Volpe GPS Vulnerability Report
Recommendations & FAA Response

1. *Public policy must ensure, primarily, that safety is maintained even in the event of loss of GPS. This may not necessarily require a backup navigation system for every application. Of secondary but immediate importance is the need to blunt adverse environmental or economic impacts. The focus should not be on determining the nature of the backup systems and procedures, but on which critical applications require protection.*

   FAA Response: We concur with the recommendation. Safety is paramount when conducting aircraft operations, whether using GPS or not. When we made our current GPS authorizations, we instituted operational authorizations that ensure the safety of those operations. For instance, operational authorizations associated with GPS operations now require the carriage of traditional ground-based navigation aids appropriate to the route of flight. In addition, the increasing number of area navigation (RNAV) procedures and the potentially decreasing number of ground-based navigation aids will warrant explicit evaluations of GPS authorizations on a continuing basis.

2. *Because requiring a GPS backup will involve considerable government and user expense, it is recommended that the transportation community determine the level of risk each critical application is exposed to, what level of risk each application can accept, the costs associated with lowering the risk to this level, and how such costs are to be funded.*

   FAA Response: We concur with the recommendation. We have under consideration a series of new studies to evaluate the impact of GPS failures on critical aviation applications. These studies are scheduled to begin in 2002. Our response to Recommendation 11 discusses these studies in more detail.

3. *Continuation of on-going GPS modernization programs involving higher GPS broadcast signal power and the eventual availability of three civil frequencies should be encouraged.*

   FAA Response: We concur with the recommendation. The GPS modernization program greatly increases the robustness of GPS for aviation. The use of three civil frequencies (anticipated availability beginning in 2010) will greatly reduce the likelihood of unintentional interference denying GPS service. Increasing the power levels of all civil signals will increase robustness against both intentional and unintentional interference. The new GPS civil signal will produce four times the power output of the current L1 signal.. At present, the GPS modernization program does not include increasing the minimum specified received signal power for the L1 C/A-code above -160 dBW. The DOT and other civil GPS users should ensure that additional civil signal power is added into the GPS III program requirements.

   The FAA established the frequency for the L5 signal and presented the requirements for its protection at the 2000 World Radiocommunication Conference (WRC). The FAA is

currently working with industry to develop the specifications and minimum performance standards for receivers that will be manufactured to operate with L5.

4. *The Federal Communications Commission (FCC), FAA Office of Spectrum Policy and Management, National Telecommunications and Information Administration (NTIA), the Departments of State and Defense, and other agencies should continue to vigorously support and protect the spectrum for GPS and its applications.*

   FAA Response: We concur with the recommendation. The FAA established an interagency task force agreement between the FCC and the Federal Bureau of Investigation (FBI) that is executed when malicious, intentional, harmful interference is impacting aviation safety. The Spectrum Policy and Management Office has met with the FCC Technical and Public Safety Enforcement Bureau and the FBI to implement an expansion of the agreement to include intentional interference to GPS. The FAA has also established research efforts with NTIA to characterize harmful interference to GPS and to defend GPS spectrum allocations at WRC's. The FAA plans to establish agreements with the Departments of State and Defense, as well as with other involved agencies.

5. *GPS receivers involved in critical maritime and surface applications should be certified by the appropriate regulatory authorities. These authorities should recommend receiver performance standards for non-critical applications.*

   FAA Response: This recommendation pertains to other transportation modes. The FAA already certifies GPS receivers for safety-critical aviation applications.

6. *Efforts must be taken to create and heighten awareness among the aviation, maritime, and surface user communities of the need for mitigation to degradation or loss of the GPS signal through unintended interference from such sources as VHF signals, mobile satellite services, ultra wideband communications, and broadcast television.*

   FAA Response: We concur with the recommendation. The FAA has a collaborative agreement with the Airline Pilots Association (ALPA) to address radio frequency interference (RFI) impact. The agreement heightens awareness within the commercial aviation pilot community of the potential degradation or loss of GPS signals from unintentional interference sources. A public Internet forum provides an awareness of unintentional RFI within the National Airspace System. Topics currently addressed on the ALPA website include the impact on GPS from VHF avionics transceivers, marine satellite telephone terminals, and amplified television receiver antennas.

