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Making Predictions: A Reality Check

ON this page 17 years ago I was bold (read foolhardy) enough to predict the state of guidance, navigation, and control technology as applied to aircraft at the turn of the century. In what can only be an aging mind's vivid recall, I clearly remember editing out a sentence in which I observed that I might very well be around in the year 2000 to face the consequences of my predictions. Although I am pleased that particular prediction turned out to be true, until George Schmidt called and informed me that it was my duty to face those predictions these many years later, I thought I had managed to dodge that particular embarrassment. Given this predicament and the fact that I spend most of my time these days in the exciting field of photonics, I consulted with the following people: John Deyst at MIT, Eli Gai at the Draper Laboratory, and Doug Arbuckle and Jim Batterson at NASA Langley. So, with some much appreciated help from these gentlemen, here are my thoughts on comparing the reality of 2001 to my 1984 predictions, together with Eli's cold-hearted scores on the accuracy of my predictions (on a scale of 5, with a 5 being a great prediction):

If you wish to be sure that I am not "accidentally" omitting some particularly onerous predictions, consult the editorial in the January–February 1984 issue (Vol. 7, No. 1) of this journal. In it there were three broad areas where I predicted significant advances, provided that financial resources were not an issue. These were aircraft performance, information integration, and integration of the aircraft with its mission environment. I then followed with four examples:

1) That software would become a significant part of the cost of systems and this would lead to methods to automate verification.

2) That full integration of aircraft propulsion, aerodynamic, structural, GN&C, and mission systems would be routine.

3) That powerful computer-aided design tools for both preliminary and detail design would be commonplace.

4) That a near full understanding of the relative role of human and automated systems would be available to designers of flight vehicles and their ground support systems.

Comparing these four with the reality of 2001:

1) Software certainly has become a significant (and in some instances dominant) cost element of modern G&C systems. Also, software generation schemes, such as autocode tools, are commonly used and have relieved some of the tedium of the development and verification processes. However, automation tools are most applicable to the core portions of the software, such as flight control code, but are not readily adaptable to the much greater portion of software, which is more logic based and usually extremely complex. Furthermore, the FAA has yet to certify even the most commonly used autocode tools, and the DoD position is similar. This lack of automation is especially critical in areas of verification and validation of software. Some progress has been made in the mathematical approaches to proving correctness of software, but so far these methods have fallen short when applied at the levels of complexity found in modern practical systems. Through places like the Software Institute, verification and reliability enhancing regimens have been developed and are commonly used in the software development process. In 1984 we all believed software was deterministic and potentially fully verifiable. Today, the combination of complex software written in higher order languages, with high-powered, sometimes specially designed chips, and complex moding and sequencing has led to a school of thought that it is not. *Bottom line: right on as far as software importance and contribution, considerable progress on verification, but only on the simplest tasks.* **Eli's score: 4**

2) Most modern aircraft exhibit high levels of integration within the GN&C function and provide mission and life critical functions in fault tolerant fashion. In addition, there has been much progress in development of fault-tolerant bus architectures, which have facilitated distributed fault-tolerant avionics in both military and commercial aerospace systems. However, although progress has been made toward the anticipated goal of restructurable controls, as well as flight beyond the linear envelope, this technology is still being developed and is not yet found in practice. Although considerable progress within the GN&C system has occurred, considerably less integration of the various technologies at the vehicle level has occurred, with the important exception that full authority digital electronic engine controls have come into common use in the interim years. Many organizations in industry, academia, and government still are set up along classic "stovepipe" departmental lines of propulsion, structures, flight controls, etc. An interesting recent development is the aggressive focus at the MIT Aeronautics and Astronautics Department on systems engineering. Graduates of this program may well lead us to a much fuller realization of this prediction. *Bottom line: Almost no advance in cross discipline integration but good progress within GN&C.* **Eli's score: 1**

3) There have been many advances in the development and utilization of design tools, including aids to verification and validation. Computer-aided design at the mechanical and electrical level is commonplace. The 777 was effectively a computer design with respect to creating the drawings, etc. In spite of this, the overall concept was developed without this level of automation. Although existing tools are useful for predicting performance during the system development phases (for traditional flight regimes only), there is still much difficulty in projecting costs for systems. There remains a strong need for systematic, quantitative methods for trading off design options to minimize production and/or operations costs. Seventeen years after this prediction NASA has an important program in this area looking toward filling some of these voids: the Intelligent Synthesis Environment program. *Bottom line: we have limited tools of the type envisioned, but they are not yet capable of the complexity associated with full integration of technical, programmatic, and economic issues.* **Eli's score: 3**

