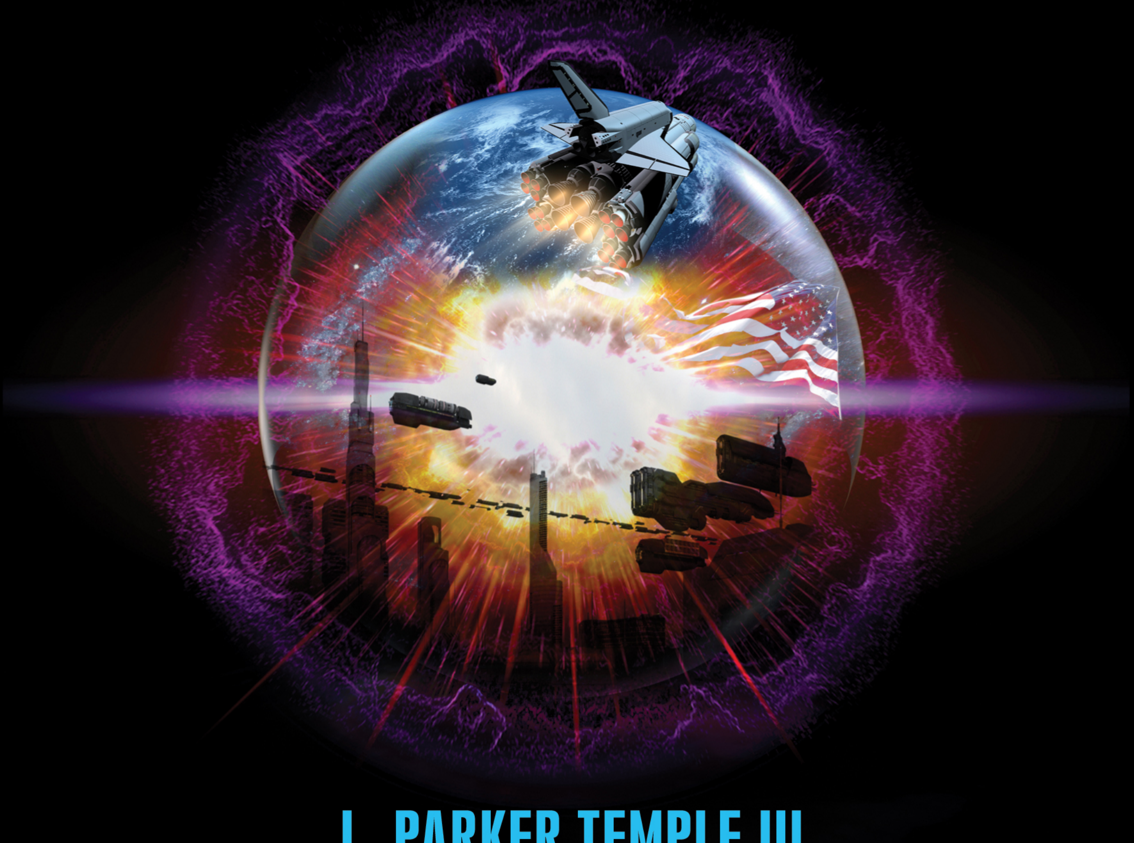
IMPLOSION

LESSONS FROM NATIONAL SECURITY, HIGH RELIABILITY SPACECRAFT, ELECTRONICS, AND THE FORCES WHICH CHANGED THEM



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Preface

The first expectation of any historian is that the story of the events he or she is relating is worth reading. In that light, the expectation that a history of high reliability electronics will enflame the passions of a reader (at least, one who is not in the high reliability electronics business) is probably a stretch. The sad part of this truth, though, is this is not the time for one's passions to be enflamed. The time is long gone for us to get so outraged at what has happened that we run to the window, fling it open, and yell that we are damned mad about what occurred and we will not put up with it any longer. That time is gone, never to be recovered. The time for outrage has passed.