   Mitigation techniques take many forms. For instance, with respect to VHF and broadcast television, standards are being put in place to eliminate unintentional interference at the source. The same approach is being taken with ultra-wideband technology. The FCC and other Federal agencies are working together to place effective limitations on UWB emissions. Interference from the Mobile Satellite Service (MSS) has been dealt with both domestically and internationally in the form of International Telecommunications Union standards that control MSS mobile station emissions in the GPS L1 frequency band.

Mitigation techniques against personal electronics carried on-board commercial aircraft are just now being investigated.

7. *Systems and procedures to monitor, report, and locate unintentional interference should be implemented or utilized in any application for which loss of GPS is not tolerable. Mitigation of signal blockage impacts should be addressed as much as possible in the GPS application system design process. RFI incidents that affect critical transportation applications should be reported to users as potential hazards to navigation, and users need to be trained in recognizing degradation or loss of the GPS signal, how to switch to an alternate navigation system or procedure if called for, and how to switch back to GPS when it recovers performance.*

   FAA Response: We concur with the recommendation and suggest that it should apply to intentional as well as unintentional interference.

   An FAA working group was formed in 1996 to address GPS interference issues. The group published a 1998 white paper on GPS interference reporting, locating and mitigation and has revised eight agency directives and two memorandums of agreement to address GPS interference. The group also developed GPS anomaly reporting procedures for use by air traffic controllers. Refresher training is provided to controllers on a periodic basis and whenever these procedures are revised.

   We have invested $2.6 million in research and development over the past 7 years to add GPS capabilities to our mobile interference locating resources and equipment. These enhancements have improved the ability of FAA spectrum personnel to respond to GPS interference incidents. The following measures have already been enacted:

   - Ten regional RFI vans were upgraded to detect and locate GPS interference;
   - Portable interference locating systems, assigned to FAA regional offices, were enhanced to include GPS frequencies;
   - Hand-held interference locating systems were upgraded to include GPS frequencies and are in place nationwide at 33 FAA systems management offices; and
   - A portion of the FAA's fleet of flight inspection aircraft is being upgraded to include a GPS interference locating capability.

   We have developed a mission need statement (MNS) that identifies shortfalls in the RFI detection, locating and mitigating capabilities for the entire radio frequency spectrum used by FAA communication, navigation and surveillance systems. We expect to present the MNS for approval by the FAA's Joint Resources Council early in 2002.

   Congress authorized the FAA to spend $1.0 million in 2001 on interference mitigation research. We awarded contracts to Ohio University for GPS antenna research, to the U.S. Naval Warfare Center at Patuxent River, Md., for GPS receiver research, and to the FAA's flight inspection fleet office at Oklahoma City for GPS locating antenna compatibility enhancements. We have funded the Volpe National Transportation

Systems Center for the past 7 years to conduct research and development on GPS interference locating systems. The results of this research are being considered in the acquisition of RFI detection and locating equipment.

The Interagency GPS Executive Board (IGEB) authorized the expenditure of Fiscal Year 2001 stewardship funds to develop and operate a website to provide planning information to all GPS users and to track GPS performance anomalies.

The FAA's Notice to Airmen (NOTAM) system provides the aviation community and other users with information pertaining to GPS outages. The NOTAM system will evolve to include a predictive reporting capability based on GPS satellite outage information and the status of aeronautical GPS augmentations (WAAS/LAAS).

Pilots are required to have a basic knowledge and understanding of how equipment operates. Pilots require familiarity on recognizing GPS receiver loss-of-signal and how to return to full operational use are the responsibility of the user. General information on how to use GPS for in-flight navigation is contained in the Aeronautical Information Manual (AIM) and in other FAA guidance materials. The AIM is currently under revision to include specific GPS anomaly reporting procedures.

8. *Continuing assessments should be made of the applicability of military anti-jam technology, including receiver and antennas, to the civil sector. U.S. government agencies should be encouraged to identify the more promising anti-jam technologies, and to work with industry to make them affordable and suitable for civilian applications.*

   FAA Response: We concur with the recommendation. One example of assessment includes our tasking the Volpe Center to evaluate ongoing military anti-jam research programs and the applicability of this technology for civilian use. We have procured a U.S. Army receiver-antenna system to research its applicability for use in a civilian airframe. We plan to install the system on an FAA aircraft and evaluate its potential for use in civilian aircraft.

