Transcript of keynote presentation by Victoria Cox

Thank you, Tom. Let me also start by thanking Chris Paredis and the CSER Program Committee for the invitation to speak here today.

I hope that my remarks will serve as an appropriate backdrop to the work to be presented over the course of the next couple of days. Systems engineering concepts and practices are key to success in project delivery, and I am sure that you will see many new and innovative ideas, systems, and processes presented along with interesting case studies outlining challenges in the delivery of complex systems.

It has been my observation that the greatest challenges are seldom limited to the integration of cutting edge technologies or the development of those technologies. Rather, other challenges are often the most difficult to plan for and overcome.

I am interested in exploring this topic because it highlights a lot of issues that I have dealt with over the course of my career. I would like to say that I am going to unveil my solutions to these difficult challenges; but, sadly, that is not the case.

However, I can say that I have examined a number of case studies; read and conducted some informative analyses; and learned from personal experience; and I have observed some commonalities across disparate projects; noted some commendable successes and, likewise, some stupendous failures.

I'd like to share some thoughts about these with you this morning.

As I said, I don't have all the answers for dealing with these non-technical – let me call them "squishy" – challenges such as those posed by economic landscape, political climate, organizational culture – they will vary from project to project. But they will invariably be those that you can't measure, define specifications for, or capture in a process or standard operating procedure.

What I want to do here is point to some common observations and draw some conclusions.

I have had the great fortune of working on some very exciting, technically challenging and complex systems over the course of my career: the Hubble Telescope; Missile Defense – known then as the Strategic Defense Initiative or Star Wars; and, most recently, the Next Generation Air Transportation System (NextGen).

For Hubble,[1] I was a young scientist working the issue of space environmental effects – crucial to the ultimate performance of the telescope. We had to select and prepare appropriate materials for operation in the vacuum of space to ensure that optical surfaces would not be contaminated by the "outgassing" of other materials.

After all, in order to meet the requirements set forth in NASA specifications, the telescope had to operate at Lyman Alpha – the spectral line of hydrogen, an ultraviolet wavelength that could be blocked by the deposition of a single molecular layer of contaminant on the telescope optics…. And there was the thorny problem of the recently discovered blurring and eroding effects of atomic oxygen.

I was responsible for testing materials and for conducting "thermal vacuum conditioning" of the component parts of the telescope to ensure its optimal performance in space.

We diligently carried out this work from our headquarters at the Marshall Space Flight Center with contractors such as Ball Aerospace in Boulder and Lockheed Martin in Sunnyvale, California.

Meanwhile, the optical components – primary & secondary mirrors - were being prepared by Perkin-Elmer in Danbury, Connecticut. As it turns out the primary mirror was being painstakingly ground to the perfectly smooth optical surface needed to meet the rigorous NASA specs ….but to the wrong optical prescription.

This problem was only discovered upon launch of the telescope in 1990.

Through integration of its component parts, thermal vacuum conditioning of the fully integrated telescope, through 4 years of storage following the Challenger disaster when all Space Shuttles, the delivery vehicle for Hubble, were grounded – through all that time - the imperfection of the optics remained undiscovered. The cleanest optical surfaces ever launched could not perform the mission.

Sen. Barbara Mikulski, whose district includes NASA's Goddard Space Flight Center - home of the Hubble project office - called the space telescope a "techno turkey."

So what went wrong? An investigation determined that a test rig used to measure the precise shape of the mirror - was thrown off slightly by a speck of paint that had lodged in an opening necessary for the test.

OK – these things happen.

Then came the really puzzling part: engineers running the test, unaware of the paint chip, tried to adjust the spacing between the mirror and the test equipment to get the expected results.

When that failed, instead of stopping and investigating the matter further, washers were inserted to change the spacing even more….to get the expected results.

What additional preparation, planning, or oversight might have prevented this error? What about the culture at Perkin-Elmer, the Danbury contractor, might have contributed to the failure to question the test anomalies? Did the distributed management of various aspects of the Hubble across multiple NASA Centers play a part? Would the inclusion of our team in the assessment of the problem have made a difference – after all we were the contamination experts and contamination such as the paint particle was a big concern with the telescope.

