Statement of

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Committee on Science and Technology

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Good morning, Mr. Chairman, Ranking Member Hall and Members of the Committee.

I am Don Winter – Vice President of Engineering and Information Technology at Boeing Phantom Works. I am grateful for the invitation to speak with you on this subject of research on cyber-physical systems (CPS), a topic of great importance to the Boeing Company, the aerospace industry as a whole, and to our Nation. I have a great interest in this subject because of my current position managing an annual R&D budget of over $300M and my past position as one of the founders of the Bold Stroke R&D initiative at Boeing, focused largely on advancing the state of the art in cyber-physical systems.

Boeing has a somewhat unique perspective on cyber-physical systems due to our prominent position in both the military and commercial aerospace markets. Cyber-physical systems are pervasive at Boeing, and in the aerospace industry at large. They are becoming increasingly prevalent in other sectors, notably automotive and energy management. Their importance to our products is huge and their complexity is growing at an exponential rate. Demands for higher system performance and lower system cost for commercial and military systems are driving next generation systems to be highly networked and highly dynamic in nature. Lower recurring and maintenance costs will be derived from integrated vehicle health management that enhances system reliability and reduces logistics and maintenance costs. Moreover, systems will need to be designed to exhibit "predictably safe" behaviors in an uncertain environment.

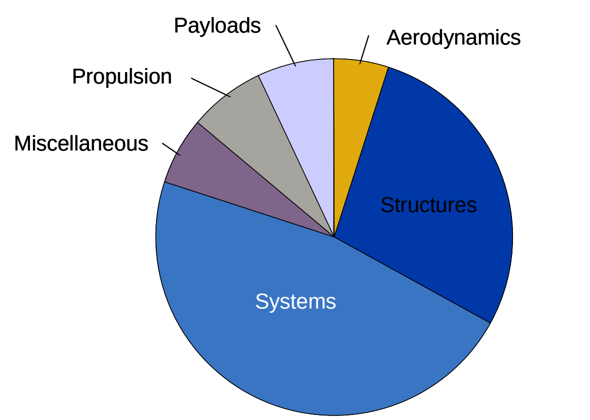

Fig. 1 - Typical Transport Aircraft Development Cost Distribution – Current Generation

In the 70's and 80's aerodynamics and structures accounted for nearly 90 percent of the development cost of a transport aircraft, with cyber-physical system development accounting for less than 10 percent. The trend has reversed, and cyber-physical system design, development, validation and certification account for nearly half of development costs for current generation system, and for next generation systems this percentage is expected to rise to 50% or more.

Several examples are germane and illustrate the exponential growth in software and system complexity of our modern systems. The 747-400 first flew in the late 1980's. The size of the software for the onboard cyber-physical systems is on the order of 10MB. The Boeing 777 first flew in the early 1990's. Its flight software size is an order of magnitude larger – 100MB (on the order of 10 million SLOC). As we evolve to systems such as 787, software size and system complexity will be increased by two or more orders of magnitude.

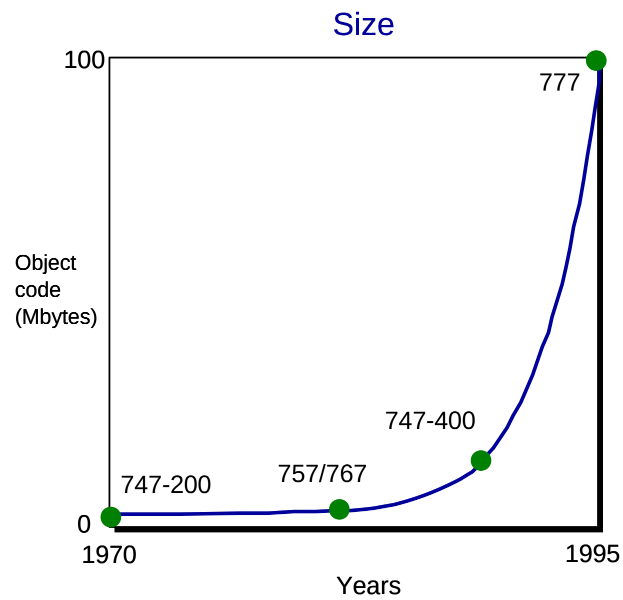

Fig. 2 - Trends in Aircraft Software Object Code Size

These are cyber-physical systems on a grand scale. Research that can support validation and verification of the complex interactions between system modules is highly important. Without advances in these technologies, the cost and risk of developing next generations of cyber-physical systems of this scale may be prohibitive, and have a significant impact on the aerospace industry.