   The pursuit with industry of affordability or suitability goals should await a more comprehensive, detailed threat and risk analysis. This technology may not be required for broad implementation across the civil transportation GPS user populace. Only certain high-safety-impact classes of civilian users (e.g., the commercial air-carrier fleet) may need this technology, in which case affordability takes on a different perspective.

9. *The DOT should coordinate with the DoD to ensure that appropriate anti-spoofing technologies are available to civilian applications, should the need arise. It is important to identify observables that may indicate spoofing in civil safety-critical receivers. In addition, DOT should develop independent information to determine the validity and extent of possible civil spoofing threats.*

   FAA Response: We concur with the recommendation. The intelligence community and members of the technical community have spoken on this threat and concluded that it is

possible. They also point out that spoofing requires a technologically sophisticated adversary. The effected area would be limited in size and would therefore impact a limited number of aircraft. It would be useful to gain a consensus among the involved agencies and the intelligence community on the threat, vulnerability and risk.

Spoofing transmissions cannot be detected or identified unambiguously without introducing additional equipage requirements. Even then, there are significant limitations associated with user receiver observables. An explicit threat definition would be useful to help determine the proper suite of observables to monitor.

10. *Within the limits of security requirements, the civil sector transportation community should be apprised of on-going threats and take effective countermeasures to those threats. Civil users should be encouraged to report GPS outages.*

    FAA Response: We concur with the recommendation. The FAA already has well-established procedures in place to evaluate threats to civil aviation and to disseminate the information to the aviation user community. Threats to GPS will affect other modal GPS users. Therefore, when there is a threat to GPS, DOT should take the lead in providing the warning. It is appropriate to heighten the awareness of civil users to report GPS outages. Civil aviation users have been encouraged to report GPS outages; current mechanisms within the aviation community disseminate this information to other users.

    The Interagency GPS Executive Board (IGEB) has provided stewardship funds in 2001 and is expected to fund the completion of a website in 2002 where all GPS constellation status, anomalies and scheduled interference tests, exercises and training can be displayed. Requirements from over 100 civil and government users were solicited in designing the website. Civil users will be encouraged to report outages, and that information will also be displayed.

11. *Create awareness among members of the domestic and global transportation community of the need for GPS backup systems or operational procedures, and of the need for operator and user training in transitions from primary to backup systems, and in incident reporting, so that safety can be maintained in the event of loss of GPS, in applications that cannot tolerate that loss.*

    FAA Response: We concur with the recommendation. The need for backup systems or procedures is institutionalized within the aviation community. Our response to Recommendation 7 discusses some of the relevant training issues.

    The FAA has recognized the need to determine how the air traffic system would recover from a postulated widespread GPS disruption. We will begin a series of studies to determine the impact of GPS failures on critical operations. These studies will assess the impact of GPS outages on air traffic controller workload, and will identify operational issues that may arise as a result of the outages. We plan to simulate conditions in both the en route and terminal airspace environments starting in 2002.

A 1996 International Civil Aviation Organization (ICAO) circular provided guidelines for the implementation of global navigation satellite systems (GNSS). The circular addressed RFI mitigation techniques. ICAO is presently developing a manual to provide additional information to assist in the introduction of GNSS operations. The manual is intended to help the air navigation service providers responsible for fielding and operating GNSS elements and the regulatory agencies responsible for approving the use of GNSS for flight operations. It addresses implementation planning (including training), procedures development, air traffic control considerations, certification and operational approval, and interference issues and mitigation techniques.

12. *Encourage all the transportation modes to give attention to autonomous integrity monitoring of GPS signals, as is being done in the aviation and maritime modes (Receiver Autonomous Integrity Monitoring, RAIM).*

    FAA Response: This recommendation pertains to other transportation modes. The FAA already requires RAIM for GPS receivers used in safety-critical aviation applications.

13. *In an effort to provide the greatest benefit to the users, encourage the development of affordable vehicle-based backups such as GPS/inertial receivers, and, in the event Loran-C becomes a viable backup to GPS, aviation certifiable Loran-C receivers, and GPS/Loran-C receivers. All GPS receivers in critical applications must provide a timely warning when GPS positioning and timing signals are degraded or lost. Conditions for setting the warning indicator in the receiver, and for displaying it to users, should be standardized within each mode.*

    FAA Response: We concur with the recommendation. The FAA is monitoring the development of improved low-cost inertial navigation systems. Some breakthroughs are possible to provide a $500-1500 inertial system that can be integrated with GPS and provide an independent un-jammable complement to any radionavigation. The expected error rate in these low-cost inertial systems is nominally one degree per hour, which would be sufficient to support en route navigation.