When, in the early part of the 21st century, extremely important satellites began to fail, reviews of the failures pointed to elimination of some military standards about a decade earlier. The failed satellites not only cost a great deal of money, the problems created by their loss affected our national security and national defense. Whether the reader is aware of the specific satellite failures or not, he or she must understand just how dependent the United States is on these machines and how serious was the jeopardy in which the nation was placed when they failed. The essential thing for the reader is to see that the failures were not simply due to the elimination of the standards.

How the failures occurred is, of course, the central story told here. Just as important for everyone who reads this is the understanding of what was lost. High reliability electronic parts were and are fundamental elements of U.S. national security and defense, the economy, and long-lived spacecraft. A convergence of many different factors, forces if you will, combined to bring a highly successful enterprise to an end. The task to recover some of what was lost depends in great measure on understanding what was lost. Some of the loss can be recovered; some cannot. The difference informs us about how to avoid similar mistakes stemming from the best of intentions.

This history mainly follows the military portion of high reliability electronics which, at first, went into missiles and shortly thereafter into satellites. Clearly, not all high reliability electronics went into the military, as we consider the civil space program's human spaceflight efforts such as the Apollo program of sending people to the moon. Such civil space programs of the National Aeronautics and Space Agency are generally outside the scope of this history, because so much depends on the evolution of the military standards. Also, the emphasis on high reliability electronic parts is mainly about active components such as microcircuits and transistors, with less emphasis on passive devices such as resistors. The reason is passive component technology did not experience the same rapid acceleration of capability, technology, and shrinking feature size that the active components did. A massive convergence of a number of forces hit active components hard but left only a little sea sickness for passives. To tell a coherent story, passives are not considered extensively, except as they were included in hybrid devices.

The heavy focus of the story is how electronic component technology developed high reliability as a response to the criticality of the uses (especially for national security and national defense), evolved processes and the necessary controls to improve over time, and managed increasing complexity. Then, in nearly the blink of an eye, well-meant changes caused the system to collapse. The full set of consequences cannot be described adequately for a variety of reasons, so the story pauses at times to benchmark the importance of the end uses of the parts—that is, for the national security and defense of the United States.

Numerous studies have examined the history of the semiconductor industry. At first, most paid little or only passing attention to the role of the military.[1] Later studies began to recognize a simplistic relationship. Eventually, as the scope of the involvement and influence became clear, historians saw that the scope, focus, and direction of the semiconductor industry was due to the early and continued interest by the military.[2] Even that level of insight was insufficient, because little, if any, distinction was made in terms of classes of parts. Most discussion has been on commercial parts, and the involvement of the military was in terms of reliability.[3] That is correct, as far as it goes.

This history goes the next important step, and has benefited from the gradually increasing awareness and understanding of the role of national security and national defense with industry. The awareness has increased with the extent to which information about the military programs was declassified and released.

At first, the Cold War precluded release of extensive details on parts, processes, and program relationships. Then, as more information became available about Minuteman and related missile developments, the understanding of the military influence

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[1] Typical of this literature are Douglas W. Webbink, *The Semiconductor Industry: A Survey of Structure, Conduct and Performance* (Washington, D.C.: Federal Trade Commission, 1977); Ernest Braun and Stuart Macdonald, *Revolution in Miniature: The History and Impact of Semiconductor Electronics* (New York: Cambridge University Press, 1982); Robert W. Wilson, P.K. Ashton, and T.P. Egan, *Innovation, Competition, and Government Policy in the Semiconductor Industry* (Lexington, Massachusetts: Lexington Books, 1980); David C. Mowery and Nathan Rosenberg, *Technology and the Pursuit of Economic Growth* (New York: Cambridge University Press, 1989).

[2] This literature is well represented by Norman J. Asher and Leland D. Strom, *The Role of the Department of Defense in the Development of Integrated Circuits* Paper P-1271 (Arlington, Virginia: Institute for Defense Analysis, May 1977), and James M. Utterback and A. Murray, *Influence of Defense Procurement and Sponsorship of Research and Development on the Civilian Electronics Industry* (Cambridge, Massachusetts: MIT Center for Policy Alternatives, 1977).

