek alternatives that would allow them to continue with their design and reduced peak funding. Two versions of a similar idea, one advanced by Marshall's former director, Wernher von Braun and the other proposed by the new Associate Administrator for Manned Space Flight, Dale Myers, involved spreading the development costs over a longer period by phasing the programme. Von Braun started his campaign early in an attempt to persuade top NASA officials that the agency should develop the reusable booster first, thus allowing NASA to go operational with an expendable orbiter while the reusable version was under development.[66] The concept did gain credence within

certain sections of NASA. Milton Thompson, from the Flight Research Center, described the idea as ‘not only ... the most attractive alternative, but also the most logical.’[67] Von Braun and his advocates considered that if NASA did develop the reusable booster first, then not only would it provide a proof of concept, but the next logical step would be to build the reusable orbiter.[68]

It was during a meeting on November 27, 1970, at the home of NASA's Deputy Administrator, George Low, that Myers suggested 'a course of action in which a reusable orbiter could be developed for initial operations using an expendable Saturn-IC booster.'[69] For Myers it was clear that the development of the orbiter first was the logical path to take because 'it focussed all the attention on the toughest technology problem.'[70] Low, however, was not convinced by the argument for an interim booster and told the Aeronautics and Space Engineering Board in 1971 that:

> … the most promising [expendable interim booster is] the S-IC, the Saturn V first stage. But even the S-IC presents formidable problems. There are technical difficulties, especially in the area of combined vehicle control, and also economic problems arising from the high cost of modifying the SI-C and the high repetitive cost of each launch.[71]

Nevertheless, the concept of a phased approach became increasingly attractive within NASA, though the agency found it much harder to sell to the contractors working on Phase-B. Discussions held at McDonnell Douglas resulted in them recommending 'against any interim booster system' preferring instead 'a slip of a year or so in the launch date.'[72] North American Rockwell 'also presented similar arguments to those heard at the McDonnell Douglas briefing'.[73] North American Rockwell’s

Shuttle Project Manager, Bastian Hello, highlighted the reasoning behind their negative reaction:

> As the programme went on doubts were raised about the R&D costs ... NASA started looking at partially reusable and partially throw-away vehicles ... we thought we were leading the pack ... in the all-reusable design and we were a little reluctant to let go of what we thought was our advantageous perch.[74]

As the programme moved into 1971 the orbiter-first strategy gained more weight. Despite Milton Thompson's observations that NASA had 'some tremendous gaps in the knowledge and experience required to design a successful shuttlecraft,'[75] development of the reusable booster first was 'never taken seriously by the shuttle program management' and after 1970 gained no further credibility.[76]

An Inconspicuous Coup

Tensions between NASA Administrator Thomas Paine, the Congress, and other executive branch officials had been working against NASA. Constantly agitating for additional funding, Paine publicly criticized the Nixon Administration for cutting NASA's budget[77] and after the White House ignored the Space Task Groups recommendations, he resigned from the post of NASA Administrator.[78]

Deputy Administrator George Low was thus in the position of Acting Administrator at a crucial juncture in the organizations history.

> Low then led what was a very interesting exercise ... he said we have got make a choice, whether to do the space station first or the shuttle first. ... Technically the space station was easier but, we recognized that the shuttle was the pacing item in this thing and, therefore, we said look ... let's do the difficult thing first and the space station will follow.[79]

> It was clear that the Station would be very expensive using expendable launch vehicles to build ... so it was deferred until the Shuttle was assured.[80]

Initially this idea met with some scepticism, as future NASA Administrator, James Fletcher reflected:

> When we first began thinking about the Space Shuttle, we thought of it as a vehicle to serve a large space station in Earth orbit. But we ran into a dilemma: we found that we could not expect to get funding to build both a large space station and the Space Shuttle in this decade. A space station would be of no use without the Shuttle. And at first we thought that the reverse was also true - that the Shuttle would be of little use without a space station to serve. But the more we looked at this, the clearer it became that no dilemma existed but rather an opportunity.[81]

As NASA's programmatic plans were remodelled, justifications for the shuttle became more elaborate. The predominant rationale for the shuttle was based upon a perceived requirement for a new vehicle to serve a space station. Now that NASA postponed hardware development of the space station, the role of the shuttle needed to expand.[82] Early conceptual thinking had characterized the shuttle's operational goals as 'broad' and able to serve 'a large number of users'.[83] Revitalized, these justifications now served as the key to the shuttle's promotion. During a meeting on November 27, 1970, top NASA officials, agreed that:

> [NASA] should probably change the baseline mission for the shuttle ... [from] the 270 nautical mile orbit and 55 degrees which is primarily for the space station to something more representative of the needs of NASA and DOD. This step would uncouple the prime justification of the shuttle as support for the space station to one of a transportation system for space satellites.[84]

The shuttle, now unhinged from the space station, was touted as a utilitarian space vehicle that would usher in a new age of space transportation. To emphasise the economic impact the shuttle would have on future space operations, Myers went as far as to suggest the possible savings the shuttle would bring:

> With the largest and most efficient present launch vehicles, the present cost is somewhat under $1,000 a pound. With the Space Shuttle, we expect to get this down to less than $100 a pound.[85]

This statement eventually proved controversial and stirred up a debate both within and outside of the political forum that continued throughout the programme and placed the economic rationale in jeopardy.

George Low appreciated that the economic argument might prove tenuous. Indeed true to Mueller's vision, importance for Low was in the new capabilities that the shuttle would provide.

> NASA is not seeking to justify the space shuttle program on purely economic grounds. The principal justification for the space shuttle is the new capability it can bring both to our civilian and military space programs for versatile and efficient operations in space.[86]

Routine access to earth orbit was seen as the catalyst for future infrastructure building in space, as one NASA official recalled:

> George Low, when we started this program, had a vision of making NASA more relevant and that relevancy would come when we had a whole new group of customers, and these would be the entrepreneurs and the cheap experimenters and the Edison's of their time, and we would provide them, easy, cheap access to space and they in turn would come up with new industries.[87]

After Paine's resignation Low, 'attempted to heal the breach between NASA and other agencies in the executive branch'[88] while simultaneously embarking upon a potent campaign for the shuttle. The aftermath of the 1970 Congressional battle left NASA in the role of appeaser. George Low aimed to win the Congress over by arguing that NASA's requests were moderate.[89]

> We believe that in moving toward the decision on the development of the space shuttle, NASA is proceeding in a conservative manner ... In connection with the decisions on FY 1972 budget request, we have deferred the development of the space station to avoid what would other wise have been unrealistic funding peaks during the 1970s.[90]

In an effort to rebut criticism, Low emphasised that Mars was not the hidden agenda and he stressed that:

> the space shuttle program does not represent a commitment to a *huge manned space program*. ... The space shuttle can be justified by its potential contributions to programs relying entirely on unmanned spacecraft. Decisions on future manned space programs ... can and have been decoupled from the decision on the space shuttle.[91]

Upgraded in status as NASA's principal programme for the 1970s, the shuttle 'became more and more important relative to the other elements' of the space programme. [92]

Precarious Affiliations

Left at the end of 1970 with no human missions beyond 1975 and concerned by the Office of Management and Budget's emphasis on cost-effectiveness, NASA believed that in order to gain political approval, it had to show that the shuttle could perform a much larger role than they had originally intended. NASA thus embarked on a campaign to persuade other communities of the benefits of its new launch vehicle; especially the national security community whose space hardware were projected to constitute some 34 per cent of all future space traffic.[93]

Since the establishment of NASA, the United States has had two space programmes; a civilian one, housed in NASA, and a military one controlled by the Air Force. NASA's long relationship with the US Air Force has invariably been both confrontational and cooperative. In the race for space among the services during the post-Sputnik months of 1957/58, the Army, Navy, and the Air Force all had their long-range space programmes on the table. The Air Force saw space power as 'merely the cumulative result of the evolutionary growth of air power' and, space flight as the 'natural and logical extension of air flight.'[94]

Although left out of the competition to launch the first American satellite, the failure of the Navy's Vanguard rocket and the transfer of the Army Ballistic Missile

Agency to NASA in 1960 solidified the Air Force's hold on military space flight.[95] The Air Force, however, considered that a programme split between them and NASA was unworkable. They lobbied hard in both the Pentagon and the Congress during the early 1960s to gain dominion over human space flight. Submerged in the rhetoric of space as a "sanctuary", exploited only for peaceful purposes and scientific advancement, arguments for total military control over space operations failed to dislodge NASA's hold over the Lunar-landing programme.[96] This did not mean that the Air Force were driven out of space entirely. As the Moon-landing programme progressed the transfer of Air Force technology (the Atlas and Titan rockets) and personnel to NASA impacted significantly on the space agency's culture, management systems, and relationship to the service.[97] The Air Force continued to fund research projects for human space flight during the 1960s, but the termination of its space-plane, Dyna-Soar in 1963 and the cancellation of the Manned Orbital Laboratory in 1969, had left the Air Force hesitant over its role within a national space programme.

Despite this, the Air Force had demonstrated an interest in NASA's space station/shuttle development programme. Although NASA and the Air Force conducted their research separately, there was some cooperative agreement between them in generating shuttle concepts during 1969.[98] They established a framework for DOD participation in NASA's shuttle programme through two groups: the Aeronautics and Astronautics Coordinating Board and the Space Transportation System Committee. The Aeronautics and Astronautics Coordinating Board had been in existence since 1965 and served primarily as a mechanism for the formulation of policy. The Space

Transportation System Committee signed into existence on February 17 1970, was co-chaired by Grant Hansen, Assistant Secretary of the Air Force for R&D, and Dale Myers, NASA's new Associate Administrator for Manned Space Flight. The committee had a broad mandate to review shuttle operational plans, technology requirements, programme objectives, and development plans to ensure that both NASA and DOD could agree on specifications.[99]

Cooperation in developing concepts for a reusable space vehicle between the Air Force and NASA had begun in 1966. At the time, NASA and the DOD concluded that the numerous cost uncertainties and technical risks could not be resolved. Their report did, however, consider that future demand for access to space would encourage the development of reusable launch vehicle technology and, that the current (1966) launch vehicle system would only fulfil NASA and DOD requirements for the next 7 to 10 years.[100]

Though the DOD viewed a NASA operated shuttle as potentially useful, the Air Force were not prepared to fund any part of the programme from its own budget. Secretary of the Air Force Robert Seamans was a former NASA top official and as such, sympathetic to the agency's aspirations, but few other high ranking Air Force officers favoured the shuttle and were content with their expendable launchers like the Atlas and Titan.[101]

The job of securing Air Force support had become paramount for NASA if the economic arguments given to the White House and the Congress were to stand ground.

