Space Safety 2005

Executive Report

SPACE SAFETY REPORT:

Vulnerabilities and Risk Reduction

In U.S. Human Space Flight Programs

Prepared by the Space & Advanced Communications Research Institute (SACRI)

George Washington University
Washington, D.C., USA

A Research Report Conducted under a grant from the Space Shuttle Children's Fund (SSCF)

Investigators:

Joseph N. Pelton, David Smith, Neil Helm, Peter MacDoran and Philip Caughran
Special Contributor for Chapter 2: John Logsdon

Research Assistants: **Justin Borodinsky, Mark Evan Green and C. Vyas and Mamta S. Sodikumar**
Editor : Peter Marshall

HIGH LEVEL EXECUTIVE REPORT ON SPACE SAFETY

"We must face the context of human interdependence in the face of the vast new dimensions of our science and our discovery…..…of the awful majesty of outer space."

Adlai Stevenson, Geneva, Switzerland July 9, 1965

In late 2003, the Space Shuttle Children Fund commissioned a team of George Washington University faculty members to conduct a review of astronaut safety. This is a report to the SSCF that indicates our findings.

This report presents our comprehensive review and analysis of the management, technical and operational aspects of all NASA astronaut-related programs. Thus there are detailed findings related to the Space Shuttle program, the International Space Station, and various human spacecraft and escape vehicles that have been initiated by NASA within the past fifteen years. It also includes analysis of the evolving plans and concepts for new initiatives such as the Crew Exploration Vehicle (CEV) and some discussion of new private entrepreneurial programs to develop manned access to space. This study represents a combined cumulative effort by a dozen faculty and graduate students that totals about 1.25 man-years of research during 2004 and the early part of 2005.

SUMMARY FINDINGS

Our major findings are presented in summary form below. Further updates and information can be found at the http://www.spacesafety.org web site.

Figure A : Findings Concerning the Space Shuttle and Possible Safety Enhancements

1.	We support the full implementation of the Independent Technical Engineering Authority within NASA. This includes full oversight of safety, control of waivers, full control of the NASA Engineering and Safety Center and with jurisdiction over the computerized implementation and scheduling system for the Shuttle and ISS that is being established in response to recommendation 13 of the CAIB report.
2.	A replacement crew vehicle system for the Shuttle should be developed as soon as possible and any financial benefits resulting from shutting down of the Shuttle at a somewhat earlier date reinvested in the earlier development of the replacement vehicle or other system requirements of the New Exploration Space Vision.
3.	In general, robotically controlled cargo vehicles should in the future do the heavy lifting into space to minimize astronaut risk and specially designed crew vehicles should fly separately or in tandem with cargo vehicles and should provide a full envelope escape mode for the crew.
4.	We are in general agreement with the findings of the CAIB, the Rogers Commission, the Diaz Committee report and the findings of the BST Inc. and believe these all aid Shuttle safety.
5.	Serious consideration should be given to the feasibility of converting and operating one or more of the orbiters as a "robotic" cargo vehicle because it could reduce risk to astronauts on missions where crews were not essential and increase cargo lift capability.
6.	Explore reducing the number of remaining flights for the Shuttle by limiting some aspects of ISS construction. This should be considered in concert with the international partners and should not involve reduction of flights related to major international subsystems such as the European Columbus Space Lab and the Japanese CAM and JEM. (Simply put, more flights of the Shuttle increase the odds of another catastrophic failure as indicated in Figure 1.3 of this report.)
7.	Several safety issues and possible improvements to the Shuttle, as listed in Figure 3.1 and Figure 3.2 of the full report, are offered as possible ways to reduce risk although it is recognized that many of these involve considerable expense and many have also been previously considered.

Figure B : **Findings Concerning the International Space Station and Possible Safety Enhancements**

1.	As noted above a reduction in scope of the ISS that would reduce the number of Shuttle missions and thus would also reduce the probability of a major accident and in theory allow the development of a new replacement "manned" launch system sooner.
2.	The lack of an effective escape capability from the ISS or the ability to use the ISS as an extended safe haven when the Shuttle is not available is of major concern. In this regard either the immediate re-activation of the X-38 program or the obtaining of U.S. legislative authority and funding to support obtaining additional Soyuz (including expanded crew-capacity Soyuz vehicles) to be used as access and escape vehicles is considered to be of priority concern.
3.	The various safety issues and possible improvements to the ISS as listed in Figure 4.1 and Figure 4.2 are offered as possible ways to reduce risk although it is recognized that many of these involve considerable expense and many have also been previously considered. Observations with respect to the gyro system, the environmental systems, and debris hazards , are considered among the most important issues.
4.	International components of the ISS have certain safety implications. These fortunately do not give rise to any major concerns. The formation of the International Association for the Advancement of Space Safety might well provide new opportunities for a more integrated ISS operational process for safety and emergency procedures that go beyond the "national franchises" on the ISS.
5.	The Independent Technical Authority and the NESC could provide significant strength to the oversight of ISS safety operations, better control of "waivers", and also might usefully address the issue of so-called "risk creep" that has accompanied the current operational procedures that have "evolved" during the period of the grounding of the Shuttle.

