DISCUSSION CONCLUDING AAS 13-508

JIM KIESSLING finished his presentation by mentioning the HALO II project, which demonstrated some discussed concepts using a 35 cm telescope with multiple IR cameras. ROB SEAMAN asked how much of the $34 million spent on HALO II was devoted to software. KIESSLING replied that software cost under $8 million, which included all the processing software for a 16-processor Mercury system doing simultaneous real-time image processing, navigation, *etc*., with six cameras.

STEVE ALLEN supposed that the proposed system outlay, complexity, and accuracy are largely the same as buying a sextant and training a navigator to use it; thus, he wondered where the trade-offs were by using this technology. For example, would mass-production bring down costs? KIESSLING said he was pretty sure that sextant users do not expect position uncertainty on the order of 50 meters. ALLEN asked whether sextant users need that level of accuracy. KIESSLING admitted that LORAN provided accuracy worse than 50 meters, so if the sole justification of this proposed system was to provide a replacement for LORAN, then that level of accuracy is not needed. However, it had been speculated that the abandonment of LORAN in Europe was prompted by increasingly crowded airspace. Reduced vertical separation between aircraft required better positional accuracy than LORAN could provide, and so a value of 50 meters is supposed as an operational necessity for the near future. The problem with sextant navigation is that human observations limit the accuracy, both in terms of angle measurement and in terms of time discrimination. KIESSLING does not think that humans "are in the business of doing sub-arcsecond observations with a sextant."

GEORGE KAPLAN said there had been quite a bit of work within the U.S. Department of Defense (DoD) over the last ten years on these kinds of concepts, and there is a DoD working group trying to coordinate research. As it relates to a hypothetical GPS outage, there are "a lot more time users of GPS than there are position users"—a point that is often overlooked. KIESSLING agreed, considering that many cellular-telephone networks are now disciplined by GPS time receivers.

KAPLAN continued, saying that stellar-inertial navigation systems have a very long history going back to the "smart missile" of the 1950's. Such systems have been in operation on the SR-71 and probably just about every intercontinental ballistic missile. These systems use gimbals and outdated sensors considered to be old technology. A major effort is ongoing in the DoD to bring in newer technology, leveraging modern star-trackers used by spacecraft. This would bring technologies such as CCDs and near-IR sensors down to ordinary navigation to observe stars during daytime. This could potentially improve the observation accuracy to the arc-second level, in order to obtain positional accuracy on the order of 30, 40, or 50 meters. The goal is to accomplish this in a very robust matter using "strap-down" systems that just look at whatever happens to be overhead, automatically determine the star-field being observed, and then perform geo-location from that.

KIESSLING responded that he was modestly aware of some of the DoD efforts, but clarified that his thrust was with regard to open-source approaches. It was KIESSLING's opinion that DoD

efforts are not targeting a civilian market to provide robust GPS backup, which KAPLAN granted as correct. KIESSLING said his project focused on approaches for a civil market which is more exposed to risk than DoD systems. KAPLAN responded that some contractors involved in developing DoD systems would be happy to market to civilians. KIESSLING did not disagree; however, he thought that the U.S. "could not print enough dollars to fund our current aerospace companies to penetrate the civil market."

DENNIS MCCARTHY said that, having been involved in a working group looking into this sort of thing, it looked like a combination of inertial systems plus, say, "targets of opportunity" from a dense infrastructure of available signals, might be used for navigation at some point in the future, particularly if technology ventures into things like "intelligent transportation systems" both on the road and in the air. This could require the implementation of synchronized cell towers everywhere. KIESSLING said that this sort of system has the potential to work reasonably well providing that one is over terrestrial sources, and providing that one is not particularly afraid of Fort Meade, which may have strong feelings regarding the equivalent of performing signals-intelligence on all signals received.

MCCARTHY added that such techniques would make every communication satellite potentially a navigation satellite, and this pointed out "the necessity for really incredible precise synchronization of time." KIESSLING responded that every communication satellite is potentially a victim of the same threats rendering GPS navigation inoperable, and that he was still stunned at the willingness to direct the U.S. Coast Guard to turn off LORAN in 2010. He had little doubt that discussions must have taken place regarding contingency planning if all space assets are lost; however, it seemed reasonable to suppose that it is not possible to address "the full magnitude of bad things that bad people could do in the event of conflict."

CHRIS TUASON said that actually there would be more costs involved. A configuration like HALO II would have a limited need for a backup navigation system if its glass cockpit could not protect it against an electromagnetic pulse (EMP) from nuclear detonation. KIESSLING replied that particular aircraft had a metal skin which acted like a partial Faraday cage; this offered some protection to onboard electronics. It also used optical fiber instead of wiring.

If HALO II is considered a proof of concept, SEAMAN wondered what the concept was: should a commercial jet have a hole in the top of its fuselage to accommodate telescopic navigation? KIESSLING replied that the reason why this demonstration system uses an open port is because it operates in the infrared, and it requires a refrigeration system for the sensor which stays within the aircraft. There is no reason why there could not be a miniaturized system sitting on top.

STEVE MALYS pointed out that visibility is critical for the system to work. Operation appeared limited to clear days or at certain altitudes above cloud levels. KIESSLING replied that most factors contributing to sky obscuration still result in 80% to 90% sky availability, which "beats the heck out of zero." Also, it must be kept in mind that KIESSLING's proposal is for a civilian backup to the primary navigation system. One must appreciate that it is not a proposal for a militarily hardened system, because consumers would not pay the high prices associated with inertial navigation at a military-system level.

MALYS said KIESSLING's proposal could be considered to be one within a family of what MALYS called "database reference navigation system." There are other sources of navigation information besides the celestial sphere; terrain has been used for decades with certain categories of cruise missiles and it works quite well providing there is sufficient variation in the terrain. KIESSLING said that most civilian aircraft are not equipped with terrain-contour (TERCON) capable radar; his application is focused on civilian purposes and is relying on open sources.

ANDREW MAIN asked about the latency between observation and subsequent coordinate fixes. KIESSLING replied that the existing system generates coordinates continuously and is essentially running at the video frame rate, generating output every 24 milliseconds. MAIN wondered in jest if such a system could be used to initialize a GPS receiver; KIESSLING thought that approach sounded backward. KIESSLING's system was experimental, researching assumption-free estimation of trajectories of non-cooperative objects. A by-product of that research was the estimation of one's own position at a high rate. Use of multiple cameras, compensation for atmospheric refraction, and other experimental factors, were being researched as well. Normal alignment is done with six stars, above 45° elevation, at infrared wavelengths, which is not the typical navigation scenario.

HARLAN STENN asked how much time it takes to get a navigation solution from a "cold start". KIESSLING replied that value is tied to the agility of the system and how much time is spent fixated on any particular star. Some level of convergence is typically practiced using a Kalman filter, which results in a navigation fix after about one minute.

MALYS asked for clarification as to whether an inertial navigation system was integrated into the system. KIESSLING replied that the aircraft has an inertial navigation system which is updated with GPS navigation solutions due to the coarseness of the inertial system operating alone, although short-term coasting is not a problem. KAPLAN said inertial systems have been used in commercial open ocean navigation long before GPS. KIESSLING said that the drift rates in the commercially available "low-cost" sensors are still unacceptably high.

SEAMAN thought that this type of system would be, in effect, the alternative to having Harrison's chronometer, where midshipmen on a sailing vessel also relied on bizarre items to observe the stars. KIESSLING said in the modern use case, the midshipman is replaced with software.