Before 1971 ended, NASA's efforts to gain the Air Force as an ally would have a significant impact on a shuttle design.

Three key shuttle requirements insisted on by the Air Force were: lifting capability, orbiter payload bay size and orbiter crossrange (the lateral manoeuvrability of an aircraft). The Air Force based the dimensions of the payload bay and the lifting capability of a shuttle on a new generation of DOD reconnaissance satellites. Far heavier and larger than any previous observation satellites, it was lifting these kinds of payloads that the Air Force saw its most frequent use of the shuttle.[102] Air Force projections for the 1980s required a shuttle capable of lifting payloads between 40 000 to 50 000 pounds to orbit, within a 15 feet diameter by 60 feet long payload bay.[103]

The crossrange requirements arose from a tactical judgement. The Air Force wanted an orbiter that could rendezvous with a satellite and return to Earth after completing only one orbit, thus removing the need for flying over hostile territory in times of crisis. This demanded a high-crossrange capability of between 1100 and 1500 nautical miles on either side of the orbiter's re-entry ground track. A requirement that arose from the physical reality that the landing strip would have moved east some 1100 miles as the Earth rotated during the shuttle's first orbit. This requirement for a return to runway after a single orbit dictated a relatively shallow angle of attack and the high lift of a delta wing. In a series of reports, the Air Force also argued that a delta wing would produce a more aerodynamically stable and thus far safer orbiter.

Nonetheless, crossrange was of no great concern to some of NASA's engineers. Their primary interest was providing a routine daily opportunity to return to the

Kennedy Space Center, which only demanded a low 200 nautical mile crossrange capability. Many of the orbiter configurations emanating from Johnson, the NASA Center that traditionally controlled spacecraft design, thus adopted straight wings, essentially for simplicity. Indeed as Max Faget recalled, several of Johnson's engineers were:

> dead set against the [high] crossrange, it cost us a lot on performance. Having a [higher] crossrange on the way down meant you had to carry a heavier vehicle up there, and that extra weight on the vehicle meant less payload.[104]

Advocates of the low crossrange design also claimed that the Air Force did not appreciate NASA's expertise in low-lift-to-drag ratio wing designs that used exceptionally high angles of attack; a critical point in safely operating a straight winged orbiter.[105] Nevertheless, the Air Force rejected arguments for a straight winged orbiter.

The controversy over crossrange continued through 1970 because the Office of Manned Space Flight failed to generate any decision on the subject. Indeed both the 200 nautical mile and 1500 nautical mile crossrange options were still included in a second Office of Manned Space Flight shuttle requirements document released in December 1970.[106]

In contrast with other modes of transportation, such as ships, cars and trains etc, the problems associated with the stability and controllability of an aircraft take a position of pre-eminence in its design, because it has to move within three dimensional space as opposed to two.[107] Determining design issues were: wing design, wing-body

integration and integration of aerodynamic and flight control requirements. For the orbiter (as with all aircraft), wing design was key, because of its influence on vehicle weight, thermal environment, aerodynamic stability, buffet characteristics and gliding and landing performance.[108] Wing shape was also important because it determined the vehicle's aerodynamic performance. To define the shape of a wing, aerodynamicist need to make a decision about the planform (the outline of the wing when viewed from above) and the profile of the fore and aft sections, referred to as the airfoil. Two kinds of forces exert on the surface of a wing; pressure at right angles to the surface, known as lift and, skin friction tangential to the surface, known as drag. Lift depends almost entirely on the distribution of pressure. Drag, by contrast, depends primarily on the skin friction, which exists by virtue of the viscous flow in a thin boundary layer next to the surface of the wing.[109] The problem confronting the aeroplane designer is how to shape a wing that will obtain the optimum lift and drag characteristics needed for the vehicle's performance requirements. Wing design for the orbiter was further complicated however, because it had to satisfy the conflicting aerodynamic characteristics of the entire flight regime. Stuart Treon, chief of the Experimental Investigations Branch at the Aimes Center, told *Aviation Week and Space Technology* at the time, that the aerodynamic problems posed by the shuttle were 'extremely unusual'.[110]

Orbiter configurations emanating from Johnson had adopted a straight wing design, essentially for simplicity. During the re-entry phase of flight, the orbiter’s position would be at a very high angle of attack, almost 60 degrees. This would

produce a lot of drag to slow the vehicle down until it reached adequate velocity for level flight. Max Faget, the champion of the straight wing design, maintained that the important advantage of this configuration was that it minimized heating rates and reduced overall system weight. At such a high angle of attack, only the lower surfaces would be directly exposed to the on-coming airflow, which reduced the amount of protective insulation. Nevertheless, as highlighted above, the low crossrange produced by Faget's straight wing design combined with a high angle of attack at re-entry was unacceptable to the Air Force. Demand for a return to runway after a single orbit dictated a relatively shallow angle of attack and the high lift of a delta wing to produce the desired 1500 nautical mile crossrange.

Crossrange was not the only point of contention between the straight and delta wing designs. Slight centre of gravity shifts and balance consideration tended to move the straight wings aft, closing the gap between the tail and the wing. Many of the early orbiter designs carried internal fuel tanks, resulting in the centre of gravity being near the middle of the vehicle's length. It thus made sense to have the wings in roughly the same position for stability. But when the external tank was introduced and the weight of the orbiter's main engines grew, arguments were raised that Faget's design, with its long leading and trailing edges, would incur more heating problems than a shorter vehicle with lower aspect ratio delta wings. Wind tunnel and drop tests of models also indicated that the straight wing design might be dynamically unstable. The tests suggested the possibility of a divergent oscillation in a falling-leaf mode and a tendency for the orbiter to flat spin. Further analysis did show that the motions could be

easily dampened by reaction control thrusters, but performing complex control commands during reentry was not favoured by many at NASA or the Air Force.[111]

Although both configurations were technically feasible, Air Force pressure eventually swayed NASA away from the straight wing design. Despite the weight penalty and increased complexity of thermal protection, in the political arena Air Force support for the programme was far more important. As NASA winnowed out various shuttle concepts, they eventually adopted an orbiter configuration that incorporated a blended delta wing in August 1972.[112]

A series of wind-tunnel tests conducted during 1972 indicated that the original configuration did not meet NASA's landing performance requirements. Initially NASA had not stipulated a landing velocity on which to design the orbiter's wings, but midway through Phase-B the Office of Manned Space Flight defined a subsonic design velocity of 165 knots. This would produce a touch down velocity of between 180 to 190 knots, which was well within the state of the art in landing gear systems. The need to meet these requirements, then led to a re-configuration of the wing in late 1972. In-house studies by NASA and activity at Grumman indicated that a double-delta planform produced a more efficient lifting surface than the blended delta and had exceptional landing performance. In late 1972, NASA instructed Rockwell to incorporate a double delta wing design. In addition, the double-delta wing allowed for aerodynamic stability and trim adjustment by modifying the lightly loaded forward delta (glove). This simple control of aerodynamic features meant that the design of the main delta wing box could be frozen and any centre of gravity shifts or aerodynamic

stability problems could be corrected by glove modification, thereby minimizing the impact on the shuttle programme as a whole.[113]

Shifts in the Baseline Design

In line with Nixon's original request to former NASA Administrator Thomas Paine, to cut NASA's human space flight budget in half, NASA had come to the conclusion in early 1971 that by postponing the space station they could continue with the reusable two-stage shuttle at a development cost of $12 billion.[114] The National Academy of Engineering, however, were still troubled by the proposed development cost of NASA's shuttle, as the following letter extract shows:

> Basically, I'm afraid our concern today, as it has been in the past, is that the justification of the space shuttle program is still weak. It appears to us that the reason for this weakness is not so much the ultimate utility of the system but the fact that we still have not found the way to spread out the development costs in order not to have such a tremendous development peak that the entire NASA budget is placed in jeopardy. In the present environment of the anti-technologists, it seems to us even more important that we somehow solve the cost problem, particularly the development cost impact.[115]

In replying to the National Academy of Engineering, George Low alluded to the shifting position of NASA's higher echelons towards an alternate shuttle system:

> Spreading out the development costs of the shuttle so as not to place the NASA budget in jeopardy has been a subject of concern both to NASA and to our Phase-B shuttle definition contractors. We are devoting a great amount of study to cost reduction and cost alternatives. ... As part

> of our Phase-A activity, we have under study several alternate concepts for the space shuttle.[116]

The preferred orbiter configuration to emerge from the Phase-B and alternate Phase-A studies was a delta wing vehicle, which incorporated external liquid hydrogen fuel tanks that would jettisoned before entering orbit.[117] The incorporation of external fuel tanks allowed for a simplification of the orbiter's design, with the overall size of the orbiter now driven by the payload bay rather than the size of the internal tanks. Removal of the orbiter's internal fuel tanks represented the most significant deviation from NASA's original shuttle design and paved a way for NASA to manoeuvre around both the political and economic obstacles that stood in the way of the shuttle's development. Space Shuttle Program Manager, Robert F. Thompson considered the removal of the fuel tanks from the orbiter as 'the single most important configuration decision made in the shuttle program.'[118]

> I think the biggest thing that broke [the] logjam was our willingness to give up on everything being reusable. To take the propellants out of the orbiter. Propellants just made a mess out of trying to build the orbiter. You get them out and get them in a fairly simple tank, get some great big manifolds there to pump the propellant through and then throw that aluminum tank away, looked like a good common sense way of going.[119]

