UNSAFE AT ANY AIRSPEED?

CELLPHONES AND OTHER ELECTRONICS ARE MORE OF A RISK THAN YOU THINK

BY BILL STRAUSS, M. GRANGER MORGAN, JAY APT, & DANIEL D. STANCIL

IS IT SAFE to use cellphones on airplanes? The U.S. Federal Communications Commission (FCC) thinks it may be. In December 2004, the agency began soliciting comments on proposed regulations that would allow airline passengers to use cellphones and other electronic devices. To be sure, it acknowledges that a sister agency, the Federal Aviation Administration (FAA), has ultimate authority regarding regulations that govern airline safety. Yet a July 2005 report by a U.S. House of Representatives subcommittee, which held hearings on the matter, noted: "The FCC hopes to issue a final ruling in 2006, stating that its ultimate objective is to allow consumers to use their own wireless devices during flight."

In the meantime, more and more passengers are bringing cellphones, PDAs, laptops, DVD players, and game machines on board. All of these items emit radiation and have the potential to interfere with aircraft instrumentation. More and more passengers, however, do not believe that using portable electronic devices presents a risk to their safety. We, on the other hand, have had our doubts that such use was safe.

OVER THE COURSE of three months in late 2003, we investigated the possibility that portable electronic devices interfere with a plane's safety instruments by measuring the RF spectrum inside commercial aircraft cabins. What we found was disturbing. Passengers are using cellphones, on the average, at least once per flight, contrary to FCC and FAA regulations, and sometimes during the especially critical flight phases of takeoff and landing. Although that number seems low, keep in mind that it represents the furtive activity of a small number of rule breakers. Should the FCC and the airlines allow cellphone use, the number of calls could rise dramatically. In addition, regulations already permit a wide variety of other portable electronic devices—from game machines to laptops with Wi-Fi cards—to be used in the air today. Yet our research has found that these items can interrupt the normal operation of key cockpit instruments, especially Global Positioning System (GPS) receivers, which are increasingly vital to safe landings. Two different studies by NASA further support the idea that passengers' electronic devices dangerously produce interference in a way that reduces the safety margins for critical avionics systems.

There is no smoking gun to this story: there is no definitive instance of an air accident known to have been caused by a passenger's use of an electronic device. Nonetheless, although it is impossible to say that such use has contributed to air accidents in the past, the data also make it impossible to rule it out completely. More important, the data support a conclusion that continued use of portable RF-emitting devices such as cellphones will, in all likelihood, someday cause an accident by interfering with critical cockpit instruments such as GPS receivers. This much is certain: there exists a greater potential for problems than was previously believed.

THERE IT WAS— THE CLEAR SPECTRAL SIGNATURE OF THAT CELLPHONE CALL

Although our data are more than two years old, they still represent the best available in this critical area of air safety. Ours is the first documented study of in-flight RF emissions by portable electronic devices and, we believe, the first such scientific measuring other than what has been done by individual airlines. And as far as we know, it is the first in-the-field examination ever into the critical question of emissions interference with the spectrum bands used for navigation. Yet despite the paucity of available data, regulators and the airlines seem poised to yield to public demands to allow the use of cellphones in flight and the use of other devices, such as PDAs, during critical phases of flight. We believe additional studies are needed to characterize potential risks, followed by regulations that ensure the safe use of radiating devices, and we conclude with a suggested five-point program for such studies. And we argue that in the meantime, the public needs to be more clearly informed about the risks of its current behavior.