Figure C : **Findings Concerning the Future Human Space Programs and Safety Enhancements**

1.	It is important that historical lessons from the Shuttle be learned and applied to future planning. Key aspects in this regard: (i) Don't combine too many missions and capabilities; (ii) Ensure the ongoing infusion of new technology; (iii) Provide complete launch-to-land escape capability; (iv) Seek simplicity of design, operation and retrofit (especially of passive systems); (v) Design in safety at the beginning including sensor warning systems, shutdown & escape; (vi) Recognize that safety is only as strong as the weakest link (i.e. a highly reliable CEV on top of a launch vehicle that is not as highly rated could still represent a "questionable" system.)
2.	Cargo systems that can be robotically deployed are not only safer (i.e. no crew) but may very well be faster and more economical.
3.	Advanced technology is not necessarily more "complex technology." Simplicity of design (such as throttle-able solid fuel systems) and other systems that provide increased performance at lower cost and with few active components might represent the best designs. (Input from smaller entrepreneurial organizations should be actively sought in designing future launch systems.)
4.	The coordination and relationship between NASA and defense-related manned space programs is not clearly delineated and certainly not transparent. This could lead to safety issues in terms of key information not being shared, overlap or "underlap" of programs and best practices observed in one sector but not another.

Figure C : Findings Concerning the Future Human Space Programs and Safety Enhancements (Continued...)

5.	Private initiatives to develop new manned space capabilities, space tourism and even private "spacehabs" are moving forward in response to "prize awards", new "entrepreneurial capital" and new regulatory authority provided to the FAA. This provides new paradigms with regard to "private" astronauts and even approaches to passenger liability, insurance, and risk assessment. This may offer NASA new opportunities in the future. It may eventually also allow NASA's "manned space and astronaut" programs to work in parallel or competition with private ventures. This may not reduce risk but nevertheless help redefine "public" and "private" safety definitions and accepted standards for safety performance.
6.	The Crew Exploration Vehicle if launched by an upgraded expendable rocket such as Delta, Atlas or Titan will likely remain limited in its safety and reliability rating by this design approach
7.	Evolution to launch systems that use new technology such as ion engines, tethers, or electrical and nuclear propulsion systems instead of "chemical explosions" may represent the key to providing safer and more reliable access to space in the future.
8.	The longer-term future of astronaut safety will evolve so that developing the safest transportation systems may not be the greatest challenge. Instead the prime issues may relate to protecting astronauts in space from debris, micro-meteorites, comets, radiation, zero and/or low gravity environments, and thus a move toward the more difficult aim of long-term survival in space.
9.	All new human space transportation systems should be developed to common international standards that would permit compatibility for emergency crew rescue contingency capabilities, when needed. These standards should be developed in concert with international partners, and the specifications should be made widely available for the public and private sectors for any nation seeking to develop these capabilities to use as they deem warranted. This is a key consideration in making possible, affordable, reliable alternative access, by dissimilar redundancy.

REPORT SUMMARY

Exploration is one of the hallmark characteristics of a dynamic civilization. From Lewis and Clark's travels to the first Moon landing, this willingness to define and explore new frontiers is a basic American trait. We know that the exploration of space by humans is not risk-free. Nor will major risks soon be eliminated. Yet, we think that this Report, if considered and acted on, can help to make future space exploration and travel safer. Indeed the first step in this regard would be for the new NASA Independent Technical Authority, when fully implemented, to define astronaut safety and safety guidelines more precisely. The clear definition of safety standards such as the FAA has done for commercial aviation and experimental aircraft would be desirable. This effort could start with a clear definition of what safety for a "human-rated vehicle" means, not only in terms of development standards, but also for on-going operations.

We know that NASA works hard to protect its astronauts and is trying hard in its Space Shuttle "return to flight" program to take all reasonable precautions to reduce risks to the crew. Even so, some possible program changes to increase astronaut safety may have merit even though the GW review team realizes that many of these steps are difficult to take both because of basic design constraints and budget and schedule restrictions.

We feel NASA and the U.S. Government should, if at all possible, consider certain options. These options would include: (i) Restructure plans for the "full completion" of the International Space Station and thus allow re-examination of the scope of the 28-flight manifest for the Shuttle that is now essentially aimed at completing or servicing the ISS; (ii) Convert at least one of the Shuttles to robotic operations and thus allow a number of the remaining flights of the Shuttle to be carried out without an on-board crew; (iii) Consider rapid reactivation of the X-38 program to allow upgraded escape capabilities for astronauts from the ISS (if it could be done quickly and fairly economically) or alternatively to obtain Congressional authorization to order a number of Soyuz craft, with some having expanded flight rescue

capability; and (iv) Consider the various other findings about Shuttle safety concerns as set forth in Section 3 of this Report.

Further, we have considered safety associated with the operation of the International Space Station and believe that certain additional upgrades to ISS safety should be implemented as discussed in Section 4 of this report.