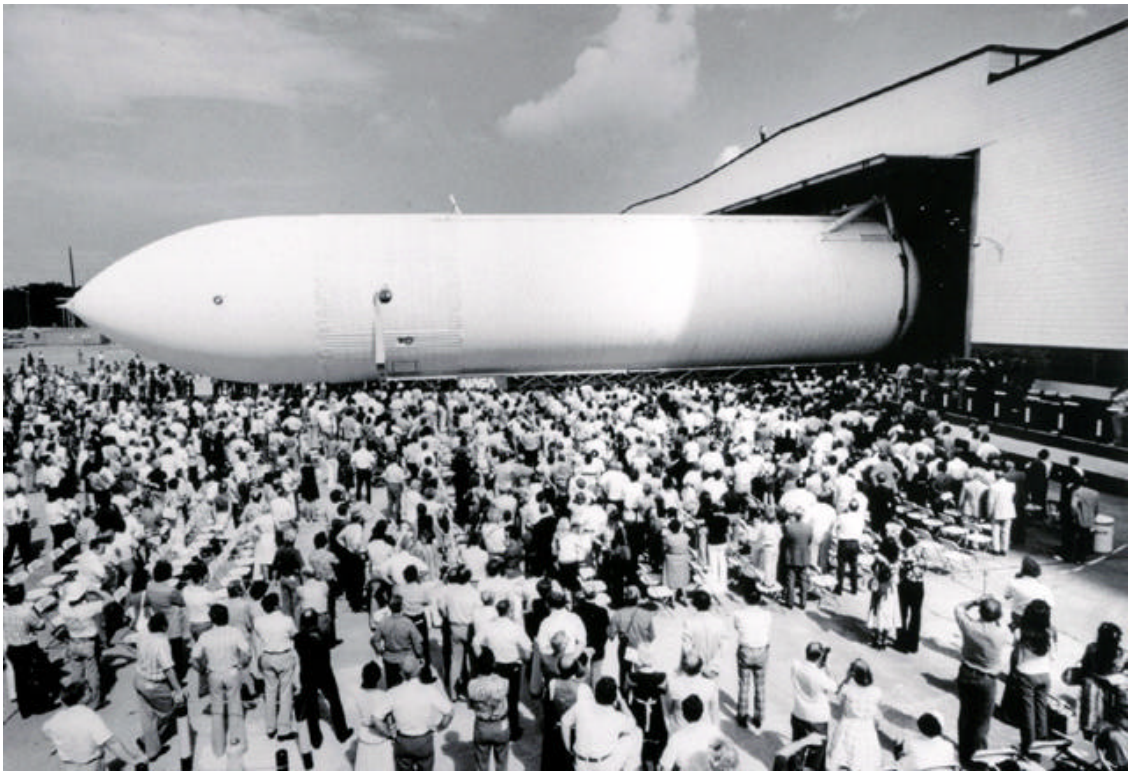
Grumman Aerospace had put forward the idea was most forcefully in its alternate Phase A studies, persuaded by some early ideas emanating from Johnson, as Grumman's Shuttle Engineering Manager, Richard Kline, recollected:

> When we heard those we felt that really was the answer. Not the technical answer but the pragmatic answer in view of the financial restrictions. So we went after the external tank concept quite heavily and validated the practicality of doing that.[120]

A series of design reviews conducted in early 1971, indicated that significant advantages when the orbiters liquid hydrogen fuel tanks were an external structure. The innovative move by Grumman was to extract the orbiter's liquid hydrogen tanks, which were far larger than the liquid oxygen tanks, and place them externally either side of the payload bay. The concept allowed the orbiter to shrink in size, thus altering the energy balance between the orbiter and the booster. Further studies by both NASA and the shuttle contractors demonstrated additional savings in development costs when both the liquid hydrogen and the liquid oxygen tanks were housed in a single external tank structure. The complexity of building and operating an orbiter with internal fuel tanks had also aroused a lot of concern within NASA and that, as Johnson Director, Chris Kraft, recalled drove the tanks outside:

> The structure was driven by our lack of confidence in being able to build a tank that could be an internal part of the aeroplane structure, because you had to be able to test it structurally after every flight ... and there was no way you could guarantee you weren't going to blow the aeroplane up by testing it. ... That's what drove the tank out of the machine ... I don't think structurally we could have done otherwise.[121]

In August 1971, the introduction of a single external structure housing both the liquid oxygen/hydrogen tanks for the orbiter had become a NASA baseline design.



The first Space Shuttle External Tank (ET), the Main Propulsion Test Article (MPTA), rolls off the assembly line on September 9, 1977 at Michoud Assembly Facility in New Orleans, Louisiana.

The primary function of the external tank, namely to house the liquid oxygen and liquid hydrogen that would fuel the orbiter's three main engines, was the basic determinant of its overall size. Thrust output and the operation time of the orbiter's three main engines both dictated the amount of fuel the system would be required to carry. A thrust specification of 400,000 pounds for each engine translated into a combined consumption rate of over 64,900 gallons of liquid propellant per minute. Since NASA had selected a parallel burn stacking arrangement, the main engines, ignited before lift-off, would have to propel the shuttle virtually all the way to orbit: a duration of about eight minutes. The external fuel tank, thus had to be sized to contain over 520,000 gallons of liquid propellant.[122]

Another critical design parameter shaping the external tank was its mass ratio. As the external structure had to go virtually all the way to orbit, it had to withstand all the aerodynamic forces, vibrations and speeds (around 27 000 feet per second) of the flight. In addition, because mass is of vital importance in travel to orbit, every pound of tank was equivalent to every pound of payload. Hence, NASA's tank designers had to keep the mass fraction of the tank as high as they could get it: the tank had to be very light, yet structurally very sound. The result was a unique tank design that comprised a very thin aluminium wall, which would call for some innovative steps in welding techniques.[123]

Although distinct in its requirements, the design of external tank drew heavily on NASA's experience with the tanks in the Saturn rockets.

> In concept [the external tank] ... was from the Saturn V, but it was designed differently because its shape was different. It was not as big in diameter ... it used less pieces to make a circle. ... The bulk heads were different shapes ... The technologies however, were the same.[124]

The Saturn tanks were several feet in diameter larger, so NASA had learnt a lot about welding capabilities. Nevertheless, in each tank there was going to be almost a mile and a half of weld:

> So every weld had to be perfect because if any one of them starts leaking, it doesn't have to rupture, just leak, then you can ... lose a vehicle.[125]

Predictions of aerodynamic forces on ascent were one of the first factors to modify areas of the external tank's design. Late in 1972, Martin Marietta changed the external tank's original cone-shaped nose to an ogive shape as early aerodynamic studies indicated that this shape would give a better performance and throughout 1973, they gradually decreased the overall length of the external tank and increased its diameter as the aerodynamic characteristics and interference effects of the integrated vehicle were better understood.[126]

> To be able to fly a vehicle stable you want to have the center of pressure in front of the center of gravity. So what we had to do was balance the diameter and the size to where basically the center of gravity was countered near to what we call the intertank, that bolts the [liquid oxygen and liquid hydrogen tanks] together, because that was about where the combination of the whole vehicle center of gravity would be. We wanted the center of pressure to be a few feet ahead of that; that way, as long as those two are separate, then your control laws are a lot simpler.[127]

Towards the end of 1973, negotiations and further refinements to an external tank design tapered off as a configuration acceptable to NASA was established. In early 1974, the design process appeared at a satisfactory point of closure and hardware development began.

Ballistic Solutions

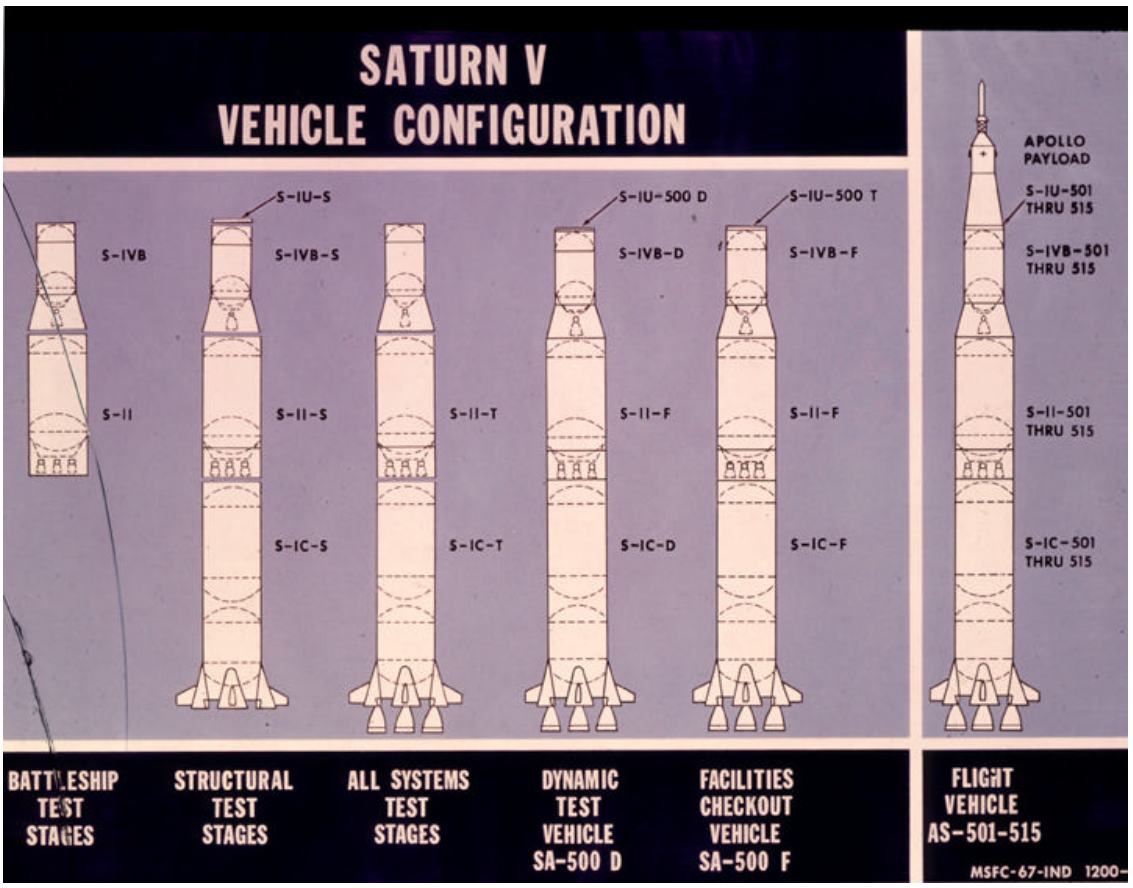
To circumvent criticism by the Congress and the White House, NASA's higher echelons publicly announced in June 1971 what they had been considering at the end of 1970: to proceed with phasing the shuttle's development. NASA would develop the

orbiter first followed by the booster. An interim, expendable booster would then serve the system while the reusable, human operated booster was under development. NASA argued that this would keep programme peak funding to just under $2 billion.[128] This change in the programme's approach translated into very different set of booster requirements.

Multi-stage rockets had played a vital role in NASA's crusade to the Moon. Staging methodologies provided stepwise increases in velocities with systems of conservative propellant-to-stage mass ratios.[129] Staging the rocket was a practice established very early in the history of space flight and continued on into the shuttle.[130] Indeed, in 1970, neither NASA nor the contractors considered that structural design, materials or fabrication techniques were sufficiently advanced to produce a single stage to orbit vehicle, which is why a vehicle incorporating two separate stages was first considered as the most viable configuration.[131]

NASA explored two sets of staging criteria when it moved to the interim booster approach: series burn and parallel burn systems. Series burn was a known stacking arrangement, traditionally exploited on NASA's previous launch vehicles. Orbital velocity would be achieved via stages, with the booster powering the initial ascent on its own and then, after separation, the orbiter's engines would ignite for the final climb. Three different booster concepts came under consideration within this category: the Saturn I-C as proposed by Dale Myers; a winged version of the Saturn V, proposed by Boeing; and a modified Titan III, proposed by the contractor Martin Marietta. Although NASA favoured the use of the SI-C, David Vine, Vice President of

Martin Marietta, lobbied hard for the Titan III, claiming that development costs would be low because most of the components were already in production and that a modified Titan would also provide a basis for active Air Force participation in the shuttle programme.[132] Boeing's idea, to convert the Saturn V into a booster system that could be recoverable after a sea ditch or a human-occupied fly-back vehicle, met with mixed reaction within NASA. Some considered the approach pragmatic because it utilized technology already in existence, while others were concerned that such a system would mean that the two-stage, fully reusable shuttle would 'never come to full fruition.'[133]



This illustration shows different configurations of the Saturn V test vehicles and flight vehicle.