SOME FOLKS DOUBT that there is a risk, arguing that the evidence of cellphone use on planes is merely anecdotal. However, take, for example, one flight on a Boeing 737 in the busy eastern U.S. air corridor. One of us watched a passenger pull out a cellphone and make a call shortly after the wheels left the ground. Normally, that would have been dismissed as just another undocumented story about possible cellphone use on a commercial airliner, but not this time: on this occasion, it was thoroughly documented. Unbeknownst to everyone on board (except one of us and the flight crew), an innocuous-looking carry-on bag was stuffed in the overhead luggage rack [see photo, "Overhead Instrumentation"]. It contained a broadband antenna connected to a compact portable spectrum analyzer. A laptop computer controlled the system and logged the data. The whole package had been carefully tested for safe in-flight operation and was allowed on board by the airline and the two relevant U.S. safety agencies, the FAA and the Transportation Security Administration. When the flight was over, we downloaded the data, and there it was—the clear spectral signature of that phone call.

With support from the FAA and assistance from three major airlines, we first tested our equipment on parked airliners. We next ran a trial on a maintenance flight. Thus prepared, we then measured the RF environment on 37 passenger flights in the eastern United States from September 2003 through November 2003. We collected more than 50 hours' worth of data. (We did not listen in on or record the cellphone conversations themselves.)

On our tests, the airlines—which by agreement remain unnamed—imposed two simple requirements: that the test equipment fit easily in a carry-on bag and that it not be opened while passengers were on board. Because of these size limitations and cost considerations, our equipment could not simultaneously monitor multiple frequency bands, although the computer could switch the spectrum analyzer between bands and change the resolution of the observations according to a program set prior to each flight.

While mobile phones are obvious emission sources, wireless devices in computers and spurious emissions from a variety of other electronic products are also of concern. The airline industry refers to all portable electronic devices collectively as PEDs. We logged PED emissions in nine different frequency bands of interest. However, we focused much of our attention on the bands used by cellphones and by navigation systems, including GPS [see chart, "Cellular Stands Out"].

Several different mobile phone technologies are used in the United States. The two principal frequency bands are the cellular band, 824 to 849 megahertz, which uses a combination of analog and digital technologies, and the PCS (Personal Communications Services) band, 1850 to 1910 MHz, which is all digital. The more dominant cellular technologies are code-division multiple access (CDMA), used by carriers like Verizon and Sprint; Global System for Mobile Communication (GSM), used by Cingular and T-Mobile; and time-division multiple access (TDMA), used by older Cingular base stations and several other carriers.

Other frequency ranges are increasingly being used for cellular service, such as Integrated Digital Enhanced Network (iDEN), in the 806 to 821 MHz frequency range, a technology made popular by the push-to-talk service of Nextel, formerly an independent network but now part of Sprint. Sprint is also the best-known PCS operator. The technologies that transmit in the cellular and PCS bands accounted for more than 75 percent of the mobile phone service in the United States at the time of the study, so our in-flight monitoring concentrated on these frequency bands.

For the cellular and PCS frequency bands, given the monitoring parameters we selected, we couldn't conclusively identify the technologies underlying the signals we detected. However, the FCC permits only cellular telephones to operate in these frequency bands and restricts emissions from unintentional radiators. The recorded power levels are also evidence that the signals are due to cellphone use: an unintentional PED radiator operating at the maximum allowable emission level would show up as being at least 70 decibels below that of an onboard cellular signal.

We could easily identify CDMA cellphone signals in the frequency spectrum analysis by their correlation to prescribed CDMA channels, their relatively wide bandwidth (1.23 MHz), and a distinctive flat top. In other words, it is almost impossible to miss the "Bart Simpson hairdo" profile of a CDMA call. It was