    Loran is a standalone positioning and timing system and has the potential to provide redundancy to GPS in all phases of flight through non-precision approach. (Because Loran does not provide vertical position, it cannot provide a full backup to GPS.) The FAA is not able to declare Loran as a viable backup until research and testing of avionics are complete and an adequate market exists to warrant continued Loran investment.

    The FAA is sponsoring development of new-technology Loran-C receivers to overcome limitations of older systems. Success in these efforts will significantly improve the availability and continuity of service performance needed to meet aviation certification requirements. This research will be expanded to include the integration of these Loran-C devices with GPS receivers, to serve as an integrated navigation system with complementary failure and recovery modes. Loran receivers are also capable of integration with inertial inputs. The FAA and NASA are also continuing to sponsor research involving the integration of small inertial sensors with radionavigation receivers.

Airworthiness criteria already exist for GPS navigation receivers used in safety-critical applications. These criteria ensure that timely warnings are provided to the user when positioning signals are degraded or lost.

14. *Conduct a comprehensive analysis of GPS backup navigation and precise timing options including VOR/DME, ILS, Loran-C, inertial navigation systems, and operating procedures. Consideration must be given to: (1) the cost of equipage for both general and commercial users – national and international in aviation uses; (2) navigation and precision timing system capital and operating costs; and (3) operating procedures and training costs associated with the need for situation awareness when the GPS signals are degraded or lost.*

    FAA Response: We concur with the recommendation.

    Navigation backup: While we have already formulated and published (in the Federal Radionavigation Plan) our basic plan to retain a subset of existing ground-based navigation aids as a backup to GPS, the plan needs to be refined in several key areas. The Volpe report underscores the GPS vulnerability that, if supported by a civil threat analysis, could warrant the retention of additional ILS facilities. The role of inertial systems needs to be defined more clearly, as well as re-evaluating the coverage of DME/DME area navigation to serve terminal areas where intentional GPS interference is a threat. If Loran-C attains a role as a primary navigation aid, we may be able to decommission more VOR's than presently planned.

    Timing backup: We know that FAA communications systems need to be designed with the possibility that GPS will fail. Section 5.1.4 of the Volpe report itself mentions the timing mitigation strategies that FAA plans to implement in our next-generation communication program (NEXCOM). Further analysis of backup timing options is not necessary from an aviation perspective.

    Finally, the FAA will review the NAS Architecture to identify any additional vulnerabilities. For example, Automatic Dependent Surveillance – Broadcast (ADS-B) is currently planned to use GPS. The operational use of ADS-B must ensure continued safe operations in the event of GPS interference, which could limit the operational applications of ADS-B.

15. *Continue the Loran-C modernization program of the FAA and USCG, until it is determined whether Loran-C has a role as a GPS backup system. If it is determined that Loran-C has a role in the future navigation mix, DOT should promptly announce this to encourage the electronics manufacturing community to develop new Loran-C technologies.*

    FAA Response: We concur with the recommendation, with a caveat.

The Loran system modernization program is currently in progress, with congressionally supported expenditures projected to occur over a number of years. Our response to Recommendations 13 and 14 discussed the Loran system's potential role as an aviation backup navigation system.

Initial discussions with potential receiver manufacturers have not been productive. This appears to reflect industry reluctance to undertake R&D efforts in the absence of a proven market, and in the absence of a formal U.S. Government commitment for continued system operation. Although such discussions are continuing, they are unlikely to become more productive unless the Department publishes a policy projecting the long-term operation of the system. The manufacturing and user community appears to uniformly define "long term" as being at least until the year 2015, as was published in the 1992 Federal Radionavigation Plan.

16. *DOT should take an active role in developing a roadmap for the future navigation infrastructure that will be stated clearly in the Federal Radionavigation Plan, and will be followed by the DOT modes and navigation user communities in their navigation activities.*

    FAA Response: We concur with the recommendation and will actively support the Department in this activity.