Our Report is indeed a call to action to work toward retiring as soon as feasible the aging Shuttle fleet for human space flight, i.e. before 2010 if possible. The options in this regard include converting one or more of the Shuttles to robotic operation, building a completely new robotic Shuttle, (although this would entail a very major expense and considerable time to build), and/or curtailing the scope of the ISS. Earlier retiring of the Shuttle could lead to cost savings (as of the ending of the program) both in space and on the ground that could be re-invested in accelerating the development of a new astronaut-rated vehicle for crew access to space or other elements of the President's January 2004 Vision for Space Exploration

In designing the new human-rated launch system, we suggest a "return to safety basics" by applying principles that evolved during the Mercury, Gemini and Apollo years of astronaut flight. This involves a primacy of focus on safety engineering and having needed redundancy and escape capabilities. Historical review over all the space programs to date also suggests the desirability of the following steps: (i) Separation of crew and cargo to reduce exposure to risk; (ii) A significant reduction in "waivers"; (iii) Increased in-orbit repair capability; (iv) Full creation of the Independent Technical Authority as recommended by the Columbia Accident Investigation Board (CAIB); and (v) Other steps reported in our findings.

The challenges of exploring outer space and human space flight have inspired mankind for millennia. Reportedly, an ancient Chinese "astronaut" tried to ride a cluster of firework-like rockets into space over a thousand years ago, only to meet a fiery death. It is only in the last four decades, however, that meaningful exploration of space by humans truly began with the hope of survival. As with all areas of human exploration and discovery — in the oceans, in the mountains, in the air and in space— there are risks attached to each step along the way.

In the wake of the Apollo program in the early 1970s, the prospects for both ambitious and truly "safe" space probes by astronauts were thought to be achievable goals. Heady expectations of public space travel to the Moon and Mars and other such feats were considered for a time as something that NASA might easily achieve in only a few years. The rocket pioneer von Braun predicted that there would be permanent space colonies on the Moon by 2010. But space exploration and safe and capable reusable launch vehicles have now proved to be much harder to achieve than we thought 30 years ago.

In this Study we have attempted to evaluate the degree of risk associated with past and current space programs and to identify other safety-related problems experienced in the past, all in the hope of drawing useful lessons for the future. We have also assessed the current risks associated with today's Space Shuttle and International Space Station. We have undertaken these investigations to see how space exploration can be made safer for future astronauts; and especially we have sought to use this accumulated knowledge in planning for the even more hazardous space challenges of the future. From a safety perspective we believe that 30 or more additional launches of the Shuttle system with a full crew represent an increasingly unacceptable risk for an aging system that may have something like a 1 in 50 to 1 in 60 chance of a 'category one' failure with every launch.

From the outset, the central objective of the Study team from George Washington University and of its sponsors, the Space Shuttle Children's Fund, has been to reach a series of conclusions and findings that could minimize risks of and enhance the safety for future human space flight. We realize that NASA, although it clearly values astronaut safety, has a broader mandate and perspective that includes many goals and objectives. Nevertheless, we include in our report both concerns and potential risks that may be of importance, even after the recommendations of the Columbia Accident Investigation Board (CAIB) have been implemented. We thus are now reporting to the Space Shuttle Children's Fund our independent findings and conclusions on how we believe astronaut safety can be improved both today and tomorrow.

During a research period of over a year, the team's researchers studied thousands of documents relating to the space programs of NASA, as well as those of Russia, Canada, Europe, and Japan, as they relate to U.S. space programs. We also carried out a series of interviews with many people experienced in all aspects of human space exploration. These include engineers, scientists, astronauts, administrators and academics. The research covered safety-related aspects of the Space Shuttle program and the International Space Station (ISS) and went on to consider the merits of a wide range of next generation options including planning for the Crew

Exploration Vehicle and its so-called future "spiral development". Thus the Study took into consideration the "return to flight" activities for the Shuttle, the creation of the NASA Engineering and Safety Center (NESC) and plans for a new Independent Technical Authority (ITA), the current deployment and utilization plans for the International Space Station (ISS), safety issues related to the ISS's operation and the impact of the new "Space Vision" announced in January 2004 for exploration to the Moon, Mars and beyond. We realize that there may be many internal NASA documents that might modify our findings, but if this study had been simply conducted on an "insider basis" it would have lost its independent perspective. We concede our review team had very modest capabilities and limited access to information in comparison to NASA. Thus we understand that many of our findings may indeed be incomplete or out of date. We are only asking that our findings and recommendations be fully and carefully reviewed by SSCF and for NASA to determine what response or action is indeed appropriate. This safety review effort by the GW University has involved the equivalent of 1.25 person years of effort since December 2003.

We thus do not see this study as an attempt to re-shape U.S. Space Policy but rather as an additional input on astronaut safety that may be important because it is independent and guided only by the objective of astronaut risk reduction.

In addition to technical and operational aspects, this research work considered the administrative structure and management systems of NASA, its Centers and its contractors as we saw these in the context of space safety. We also considered the responsibility of the United States towards its international partners in respect to the International Space Station as measured against space safety.

The Report that follows sets out in detail the historical background of NASA's approach to crew safety and key areas of potential vulnerability that we identified as possible risks in the Shuttle and ISS programs. We also suggest in some cases what seem to be reasonable strategies and measures to reduce vulnerabilities in existing and future programs. The Report further explores how next-generation systems can reduce the level of risk and discusses the role that might be played by the private sector and entrepreneurial ventures as we plan future missions into space. Use of robotically-controlled launch operations where human involvement can be minimized seems a particularly prudent strategy. Creation of new vehicles that combine crew and space freighter operations does not seem cost efficient, wise and certainly not the safest way to space for astronauts in the future, based on the experience of the Space Shuttle and the recommendations of the CAIB.