Fortunately, the Hubble was designed to accommodate on-orbit upgrades and maintenance missions by space walking astronauts. NASA found a correction for the problem and launched a repair mission in 1993 – 3 years after Hubble's 1990 launch.

Since the repair mission, Hubble has revolutionized optical astronomy, becoming the most significant spacecraft ever launched in terms of its overall scientific impact and its impact on Earth's cultural heritage.

What say we today about its being 7 years behind schedule and $1billion over budget at its launch – 10 years behind and with the additional cost of the repairs before it became usable?

Perspective is another "squishy" proposition – difficult to attain in real time.

Complex systems can pose many problems, raise many questions, cost a lot of time and money but often produce historical results.

For me, still a relatively young scientist, it was quite exciting back in the mid - 80s to be working on the "Star Wars" program. The technology was state-of-the-art and the funding was extremely generous. I worked on a project known at the time as the Space-Based Kinetic Kill Vehicle or KKV.

The technical challenge was to design a capability without a warhead that could hit an enemy ballistic missile enroute through outer space so precisely that it would be broken apart or otherwise diverted from hitting its target. The Stars Wars program has morphed into today's **National Missile Defense System**,[2] managed by the Missile Defense Agency or MDA.

The MDA faces challenges common to many of today's complex systems – certainly similar to those faced by the Federal Aviation Administration's NextGen program.

During the time that I was responsible for NextGen at the FAA, I commissioned a study to look at management of projects similar to NextGen. Stevens Institute conducted the study, and they took a look at MDA.

The Missile Defense Agency oversees work executed across all of the military services. The MDA Headquarters organization, which oversees and budgets for all of the work, is divided into Functional and Execution divisions.

Engineering, architecture, test, acquisition, strategic integration, international and administrative efforts, fall under the Functional side of the organization. Programs are managed and integrated on the Execution side. Execution itself takes place in the services.

The MDA manages lead systems integration contracts for ballistic missile defense efforts. MDA's is a hierarchical system with a board that manages changes, which have impact across programs, and with the MDA Director having ultimate decision authority.

One might think that because the end users of missile defense systems are the military services that a more distributed form of decision making would prevail with the services having equal voices.

Stevens investigations found that attempts at distributed governance were not successful due to incongruent objectives – in the case of MDA with the various military services - and in other cases with industry partners and government entities.

Another point to consider: of the five government projects studied by Stevens for the FAA, four use private sector lead system integrators. Two of the four, MDA and the International Space Station, were deemed a success. The FAA is acting as Lead System Integrator for NextGen. The jury is still out on its ultimate success.

NextGen faces many of the same issues faced by the National Missile Defense program: long-term development timeline; multiple and diverse stakeholders; strong Congressional interest; multiple points of execution with differing cultures; systems integration; global interoperability; stakeholder, Congressional and public expectations.

Notice that I haven't mentioned a technology challenge yet although there certainly are those. However, I would put them below the issues I just listed in order of importance to the success of these programs.

In many ways NextGen's integration issues are more complex than those of missile defense. While there are certainly integration issues within the various missile defense programs, major systems, in general, operate independently.

NextGen is transforming all aspects of the nation's integrated air transportation system – while it maintains continuous daily operations. Each new capability being delivered must integrate into the overall system for real-time operations.

All new capabilities introduced must operate seamlessly at an extremely high level of performance from day one of 'going operational', and they must not have unanticipated impacts on other pieces of the existing, somewhat randomly interconnected, air traffic system in place today.

For those of you unfamiliar with NextGen - it is not a single program; rather, it's a comprehensive initiative that integrates new and existing technologies. It represents the complete transformation of our national airspace system.

NextGen is intended to move today's mid-twentieth century system into the 21st century resulting in operations in low visibility conditions where aircraft cannot operate today; shorter, more efficient flight paths; reduced emissions and noise; and a better passenger experience – thus ensuring the long-term viability of this vitally important economic sector.

There are many challenges faced by the government as lead systems integrator. The challenges are not primarily technical.

Successful NextGen integration relies heavily on the delivery of government functions with internal capabilities and cultures that must be managed for successful implementation. The challenges of integration with existing infrastructure currently operated by entrenched government processes and personnel, coordination with strong labor unions, and the necessity to work across multiple internal FAA Offices – Air Traffic, Airports and the Regulator – all contribute to the complexity of integration of this transformative undertaking.