[3] For an outstanding history, though focused only on the transistor, see Thomas J. Misa, "Military Needs, Commercial Radios, and the Development of the Transistor, 1948–1958", in *Military Enterprise and Technological Change, Perspectives on the American Experience*, ed. Merritt Roe Smith (Cambridge: Massachusetts: MIT Press, 1987). See also R.E. Anderson and R.M. Ryder, "Development History of the Transistor in the Bell Laboratories and Western Electric (1947–1975)" (unpublished manuscript, AT&T Archives, 45 11 01 03), 186, cited in Daniel Holbrook, "Government Support of the Semiconductor Industry: Diverse Approaches and Information Flows," *Business and Economic History* 24, no. 2 (Winter 1995): 138–139.

on the semiconductor industry matured. For instance, we will see and appreciate the importance of "Minuteman reliability" as a descriptor for discrete parts well into the 1970s, and see that program's reliability emphasis did not end after the fielding of the Minuteman III. In fact, Minuteman processes were generalized and fed directly into the creation of space quality parts.

The extreme compartmentalization of the national security space program, whose existence was not even acknowledged until the early 1990s, precluded a real appreciation of the importance of high reliability electronics, from the standpoint of how they were used. With the declassification of the National Reconnaissance Office and its early satellite reconnaissance programs, a new appreciation of the role of space programs became possible. Not only did these programs help keep the nation secure, they helped shape the direction of the semiconductor industry through the processes and materials developed to meet the needs of the highest reliability parts.

This present history places into context the story of reliability engineering, the highest reliability parts, how they came about, their influence on the larger commercial industry, and their importance in the context of national security and national defense.

To keep the story manageable, the early scope was limited to missiles and eventually space, but mostly as part of the Air Force's efforts in these areas. Although aircraft also require high reliability parts, they are maintainable, and do not require the same extremes of high reliability needed by satellites. Therefore, though much of what is said about spacecraft is true of aircraft, the latter deal with the consequences of the breakdown in electronics reliability in terms of higher maintenance, lower in-service rates, and longer logistics tails. None of these consequences have corollaries in satellites, which once in orbit are essentially on their own from a mechanical replacement standpoint. Also, the strategic missile systems of the Navy (Polaris, Poseidon, and Trident) are not extensively covered because the consequences to them are essentially the same as those of the Air Force covered in this part of the story. The story is complicated enough using the exemplar of the Air Force's efforts, but there is no denying that the Navy's efforts also made important contributions, particularly as these programs were in the design and buying phases. Where necessary, the Navy troops across the stage, but not as a main theme.

Keeping in mind the complexity of the subject and the myriad of military standards, choices had to be made about which standards to discuss. Inevitably, some important standards were not included. The standards that are discussed should adequately illustrate the evolution of standards and their importance.

Implementation of policy takes center stage at times, and properly so. The history demonstrates several important principles. Among these are that an acquisition system optimized to attain the highest level of reliability cannot also be the least expensive. Further, no matter how well intentioned, top-level acquisition reforms implemented as political expedients without understanding the implications at the lowest levels of the acquisition processes cannot succeed. Few enterprises evidence these truths more than high reliability space programs did. The best of intentions generating well-meant policies followed by flawed implementation rarely lead to positive results. Public policy analysts will find this an extensive discourse on implementation. Implementation of the policies and procedures leading to the high degree of optimization creating highly reliable space systems at the lowest level contrasts with the imperfect changes to acquisition at the highest. Everything starts with parts, but in the end, it is the implementation of policies that makes the biggest difference.

Tracing the evolution of the highest reliability parts provides the framework that eventually ties together such disparate topics as overseas production, extremely small feature sizes, the Cold War (or lack thereof), marketplace economics, failure modes and effects, and much more. Along the course of these events the baby was thrown out with the bathwater, and a very successful enterprise got off track due to a number of coinciding factors to yield the current state of affairs.

Thus, occasionally interspersed in sections dealing with the evolution of the high reliability parts in spacecraft, the reader will find references to events on the world stage. Our hope is these references, though sometimes intentionally jarringly out of place with the immediate story, will help remind the reader these events took place against, and contributed to, some of the most dramatic events of the Cold War and its aftermath. Additionally, as the story unfolds, coming to the nexus of the 1990s, these seemingly irrelevant strands of events will come to make sense in a larger picture of many forces at work affecting high reliability electronics and spacecraft.