Launching of the first human Gemini flight, Gemini-Titan 3.

Parallel burn was a new procedure and presented the 'challenge of a previously untried stacking arrangement.'[134] The concept involved the orbiter's main engines working simultaneously with the boosters allowing both to provide the necessary thrust for lift-off. The stacking arrangement was conducive to the use of relatively low performance boosters, as the orbiter's main engines would perform a larger share of the boosting, so the staging velocity could be reduced to around 3000 to 4000 feet per second. In addition, the parallel burn concept meant that verification of main engine ignition could be made before booster ignition.[135] The technical proposals were due on

the December 15, 1971, but as late as November NASA was still undecided on whether to opt for a series burn or parallel burn configuration.

The type of booster technology to be used, however, was not established until after Nixon's decision to approve the programme.

> When we first got the go-ahead for the program ... we were still not clear whether we were going to use liquid boosters ... or solid rockets and that was a major controversy in the early part of the program.[136]

The choices surrounding booster technology at the outset of 1972 were development of a new liquid fuelled pressure-fed system or modification of a solid propellant rocket.[137] Grumman Aerospace and Boeing Corporation were also promoting the traditional series-burn, pump-fed liquid system.[138]

Recovery versus expendable, coupled with development versus operational costs, hinged the debate between liquid fuelled and solid fuelled booster technology. Initial thinking within NASA had centred around reusable liquid systems fashioned for recovery after a sea ditch. This would keep operational costs low because NASA could reuse the rockets, but development costs would be high, because they were complex boosters to fabricate. Hence, NASA also examined expendable solid fuelled booster systems, because as relatively simple vehicles they would keep development costs low. However, throwing them away after each launch vastly increased operational costs.[139] Liquid fuelled rocket technology had been the mainstay of NASA's experience in human space flight. For many, both within NASA and the aerospace industry, it

appeared a given that NASA would use liquid propellants for the shuttle's booster system.

> The solid rocket people didn't understand why they were still being asked to study this and study that because we had never used solid rockets on a manned program as a major propulsion element. ... they came to me ... and said you are kind of stringing us along, we could be doing some other things here. We just can't understand why you are having us carry on these studies because we don't believe NASA can be serious about using solid rockets. ... They asked von Braun's opinion, he told them he felt sure that NASA, when they settled down, they would make the decision to go with the liquid booster. ... So the contractors were a little perplexed as to why we were still pushing that way.[140]

The liquid booster technologies though, were presenting a number of problems for NASA's engineers.

> The initial approach was to use liquids ... stay with what we know. However, a group came into the picture which said I think we can recover these [solid] boosters and reuse them. It [was proving] pretty difficult with the liquids. Once you get those engines soaked in sea water the probability of using them over is pretty remote, but the solid, which doesn't have a lot of complex mechanisms or machinery, has a chance. And so Thiokol and a couple of other solid people worked on it ... and when they went out and began demonstrating and throwing the thing into salt water and pulling it out and trying to reuse it, it became pretty convincing.[141]

External political pressures also influenced NASA's booster technology decision. Although the Office of Management and Budget had agreed not to become directly involved in any technical judgment after Nixon's announcement, their power over NASA's budget commitments was an effectual leverage on the agency's

technological decision making. Office of Management and Budget Director, George Shultz told NASA Administrator James Fletcher, early in 1972:

> With these very real funding constraints in mind, I believe that NASA would be well advised to select a shuttle system which minimizes the risk of cost overruns and allows flexibility to absorb possible cost increases within overall funding constraints. Otherwise, a cost overrun on the shuttle could lead to an undesirable stretch-out of the operational date for the shuttle or serious cutbacks in other productive NASA programs which, in turn, could jeopardize the shuttle program.[142]

In addition, Congress was forcing NASA to act quickly on a final configuration commitment. The House Committee on Science and Astronautics had 'demanded a firm decision' on NASA's choice of booster and shuttle configuration by the time they appear before the committee on March 16, 1972,[143] which especially concerned William Lilly, NASA's Comptroller:

> In reviewing the approach to the shuttle cost analysis ... we [have] become a bit apprehensive that some considerations that appear vital to a well rationalized decision on the shuttle configuration may not be adequately treated in the time frame which has been established for the final study effort.'[144]

In connection with the booster technologies Lilly felt that it was important to expose 'the degree of uncertainty associated with pressure-fed development costs versus solid development costs,' given the tight budget and lack of flexibility for contingencies.[145]

Early in March, NASA Administrator James Fletcher came to the conclusion that the 'use of solid boosters in the parallel staged configuration represents the optimum choice from combined technical and budgetary points of view:'[146]

> The decision concerning liquid or solid boosters was a difficult one. It involves a trade-off between future benefits ... and earlier savings ... liquid boosters have lower potential operating costs, while solid boosters have lower development cost. The decision concerns development risk which is lower for the solids because the technical unknowns are less, and also risks in operational costs which favor the solids because the economic exposure of failing to recover a booster is much less. Another approach to reaching this decision involved adding all costs together - development, investment and operating. However the conclusions here are heavily dependent on the mission model, with the liquid booster favored if we assume a large number of flights per year, and the solids if the number of flights per year is less. Based on the results of our contractor studies and our in-house estimates, and with our great concern about holding down development costs in these years of tight fiscal constraint, our decision must be in favor of the solid booster.[147]

A meeting between George Low and Donald Rice, of the Office of Management and Budget on March 7, confirmed that NASA was going to go ahead with the development of the solid rocket boosters for the shuttle.[148] In announcing the decision, Fletcher said the development costs would be reduced by $350 million and that the decision was based on lower development costs at less technical risk.[149]

Enervation, Resurgence and Ratification

George Low's role as NASA's acting Administrator ended with the appointment of James Fletcher in March 1971. Fletcher, after a long career in industry as a physicist and as president of the University of Utah, came to NASA with strong Republican credentials. Initially he presented a very cynical attitude towards human space flight and questioned the judgement of NASA's top officials on the need for a shuttle. Within a short time, however, he had become convinced that approval of the shuttle programme was essential.[150] With over $4 billion invested in facilities to support human space flight and NASA's three main Centers, Kennedy, Johnson, and Marshall almost totally dedicated to it, support was imperative if NASA's organizational structure was to remain intact.

Within Congress, a continuing rise in unemployment was spurring on a campaign for increased public spending. The 1970 recession and the refusal of Congress to hold down public spending meant that the deficit for the fiscal year ending in June 1971 was $23 billion, far more than in any post-war year except 1968. Unemployment was up to 6.1 per cent in May and the dollar had steadily grown more vulnerable in the international exchanges. A flight from the dollar in the money markets grew to rout proportions, finally leading to the Bank of England requesting that the US guarantee convertibility of Britain's dollar holdings into gold. In an attempt to stabilize the economy, on August 15 Nixon made a radical economic policy u-turn reverting to tight controls, including: a ninety day freeze on wages and prices;

suspension of convertibility of the dollar into gold; and a $4.7 billion cut in federal spending.[151]

> James Fletcher, [NASA's new Administrator] by a total mistiming went to see Nixon on the day that the dollar was floated and Nixon said, listen I don't have $12 billion ... do something for half.[152]

The Office of Management and Budget, equally concerned to limit budget requests going to the Congress confirmed the reduced sum. The two-stage shuttle that top NASA officials had been pushing for the past two years had an estimated peak funding level of over $2 billion.

Top NASA officials had earmarked December 1971 as the deadline for a presidential decision on the shuttle. Many in NASA were growing concerned about both the costs and psychological effects of a stretch out. Holding the industrial teams together would become problematic if the White House and Congress deferred the programme for another year. Once it was clear that the economic climate would not sustain a $12 billion programme, Fletcher instructed the Phase-B contractors to develop alternative design configurations that would cost no more than $5 billion to develop.[153] This was no easy task as North American Rockwell's Shuttle Manager, Bastian Hello, reflected:

> We were directed to move over to the other vehicle, and proposal time was hurrying along and we had some catch up work to do. So it became ... intense ... we were given some three months to propose and that became a nightmare.[154]

In addition to the new Phase-B contracts, Fletcher also let out a new contract to Mathematica to study all the alternative designs emanating from the extensions. The Office of Management and Budget forced the first study upon NASA – they went into the second voluntarily in the hope that it would justify an economical and practical programme.[155]

The key factor in the economic analysis was market demand; the number of flights. Accurate mission models were elusive and scenarios for future flight traffic rates over the 1979-90 time-period varied considerably.[156] Indeed forecasting future demand was an impossible task and so political considerations drove it as much as anything else. It was believed that the agency's 'position would be significantly weakened'[157] if Mathematica's economic analysis eliminated the space station. Some models, therefore, included the space station while others simply escalated the commercial demand. The debate over the number of flights persisted for some time before Mathematica eventually settled on a 514-mission model for its study.[158] Controversy, nevertheless, persisted, with traffic models and estimates of operational costs continually modified and attacked as the programme progressed.