The trends towards CPS complexity are not exclusive to the aerospace industry. The automotive industry has a similar experience. For the last several years, Boeing has been participating in CPS forums across aerospace, automotive, and energy sectors. At a May 2007 CPS Round-table, representatives from USCAR (the US Council for Automotive Research – an umbrella organization for collaborative research among Chrysler, Ford, and General Motors) reported similar trends. Currently the percentage of vehicle cost due to electronics content is approximately 30 percent. The electronics content is increasing in complexity and number of functions. USCAR likewise indicated that "the most difficult issues lie not in the design of the software in individual modules, but in the interactions between different modules and components – i.e., integration of embedded systems composed of heterogeneous components designed and implemented by different suppliers."

Cyber-physical systems are pervasive in other military systems. Emerging systems (manned and unmanned) are incorporating greater intelligence and autonomy. Collaborative, network-enabled operations between multiple systems are becoming the rule rather than the exception. The CBO (published in, "The Army's Future Combat System Program", April 2006) has indicated that at least 34M lines of software code, much of it for CPS, will be generated for Future Combat Systems – about twice current estimates for the Joint Strike Fighter. Today's generation of fighters (figure below) incorporate many cyber-physical systems. These systems operate in highly dynamic environments with real-time mission specific behaviors. This imposes challenges on the cyber-physical systems in the areas of networking, information management, verification, validation, and certification, to mention a few.

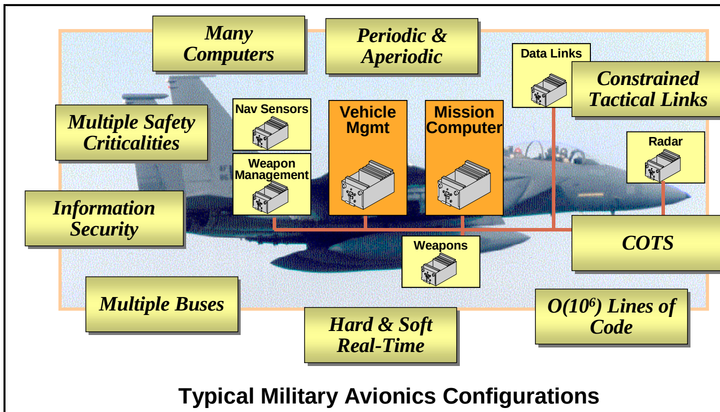

Fig. 3 –Avionics CPS Characteristics

Future aerospace systems will require cyber-physical systems of even greater complexity. Systems will operate with autonomy and will collaborate among themselves to provide vast gains in operational effectiveness. Enabling capabilities in active resource management, dynamic scheduling, and software enabled control mode changes will be needed to support these behaviors. Systems of this sort have flown today in research focused demonstrations. They will be the norm in the future.

Estimates on source lines of code for systems beyond the current generation of developing systems are several orders of magnitude higher – and will likely exceed one billion lines of code.

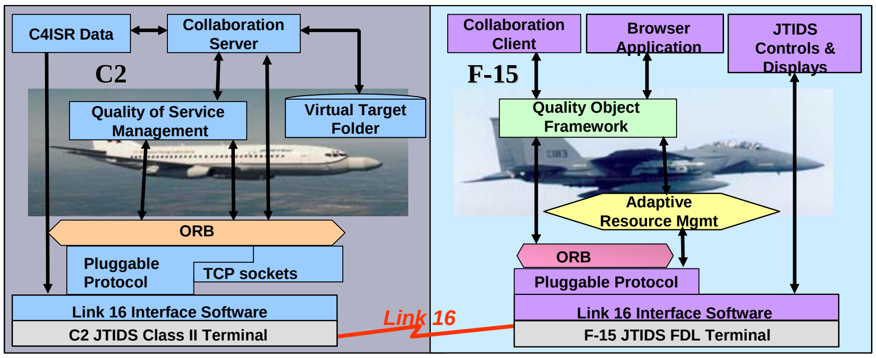

Fig. 4 - Example Collaborative & Dynamic Behaviors

Requirements for cyber-physical systems and software are far more stringent than those for typical office automation applications. Our systems must support real-time behavior. We require ultra-high reliability and many of our systems are safety critical and require certification by the FAA or equivalent military authority. While the occasional "Blue Screen" may be painful in the office environment, it can have extreme consequences in the air. Many of our military systems need to be designed to support coalition operations with multi-level security requirements. Our systems must also be hardened to withstand future cyber attacks by adversaries. Because of these unique requirements and the relatively small numbers of systems, we do not expect a large investment from the commercial IT sector in these technologies.