Important distinctions must be held in mind. The manufacture of high reliability electronics continues, of course. Such manufacturing is significantly different from that of the late 1980s and early 1990s. Thus, an impression that highly reliable parts are no longer available is only partially true. More to this history's overall point is that highly reliable spacecraft depend on the best possible parts as the warp and woof of their creation. But that creation has been affected by much more than changes to the reliability of parts.

Finally, this history distinguishes between national security and national defense space programs. This is a convention based in history, when the Air Force developed most military satellites, and the National Reconnaissance Office developed those for the Intelligence Community and the National Command Authority. Recent practice has merged references to the two different space programs under the rubric of national security space. However, the usage here mirrors and complements that of an earlier work, *Shades of Gray: National Security and the Evolution of Space Reconnaissance*, because the distinctions remain meaningful. This history and its historian are ever mindful of things that were and remain classified because the purpose here is to improve national security, not to exploit or damage it in any way. Thus, our mention of things needing continued security protection is at best deliberately vague. Inquiring minds might find some place where lack of detailed specifics is annoying, for which the author begs tolerance. Such specifics are unnecessary for understanding the larger history and what it has to teach us.

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Acknowledgments

When it became clear to me that this topic had never been approached in anything remotely like the way I had intended, there were two immediate choices for research, and I must express my gratitude to Dr. George “Skip” Bradley and his Space Command History Office staff for their help, and especially Dr. Harry Waldron of the Space and Missile Command with his staff. Too much of the history of the United States in space has been devoted to the civil space program, while the more vast and critically important military and national security space programs’ history resources remain virtually untapped, resulting in a skewed perspective.

My subject grew in complexity rapidly as the extent of the disaster known as Acquisition Reform became clear. It became equally clear that not all of the problems were created by Acquisition Reform, though the most damaging ones surely were. To help clarify the issues and separate them, and then to make them available to a audience wider than the microelectronics parts community, I could not have accomplished this without the help of my reviewers and contributors: Lawrence I. Harzstark, Melvin H. Cohen, John Ingram-Cotton, James F. Bockman, and S. Lynn Sanchez.

As with any work of this scope, there are a few key individuals without whom things simply could not have proceeded. First, I owe a debt of gratitude to Michael J. Sampson, Manager NASA EEE Parts Program at Goddard Space Flight Center. His constant involvement in a broad range of topics culminates in a weekly telephone conference as enlightening about current problems as it is about how things got to be the way they did. His management of the NASA program, though not directly on point for this view of the military involvement in high reliability spacecraft, inspired the idea that perhaps this topic was worthwhile and achievable. Second, the fact that the current state of the world did not reflect its history in detail, but that those details could be recovered (with some pain), was an idea that I owe to my colleague David M. Peters, who inspired parts of this work and also was gracious enough to review and improve it. Third, my words are inadequate to express all that I owe to two career-long friends and colleagues whose intellectual inspiration for this and other works of mine simply cannot be explained in a few words. Without Russell C. Cykoski and Julius F. Sanks, so much in my professional career would not have happened that I am in awe of their unselfish sharing, encouragement, and constancy. Don’t worry, it’s okay—I have mine. What about the Navy?

And if anyone thinks that he or she can do this kind of thing regularly without the support, or at least acquiescence, of his or her spouse, they are, frankly, nuts. I would be nowhere were it not for the love of my life, Betty.

L.P.T.