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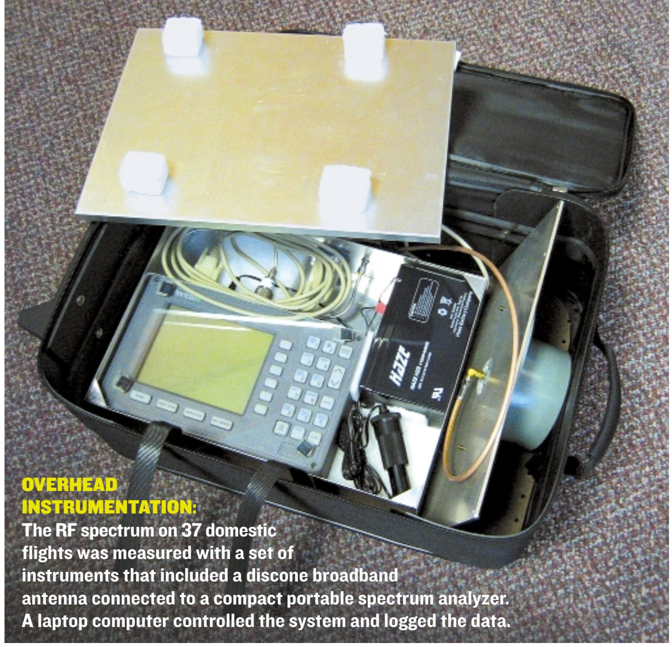
harder to identify other cellphone signals unambiguously, such as TDMA or those of older analog phones. While the particular technology associated with these signals could not be identified, there is little doubt that they were cellular in nature, given the high emission level typically observed.

We were able to clearly identify some cellphone signals that originated from on board the aircraft [again, see chart, "Cellular Stands Out"]. Ours was a conservative estimate, since a call made at the other end of the cabin from the instrumentation would be below the threshold we could observe. Our measurements also found emissions from other onboard sources—devices used by passengers—in the frequency used by GPS.

Our research shows clearly that, in violation of FCC and FAA rules, calls are regularly made from commercial aircraft. Results from our analysis imply that calls from on board scheduled commercial aircraft in the eastern United States occur at a rate of one to four per flight. In addition, we saw other signals that suggest that at least one passenger neglects to turn off his or her cellphone on most flights.

Why are passengers ignoring the rules? In 2001, with the assistance of a travel agent, we conducted a small survey of frequent flyers. As it turns out, passengers are unaware of the reasons for current PED policies, and they doubt that there are any serious safety risks. As a result, they admit to using prohibited devices and also to using permitted PEDs at prohibited flight phases, that is, during takeoff and landing.



OVERHEAD INSTRUMENTATION: The RF spectrum on 37 domestic flights was measured with a set of instruments that included a discone broadband antenna connected to a compact portable spectrum analyzer. A laptop computer controlled the system and logged the data.

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CONSUMER DEVICES that meet FCC emission limits can exceed safe interference limits set by the FAA for avionics, because the FCC and the FAA do not harmonize their regulations. A 2003 study of cellular telephones by NASA highlighted the problem. On the one hand, the study found that of eight cellphones tested (four CDMA and four GSM), no individual unit would be likely to interfere with any of the commonly used aircraft navigation radio systems, although there was still some potential for interference in worst-case scenarios. However, the same study determined that spurious emissions from cellular phones at the allowable FCC limits would cut dangerously into safety margins for avionics, even when considering "reasonable minimum" radio receiver interference thresholds. More troubling, the study found that intermodulation between some cellular phones caused emissions in the frequency bands used by an aircraft's GPS and distance-measuring equipment. The report identified other combinations of common passenger transmitters that could potentially produce intermodulation effects in aircraft communication and navigation RF bands.

The report also found that spurious emissions from most intentional transmitters do not have to meet more rigorous FCC standards applicable to nonintentional transmitters. Furthermore, PCS is regulated separately from cellular; the FCC does not restrict airborne use of PCS wireless handsets. FCC limits for spurious radiated emissions for PCS handsets are the same as for cellular handsets; however, only cellular handsets are restricted from airborne operation.

Another NASA report, also released in 2003, established that wireless local area network devices (such as Wi-Fi cards) were in compliance with one general set of FCC regulations that govern them but exceeded permitted levels in other regulations—specifically, FAA emission limits for installed avionics in the several frequency bands important to commercial aviation. The report also demonstrated that spurious emissions from two-way radios such as those used for Family Radio Service (FRS) or General Mobile Radio Service (GMRS) exceeded the installed-avionics emission limits.