Coping with Aging or Outmoded Space Technologies

Many of the conclusions and recommendations of this Report point to the problems of continued operation of the now outmoded Space Shuttle for many more years, unless national space policy makes this absolutely necessary—and we note with our endorsement that this policy is indeed a part of the current new Vision for space exploration. The Shuttle is a launch system that was designed more than 30 years ago during the Nixon Administration. This system was described by the Paine Commission report after the Challenger accident in 1986 as a system that would be completely "obsolete" by 2001. The Paine Commission, that included notables such as astronaut Neil Armstrong, UN Ambassador Jeanne Kirkpatrick and test pilot Chuck Yeager, urged the "immediate development" of replacement vehicles back in 1986 — nearly twenty years ago.

In short, the Paine Commission noted the risks inherent in the highly complex Shuttle architecture with some 30,000-plus parts, as well as observing the rapid rate of obsolescence incurred by high-tech space systems and urged in their 1986 report the replacement of the STS with newer technology as soon as possible. Ultimately, these recommendations were financially undercut by the drive to keep the Shuttle flying, to build the International Space Station (ISS) while also developing a National Aerospace Space Plane, then an X-33 technology demonstrator and an ISS crew escape vehicle. This is a result, as characterized by the CAIB, not of a NASA failure, but of a national leadership failure and of an unrealistic budgeting process.

It is for these reasons and more that our Study asks serious questions, some about the current "Return to Flight" program, but others about the scope of the 25 to 30 remaining Shuttle flights planned, starting in mid-2005. We believe that the current 28-flight Shuttle manifest is based on a total success scenario that seems unlikely to be achieved. These flights will cost the American taxpayer on the order of $25-billion when taking into account the cost of the return to flight program, the cost of the Shuttle launches and their refurbishment and maintenance, and the cost of the staff and infrastructure to support these flights. If one undertakes a statistically-based risk analysis of the 30,000-plus part Shuttle, the calculations suggest that with a 1-in-50 accident

rating, and with 25 flights, there may perhaps be a 40% chance of a category one (or catastrophic) failure. With 30 flights the chance of another tragedy goes up to 45%. This statistical analysis is a cause for concern, since we have indeed had a launch failure of about one in every 55 flights.

The main reason for the continuation of the Shuttle program is to complete the ISS at a time when the Administration and Congress is cutting back funding to conduct many of the experiments for which the Space Station was built. This in essence seems to be a fundamental *non sequitur* in current U.S. space policy. The finding of this Study is that developing a way to streamline or curtail the full completion of the ISS and reducing the 28-flight Shuttle manifest is prudent public policy for three reasons:

- The Shuttle is in many ways outmoded as explained in detail in the full Report. The bottom line is that the Shuttle needs to be replaced with safer technology that is also more cost effective. Cargo systems that are robotically controlled would be safer and more economical for completing the ISS and ferrying materials to the Moon or Mars. We believe that the Shuttle itself might be reasonably adapted to this purpose by simple conversion to robotic operation or perhaps by use of its motors for a robotic freighter system (even though past studies show this option also remains a high cost solution). Alternatively, a new Shuttle without life support and designed for full-robotic operation, but this will obviously require some time to accomplish and expenditure of sufficient funds so as to not make this a viable option at this time. The reasons for designing and building the "fully deployed" ISS are questionable today. Much has changed since the space station was first envisioned in the 1980s, and these changes must not be ignored. The space station was originally scheduled for completion in 1992, and then was redesigned as the ISS with a finish date of 1994.. This Space Station completion date has slipped so many times that no date is now creditable. Obviously much has changed in over a decade and more will change in the years required to finish the ISS as now envisioned. We believe that NASA and its 15 international partners should address as quickly as possible the issue of streamlining the ISS to meet current needs and reduce Shuttle launches so it can be retired or operate in robotic mode prior to 2010. We believe that all partners must reasonably put safety considerations first.
- Curtailing or streamlining the ISS to some extent would be desirable so that no more than four Shuttle launches a year would be planned. This would avoid overstressing the Shuttle and its refurbishment teams and would not overextend Orbiter performance capabilities. Planning for 4 rather than 5 or 6 launches a year in our assessment would allow a more thorough and less rushed retrofit of the Orbiter, increase safety and help prevent another space disaster—an

Space Shuttle Liftoff at the Kennedy Space Center (Photo courtesy of NASA)

event for which neither NASA nor its international partners seem to have an acceptable exit strategy. There are those who have examined the construction schedule for the ISS and they now believe that to complete the full program requires more than 30 launches of the Shuttle. If true, this could also lengthen the construction program out to at least 2012 and further increase costs. If an extended launch schedule were required, this would increase the safety risks even further.

Finally, there are several findings in the GW Study concerning the best strategy for improved safety. These findings suggest that improved safety flows from (i) An appropriate and comprehensive organizational safety policy; (ii) Effective management; (iii) Original designs that emphasize safety; (iv) An attentive and detailed design, as well as a comprehensive validation and verification process; (v) Operations where safety is a dominant factor not overruled by budget, schedule or management policy.