Acronyms, Abbreviations, and Program Names

ADVENT	Early communication satellite
AEDC	Arnold Engineering Development Center
AEHF	Advanced Extremely High Frequency (communications satellites)
AFB	Air Force Base
AFBMD	Air Force Ballistic Missile Division
AFCMD	Air Force Contract Management Division
AFPRO	Air Force Plant Representative Office
AFSAB	Air Force Scientific Advisory Board
AFSC	Air Force Systems Command
AFSPACE	Air Force Space Command
AGREE	Advisory Group on the Reliability of Electronic Equipment
AJAX	Army Nike anti-aircraft missile
ALERT	NASA parts problem information sharing program
ALMV	Air Launched Miniature Vehicle antisatellite
Apollo	NASA human lunar spaceflight program
ARDC	Air Research and Development Command
ARPA	Advanced Research Projects Agency
ASD	Aeronautical Systems Division or Assistant Secretary of Defense
ASIC	Application specific integrated circuits
ATLAS	Air Force Intercontinental Ballistic Missile
BAMBI	Boost-phase Antiballistic Missile Interceptor program
BAR	Broad Area Review
BRAC	Base Realignment and Closure Commission
BrigGen	Air Force brigadier general
BSTS	Boost Surveillance and Tracking System
C4I	Command, Control, Communications, Computers, and Intelligence
Centaur	Launch vehicle upper stage
Challenger	NASA space shuttle
CMOS	Complementary MOS
Corona	First U.S. photoreconnaissance satellite
COTS	Commercial-Off-The-Shelf
CPSU	Communist Party of the Soviet Union
CQAP	Component Quality Assurance Program
CRHS	Navy Component Reliability History Survey Program

DCAS	Defense Contract Administration Services
DDOU	DLA Depot Ogden
DDR&E	Director of Defense Research and Engineering
DESC	Defense Electronic Supply Center
Discoverer	Unclassified name of the Corona photoreconnaissance satellite
DLA	Defense Logistics Agency
DMSP	Defense Meteorological Satellite Program
DoD	Department of Defense
DODAC	DoD Activity Code number
DODI	DoD Instruction
DSA	Defense Supply Agency
DSB	Defense Science Board
DSCC	Defense Supply Center Columbus
DSCS	Defense Satellite Communication System
DSP	Defense Support Program
Dyna-Soar	Air Force spaceplane, also called Program 624A and X-20
EIA	Electronic Industries Association
ELV	Expendable Launch Vehicle
ERD	Electronics Reliability Division of Rome Laboratory
ERDA	Reliability and Diagnostics Branch of Rome Laboratory
ERDB	Design and Diagnostics Branch of Rome Laboratory
ERDR	Reliability Physics Branch of Rome Laboratory
ERDS	Design Analysis Branch of Rome Laboratory
ESD	Electronic Systems Division
EW	Early Warning
Explorer	First U.S. satellite
FAR	Federal Acquisition Regulation
FARADA	Failure Rate Data program to collect and analyze reliability
FASA	Federal Acquisition Streamlining Act
FCRC	Federal Contract Research Center
FFRDC	Federally Funded Research and Development Center
FIA	Future Imagery Architecture
FLTSATCOM	Fleet Satellite Communication program
Hercules	Army Nike anti-aircraft missile
Hubble	NASA space observatory program
GAO	General Accounting Office
GEIA	Government-Electronic Industries Association
Gen	Air Force general
GIDEP	Government–Industry Data Exchange Program
GMDEP	Navy Guided Missile Data Exchange Program
GPS	Global Positioning System
HQ	Headquarters
IC	Integrated Circuit
ICBM	Intercontinental Ballistic Missile
IDCSP	Initial Defense Communication Satellite Program