Of the cockpit instruments that can be interfered with by RF emissions from portable devices, the most problematic might be those used for navigation. To understand what's at stake, we need to first note the variety of different technologies used today for aircraft navigation. The most common are the VHF omnidirectional range system and the instrument landing system, both of which operate near 100 MHz, and GPS, which operates between 1200 and 1600 MHz. PEDs have the potential to interfere with each of them, but the most serious concern has to be for GPS receivers, which are becoming key navigational aids these days—particularly when clouds or other weather problems make it impossible for pilots to see runways.

GPS-certified landing approaches are now widely used in general aviation. Though most airliners presently use instrument landing systems, use of GPS technology will increase significantly over the next few years. There are three times as many GPS-certified approaches as instrument landing system approaches in the United States.

In March 2004, acting on a number of reports from general aviation pilots that Samsung SPH-N300 cellphones had caused their GPS receivers to lose satellite lock, NASA issued a technical memorandum that described emissions from this popular phone. It reported that there were emissions in the GPS band capable of causing interference. Disturbingly, though, they were low enough to comply with FCC emissions standards.

Our data and the NASA studies suggest to us that there is a clear and present danger: cellphones can render GPS instrument useless for landings. Clearly, the cause of the problem is that the FCC issues RF emission standards for consumer electronics, con-

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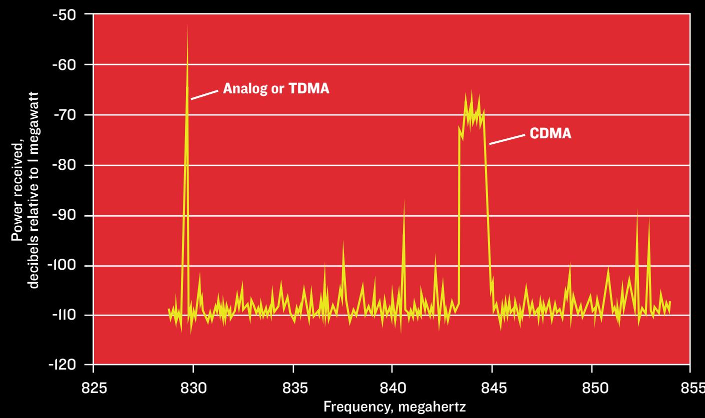

FREQUENCY BANDS

MHz	MOST COMMON USES
108–118	Navigation (VOR and ILS localizer)
329–335	ILS glide slope
824–849	AMP, CDMA, and TDMA (cellphones)
902–928	ISM band for commercial electronics
960–1215	DME, TCAS
1215–1240	GPS 1227.5
1565–1590	GPS 1575.42
1850–1910	PCS phones
2400–2484	ISM band for commercial electronics

KEY
VOR—VHF omnidirectional range system
ILS—instrument landing system
ISM—industrial, scientific, and medical
DME—distance measuring equipment
TCAS—traffic-alert and collision avoidance system

CELLULAR STANDS OUT: The wideband signal on the right side of the graph is a CDMA signal (CDMA channel 466). The narrowband signal on the left is likely either an analog or a TDMA signal. The wideband signal's weaker appearance is due in part to the settings of the measuring equipment.

ferring only minimally with the FAA and with no formal consideration of the implications of those standards for the aircraft environment. For its part, the FAA relies on the airlines to initiate safety plans and, like other government agencies, defers to the FCC on questions of electromagnetic radiation.

HAVE CELLPHONES CAUSED ACCIDENTS? We cannot be sure they have, but the data support the belief that they may have. Without any direct record of the RF environment in a plane at the time of its crash, it is difficult to see how one could definitively attribute a crash to PED interference after the fact. This holds true even if investigators were to look for PED interference as the primary cause of the accident, which, typically, they do not.