For this safety system to work it must be reflected in the structure of NASA, and especially in the new Independent Technical Engineering Authority (ITEA). This report is thus a call to strengthening further the "safety culture". It is an endorsement of the Independent Technical Engineering Authority having control over the process of granting "waivers" that were a factor in the past failures of the Space Shuttle and even the Apollo fire. All of the key conclusions and findings are provided in Section 8 of our report.

Specific Shuttle Safety Concerns

The research and interviews carried out during the Study suggested that the Shuttle, even after the implementation of the CAIB's recommendations, would still have a probability of a 'category 1' failure of between 1 in 60 to 1 in 50 that it had in the 1980s. Significant reductions in flight risks associated with the Shuttle cannot be achieved, simply due to the spacecraft's complexity and the fact that some 30,000-plus parts must be integrated together with little tolerance for error. Even so, only 10 percent of those interviewed favored the immediate grounding of the Shuttle and moving on a greatly accelerated basis to a new and much more reliable launch vehicle that employs new technologies now available. But others certainly favored a reduction of the Shuttle flights down from the 28-flight manifest. Some have suggested a "computer controlled" Shuttle that could become a *de facto* cargo freighter that would help to limit the risk to human lives in finishing the ISS. And a few have suggested converting one or more of the Shuttles to robotic operation so as to serve as the prime cargo-lifting system to complete the ISS. At this time, the Russian Progress IM/Soyuz is the only alternative to the Shuttle for providing human access to and limited escape from the ISS. Also the ATV is designed to provide ISS re-boost and re-supply. Without the Shuttle or a replacement vehicle the US is dependent on Russia for rescue of its astronauts. A rapidly reactivated X-38 or an increased and augmented Soyuz capability could provide crew return capability that augments the Shuttle until the CEV is available.

Several interviewees believed that the projected 28 missions to complete the Space Station was a fruitless effort to complete a project that some have priced as high as $100-billion in cumulative expenses when finished. These critics also claim there are no clear-cut and major U.S. objectives for the ISS. This criticism is further fueled by observations that the high cost of construction of the ISS is continuing at the same time that there are $400-million in cut backs for U.S. Shuttle experiments. A *New York Times* editorial recently characterized the continuation of the ISS on the part of NASA as essentially "stubborn determination to finish a project".

However, the great majority felt that honoring U.S. international commitments to complete the ISS and carrying out as many Shuttle missions as needed to "complete" the ISS on the basis of an "international consensus" was the best way to proceed. Many felt that exploring a revised plan for an "acceptable ISS configuration" among the international partners was a valid way to proceed. In short, the majority believed that a return to the construction of the ISS was an "acceptably safe" space program goal but reduction of the remaining number of Shuttle launches, either by the use of more expendables, converting the Shuttle to robotic control, or reducing the ISS scope, were all serious alternatives prudent to explore.

The key risks associated with the Shuttle that should be avoided in future programs are as follows:

a. Thermal Protection System. The 26,300 parts associated with the current ceramic tile-based heat shield could be replaced with better technology, but on a new launch system — most likely a metallic TPS on the CEV.

b. Lack of Launch-to-Land Escape System. The lack of a complete mission (Launch-to-Land) escape system is a major hazard that

should be corrected with future systems; clearly no such comprehensive and cost effective escape system could be accomplished by retrofitting the Shuttle.

c. Waivers to Launch Systems Problems. Granting of too many waivers for the Shuttle as it is prepared for launch must be avoided. Problems need to be "fixed" and not simply resolved via a too-lenient waiver system. The new Independent Technical Authority could help to define standards for safety and establish clear guidelines for granting of waivers as well as control their approval.

Shuttles a year for the next five years, which appears excessive in terms of ground crew capabilities and maintenance and refurbishment capabilities. Four launches a year appears to be a more sustainable level. Further it is suggested that if there should be another Shuttle failure there is no truly viable "exit plan" in place with regard to the ISS or even a continued "human exploration program."

f. Separate Crew and Cargo. Cargo missions that need no life support system should be separated from "crewed missions" wherever

Image of the International Space Station in Space (Photo courtesy of NASA)

d. Solid Rocket Boosters (SRB). The lack of a shutdown capability with a SRB once ignited prevents a viable escape option for the first few minutes of flight. Solid propellants should be eliminated from future human-rated launch systems, or alternativelsy, these should be redesigned to allow escape capability and the use of "throttle-able" solid fuel, or hybrid rocket systems.

e. Safety and Performance Margins. The design and use of human-rated vehicles should have "greater" safety margins, and their use should never exceed a reasonable percentage of expected performance capabilities for the most active parts of the launch system. This view strongly places into question NASA's plans to launch five or more

possible by using robotically controlled cargo spacecraft or redesign of current systems.