IDEP	Interservice Data Exchange Program
IEEE	Institute of Electrical and Electronics Engineers
IG	Inspector General
IRBM	Intermediate Range Ballistic Missile
IRE	Institute of Radio Engineering
ITAR	International Traffic in Arms Regulations
IUS	Inertial Upper Stage
IW	Indications and Warning
JAN	Joint Army Navy
JEDEC	Joint Electron Device Engineering Councils (originally, now no longer an acronym)
JHU/APL	Johns Hopkins University, Applied Physics Laboratory
kHz	Kilohertz, or thousand cycles per second
LtGen	Air Force lieutenant general
LSI	Large Scale Integration
MajGen	Air Force major general
Mercury	First NASA human spaceflight program
MFG	Manufacturing
MHV	Miniature Homing Vehicle antisatellite
MHz	Megahertz, or million cycles per second
MIDAS	Infra-red early warning satellite
Milstar	Air Force communications satellite program
MILSTRIP	Military Standard Requisitioning and Issue Procedures
Minuteman	Air Force solid fuel Intercontinental Ballistic Missile
MIPS	Minimum In-plant Surveillance program
MIT	Massachusetts Institute of Technology
MMIC	Monolithic Microwave Integrated Circuits
MOL	Manned Orbiting Laboratory
MOS	Metal oxide semiconductor
MOSFET	Metal oxide semiconductor field effect transistors
MOSIS	Metal Oxide Silicon Implementation Service
MOU	Memorandum of understanding
MQPL	Military Qualified Products List
MSI	Medium Scale Integration
NASA	National Aeronautics and Space Agency
NAD	Naval Ammunition Depot
NESRC	Nuclear and Space Radiation Effects Conference
NOL-Corona	Naval Ordnance Laboratory at Corona, California
NPOESS	Naval Polar Orbiting Environmental Satellite System
NRL	Naval Research Laboratory
NRO	National Reconnaissance Office
NSC	National Security Council
NSN	National Stock Number
NSR	National Security Review (for President George H.W. Bush)
OASD	Office of the Assistant Secretary of Defense

OASD (S&L)	Office of the Assistant Secretary of Defense, Supply and Logistics
ODM/SAC	Office of Defense Mobilization's Scientific Advisory Committee
OEM	Original equipment manufacturer
PARC	Palo Alto Research Corporation
PAT	Process Action Team
PCP	Parts Control Plan
Peacekeeper	Air Force Intercontinental Ballistic Missile
PEO	Program Executive Officers
PM&P	Parts, Materials, and Processes
Polaris	Navy ballistic missile program
Poseidon	Navy ballistic missile program
PRB	Program Review Board
PSAC	Presidential Science Advisory Committee
QA	Quality assurance
QML	Qualified Manufacturers List
QPL	Qualified Parts List *or* Qualified Products List
RADC	Rome Air Development Center
RAND	Project R and D; *later* RAND Corporation
RCA	Radio Corporation of America
RDB	Research and Development Board
SAC	Strategic Air Command
SAFSP	Secretary of the Air Force Special Projects
SAGE	Semi-Automatic Ground Environment
SAINT (SATIN)	Satellite Interceptor program
SAMSO	Space and Missile Systems Organization
SBIRS	Space-Based Infra-Red Satellite
SCD	Source Control Drawing
SD	Space Division
SDI	Strategic Defense Initiative ("Star Wars")
SGLS	Space-Ground Link System
SMD	Standardized Military Drawing (occasionally, Standard Microcircuit Drawing)
SOLAR MAX	NASA space observatory program
SPO	System Program Offices
Sputnik	World's first artificial satellite
SPWG	Space Parts Working Group
SSI	Small Scale Integration
SSTS	Space Surveillance and Tracking System
STL	Space Technologies Laboratory
STS	Space Transportation System
TENCAP	Tactical Exploitation of National Capabilities
Thor	Air Force Intermediate Range Ballistic Missile
TI	Texas Instruments

Tinkertoy	Early Navy program on microelectronics
Titan	Air Force ICBM and space launch vehicle
TOPEX	NASA Topological Experiment Program
TPPC	Total Package Procurement Concept
TQM	Total Quality Management
TRADIC	Transistorized Digital Computer
TRANSIT	Early communications satellite
TSPR	Total System Performance Responsibility
TWT	Travelling wave Tube
USSPACECOM	U.S. Space Command
Vanguard	U.S. satellite program intended to be first U.S. artificial satellite
Vela	Nuclear detonation detection system
VHSIC	Very High Speed Integrated Circuit
VIKING	A NASA space exploration program
VLSI	Very Large Scale Integration
WDD	Western Development Division
WGEPP	Working Group for Electronic Piece Parts
ZEUS	Army Nike anti-ballistic missile and anti-satellite missile

Part I

Activation Energy (1931–1968)