By the end of the summer, the Mathematica study had revealed that even if operational costs rose to $10 million per launch all but 5 per cent of the shuttle's planned missions would be cost effective.[159] The configuration favoured by Klaus Heiss, who was leading the Mathematica staff, was a parallel burn Thrust Assisted Orbiter System based on a design first derived at McDonnell Douglas.[160]

> ... WE CONCLUDE THAT THE DEVELOPMENT OF A TAOS [Thrust Assisted Orbiter System] SPACE SHUTTLE SYSTEM IS ECONOMICALLY JUSTIFIED, within a level of space activities between 300 and 360 Shuttle flights in the 1979-1990 period, or about 25 to 30 Space Shuttle flights per year, well within the U.S. Space Program including NASA and DOD.[161]

Resistance to the thrust assisted orbiter configuration primarily came from Marshall because it eliminated the need for a future human piloted booster, which Marshall hoped to build.[162]

Heiss's strongest recommendation came in the form of a memo sent to Fletcher on October 28, 1971. In it, he stated that the Mathematica studies showed the thrust assisted orbiter to be the economically preferred choice. Among the reasons given for its economic superiority were: lower development costs of less than $6 billion; lower development risks; equal capability with the originally proposed system; elimination of the need for an immediate decision on a reusable booster; and the assurance of an early programme definition and thus a purpose to the agency.[163]

Although the final Mathematica report was not due for release until the end of January 1972, the memo gave a clear indication to Fletcher of its conclusions. Armed with this information and under pressure from the Office of Management and Budget, the Office of Science and Technology and the Presidents Scientific Advisory Committee, the Program Office began to push hard for the thrust assisted orbiter configuration.[164]

The debate continued right through November and December, but TAOS eventually emerged as the leading candidate presented to President Nixon on January

5, 1972. During that 40-minute meeting, Nixon stated that both military and civilian applications should be emphasised if the programme was to be accepted. He also appeared to like the idea that 'ordinary people' would be able to fly in the shuttle. Low and Fletcher stressed 'the fact that the shuttle is not a $7 billion toy, that it is indeed useful, and that it is a good investment'.[165] Nixon replied:

> ... that even if it were not a good investment, we would have to do it anyway, because space flight is here to stay. Men are flying in space now and will continue to fly in space, and we'd best be part of it.[166]

Nixon thus accepted the programme on the terms set out by Fletcher and Low and on the same day he publicly announced

:

> I have decided today that the United States should proceed at once with the development of an entirely new type of space transportation system designed to help transform the space frontier of the 1970s into familiar territory, easily accessible for human endeavour in the 1980s and '90s. ... It will revolutionize transportation into near space, by routinizing it. It will take the astronomical costs out of astronautics. ... The new year 1972 is a year of the conclusion for America's current series of manned flights to the moon. ... they bring us to an important decision point - a point of assessing what our space horizons are ... and of determining where we go from here. ... the space shuttle program is the right next step for America to take, in moving out from our present beach head in the sky to achieve a real working presence in space.[167]

Nixon also sent a letter to the chairman of his New Hampshire campaign committee on that day announcing his candidacy for reelection.[168]

President Richard M. Nixon and Dr. James C. Fletcher, NASA Administrator, discussed the proposed Space Shuttle vehicle in San Clemente, California, on January 5, 1972.

Unbeknown to NASA, senior White House staff members had started to support a shuttle development programme. Although Nixon's economic policies were slowing down the rate of inflation, unemployment continued to hover around 6 per cent. While much of the domestic bureaucracy was busy implementing the new economic policy, a few technicians at the Office of Management and Budget were assigned to develop statistical models plotting the effect of economic conditions on the outcomes of presidential elections. The study's results not surprisingly showed that rapid economic growth benefited an incumbent president seeking re-election.[169] Nixon

did not need statistical models to know that falling unemployment in 1972 would increase his chances of reelection. He thus decided to plunge ahead with increased federal spending to produce boom conditions in the election year.[170] The approval of the shuttle programme may well have been part of that agenda. It is certainly believed that Peter Flanigan, a White House policy level staffer, persuaded Nixon to go ahead with the shuttle because the continuing depression in the aerospace industry and that the relatively high rate of unemployment among the national pool of scientists and engineers would soon become election issues.[171] Whatever Nixon's motivations were, the shuttle's proponents had finally cleared the first hurdle, presidential approval, and the shuttle's development was programmed into NASA's FY 1973 budget.

Nixon's January 5 decision, to commit $5.15 billion to the development of a partially reusable shuttle initially prompted an adverse response in Congress. As Representative Don Fuqua (Democrat, Florida) recalled, many members of the congressional space committees were perturbed by NASA's conversion to a partially reusable system:

> We had just finished defending one configuration on the Floor and then suddenly they announced they were going to change it. ... We all wanted to know how long they had known they were going to change and how much of this kind of thing was going on behind the committee's back. They explained the reasons behind the changes, and everybody calmed down.[172]

Despite the initial consternation over NASA's "sudden" shift, strong allies quickly mobilized in support of the new configuration against a notably weak opposition. After

a morning of government and industry witnesses describing how necessary the shuttle was for America's future, Representative Bella Abzug (Democrat, New York) told the Manned Space Flight Subcommittee:

> Now that NASA has reached the Moon, it is seeking a new, similarly glamorous toy for its next project and it feels that the Space Shuttle would be just the ticket. ... I would remind you that the President recently vetoed as fiscally irresponsible a bill that would provide only $2 billion for child care Centers, a mundane but urgent issue for the millions of working parents in this country.[173]

Defenders of the shuttle counteracted such arguments by portraying the programme as one solution to America's rising unemployment problem. Support for Nixon's decision came from the American Federation of Labour and the Congress of Industrial Organizations (AFL-CIO) executive council, which Congress to defend the programme and its potential 50 000 jobs.[174] NASA's authorization bill thus passed with a comfortable majority: 277-60.[175] Opposition in the Senate also found themselves in a similarly weak position. A bipartisan coalition of 61 Senators successfully defeated Walter Mondale's amendment to cut shuttle funding, which only received 21 votes.[176] The shuttle plans had thus passed through both houses giving NASA the sanction to proceed.

However, 1972 was an election year and the award of a multi-billion dollar project during such a volatile period did not go unchallenged. NASA's selection of North American Rockwell sent out minor shock waves, which caused some factional eruptions in Congress. Jean Westwood, Chair of the Democratic National Committee,

considered that NASA's preference for North American Rockwell had come from more than just practical considerations. Five directors of North American Rockwell had contributed to Nixon's 1968 election campaign, so Westwood claimed that the Rockwell award represented the 'latest, and perhaps most blatant example of President Nixon's calculated use of the American tax payers dollars for his own re-election purposes.'[177] As such, Westwood pushed for an investigation into the relationship between contributions from directors of North American Rockwell to the presidential election campaign and NASA's award of the shuttle contract.[178] North American Rockwell declined to make any comment on the allegations, but NASA was eager to deny that politics played any part in the selection process and stated that North American Rockwell was 'chosen on technical and management merits alone.'[179] Within Congress Westwood received severe criticisms from her fellow Democrats. Representative Olin Teague (Democrat, Texas), claimed the shuttle contract was 'one of the most thoroughly and objective studied contract awards in any recent major government program.'[180] The call for an investigation was seen by others as a political manoeuvre to force ground between Nixon and one of the Democratic candidates, George McGovern

As in 1968, the continued involvement of the US in Vietnam dominated the 1972 election. Nixon's 'secret plan' to end the war in six months and ensure 'peace with honour' had proven disastrous. The Administration appeared no closer to a solution at the end of their four-year term, in spite of their detente and Vietnamization policies.[181]

A resolution to Vietnam, therefore, clouded many other issues during the election campaign, including Watergate.

An overwhelming majority in all the Republican primaries ensured Nixon his nomination to stand again.[182] The Democratic primaries had furnished a sufficient majority for Senator George McGovern to stand as Nixon's adversary: a nomination that had surprised many because of McGovern's radical platform. The mainstay of McGovern's manifesto was his proposals for a 'peace economy', which involved: the immediate pull out of US troops from Vietnam; the 'phasing down' of military spending and a corresponding increase in government spending on welfare, education, health, housing and other civilian projects; and the tightening up of the tax structure which was perceived as 'only benefiting big business.' For the aerospace industry in particular, McGovern's plan was for conversion, with military production replaced by civilian production.[183] Although NASA was a civilian agency and prided itself on its civilian status, McGovern believed the shuttle to be primarily a military programme. Two weeks after Nixon's announcement to develop the shuttle, McGovern told a Florida campaign audience that if elected he 'wouldn't manufacture a foolish project like the Space Shuttle to provide jobs' and that furthermore he considered the programme to be 'an enormous waste of money.'[184] The shuttle had thus become part of the divide between the McGovern and Nixon tickets.

An early campaign speech from Vice President Spiro Agnew also focused on the shuttle as an election issue. Agnew launched a vicious attack on the shuttle's critics labelling them as 'reactionaries, utopians and unrealistic' in arguing that spending on

space technology should be redirected to social problems. Such policies he argued, would 'bring to a virtual halt this country's technological progress.'[185] The advancement of science and technology, the accumulation of new knowledge, spin-off technology and investment in high skilled employment were all well rehearsed compositions of promotional rhetoric for the space programme and Agnew cited them all as examples of the 'benefits from the space program that will improve the quality of life for all mankind.'[186]

On the side of the Nixon campaign, was a large portion of the aerospace industry. The shuttle's relationship to jobs in that sector and its embodiment of scientific and technical progress meant that McGovern's intentions received a hostile reaction from many in the business. One of its public voices, *Aviation Week and Space Technology* took a strong stance against McGovern in its editorial at the time:

> His campaign speeches make it clear, that if elected, he intends not only to wipe out the future defense posture of this nation, but also strip its new technology to bare bones.[187]

The diatribe went on to claim that McGovern stood against 'every major aerospace technical development program including the shuttle,' and that his policies would 'wreak havoc upon the US.' In their view, 'for an aerospace worker to vote for Sen. McGovern would be to vote for self-destruction'.[188] Much the same conclusion had also been drawn within the higher echelons of the aerospace unions. The American Federation of Labour and the Congress of Industrial Organizations (AFL-CIO) were so

vexed by McGovern's nomination that for the first time in its history the executive council adjourned without voting for any presidential endorsement.[189]

The AFL-CIO's declaration of neutrality however, did not prevent considerable labour support for McGovern, even among central labour bodies constitutionally subject to official policy.[190] Delegates to the 1972 International Association of Machinists and Aerospace Workers (IAM) convention voted to endorse McGovern despite a resolution urging the IAM to remain neutral because of McGovern's opposition to the Super-Sonic Transport programme, the Lockheed loan and the B-1 bomber. Nixon found no support among the IAM delegates.[191]

Nevertheless, Nixon had the support of his "silent majority". A Gallup poll at the end of August put Nixon in the lead with a 64 percent share of the vote and had McGovern trailing behind with only 30 per cent.[192] Kissinger's secret talks in Vietnam with Le Duc Tho had almost reached a point of agreement, inspiring Kissinger to announce on October 26, just in time for the election, that 'peace is at hand.' Despite McGovern's plea to the electorate, to not 'let this man fool you again', 60 per cent of the voters chose Nixon in what was the largest election victory in modern American history.[193]

Although Nixon's Administration could not be described as ardent champions of the human space programme, a Republican triumph assured relatively strong support for NASA's shuttle programme. Presumably, given McGovern's rhetoric, the shuttle would have been a symbolic peace economy victim. Even assuming that McGovern

could not have forced through all of his radical policies it is conceivable that a Democrat win would have resulted in the programme's cancellation.