The FAA has thus far concluded that the government is in the best position to lead the integration efforts.

It does this through a central NextGen organization responsible for planning and budgeting and oversight of system integration and implementation assisted by near, mid and far-term CONOPS, a robust Enterprise Architecture, and detailed Implementation Plans that describe new capabilities as well as how and when they will be delivered.

A NextGen Management Board comprised of senior FAA officials provides direction and oversight with final decision authority resting with a Chief NextGen Officer, currently defined as the Deputy FAA Administrator.

As you can see – NextGen has much in common with the Missile Defense Agency.

Much depends on NextGen's success. Airlines, General Aviation, Airports, manufacturers, tourism, the flying public, Congress, aviation workers (including labor unions), and communities dependent on aviation all have expectations of what it means to transform the air transportation system.

Earlier I mentioned that I had asked for an assessment of other programs with similarities to NextGen. It was also instructive for me to look at past FAA endeavors at modernization. Here's what I learned:

Back in the 1980s, FAA undertook a broad-based modernization. You may have heard of it in case studies of how NOT to manage complex projects.

It has been said of the **Advanced Automation System**[3] or AAS project that "It may have been the greatest failure in the history of organized work."

…….hmm – imagine NextGen's challenges with building a new modernization effort on that legacy!!

First conceived in 1981, in 1994 the FAA declared that $1.5 billion worth of hardware and software out of $2.6 billion spent was useless. (In all fairness, I should point out that the $1.1

billion of useful products delivered by AAS are now serving as a foundation for the NextGen program.)

So what went wrong with AAS? According to many sources – just about everything. The GAO found that "FAA did not recognize the technical complexity of the effort, realistically estimate the resources required, adequately oversee its contractors' activities, or effectively control system requirements." "It was basically a Big Bang approach, gigantic programs that would revolutionize overnight how FAA did its work."

One fundamental flaw in such an approach is that it fails to recognize stakeholder expectations. It is unrealistic to expect Congress to spend multiple billions and wait 13 years to see a penny's worth of result.

Segmented delivery of AAS capabilities might also have curbed the requirements creep that plagued the program.

I've talked a lot about stakeholder expectations. In the case of AAS, the FAA and its prime contractor, IBM, may have actually been the stakeholders with the unrealistic expectations.

Robert Britcher, who later became a Systems Engineering professor, worked on AAS for IBM and wrote a book entitled: "The Limits of Software: People, Projects and Perspective" He writes that IBM and the FAA approached AAS as if it ought to be easy thanks to new programming languages (in this case ADA), modern development tools and distributed systems.

Maybe so…..however, IBM and FAA failed to account adequately for the "People" part of the equation. AAS started on the heels of the infamous Reagan controller firings. Clearly the FAA hoped that automation would allow them to reduce the numbers in the controller workforce and to consolidate to fewer facilities. However, the new controller union, NATCA, was just starting to grow and they had a lot of motivation to resist these goals of modernization.

According to Britcher's assessment, IBM encouraged the FAA to set unrealistic requirements and then - rather than admitting problems, IBM "turned AAS into a research project."

Did IBM fail to understand the fundamental culture of the FAA - pressing on with the very costly development of an ultimate software and hardware package that would never be accepted by the end user?

Did FAA hand too much control of the project over to IBM and then fail to manage them appropriately? It was obvious that AAS suffered from the mis-use or non-use of systems engineering principles, did it suffer just has much from the lack of basic program management – acquisition – expertise?

Let's take a look at another complex systems development project with difficulties**. The Future Combat Systems[4],** FCS, was considered in the Stevens study that I referenced previously - it fell into the category of a failed system.

According to a Rand Study completed following the 2009 cancellation of the program, FCS was the largest and most ambitious planned acquisition in the Army's history.

It called for fielding a suite of systems organized into a brigade structure that was envisioned to operate under an entirely new – but not yet fully developed – doctrine while integrated by a wireless network.

For a number of years, FCS defined the modernization of the Army.