Discoveries in quantum physics lay fallow until breakthroughs in electronics technology made solid state electronics real. As that first began to happen, the Cold War began. The United States needed information about the intentions and preparations of the Soviet Union to determine the severity of the threat of a nuclear, Pearl Harbor–style attack against the heartland of the United States. Overflights of the Soviet Union by U.S. bombers and reconnaissance aircraft were dangerous and provocative. They would eventually have to stop, but hopefully not before some more feasible alternative was found. Based on the technologies developed by the Germans in World War II, feasibility studies of long range missiles turned into strategic realities. The military at first provided the critical funding for the nascent solid state electronics industry, which held the keys necessary for practical long range missiles. As those missiles became practical, their capabilities also enabled other studies to turn concepts of orbital space vehicles into realities to relieve the manned aircraft overflights of their most dangerous missions. The demands of strategic missiles and critically important spacecraft drove the electronics industry to make advances in reliability. Proliferation of solid state devices led to their incorporation into the military standards program, which had been created to solve similar problems with vacuum tubes during World War II.

The period through 1968 brought together these many threads of what would be the national security, national defense, and civil space programs. All of these programs relied on available technology to get started, but

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moved rapidly toward solid state electronics for advantages of weight, volume, and power consumption. Initially, national security and national defense space vehicles and strategic missiles had a clear effect on the development of commercial solid state devices. The growth of commercial solid state electronics quickly outgrew that influence except in the highest reliability uses. There, a symbiotic relationship began and secondarily nurtured the commercial electronics industry. By the end of the period, the limits of high reliability were approached within the constraints of current technology, understanding of system complexity, and the mechanisms to control these.

Chapter 1

Washington . . . We Have a Problem . . .

Toward the end of the 20th century, failure rates in space systems began to climb. Within the first years of the new century, the failures had not abated. Initial analysis showed the space systems affected had all begun to deteriorate around 1994 or thereafter. Spates of failures were not something new to the national security and defense space programs. Several episodes had occurred since the U.S. space programs began with the launch of Explorer I in 1958. The nation's first photoreconnaissance satellite, Corona, failed more than a dozen times in a row before a picture was successfully returned. Corona's time was one of inventing space programs. Each failure improved understanding, moving us closer to success. Extensive processes evolved over more than four decades since that time to identify the causes of failures, learn from failures, and then, as in a closed-loop control process, feed lessons back into the processes to be used in subsequent space systems. This learning and feedback process had always worked, and gotten even better over time. By the last decade of the 20th century, U.S. space program reliability was the envy of all other spacefaring nations. The United States had shown the way to get the most out of every ounce of every spacecraft or expendable launch vehicle, and had been emulated by most emerging spacefaring countries.

Starting as robotic spacecraft whose value had to be proven, the national security and national defense space systems evolved to a position of great importance in the affairs of state, national policy, national security, national defense, and the

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commercial marketplace. The run-up to and performance of Operation Desert Storm demonstrated that the American way of war critically depended on space systems. They had also stood the test of time, serving to maintain the strategic way of peace. Space systems were an American way of life.

Failures occur, whether they are an option or not. Whenever so much power is crammed into one place and expended over so short a time as in a launch vehicle, even the smallest problem can cascade into a devastating loss. No failures are acceptable, some are worse than others, and every failure damages some important user's needs and expectations. Failures draw significant attention.

This is even more true when failures have an upward trend over a short time. Then, each failure does not exist in its own isolated microcosm of each U.S. space program. Each begins to be seen in light of the overall space programs. When multiple agencies' space systems are affected, the trend gathers the greatest attention of the brightest minds. Reversal of the trend must be had in the very shortest time. The nation's defense and security depend on it.

Near the end of the 1990s, a Titan IV, the nation's largest expendable launch vehicle and workhorse of the national security and defense space programs, failed with loss of its critical payload. The loss of the mission affected organizations from the White House throughout the Executive Branch of government, the Intelligence Community, and the military establishment. Then another Titan IV failed, with loss of another satellite's mission. These occurred amidst the losses of other, smaller, expendable launch vehicle payloads.