---

[1] David Baker, 'Evolution of The Space Shuttle: Part 1' *Spaceflight* (June 1973), p 202.
[2] Walter McDougall, *The Heavens and The Earth: A Political History of the Space Age* (New York: Basic Books, 1985), pp 420-22; Henry Lambright, *Powering Apollo: James E. Webb of NASA* (Baltimore: The John Hopkins University Press, 1995); pp 139-141; Henry Lambright, *Presidential Management of Science and Technology: The Johnson Presidency* (Austin: University of Texas Press, 1985), pp 142-150.
[3] Bruce Murray, *Journey Into Space: The First Thirty Years of Space Exploration* (New York, London, W.W. Norton & Company, 1990).
[4] Jerry Grey, *Enterprise* (New York: William Morrow and Co Inc, 1979), p 66.
[5] Francis Hoban, interview with the author, Virginia, 15 May 1995.
[6] Sylvia Fries, '2001 to 1994: Political Environment and the Design of NASA's Space Station System,' Marcel Lafollette, Jeffrey Stine, (ed) *Technology and Choice: A Technology and Culture Reader* (Chicago: The University of Chicago Press, 1991), p 234.
[7] *A National Integrated Missile and Space Vehicle Development Program*, Report to the National Advisory Committee for Aeronautics by a special committee on space technology, The Working Group on Vehicular Program, July 18, 1958 (NASA History Office Archives, Washington DC); *The Long Range Plan of The National Aeronautics and Space Administration*, Office of Program Planning and Evaluation, December 16, 1959 (NASA History Office Archives, Washington DC); James Hansen, *Enchanted Rendezvous: John C. Houbolt and the Genesis of the Lunar-Orbit Rendezvous Concept* (Washington DC, NASA History Office, Monographs in Aerospace History Series #4, December 1995).
[8] Francis Hoban, interview with the author, Virginia, 15 May 1995.
[9] William Normyle, 'Large Station May Emerge As Unwritten US Goal,' *Aviation Week and Space Technology* (March 10, 1969), pp 103-109.
[10] NASA changed this process as the programme progressed re-terming Phase-A as preliminary analysis, and combining Phases C and D into one. Hans Mark, Arnold Levine, *The Management of Research Institutions: A Look at Government Laboratories* (Washington DC, NASA, Scientific and Technical Information Branch, 1984), p 93.
[11] 'Reusable Space Shuttle Effort Gains Momentum,' *Aviation Week and Space Technology* (October 27, 1969), pp 22-24.
[12] *Space Shuttle Program Requirements Document: Level 1*, Office of Manned Space Flight, July 1, 1970 (NASA History Office Archives, Washington DC).
[13] William Normyle, 'NASA Aims at 100-Man Station,' *Aviation Week and Space Technology* (February 24, 1969), pp 16-17; William Normyle, 'Large Station May Emerge As Unwritten US Goal,' *Aviation Week and Space Technology* (March 10, 1969), pp 103-109.
[14] 'Shuttle Group Readies Proposal Requests,' *Aviation Week and Space Technology* (January 19, 1970), pp 17-18.
[15] Hans Mark, interview with the author, Texas, 8 September 1995.
[16] Ronald Segal, *America's Receding Future: The Collision of Creed and Reality* (England: Harmondsworth, Penguin Books Ltd, 1968), pp 159-60, 242-244, 252-258, 260-261, 275-278; Noam Chomsky, introduction to *American Power and The New Mandarins* (London, Chatto & Windus Ltd, 1969); James Reichley, *Conservatives in an Age of Change: The Nixon and Ford Administrations* (Washington DC: The Brookings Institution, 1981), p 205, 219; Michael Bradley, 'The Inexorable Rise of the National Dept,' Philip Davis, (ed) *An American Quarter Century: US Politics from Vietnam to Clinton* (Manchester and New York: Manchester University Press, 1995), pp 56-57.

[17] The first Gallop poll after the Democratic convention showed that Nixon had a substantial lead with 43 per cent of the vote. Richard Nixon, *The Memoirs of Richard Nixon* (London: Sidgwick & Jackson Ltd, 1978), p 318.
[18] For a detailed analysis of the establishment of NASA see, Enid Schoettle, 'The Establishment of NASA,' Lakoff, (ed) *Knowledge and Power* (New York: Free Press, Collier-Macmillian Ltd, 1966). For detailed histories of the Apollo space programme see, Mary Holman, *The Political Economy of the Space Program* (Pacific Books, 1974); John Logsdon, *The Decision To Go The Moon: Project Apollo and The National Interest* (Cambridge MA: MIT Press, 1970); Walter McDougall, *The Heavens and The Earth*; Dale Carter, *The Final Frontier:The Rise and Fall of the American Rocket State* (London, New York: Verso, 1988); Henry Lambright, *Powering Apollo*.
[19] Dale Carter, *The Final Frontier* p 127; John Logsdon, *The Decision To Go To The Moon* pp 21-22; Enid Schoettle, 'The Establishment of NASA,' pp 185-186, 220-229; Walter McDougall, *The Heavens and The Earth* pp 141, 148-149; H. Young, B. Silcock, P. Dunn, *Journey to Tranquillity: The Long Competitive Struggle To Reach The Moon* (New York: Doubleday & Co Inc, 1970), p 53.
[20] As Walter McDougall has demonstrated, the Eisenhower Administration had been anything but complacent since the Technologies Capabilities Panel Report in 1955, accelerating research and development of both missiles and satellite technology. None of this work could be made public for security reasons. Such concerns with space strategy over propaganda left Eisenhower open to attack, but as McDougall emphasises, loss of public face was less important than loss of potential secret satellite intelligence. In practice *Sputnik* proved strategically beneficial to the US since it precluded potential Soviet challenges to the legality of American satellite overflight. Walter McDougall, *The Heavens and the Earth* pp 111, 117-124, 128, 221, 224.
[21] Dale Carter, *The Final Frontier* p 158.
[22] For a detailed analysis of the Apollo fire and its aftermath see Henry Lambright, *Powering Apollo* pp 142-188.
[23] Ibid
[24] Francis Hoban, interview with the author, Virginia, 15 May1995.
[25] Walter McDougall, *The Heavens and the Earth* pp 373-374; Henry Lambright, *Powering Apollo* pp 106-107. The Manned Spacecraft Center was renamed the Lyndon B. Johnson Space Center on February 17, 1973. Further references will cite the Manned Spacecraft Center as the Johnson Space Center notwithstanding the time period.
[26] Francis Hoban, interview with the author, Virginia, 15 May1995.
[27] Henry Lambright, *Powering Apollo* pp 200-205.
[28] Mary Holman, *The Political Economy of The Space Program* p 5.
[29] Astronauts Armstrong and Aldrin, landed the Lunar Module to the Moons surface, leaving Collins in the Command Module. Armstrong became the first human to set foot on the Moon at 9:56 pm (EDT). They remained on the surface for a period of 21 hours, returning to a splash down in the Pacific Ocean on July 24. Linda Neuman Ezell, *NASA Historical Data Book Volume III: Programs and Projects 1969-1978* (Washington DC: The NASA History Series, Scientific and Technical Information Division, 1988), p 74.
[30] Francis Hoban, *Where Do You Go After You've Been To The Moon: A Case Study of NASA's Pioneering Effort at Cost Control with Prescriptions for Today* (Virginia: Draft Manuscript, George Mason University, 1995), p 1.
[31] Dale Carter, *The Final Frontier.* p 225.
[32] 'Space Effort Attacked,' *Aviation Week and Space Technology* (January 5, 1970) p 16.
[33] Hans Mark, *The Space Station: A Personal Journey* (Durham: Duke University Press, 1987), p 37; Hans Mark, interview with the author, Texas, 8 September 1995.
[34] Spiro Agnew, quoted in Scott Pace, *Engineering Design and Political Choice: The Space Shuttle 1969-1972* (MIT, Massachsetts: Unpublished MS Dissertation, 1982), p 20.
[35] Hans Mark, *The Space Station* p 37
[36] Francis Hoban, *Where Do You Go After You've Been To The Moon* p 3.

[37] The "Think Group" consisted of George Low; Wernher von Braun, Chief of NASA Planning Robert Jastrow, Director of the Goddard Institute for Space Studies; Homer Newell, Associate Administrator; Edward Cortright, Langley Research Center Director; Richard McCurdy, Associate Administrator for Organization and Management; and others as invited. The group spent a great deal of time debating the value and appeal of watching an astronaut pushing a boulder into Hadley Rille. The slow motion fall of a huge rock into a deep canyon at one-sixth gravity would prove incredible, but the scenario was dropped when the danger was pointed out of the astronaut falling in behind the boulder. Several attempts at viewer stimulation were made, including the feather and hammer drop, racing the Lunar Rover and playing Golf. These stunts tended to reinforce public scepticism rather than capture their attention. *Ibid*. pp 2-6.
[38] M. Smith, 'The First Quarter-Century of Space Flight,' M. Schwarz, P. Stares, Ed 'Space - Past, Present, and Future' *Futures*, 14 (October 1982), p 356.
[39] Letter to Senator William Proxmire from George Low, September 28, 1970 (NASA History Office Archives, Washington DC).
[40] STG included representatives from NASA, Defence Secretary Malvin Laird, Secretary of State William Rogers, Science Advisor Lee DuBridge and representatives from the State Department, the Atomic Energy Commission, and the Bureau of the Budget. Input was also received from members of Congress, the National Academy of Sciences, the American Institute of Aeronautics and Astronautics, private citizens and industry. Normyle W. 'Broad New Space Program Urged,' *Aviation Week and Space Technology* (August 11, 1969) pp 22-23.
[41] *The Post-Apollo Space Program: Directions For The Future*, Space Task Group report to the President, September 1969 (NASA History Office Archives, Washington DC), p 19.
[42] The PSAC had released a report in early 1967 entitled *The Space Program in the Post-Apollo Period*, which recommended that studies should concentrate on more economic systems for the delivery of payloads to orbit. The impact of the report was minimal as it had come at a time when the Johnson Administration was preoccupied with the escalating Vietnam war. The United States poured more money into the war in 1967 alone than it spent on the entire Apollo programme.
[43] Hans Mark, *The Space Station* p 33.
[44] Jerry Grey, *Enterprise* p 55.
[45] Francis Hoban, interview with the author, Virginia, 15 May1995.
[46] Jerry Grey, *Enterprise* p 55.
[47] William Normyle, 'Broad New Space Program Urged,' *Aviation Week and Space Technology* (August 11, 1969), p 23.
[48] James Reichley, *Conservatives in an Age of Change* pp 205-211; Michael Bradley 'The Inexorable Rise of the National Dept,' Philip Davis, (ed) *An American Quarter Century: US Politics from Vietnam to Clinton* (Manchester and New York, Manchester University Press, 1995), pp 56-57; John Kenneth Galbraith, *The New Industrial State* (England: Harmondsworth, Penguin Books, 1977), pp 96-97, 243, 250-262.
[49] The Office of Management and Budget replaced the less powerful Bureau of the Budget early in 1970.
[50] Claude Barfield, *Ibid*.; Scott Pace, *Engineering Design and Political Choice* pp 27-28.
[51] John Logsdon, 'The Decision to Develop the Space Shuttle,' *Space Policy* (May, 1986), pp 103-119; John Logsdon, 'The Space Shuttle Program: A policy Failure?' *Science* (May 30, 1986), pp 1099-1105.
[52] Claude Barfield, 'Intense Debate, Cost Cutting Precedes White House Decision to Back Shuttle.'
[53] David Baker, 'Evolution of the Space Shuttle,' *Spaceflight* p 230.
[54] Robert Thompson, interview with the author, 7 September 1995.
[55] Ken Hechler, *Towards the Endless Frontier* p 274.
[56] Jerry Grey, *Enterprise* pp 65-66; John Logsdon, The Decision to Develop the Space Shuttle,' p 106.
[57] Ken Hechler, *Towards the Endless Frontier*. p 285.
[58] Adelbert Tischler, letter to the author dated 16 April 1996.
[59] Dennis Jenkins, *Space Shuttle* p 67.
[60] Adelbert Tischler, letter to the author dated 16 April 1996.