According to Undersecretary of Defense for Acquisition, Frank Kendall, who formerly worked for FCS Lead Systems Integrator SAIC, the program was "irrevocably damaged" by "poor systems engineering." SAIC was co-LSI on FCS along with Boeing.

The GAO said that the biggest problem with FCS was that it was too ambitious and not executable within reasonable technical, engineering, time or financial resources.

A RAND assessment, published in 2012, points to other contributors to the FCS failure some of which are:

Senior level involvement - it can motivate an acquisition effort but can also negatively affect flexibility in light of technology and other challenges. FCS got significant support from top levels of Army leadership.

This helped to put the large and complex program into existence and move it forward, but this highly visible drive to move forward likely exceeded the technical maturity of the program.

Army decisions to restructure as technical challenges emerged and as operations in Iraq and Afghanistan evolved and tapped budgets resulted in two significant restructures of the program adding new elements of difficulty. FCS became even more difficult to understand and harder to manage undermining internal and external support.

Cost estimates – these can be highly uncertain in large novel programs and subject to interpretations that can undermine program support and frustrate the budget process.

Timelines – large scale system of systems acquisition programs take time. Early overly optimistic timelines can undermine confidence. -

Revolutionary technology – assumptions that acquisition can achieve unknown and revolutionary technologies may be attractive to the contractor but can lead to cost overruns and failure. These should stay as concepts until underlying technologies are established.

Expectations – mismanagement of expectations can lead to unrealistically ambitious requirements. FCS officials did a propaganda campaign to Congress and the public early in the program that made it difficult to walk back when overstated goals were not achieved.

So far I've discussed several programs under federal government leadership. Let's take a look at a complex systems integration project in the private sector.

You are hearing a lot in the news lately about problems with **Boeing's 787 aircraft**[5] – the Dreamliner. Long before its recent woes with batteries, Boeing struggled with integration and delivery of this revolutionary aircraft.

And let me just say at this point that I believe the Dreamliner to be one of those instances where a complex systems engineering undertaking has produced historical results. The 787 represents the first fundamental change in aircraft design since the advent of the jet age.

It represents major changes in how an aircraft looks outside and in: the graceful sweep of fuselage and wings, the light and airy interior with large windows and high ceiling, more comfortable cabin air, better management of turbulence, and a quieter ride – not to mention the increased efficiency that benefits operators AND the environment.

And it owes this to new technologies that it has incorporated: 50% composite fuselage, new engine technology, new aerodynamic management capability – all come together to produce a beautiful, comfortable and very efficient aircraft.

But let's take a look at how it came to be that this extraordinary aircraft was delivered more than three and a half years behind its originally scheduled due date with the loss of billions in contractual penalties.

In its production of the Dreamliner, Boeing revolutionized not just aircraft design but its production as well. Boeing sought to manage the economic risk of this revolutionary venture by sharing not only production – but design as well – with its suppliers. The theory was to outsource the risk along with the work.

Many who have studied the problem believe that by moving away from their previous practice of outsourcing <u>manufacturing only</u> with tight control over design and specification – Boeing lost control of the process.

But why didn't this work? Can the problems encountered by Boeing be avoided so that this more efficient and economically appealing means of production can be employed successfully in other sectors in the future?

Boeing has been quoted as stating that they made too many changes at the same time – new technology, new design tools and a change in the supply chain – concluding that they outran their ability to manage effectively.

This innovation risk implied a *greater* involvement by Boeing might be necessary in the development and manufacture of the aircraft. Instead, Boeing opted for *lesser* involvement – failing to plan for the management and mitigation of risk.

In 2001, in an internal paper, Boeing Senior Technical Fellow, Dr John Hart-Smith, predicted that this approach to outsourcing would result in a loss of in-house capability "to even write the specs."

So why not take steps to mitigate this risk?

In a 2010 presentation at an MIT Systems Thinking Conference, Mark Jenks, Boeing VP for 787 Development, discussed Boeing's "cultural awareness" as crucial to the program.

He laid out 3 levels of Cultural Awareness for Boeing management: Cultural Fluency, Cultural Knowledge and Cultural Familiarity with Fluency only required for a limited number of technical and acquisition personnel

Was this wise for a program with 50 Tier 1 suppliers literally spread across the globe?