The cause had to be found and corrected immediately, as a national security and defense crisis loomed because of the satellites' loss. The satellites were to replace older versions, and were to provide enhanced new capabilities with wide-ranging impacts. Replacements could not be ready for years to come, as some represented the most complex machines ever put into orbit. A team of the best minds had to be called together and put to correcting the problem before another launch failure.

Then, orbiting satellites began failing early. Not the old ones near the end of their missions, but ones near the beginning of their lifetimes. The ones with the best, most advanced technologies. More satellites on whose data national decision makers from the President down depended on a daily basis. The problem commanded the immediate attention of the President, and thus everyone working with and for the national security and defense space programs. The root of the problems had to be found and fixed without any delay.

A high powered team began to examine the problem. That is how it had worked for more than forty years. Things had always been set right by finding each event's process flaw, immature technology, design error, or act of God, as well as could be done. This time was different.

The timing of the start of most of the failed systems suggested some cause in the early 1990s. Some sort of cause that took years to express itself. Almost immediately, the focus narrowed to the changes wrought by Acquisition Reform. Promoting a streamlined approach to acquisition, the Acquisition Reformers claimed better systems could be acquired more quickly and at less cost. Acquisition Reform had been well supported and well intentioned, driven by the end of the Cold War and the need to economize. Acquisition Reform did away with the military standards. Perhaps some military standards needed to be reinstated.[1]

This time, things were not so simple. This time was very different. As the analysis continued, the realization dawned that much more had contributed to the failures than anyone thought. This time, a fix might not even be possible. How had this happened?

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[1] Liam P. Sarsfield, *The Application of Best Practices to Spacecraft Development: An Exploration of Success and Failure in Recent Missions* (Arlington, Virginia: RAND Corporation, 2002); William F. Tosney, *Faster, Better, Cheaper: An Idea Without a Plan* (El Segundo, California: Aerospace Corporation, 2000); Steve Pavlicka and William Tosney, "An Assessment of NRO Satellite Development Practices" (El Segundo, California: Aerospace Corporation, 2003), cited in A. Thomas Young, *Report of the Defense Science Board/Air Force Scientific Advisory Board Joint Task Force on Acquisition of National Security Space Programs* (Washington, D.C.: Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics, May 2003), 49.

Chapter 2

The Quantum Leap

Space systems in service to national defense and national security have long been held as the epitome of high reliability. Achievement of high reliability equates to long operational lifetimes in space. Needless to say, that was an evolutionary process. First came the evolution of a set of feedback mechanisms to learn lessons and improve future generations based on problems, failures, and solutions. Second, evolution was Darwinian, guided by an unseen hand. No one was truly in charge of all parts of space systems from starting with electronic parts through development, to launch, operations, and then disposal at the end of the mission. The unseen hand created an optimal mix of products, processes, and applications responding to market forces and, at times, political pressures.

Since the launch of Explorer I in 1958, the government, contractors, and suppliers supporting high reliability spacecraft became partners in learning lessons from failures and anomalies as technologies emerged and as inspection and detection technologies improved. At every step, demands of mission success moved the enterprise closer to optimality.

In the modern age, the complex mixture of people, technology, and processes has created the assumption that high reliability spacecraft are the norm. What was accomplished with so much hard work and diligence in the past seems to have become routine—little more than what Henry Ford started with the modern assembly line for manufacturing cars. The fact is, complex satellites are marvels of science and technology and have never been the norm. Each is a sophisticated mixture of several kinds of constituent pieces combined using what some would claim rivals a modern “black art.” Contrary to that claim, though, stands the long-term process that created ever more reliable spacecraft. Only through a disciplined and concerted effort to understand every individual part from manufacturing at the vendors through the final assembly and launch did this happen.

This story reflects the times during which high reliability spacecraft became possible, achieved extraordinary successes, when suddenly the recipe for their reliability seemed to have been lost. Understanding this necessitates describing the roots of electronic piece parts and the evolution of high reliability for spacecraft.

Implosion: Lessons from National Security, High Reliability Spacecraft, Electronics, and the Forces Which Changed Them, First Edition. L. Parker Temple III.