[61] William Normyle, 'NASA Asks Quick Shuttle Replies,' *Aviation Week and Space Technology* (February 23, 1970), pp 16-17; Le Roy Day, interview with author, Maryland, June 29, 1995; Robert Thompson, interview with author, Texas, September 7, 1995; 'Mini Shuttle Proposed as Interim Project,' *Aviation Week and Space Technology* (February 23, 1970), p 16.
[62] It was named after the Douglas DC-3 aeroplane, which had become renowned for reliability and simplicity of design.
[63] Max Faget, interview with the author, Texas, 9 September 1995.
[64] Letter to Adelbert Tischler from George Mueller, August 25, 1969 (NASA History Office Archive, Washington DC); LeRoy Day, interview with author, June 29, 1995.
[65] Grumman001/310595; William Normyle, 'NASA Asks Quick Shuttle Replies,' *Aviation Week and Space Technology* (February 23, 1970), pp 16-17.
[66] Letter from Dale Myers to Thomas Paine, June 29, 1970 (NASA History Office Archive, Washington DC).
[67] Letter from Milton Thompson to Dr W. Von Braun, November 18, 1970 (NASA History Office Archive, Washington DC).
[68] Ibid
[69] Charles Donlan, memorandum for the record, discussion of the space shuttle program with Dr. Low,' December 2, 1970 (NASA History Office Archive, Washington DC).
[70] Dale Myers, quoted in Zack Strickland, 'Expendable Booster Gains Favor As NASA Studies Phased Shuttle,' *Aviation Week and Space Technology* (June 21, 1971), p 19.
[71] Letter from Raymond L. Bisplinghoff, Chairman The Aeronautics and Space Engineering Board, National Academy of Engineering, to George Low, December 18, 1970 (National Academy of Sciences Archive, Washington DC).
[72] Charles Donlan, memorandum for the record, trip report on visit to Phase-B contractors with Dale Myers on December 21, 1970, dated January 4, 1971 (NASA History Office Archive, Washington DC).
[73] Ibid
[74] Bastian Hello, interview with the author, Maryland, 27 April 1995.
[75] Letter from Milton Thompson to Dr W. Von Braun, November 18, 1970 (NASA History Office Archive, Washington DC).
[76] LeRoy Day, letter to the author dated 29 May 1996.
[77] Roger Launius, 'NASA and the Decision to Build the Space Shuttle, 1969-72,' *The Historian* 57 (Autumn 1994) p 25.
[78] Paine actually left office in September 1970 although his intentions were well known within NASA months before. Hans Mark, *The Space Station* p 38; W. Henry Lambright, *Powering Apollo* p 208. For background on the resignation of James Webb in 1968 and the appointment of Thomas Paine see pp 201-202, 204, 206-207.
[79] Hans Mark, interview with the author, Texas, 8 September 1995.
[80] Robert Freitag, letter to the author dated 1 June 1996.
[81] James Fletcher, banquet address before the Antelope Valley Board of Trade, *Where Do We Go From Here in Space?* Lancaster, California, October 18, 1974 (NASA History Office Archive, Washington DC), p 9.
[82] The shuttle was always a key to the space station and the shuttle's systems and configurations were driven, in part, by the station's requirements. Robert Frietag, letter to the author dated 1 June 1996.
[83] LeRoy Day, abstract to a collection of papers presented at *The Space Shuttle Symposium*, October 16-17, 1969 (Smithsonian Museum of Natural History, Washington DC).
[84] Donlan Charles, memorandum for the record, discussion of the space shuttle program with Dr. Low, December 2, 1970 (NASA History Office Archive, Washington DC).
[85] Ibid
[86] Letter to Clinton Anderson from George Low, May 28, 1971 (NASA History Office Archive, Washington DC).
[87] Francis Hoban, interview with the author, Virginia, 15 May 1995.
[88] Roger Launius, 'NASA and the Decision to Build the Space Shuttle, 1969-72' p 26.

[89] Letters to Walter Mondale and William Proxmire from George Low, September 28, 1970 (NASA History Office Archive, Washington DC).
[90] Letter to Walter Mondale from George Low, April 28, 1971 (NASA History Office Archive, Washington DC).
[91] Letter to Clinton Anderson from George Low, May 28, 1971 (NASA History Office Archive, Washington DC), emphasis in the original.
[92] Hans Mark, *The Space Station* pp 39-40.
[93] John Logsdon, 'The Decision to Develop the Space Shuttle,' *Space Policy* 2 (May 1986), pp 103-119; John Logsdon, 'The Space Shuttle Program: A Policy Failure?' *Science* (May 30, 1986), pp 1099-1105.
[94] John Logsdon, *The Decision To Go To The Moon* pp 28, 30; J. Manno, 'The Military History of the Space Shuttle,' *Science for the People* (September/October, 1983), p 7.
[95] Walter McDougall, *The Heavens and the Earth* pp 197-200.
[96] Ibid pp 312-324.
[97] Howard McCurdy, *Inside NASA: High Technology and Organizational Change in the US Space Program* (Baltimore: The John Hopkins Press, 1993), pp 14-17.
[98] This was, in part, due to the fact that the aerospace companies working for the Air Force were the same four under contract with NASA: General Dynamics, Lockheed, McDonnell Douglas, and North American Rockwell. 'Air Force Pushing Studies of Reusable Space Shuttle,' *Aviation Week and Space Technology* (August 11, 1969), p 25.
[99] Scott Pace, *Engineering Design and Political Choice* pp 100-101.
[100] *Report of the Ad-Hoc Subpanel on Reusable Launch Vehicle Technology*, September 14, 1966 (NASA History Office Archive, Washington DC), pp 1-8.
[101] Bill Sneed, interview with the author, Alabama, 21 August 1995.
[102] Joining the separate functions of area surveillance and close-look photography into one satellite was responsible for the increased size and weight of this new system. Increasing the length of the satellite made possible increases in focal length of the camera, which when combined with increases in the camera aperture provided new a new level of ground resolution. T. Greenwood, 'Reconnaissance and Arms Control' *Progress in Arms Control?* (San Francisco: W.H. Freeman and Co, 1979), p 99.
[103] The increase in diameter represented early thinking within the Air Force on the size of a third stage, or space tug that would deliver satellites to higher synchronous orbits.
[104] Max Faget, interview with the author, Texas, 9 September 1995.
[105] Scott Pace, *Engineering Design and Political Choice* pp 111-113; Dennis Jenkins, *Space Shuttle* pp 67-69.
[106] *Space Shuttle Program Requirements Document Level 1, Change No.2*, Office of Manned Space Flight, December 3, 1970 (NASA History Office Archives, Washington DC), p 3.
[107] Bernard Etkin, *Dynamics of Flight: Stability and Control* (New York, John Wiley & Sons Inc, Second Edition, 1982), p 3.
[108] James Young, Jimmy Underwood, Ernest Hillje, Arthur Whitnah, Paul Romere, Joe Gamble, Barney Roberts, George Ware, William Scallion, Bernard Spencer, James Arrington, Deloy Olsen, 'The Aerodynamic Challenges of the Design and Development of the Space Shuttle,' Norman Chaffee, (ed) *Space Shuttle Technical Conference, Part 1* (Houston, Texas, NASA, JSC, Conference Publication 2342, 1985), pp 209-263.
[109] Walter Vincenti, *What Engineers Know and How They Know It* pp 18, 34; A.C. Kermode, *An Introduction to Aeronautical Engineering: Vol 1, The Mechanics of Flight* (London, Sir Issac Pitman & Sons, Ltd, 1940).
[110] Richard O'Lone, 'Shuttle Test Pace Intensifies at Aimes,' *Aviation Week and Space Technology* (June 24, 1974), p 71.
[111] James Young, Jimmy Underwood, Ernest Hillje, Arthur Whitnah, Paul Romere, Joe Gamble, Barney Roberts, George Ware, William Scallion, Bernard Spencer, James Arrington, Deloy Olsen, 'The Aerodynamic Challenges of the Design and Development of the Space Shuttle,' Norman Chaffee, (ed) *Space Shuttle Technical Conference, Part 1* (Houston, Texas, NASA, JSC, Conference Publication 2342, 1985), pp 209-263.