Further concerns at a lower level of priority include the performance, backup capabilities and safety associated with many aspects of the Shuttle program, even after most of the CAIB recommendations are implemented. Anxieties are expressed in our report with regard to IT and telecommunications systems, power systems, space suits, environmental controls and life support systems, as well as improved maneuvering systems. There is also serious concern with regard to overall aging especially with the Shuttles being exposed to the hostile environment of a humid, coastal shore area and being housed in aging facilities at the Kennedy Space Center. These issues are addressed in the body of the report in Section 3. The NASA Return to Flight

Team has indeed seemingly strived to follow their brief mission statement: "Find it, Fix it and Fly Safely". But as indicated in our reports doubts remain as to the full scope of remedial action. We are indeed concerned that recently a member of the CAIB was "anonymously quoted" in the New York Times to say:

"Going ahead half-cocked and losing a third orbiter for known defects will affect the rest of [space] history in ways that are immeasurable, and lead to the demise of NASA as we know it." (John Schwartz, New York Times cover story, Feb 7, 2005 p.A1-A-12).

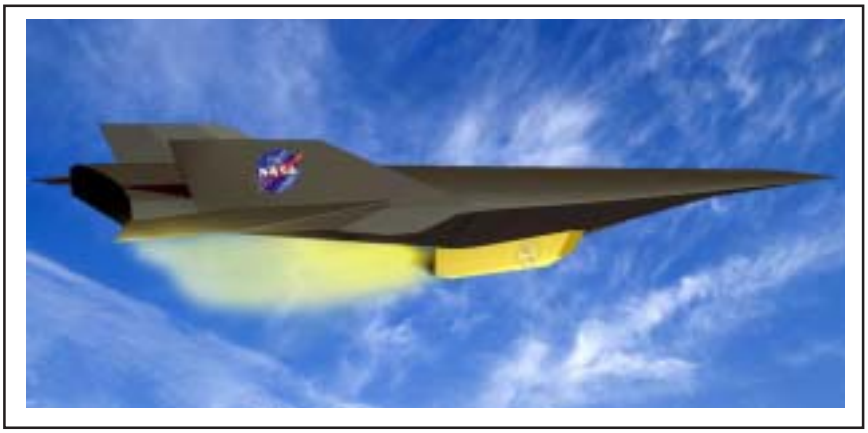

Image of the X-43A Flying at High Altitude (Photo courtesy of NASA)

International Space Station (ISS) Program Concerns

In many ways, the Space Shuttle program and the ISS program are very closely intertwined. Indeed, the primary reason for the remaining 25 to 30 launches for the Shuttle will be involved in completing the ISS, servicing it, and/or re-supplying it with crew.

The key safety concerns and risk factors related to the ISS that emerged from the GW Team research and interviews, just as in the case with the Shuttle, appear to stem from attempting to do too much with too limited of a budget. This re-examination of the scope of the ISS is complicated by the need to fulfill many international obligations with regard to the completion and operation of the ISS. Specifics are as follows:

(a) The Maintenance of Necessary Environmental Conditions. Additional steps appear to be needed to maintain a suitable environment for astronauts aboard the ISS. Issues raised include the need for a solution to the long-term slow leakage of atmosphere from the ISS. There are also serious concerns about the oxygen generator, the carbon dioxide removal system and noxious gas monitor and minimal backup for these systems, as well as the performance of valves in the ISS air lock.

(b) The Gyro-system and Stabilization. There were concerns about the performance and reliability of the gyro systems that have now failed several times, and the emergency repairs that had to be made. Also, there has been an on-going need for many extended EVAs to maintain the ISS and to adapt it to new systems. Thus there are also serious concerns about "emergency space walks" to repair the gyro subsystems, especially in conditions with no crew remaining on board—a situation that was once considered an unacceptable safety risk.

(c) Risks of Orbital Debris to the ISS and to Astronauts during EVA. The GPS and the tracking capability for the ISS lacks precision and needs further upgrades to allow more sophisticated maneuvering capability to avoid space debris. Further, the risk due to orbital debris both to the ISS and especially to astronauts during EVAs has not been clearly stated even though mitigation procedures now in place

substantially reduces the risks to Astronauts. New safety definitions need to address these issues in detail.

(d) The Reliance on Skeletal Maintenance Crews. Interviewees considered that there was a need for at least three crew at all times and the international partners have pushed for agreement on at least a four-person crew after the Shuttle flights resume. A minimum crew of three would allow for one to two astronauts to remain on board while two undertake an EVA in cases such as the emergency repair to the gyro system or in the case of preparing the ISS for docking with the Automated Transfer Vehicle (ATV). This approach is seen as much more risk-free than putting the ISS on ground-based automated control during an EVA.

(e) Pressures on Budgets and Schedules. This was a high concern with regard to both the Shuttle program and the ISS. Detailed comments noted that pressure from Congress and the Office of Management and Budget was constantly driving NASA to reduce operational costs to meet schedules and increase productivity.

The Management Record of NASA

Safety and management issues are an important part of the Report. The management based deferments of needed upgrades to the Shuttle and the ISS designs are noted in detail in the following sections. We suggest in Section 8 that a report on the status of these safety issues and resulting additional risk for the Space Shuttle and the ISS be formally requested from NASA. We further suggest that when this key information is delivered it should be subject to independent review. We have concerns with regard to the string of cancelled programs that attempted to develop new astronaut-rated vehicles for either orbital access or escape from the ISS. This record of cancelled programs appears to be due to overstressed budgets, management, and immature technology issues. These cancelled human rated space vehicle programs now include the HL-20, the X-38, the X-33, the X-34, X-37, and X-43A.