Christopher Tang and Joshua Zimmerman, of the UCLA Anderson School, looked at supply chain risks and the Boeing 787 in a paper published in 2009. They noted some linchpins for successful supply chain management that were lacking at Boeing: accurate and timely information from suppliers; knowledge of sub-suppliers; and a Management Team with supply chain management expertise.

Labor Union issues – fed, no doubt, by Boeing's increase in outsourcing of 787 development and production - added significantly to management problems as well.

Boeing had done an excellent job of selling this aircraft to customers around the globe who were anxious to take delivery. Perhaps pressure to deliver led to the rather reactive manner in which the company addressed problems. They redesigned the sub-assembly process; acquired problem partners; reorganized top management; conceded to labor unions and paid penalties to customers.

Tang and Zimmerman offer some strategies for mitigating program risks in supply chain management that port very well to other management cases. I will generalize and summarize here:

<u>Use IT to ensure transparency across the system</u> – When considering this strategy, keep in mind that culture will play a role in terms of the value and reliability of information sharing across multiple cultures.

<u>Use proper vetting of all strategic partners to determine their capability of completing tasks.</u> – This seems pretty obvious and still it can be overlooked…..

<u>Develop better risk sharing opportunities and incentives</u> for strategic partners. Because no one got paid until the entire product was delivered there was no incentive for 787 subs to rush production if they knew other components were delayed.

Establish a proper management team with appropriate expertise. This might be in systems engineering, procurement, program management, supply chain management. The importance of senior and working level competency must be acknowledged.

Perform outreach and communicate with union heads.

Treat customers as partners and communicate the potential for missing deadlines.

These are strategies that could have potentially saved some of the failed projects that we discussed and can be applied with great value to the management of any complex system.

I want to mention just one more complex system that I'd like to reference in pulling together the themes that emerge from looking at these complex systems undertakings.

At the 2005 CSER, there was an in-depth discussion of the **Channel Tunnel**[6] project.

Challenges briefed to the conference included confrontational contracts; government interference; lack of government involvement (!); rogue third parties; absence of a clear, common vision; and – too many lawyers.

You might recall that the project came in 12 months late with a 100% cost overrun. However – an entirely new transport system was delivered, which met performance specs; and the project was completed in half the time normally taken to build a new motorway. And who could doubt the value or historical significance of connecting England to the continent.

It is unthinkable now that difficulties managing this huge and complex undertaking might have left it unfinished.

So – what do these examples tell us?

I'd like to focus on five attributes for successful complex systems delivery.

First, let's consider Critical Thinking. We all recognize that systems thinking is vitally important to the success of these projects. Critical thinking goes beyond that.

Students study how to apply critical thinking to various discrete endeavors; but, in the case of complex systems, critical thinking must stretch across the whole and pervade the entire undertaking – especially for project designers, planners, managers and leaders. It is a big picture undertaking.

This is more easily said than achieved. I once took a seminar on critical thinking, and I left wondering if it can be taught.

I have found that in a lot of projects – large and small – it is difficult to find the people with the big picture.

It seems that the cases I've discussed today demonstrate some glaring examples of the failure to think critically:

Perkin-Elmer engineers who kept grinding that mirror to get to right result without due consideration of all the possibilities first.

And how about the Boeing focus on outsourcing risk without appropriate attention on the capabilities of who they were outsourcing to. Appropriate identification of the full spectrum of risk is highly dependent on critical thinking.

Another area that these examples beg us to consider is Competency.

Why would a project go forward without the appropriate mix of trained personnel? The answer to this is not an engineering answer – it's one of those "squishy" people issues.

I have often observed that project managers tend to populate their management teams with people much like themselves – particularly in terms of education and experience. A larger consideration should be assessing and applying the appropriate competencies to the project.

Boeing has been criticized for its lack of supply chain management expertise in production of the Dreamliner – a project highly dependent on a very distributed supply chain. But Boeing had never relied on that kind of expertise before – they must have thought that their traditional managers must be quite capable of building this airplane just as they had many others.