[112] Ibid
[113] Ibid; Richard Kline, interview with the author, Washington DC, 31 May 1995.
[114] Hans Mark, interview with the author, Texas, 8 September 1995.
[115] Letter from Raymond L. Bisplinghoff, National Academy of Engineering, to George Low, April 22, 1971 (National Acadeny of Sciences Archive, Washington DC).
[116] Letter to Raymond L. Bisplinghoff, Chairman The Aeronautics and Space Engineering Board, National Academy of Engineering, from George Low, May 21, 1971 (National Academy of Sciences Archive, Washington DC).
[117] Letter from James Fletcher to Dr O'Brian, June 16, 1971 (NASA History Office Archive, Washington DC); Letter from James Fletcher to Robert Seamans, June 16, 1971 (NASA History Office Archive, Washington DC); Strickland Z. 'Expendable Booster Gains Favor As NASA studies Phased Shuttle' *Aviation Week and Space Technology* (June 21, 1971) p 19.
[118] Robert Thompson, *The Space Shuttle: Some Key Program Decisions*, American Institute for Aeronautics and Astronautics, Von Karman Lecture, 22nd Aerospace Sciences Meeting, Reno, Nevada, January 9-12, 1984 (supplied to the author by Robert Thompson), pp 3-4; Michael Yaffee, 'Program Changes Boost Grumman Shuttle' *Aviation Week and Space Technology* July 12, 1971), pp 36-39;
[119] Robert Thompson, interview with the author, Texas, 7 September 1995.
[120] Richard Kline, interview with the author, Washington DC, 31 May 1995.
[121] Christopher Kraft, interview with the author, Texas, 1 September 1995.
[122] Dennis Jenkins, *Space Shuttle* pp 225-226; W.H. Morita, (ed) *Space Shuttle System Summary* p 28.
[123] James Odem, interview with the author, Alabama, 21 August 1995; James Kingsbury, interview with the author, Alabama, 16 August 1995.
[124] Ibid
[125] Ibid
[126] Ibid; 'Shuttle Weight Cut 20 Percent Over Last Year,' *Defense/Space Business Daily* (March 1, 1974), p 5; Charlie Dill, J.C. Young, B.B. Roberts, M.K. Craig, J.T. Hamilton, W.W. Boyle, 'The Space Shuttle Ascent Vehicle Aerodynamic Challenges: Configuration, Design and Data Base Development,' Norman Chaffee, (ed) *Space Shuttle Technical Conference, Part 1* pp 151-152.
[127] James Odem, interview with the author, Alabama, 21 August 1995.
[128] Robert Thompson, *Von Karman Lecture* pp 3-4; M. Yaffee 'Program Changes Boost Grumman Shuttle' *Aviation Week and Space Technology* (July 12, 1971) pp 36-39;
[129] Mass ratio is a design parameter, which relates the total mass at ignition and the final rocket mass at burn-out.
[130] Max Faget, interview with the author, Texas, 9 September 1995; Myron Uman, email to the author, 7 October 1996; Myron Uman, interview with the author, Washington DC, 24 April 1995; Adelbert Tischler, interview with the author, Washington DC, 3 May 1995; Adelbert Tischler, letters to the author dated 13 November and 4 December 1996 Lyn Dutton. Etal *Military Space* pp 30-36; Arthur C. Clark. *The Exploration of Space* pp 27-28; Joseph Thiboaux. 'Propulsion and Power Systems Perspective' Norman Chaffee. (ed) *Space Shuttle Technical Conference, Part 2.* (Houston Texas, NASA, JSC, Conference Publication 2342, 1985) pp 581-584.
[131] Single stage to orbit vehicles are only just recently becoming a distinct possibility with developments in new high-strength, light-weight materials and fabrication techniques. Adelbert Tischler, letter to the author dated 16 June 1997
[132] Z. Strickland, 'Titan 3L Studied As Expendable Booster' *Aviation Week and Space Technology* (August 2, 1971) pp 40-41.
[133] Ibid
[134] Robert Thompson, *Von Karmen Lecture* p 8.
[135] NASA. *Technology Influence on the Space Shuttle Development* p 5-20.
[136] NASA007/260695.
[137] William Hieronymus, 'Three Shuttle Booster Concept Studied,' *Aviation Week and Space Technology* (January 10, 1972), pp 46-48; 'Shuttle Decision Hailed as NASA Victory,' *Aviation Week and Space*

Technology (January 10, 1972), pp 15-16; Zack Strickland, 'Pressure-Fed Booster Explore,' *Aviation Week and Space Technology* (January 24, 1972), pp 40-41.
[138] The Grumman\Boeing concept was based on a modified Boeing S-1C, which they claimed could be developed for about half the cost of a liquid pressure-fed system and would entail less technological risk. They also cited an advantage of less weight over the pressure-fed system, 300 000 pounds as compared to 1 million pounds, because it would not need thick walls to withstand tank pressurization. Despite the obvious benefits associated with thrust to weight specifications, reduction in weight was considered less of a risk because there was great uncertainty at the time as to what would happen to a million pound pressure-fed booster on water impact. Michael Yaffee, 'Alternate Booster Evaluation Set,' *Aviation Week and Space Technology* (January 24, 1972), pp 36-37.
[139] William Hieronymus, 'Three Shuttle Booster Concept Studied,' *Aviation Week and Space Technology* (January 10, 1972), pp 46-48; 'Shuttle Decision Hailed as NASA Victory' *Aviation Week and Space Technology* (January 10, 1972), pp 15-16; Zack Strickland, 'Pressure-Fed Booster Explore,' *Aviation Week and Space Technology* (January 24, 1972), pp 40-41.
[140] LeRoy Day, interview with the author, Maryland, 29 June 1995.
[141] Robert Frietag, interview with the author, Virginia, 5 June 1995.
[142] Letter from George Shultz, Director of the OMB to James Fletcher, February 16, 1972 (NASA History Office Archive, Washington DC).
[143] Letter from James Fletcher to Casper Weinberger, Deputy Director, OMB, March 6, 1972 (NASA History Office Archive, Washington DC).
[144] Letter from William Lilly to Dale Myers, February 11, 1972 (NASA History Office Archive, Washington DC).
[145] Ibid
[146] Letter from James Fletcher to Casper Weinberger, Deputy Director, OMB, March 6, 1972 (NASA History Office Archive, Washington DC).
[147] Ibid
[148] George Low, memorandum for the record, meeting with Don Rice, March 8, 1972 (NASA History Office Archive, Washington DC).
[149] Zack Strickland, 'Single Shuttle Contractor Planned' *Aviation Week and Space Technology* (March 20, 1972), pp 14-15.
[150] Jerry Grey, *Enterprise* p 71; Joseph Trento, *Prescription for Disaster* pp 105-106; John Logsdon John, 'Decision to Develop the Space Shuttle,' p 107.
[151] James Reichley, *Conservatives in an Age of Change* pp 219-225.
[152] Hans Mark, interview with the author, Texas, 8 September 1995.
[153] The Grumman/Boeing team and Lockheed also received Phase-B extension contracts even though they had not technically participated in Phase-B.
[154] Bastian Hello, interview with the author, Maryland, 27 April 1995.
[155] Grey Jerry. *Enterprise* pp 78-79.
[156] Memorandum from Dale Myers to Deputy Associate Administrator, Planning, June 17, 1971 (NASA History Office Archive, Washing ton DC). Flight rates varied from 492 to 732.
[157] Ibid
[158] Heiss K.P. Morgenstern O. *Economic Analysis of the Space Shuttle System: Volume 1.*
[159] The two-stage fully-reusable configuration had a projected per-launch cost of $4.6 million.
[160] LeRoy Day, letter to the author dated 5 May 1996.
[161] Heiss K.P. Morgenstern O. *Economic Analysis of the Space Shuttle System: Volume 1.* p 1-11. Emphasis in original.
[162] LeRoy Day, letter to the author dated 5 May 1996.
[163] Scott Pace, *Engineering Design and Political Choice* p 40.
[164] LeRoy Day, letter to the author dated 5 May 1996.
[165] George Low, memorandum for the record, January 12, 1972 (NASA History Office, Washington DC).
[166] Ibid

[167] Statement by President Richard Nixon, press release from the Office of the White House Press Secretary, January 5, 1972 (National Air and Space Museum Archive, Washington DC).
[168] Nixon Richard. *The Memoirs of Richard Nixon* p 541.
[169] Edward Tufte, *Political Control of the Economy* (New Jersey, Princeton University Press, 1978) p 136.
[170] James Reichley, *Conservatives in an Age of Change* p 226.
[171] Francis Hoban, interview with the author, Virginia, 15 May 1995.
[172] Don Fuqua, quoted in Ken Hechler, *Towards the Endless Frontier* p 289.
[173] Bella Abzug, quoted in *Ibid*. p 290.
[174] 'AFL-CIO Backs Space Shuttle' *The Machinist* (March 2, 1972) p 1.
[175] Ibid pp 292-293; 'Senate Vote Coming on Space Shuttle' *The Machinist* (May 4, 1972), p 3; Jeffrey Banks, 'The Space Shuttle,' Linda Cohen, Roger Noll, (ed) *The Technology Pork Barrel* (Washington DC, The Brookings Institute, 1991), p 203.
[176] 'Shuttle Vote Brightens Aerospace Job Outlook' *The Machinist* (May 18, 1972), p 1.
[177] Jean Westwood, quoted in 'The Democratic National Committee' *Aviation Week and Space Technology* (August 7, 1972), p 15.
[178] The five identified by Jean Westwood were: J.L Atwood, contributed $2000; George Karch, $1000; Frederick Larkin Jr, $1000; Henry Mudd, $3000; and Willard Rockwell, $1000 (1972 dollars), Ibid.
[179] Zack Strickland, 'Shuttle costs Remain $5 billion' *Aviation Week and Space Technology* (July 31, 1972), pp 12-13.
[180] Olin Teauge, quoted in 'The Democratic National Committee,' *Aviation Week and Space Technology* (August 7, 1972), p 15.
[181] Stephen Ambrose, *Rise to Globalism: American Foreign Policy, 1938-1980* (Middlesex, England, Penguin Books Ltd, Second Revised Edition, 1981), pp 308-334.
[182] Richard Nixon, *The Memoirs of Richard Nixon* p 544.
[183] George McGovern, *An American Journey: The Presidential Campaign Speeches of George McGovern* (New York, Random House, 1974).
[184] George McGovern, quoted in Ken Hechler, *Towards the Endless Frontier* p 289.
[185] Spiro Agnew, address by the Vice President of the United States at the Florida Jaycees State Convention, Daytona Beach, Florida, January 29, 1972 (Kennedy Space Center Archive, Florida), pp 1,2.
[186] Ibid pp 5,6.
[187] R. Hotz, 'Editorial,' *Aviation Week and Space Technology* (July 31, 1972), p 7.
[188] Ibid
[189] Conservative politics prevailed within the AFL-CIO executive long after Vietnam had shattered the cold war consensus. Although its middle class allies had deserted Johnson and campaigned for an end to the war the AFL-CIO continued to support the conflict. To the AFL-CIO, McGovern's nomination was a manifestation of what they perceived as an extremist take over of the Democratic Party. David Brody, *Workers in Industrial America: Essays on the Twentieth Century Struggle* (New York, Oxford, Oxford University Press, 1980), pp 238-244.
[190] Ibid p 242.
[191] 'Convention Backs McGovern, No Support at all for Nixon' *The Machinist* (September 14, 1972), pp 1,7.
[192] Richard Nixon, *The Memoirs of Richard Nixon* p 680.
[193] Stephen Ambrose, *Rise to Globalism* pp 333-334.