We also find the NASA Engineering and Safety Center (NESC) to be too decentralized and not effectively organized to be pro-active in discovering safety issues before accidents happen. The full creation of an Independent Technical Authority that has oversight of all safety issues, control of waivers for the Space Shuttle and the ISS, and management control of the NESC would seem likely to strengthen NASA's safety program. Currently the talent of the many NASA Centers is really not well focused to solve NASA's prime problems. Reorganization of the Centers into Federally Financed Research and Development Centers (FFRDCs) and to give them focused objectives as recommended by the Aldridge Commission, if properly implemented, might prove to be a desirable step, based on our team's review of NASA's operations and its ability to work to achieve key new objectives. Even more importantly from the safety standpoint is the empowerment of the Independent Technical Authority with the tools and resources to implement an organization-wide safety program as well as the ability to call on the resources of NASA Centers as needed to achieve safety objectives.

The decision to operate the ISS with a skeletal crew and the operation of the ISS by remote control with two astronauts conducting an emergency EVA for ISS repairs represent other issues of management concerns in that the safety standards and procedures were developed on what appears to be an ad hoc basis. In short, there are some who have claimed there is "risk creep" both in the ISS program and the pending resumption of Shuttle operations. There are concerns that budget and schedule constraints and the drive to develop the CEV without major new NASA appropriations will continue to increase safety risks. This may prove to be true even with the new attempt to create a computerized system to monitor program changes on a real-time basis so as to better judge safety problems and reduce Shuttle and ISS risks. In short, despite the $1.8-billion dollars being spent to return the Space Shuttle to flight and plans to resume the ISS construction, some concerns as presented in the body of this Report remain in the technical and management programs.

In addition to explicit concerns about the Space Shuttle and the ISS design and operation, the Report also provides further findings with respect to better protection from radiation, micro-meteoroids, debris, escape systems that can handle a full crew, stabilization and orbital boost capabilities, the better integration of U.S. and Russian safety practices and communications, and the effective integration of new safety systems into ISS sustained operations. Work with the new International Association for the Advancement of Space Safety is also highly recommended.

The Future

There are some broad policy questions that could have substantial impact on the safety of the remaining Shuttle flights and the ISS. These questions include whether free flyers (i.e. the Spartan free flyer

or private projects such as those planned by SpaceDev, Space X and Bigelow Aerospace) could undertake many of the planned space experiments that are now scheduled for the ISS at lower cost and with greater safety. If so, could this allow the scope of the ISS project to be downsized so that some of the planned 25 to 30 remaining Shuttle flights that complete or service the ISS could be eliminated? We believe that some prudent downsizing might be possible while still launching the key European and Japanese systems. There are also questions as to whether unmanned launch systems, such as the Ariane 5/ATV or Progress/Soyuz, also H-IIA/HTV, could be used for more of the ISS completion and servicing. Some of these options might also allow the earlier termination of the Shuttle. Plans for continued astronaut access to the ISS via additional Soyuz launchers have also not been resolved because of current Congressional limitations on the purchase of such systems. One of the findings in Section 8 is that new launch development programs that look beyond chemically-powered rocket systems should be started by NASA and by other space-related entities in the U.S. and abroad. These efforts would be to stimulate competitive research programs in launch system and enhanced space systems safety.

Programs such as the NASA Institute for Advanced Concepts are currently stimulating the study of new launch capabilities but these are very long range and at low funding levels. Exciting new human launch systems that can be safer and more cost efficient are on the horizon. Systems for improved in-space propulsion systems include such options as nuclear powered plasma or ion engines, gravity gradient "slingshot" systems and tethered based launch systems. Further systems such as rail or coil guns and mass-driver systems can offer low-cost ways to send unmanned systems and cargo into space or return materials from the Moon or Mars as "safe precursors" to astronaut missions. These future systems can be used to create life support systems before committing human resources to distant and hostile locations.

Much of this Report finds that NASA has tried hard to achieve the safest way to return the Shuttle to flight and to complete its obligations to finish the ISS as quickly as possible, consistent with safe practices. Nevertheless, the findings and recommendations in Section 8 still set forth serious concerns that should be addressed. In short, we do suggest some alternatives that might not only reduce the risk to astronaut lives but also save scarce resources.

Future Human Rated Launch Systems

We believe that there are lessons that can be learned from the Shuttle and the ISS that would apply to the Crew Exploration Vehicle. The most important of these lessons would be not to try to build a "very extended life high-tech" system expected to serve over many decades. In short, avoid putting all of the U.S. future space launch capabilities into a single system—avoid "putting all of our space eggs in the CEV basket" along with its supporting launcher system. This would suggest that new technology can quickly overtake the CEV technology as conceived today, and thus the "spiral development" planned for the CEV needs to truly mean that new technology can be integrated over time. This would also suggest that an automated or robotic cargo system should complement a smaller and more flexible "crew based" launch system.