Analysts of the FAA's difficulties on the AAS project frequently blame the Agency's lack of program management capabilities. They also point to the fact that the FAA did not have in-house technical experts able to adequately assess the technical complexity of the project and make appropriate decisions. Rather, they relied on the prime contractor to drive system requirements – and apparently the prime wasn't all that competent at setting realistic requirements either – remember IBM was accused of turning AAS into a research project.

Perhaps the competency just didn't exist back in the day to even undertake the Advanced Automation System.

A lot of independent teams have assessed the NextGen program. The findings of an in-depth study by the Monitor group have been widely discussed. Competency was one of four areas that they deemed key to the ultimate success of the program.

They suggested that the FAA needs to bolster key individual and organizational capabilities in program management, systems integration, software engineering and communication.

One wonders why – after the AAS debacle – FAA would still have gaps in some of these areas.

Monitor suggested that a key competency for NextGen would be Communication. This is another of those "squishy" areas that I believe to be key to complex systems management.

Why "squishy" you might ask – just hire a PR firm and be done with it. But communication when it applies to complex systems goes far beyond that.

Might it have been a failure to communicate at the heart of the Perkin-Elmer engineer's failure to discover their problem? Maybe if they had gone out more broadly to discuss the problem things would have been different.

The sources I reviewed placed partial blame for the FAA's failure with AAS on failure to communicate with the air traffic controllers union, who would be the end users of the technology.

Certainly this is a lesson that FAA has learned and applied to NextGen, where it maintains a close working relationship with that union.

Communicating expectations was seen as critical in a number of projects I've discussed. This includes appropriately articulating cost and time estimates. Notice that I didn't say accurately assessing and predicting cost and time – just as important to the ultimate success of the program is how they are communicated to stakeholders. Maintaining confidence in the program while expressing uncertainty in these estimates is crucial.

Communication of the final performance characteristics of the product is critical as well. You will recall that Future Combat System officials did such a successful propaganda campaign to Congress early in the program that they couldn't walk back when technical and programmatic realities hit.

Because cutting edge technology development can result in lessons learned and accompanying design changes, communication of appropriate expectations is particularly important.

I believe that the life of a complex program may often times depend on the ability its leadership to communicate perspective to stakeholders.

By this I mean the ability to foresee the ultimate intrinsic – even historic – value of the project beyond the financial bottom line – think of the Hubble Telescope and the Channel Tunnel – even the Dreamliner. Achieving this kind of prescience is…a…"squishy" undertaking indeed.

Another exceedingly critical area is organizational Culture. This can play out in many forms. At the FAA, new systems delivered to air traffic controllers must account for and adapt to their culture. Failure to do this has dire consequences.

Boeing's view that only a few of its employees needed to be "fluent" in sub-contractor culture may have been flawed.

Did a culture that didn't like to admit mistakes prevent Perkin-Elmer engineers from recognizing a critical problem?

Organizations differ in their very mind-sets. That has got to be taken into account in the design, production and delivery of complex systems.

Cultural characteristics lead some organizations to be more resistant to change, to avoid risk, to demand certainty in a project that requires a level of uncertainty to move forward. These characteristics can and should drive project management decisions.

Questions regarding management approach and governance are highly dependent on organizational culture: Should governance be distributed or hierarchical? Should lead system integration be internally or externally executed?

The cultural makeup of the end-using organization must be understood and managed.

I promised that I would discuss five attributes; and, at this point, I notice that all four I have talked about – Critical Thinking, Competency, Communication and Culture – all begin with C. I might as well continue the trend.

The last attribute that I want to talk about - one that I deem absolutely necessary for effective leadership of complex systems - is Courage.

Key leaders of complex systems must be informed decision makers. Rarely will there be unanimous agreement on those decisions. The ability to make, defend and stand by decisions requires courage.

It requires courage to go up against an organization's cultural norms.

It requires courage to communicate uncertainty and risk to stakeholders; to convince company or government leaders to invest in a high risk/high return endeavor; to convince company or government leaders that their direction might be wrong and that another solution is in the best interest of investors; to convince these leaders of the historical potential of your own Hubble or Channel Tunnel or Dreamliner.

Don't even think about taking on leadership of a complex system if you are faint of heart.

So, the best advice I can leave you with is – whatever your level of responsibility for a project – whatever stage your project is in – consider these 5 things: Think Critically; Seek appropriate Competencies; Communicate; Consider the Culture; and be Courageous.