4) In this area there has been much progress but also some significant difficulties. For example, flight management in modern transport aircraft is highly automated, and most flight functions can be either manually executed by humans or automatically executed by onboard avionics. However, the resulting complexity of these systems has created a new set of problems in terms of the pilot's understanding of how the aircraft will function when the automated system is subjected to unusual and/or hazardous situations. This class of problems has been termed lack of mode awareness, to characterize situations in which aircrews have an incorrect or incomplete perception of how the automated system will function and how it will respond to inputs from the aircrew. In fact, the sequencing and interaction of modes has become a new source for pilot-induced oscillations. An excellent discussion of this phenomenon may be found in a 1997 National Research Council report: "Aviation Safety and Pilot Control, Understanding and Preventing Unfavorable Pilot-Vehicle Interactions." At another level of human interaction, considerable progress has been made. It has become acceptable to gather military intelligence with unmanned vehicles, a mission once the exclusive domain of reconnaissance aircraft. Cruise missiles execute missions once only possible with manned bombers. Trends such as these represent significant advances in the perception and understanding of the role of humans in mission execution. *Bottom line: Operationally we have fully functional autonomous systems, which interact with the human at a higher level than in 1984. We are now relatively comfortable on the two ends of the interaction spectrum: fully automatic and fully manual. We have advanced between these limits where the human and the system interact but still do not have a full understanding of the interactions.* **Eli's score: 3.**

These are interesting examples, but the big picture of the predictions is even more interesting. What I failed to predict was the collapse of the Soviet Union and the subsequent major decrease in the defense budget and the associated R&D investments. The result of this major event was that the "funding not a constraint" caveat in the predictions was not even closely satisfied by the norm of 1984 when we were investing heavily in new developments to counter the other super power. In reality there have been very few new airplanes designed and built which we can use to gauge my predictions. We have only a few new airliners, a prototype of the F22, the Comanche, and a few new general-aviation aircraft.

I also missed the implications of some very important technology developments. These include the widespread use of GPS navigation, and the availability of rapid-access world-wide databases that, coupled with phenomenal advances in computer speed, have revolutionized navigation, led, interestingly, by general aviation more than the airlines. Free flight, smart weapons, and the advances in both airline and general aviation avionics have all flowed from these.

In 1984 aerospace applications were a driver of computer requirements. Now aviation does not keep up with advances in digital technology: passengers carry on more computer power than resides on the flight deck. New aircraft begin service with out-of-date digital hardware. In a similar vein, the rapid advances in available bandwidth, provided principally by the telecommunications industry, have not yet been exploited to anywhere near the extent they could be. We can probably expect some new models, such as the 777, to be in service for 50 years. Fortunately some thought was given to retrofit of its digital systems, but this clearly must be an important design consideration for all new aircraft.

That is as close as I dare get to the obvious interesting question: "What will happen in the next 17 years?" Being 17 years older than the last time I attempted to answer that question, I am wiser along the lines of Mark Twain, who issued a caution about making predictions, "especially those about the future." With that thought in mind, I will not succumb to the temptation. I think George Schmidt should jump onto that slippery slope in his January 2002 editorial and that some future Editor-in-Chief should invite him back in 2019 for the sequel.

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DONALD C. FRASER founded the *Journal of Guidance and Control* in 1978 and served as its Editor-in-Chief for 14 years (*Dynamics* was added to the title in 1982.) Prior to the creation of the *Journal of Guidance and Control*, he served as Associate Editor and then Editor-in-Chief of the *Journal of Spacecraft and Rockets*. When not working for the AIAA, he has served in other positions, such as Executive Vice President of the Draper Laboratory and Principle Deputy Under Secretary of Defense for Acquisition. In the latter position, he was responsible for the overall management of the Defense Department's approximately $100 billion annual worth of procurement and R&D. After leaving government service, he founded the Photonics Center at Boston University, which leverages the expertise and facilities of the University in combination with business and financial partners to create companies whose products are enabled by the use of light. Dr. Fraser is a Fellow of both the AIAA and the AAS, a member of the National Academy of Engineering, and a recipient of the Defense Distinguished Service Medal.