Principles that evolved from the first "manned flight" programs included "engineering-in" safety from the start of a program, having sensor and alarm systems capable of triggering instantaneous launch aborts, being able to have a "launch-to-land" escape capability, and separation of crew and cargo and crew-carrying and launch systems to the maximum extent possible.

Thus the first step in designing the CEV is the establishment of clearer safety definitions for "manned vehicles" and setting clear and basic safety criteria that can be applied in a fundamental way into concept development. This involves not only escape and shutdown capabilities for the launch system, but includes considerably more emphasis on in-flight repair than has been accomplished to date. Self-diagnostic and alert systems must be introduced that are coupled with a spares-and-repair philosophy for reconstitution of the vehicle for safe operation. This represents a new paradigm that goes beyond the design concepts inherent in the Space Shuttle. The recent narrowing of the field of the CEV design contractors through new subcontracting arrangements and other actions has led some to question whether NASA will find fresh ideas with a high focus on safety or simply conventional ideas as the process moves forward. We believe that current planning that points toward the CEV likely being dependent on its launch from atop an up-rated conventional expendable rockets is a significant safety risk. This indeed appears likely to be the weakest link in the safety design of the next generation of U.S. human launch systems. Also the linkage of the Centennial Prize process to issues of safety represents yet another key question worthy of further discussion.

Finally, safe, reliable alternative access is key to the future of human space flight. Unfoitunately, in order to develop a new replacement system, it is

generally deemed necessary to shut down the current system to make this funding stream available to develop the new capability. This was true of the Apollo era transition to Shuttle, and it is the circumstance that NASA finds itself in today, as it will be necessary to curtail Shuttle flights to create the revenue stream required for its replacement. This can result in a significant disruption of our ability to sustain human space flight during the transition period.

A possible effective additional means to achieve the goals of safe, reliable, affordable alternative access to space is by the adoption of international standards for all future human space craft to afford 'international alterantive access'. Therefore, all new human space transportation systems should be developed to common international standards that would permit compatibility for emergency crew rescue contengency capabilities, when needed. These standards, as are being pursued by the new International Association for the Advancement of Space Safety, should be developed in concert with international partners, and the specifications should be made widely available for the public and private sectors for any nation seeking to develop these capabilities to use as they deem warranted. This is a key consideration in making possible, affordable, reliable alternative access, by dissimilar redundancy.

Further we feel there may be lessons to be learned by NASA from other high-risk industries such as aviation, mining and nuclear power as well as other outside sources. As planning for the future goes forward NASA often tends to look within itself for answers because of its specialized field of study and high-tech environment, but management and safety practices from other entities (in government and industry) might well produce useful new approaches to the future. There might, therefore, be merit if NASA were to look outside of itself more and to seek independent assessment when considering safety and innovation. Its benchmarking efforts on overall safety statistics and safety practices in other organizations are certainly a useful step in the right direction.

A final observation is that while the aerospace industry and NASA have undertaken a great deal of research and placed great stress on astronaut safety, it is not clear that safety has been or is currently the highest concern for day-to-day operations, particularly in high risk areas such as rocket motor test standards, combustion research, etc. It is worth noting that overall safety standards and performance in the aviation, air transport and aerospace industry do not compare well with what many consider high risk professions such as "mining". Again the safety culture within NASA should explore every aspect of its operation and not just astronaut programs.

We sincerely hope that the full Report on space safety will be carefully read and reviewed and, particularly, we urge that the findings and recommendations as contained in Section 8 be carefully considered by the SSCF Board, NASA, the White House, Congress, the GAO, FAA, DOD, by professional organizations involved in space and by the media. We hope that by careful consideration of the most viable of our recommendations for enhanced safety NASA can further upgrade its program and that other findings that are out of date or off the mark can be discarded or corrected in providing NASA with a new certification of "safety first." .

The purpose of this Report to the Space Shuttle Children's Fund was to provide an objective, independent and non-partisan review of NASA's human space flight program and how safety could be improved. In general we feel NASA has for the most part done very well within the constraints in which it has had to operate. A review of safety necessarily focused on concerns and provided less space to commend NASA's scientists and engineers that truly work night and day for astronaut protection. At the most fundamental level NASA will have to convince the American public that its programs are relevant and necessary to secure support at a level of funding needed to ensure safety and overall future program success. Thus not only astronaut and astronaut safety programs remain at risk but indeed, all NASA programs. Unless the public imagination is newly captured in supporting NASA programs, and these initiatives are generally considered to be well managed and not overly risky, NASA's sustained funding could well remain in doubt. This is not unique to NASA, in that similar issues arise with regard to space agencies in other countries. Unless substantial public support for space exploration on the part of NASA and other U.S. Government agencies is re-ignited in coming years it may be that private enterprise will, of necessity, evolve to play an ever-increasing role in this regard. Yet if NASA becomes not only highly safety conscious but perhaps reacts in extreme fashion and becomes "overly risk adverse," it may well not be able to accomplish new major space exploration goals at all. Seeking a "new balance" between space exploration goals and safety programs will remain a challenge and dilemma for NASA for the foreseeable future.

This is a report for the Space Safety Children's Fund

Space and Advanced Communications Research Institute
George Washington University
Principal Investigator: Joseph N. Pelton, Ph.D.

For access to the full report go to: http://www.spacesafety.org/