[1] Hubble Space Telescope References

i. NASA.gov, "A Brief History of the Hubble Space Telescope," http://history.nasa.gov/hubble/
ii. Hubblesite,"We Have A Problem," http://hubblesite.org/the_telescope/hubble_essentials/#we
iii. William Harwood, CBS News Space Consultant, "STS-125 Mission Preview: A Brief History of the Hubble Telescope," http://www.cbsnews.com/network/news/space/125/125_HST_history.html
iv. Robert S. Capers & Eric Lipton, "Hubble Error: Time, Money and Millionths of an Inch," http://people.tamu.edu/~v-buenger/658/Hubble.pdf
v. BBC News Horizon, "Hubble's Painful Birth," http://news.bbc.co.uk/2/hi/science/nature/638187.stm
vi. NASA, TM-103443, "The Hubble Space Telescope Optical Systems Failure Report," November 1990

[2] Missile Defense Agency References

i. Missile Defense Agency Website, http://www.mda.mil/
ii. Dinesh Verma, Richard Turner, Mark Weitekamp, Stevens Institute of Technology, "Recommendations for NextGen Based on Lessons Learned from Comparable Programs," Final Report, August 2009

[3] Advanced Automation System References

i. Baseline Online, Edward Cone, "The Ugly History of Tool Development at FAA," Baseline Magazine, Posted April 9, 2002, http://www.baselinemag.com/c/a/Projects-Processes/The-Ugly-History-of-Tool-Development-at-the-FAA/
ii. U.S. Department of Transportation Inspector General, Audit Report, "Advance Automation System, Federal Aviation Administration," Report Number AV-1998-113, April 15, 1998
iii. United States General Accounting Office, Testimony Before the Subcommittee on Aviation, Committee on Public Works and Transportation, House of Representatives," Advanced Automation System: Implications of Problems and Recent Changes," Statement of Allen Li, April 13, 1994
iv. Robert N. Britcher, "The Limits of Software: People, Projects, and Perspective," (Addison-Wesley, 1999)

[4] Future Combat Systems References

i. RAND Arroyo Center, Christopher G. Pernin et al, "Lessons from the Army's Future Combat Systems Program," www.RAND.org, 2012
ii. Bloomberg Business Week Online, Tony Capaccio, "Kendall Cites Flawed Army Future Combat Systems as Costly Lesson," Posted December 2, 2011, http://www.businessweek.com/news/2011-12-02/kendall-cites-flawed-army-future-combat-systems-as-costly-lesson.html
iii. Dinesh Verma, Richard Turner, Mark Weitekamp, Stevens Institute of Technology, "Recommendations for NextGen Based on Lessons Learned from Comparable Programs," Final Report, August 2009

[5] Boeing 787 References

i. Christopher S. Tang and Joshua D. Zimmerman, UCLA Anderson School, "Managing New Product Development and Supply Chain Risks: The Boeing 787 Case," 2009
ii. The Seattle Times Online, Dominic Gates, "Boeing 787 Problems Blamed on Outsourcing, Lack of Oversight," Originally Published February 2, 2013, http://seattletimes.com/html/businesstechnology/2020275838_boeingoutsourcingxml.html
iii. L. J. Hart-Smith, "Out-Sourced Profits, The Cornerstone of Successful Sub-Contracting," Boeing Paper MDC 00K0096, Presented at Boeing Third Annual Technical Excellence Symposium, St Louis, Missouri, February 14-15, 2001
iv. Mark Jenks, "Boeing 787: Challenges of Complex Global Systems," 2010 MIT SDM Systems Thinking Conference Presentation, October 21, 2010
v. Daily Finance Online, Peter Cohan, "Boeing's Dreamliner Delays: Outsourcing Goes Too Far," Posted January 21, 2011, http://www.dailyfinance.com/2011/01/21/boeing-dreamliner-delays-outsourcing-goes-too-far/

[6] Channel Tunnel Reference

i. John Boardman, "Major Projects: Can We Afford Them?" 2005 Conference on Systems Engineering Research, Hoboken, New Jersey, March 23-25, 2005