In order to achieve these cross-cutting capabilities, we will need advances in technologies such as model-based development tools, methods, and validation environments to build systems rapidly and affordably. Moreover, we will require product-focused technologies including software reuse, architectures, real-time theory, languages, and product line architectures to achieve system affordability by recouping investment across multiple system developments.

We have achieved some measure of progress. Several years ago, Boeing developed middleware-based product line architectures to support our military system developments. Sizeable investments were made in new CPS architectures and infrastructures (e.g. Bold Stroke and the FCS System of Systems Common Operating Environment) and substantial gains in productivity were realized. The middleware-based approach is critical since the days where military systems lead and dominate the IT industry are long past. Specifically, CPS architectures like Bold Stroke (illustrated below) were developed in part to provide layers of isolation between the avionics software for DoD systems like F/A-18 and F-15 from hardware and operating systems from the commercial IT industry.

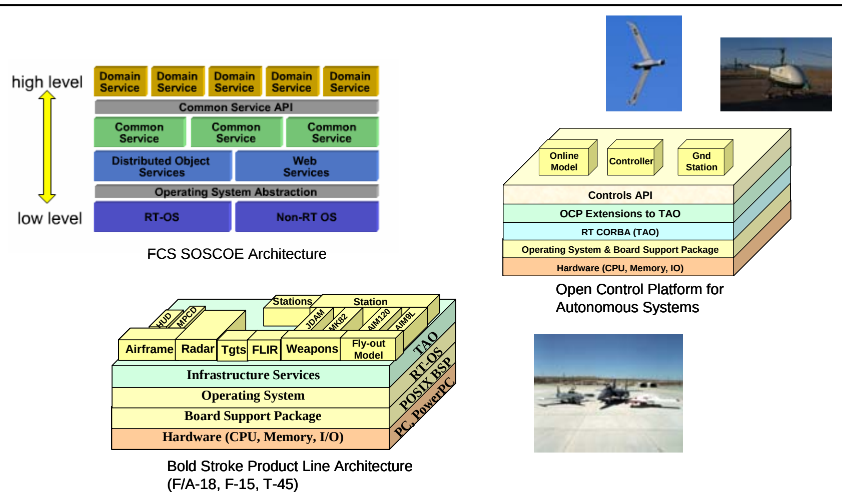

Fig. 5 – Industry-Developed Middleware Based Architectures to Provide Hardware and Software Independence for CPS

The challenges today are far greater than those faced in even the recent past and continue to grow as individual systems evolve, operate with greater autonomy and intelligence, and operate as part of a networked system of system. The challenges grow even larger with future generations of unmanned air systems operating in national air space.

What is the way ahead? Efforts to date have largely been fragmented across the industry and limited by internal funding constraints. CPS investments cross multiple technology domains and will require industry-level critical mass to achieve the needed results.

We need a national strategy in which long-term CPS technology needs are addressed by combined government and corporate investment. Boeing, for its part, can focus our long-term CPS investments on collaborative research in which we provide challenge problems and in-kind participation in government-industry research consortiums. I'm confident our industry partners are willing to do the same. We also need to develop new ways to facilitate the transition of research products back to industry and into our products. This point is critical and is a matter of national competitiveness. The European Union's (EU) Advanced Research and Technology for Embedded Intelligence and Systems (ARTEMIS) program is funded by a public-private investment (over $7B in mid-2007 dollars) and is pursuing R&D to achieve "world leadership in intelligent electronic systems" by 2016. European industry is fully partnered with academia in ARTEMIS. From our perspective, partnership between industry and academia in CPS is absolutely essential to reap the benefits of this advanced research. This partnership needs to reach deeper than the rather "indirect" approach used for industry involvement today.

In summary, we support the proposed expansion of the NITRD program's research objectives to address cyber-physical systems and we look forward to the opportunity to participate.

That concludes my testimony. I'd be pleased now to respond to your questions.