For this reason, we conducted two statistical analyses. First, we examined 385 commercial aircraft accidents for the period 1990 to 1999, to set an upper limit on the proportion of crashes in which interference from PEDs might have played a role. If PEDs had contributed to any accidents, they did not play a role in any more than about 6.5 percent of them.

Next, we studied the Aviation Safety Reporting System (ASRS), a database to which aircrews and others can submit anonymous reports on safety problems they observe. For many years, NASA has maintained this database. To ensure confidentiality, NASA removes identifying information from the reports, a time-consuming and costly task. NASA can afford to enter only about 15 to 20 percent of the received safety reports into the database. Until budget cuts ended the practice in 2001, NASA included a random sample of incidents drawn from across all reports, and it was this sample that we used in our analysis.

All in all, we found 125 entries in the ASRS database that reported PED interference. Of these, 77 were considered highly correlated, based on the description of observed PED use and interference occurrence. The reports included cases of critical aircraft systems such as navigation and throttle settings being affected. Based on the random sample entries from 1995 to 2001, we estimate that the average number of reported interference events might be as high as 23 per year. There is considerable uncertainty about how many incidents actually occur in a year; a number of factors could make the number higher—or even lower—than the estimate of 23. Some reported incidents have not been entered into the database, and some of the reported incidents may not be interference events (that is, they might be false positives). But the data certainly suggest that PED interference events occur a few times each month.

In one telling incident, a flight crew stated that a 30-degree navigation error was immediately corrected after a passenger turned off a DVD player and that the error reoccurred when the curious crew asked the passenger to switch the player on again. Game electronics and laptops were the culprits in other reports in which the crew verified in the same way that a particular PED caused erratic navigation indications.

So what about accidents? We can extrapolate by looking at the existence of interference. Beginning in the 1930s, industrial safety pioneer H.W. Heinrich found—across many industries—that the ratio of incidents to accidents is about 300 to 1. Since then, this ratio has been approximately confirmed in a number of studies, including ones by the U.S. Air Force in the early 1970s. If this ratio holds true for the aviation industry, then we would expect PED interference to be a factor in an accident about once every 12 years, if we use the upper boundary for reporting that we described previously. If cellphone use increases dramatically with new regulations, we can expect the risk to rise correspondingly.

WHAT SHOULD BE DONE? Our research has indicated that PED interference occurs at an appreciable rate and that some of these events create hazardous situations. The rapid growth of wireless and other devices emitting RF radiation poses increasing risks for airlines.

Safety purists might argue that airlines should simply ban the use of all consumer electronic devices in aircraft cabins. In fact, the airlines could do so under the authority they have through existing FAA regulations, which specify that "no person may operate...any portable electronic device on...aircraft" unless an airline has determined that use of the device "will not cause interference with the navigation or communication system of the aircraft on which it is to be used." It is unlikely, however, that airlines will issue such a ban.

Competitive pressures among airlines are large and growing. Business travelers, who want to stay connected and networked, are also the airlines' most profitable group of customers. There will be enormous pressure to introduce new services as airlines search for sources of comparative advantage. Indeed, pico cell systems, which would allow passengers to use their cellular phones while in flight, have already been tested. (The seat-back phones that some planes have had for years do not use pico cells. Rather, they are hardwired to a satellite communication transceiver. The antenna is outside the aircraft and is tested to ensure compatibility with the aircraft.) If the FCC lifts its ban on in-flight cellphone use, it may be removing the only remaining obstacle to their widespread use.

Airlines, aircraft and equipment manufacturers, and regulators need to make greater use of classic tools of risk analysis to examine the problem of RF interference. Given the enormous diversity and complexity of the systems involved, the constantly changing aircraft environment, and the limited analytical resources, however,

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such conventional studies cannot identify and assess all important potential accident sequences. We recommend five broad strategies to foster adaptive management and control, listed here in approximate order of importance and feasibility:

1. Expand industry-government cooperation: Most airlines do not have adequate resources to evaluate all systems under development, nor, given the pressures of competition, do they rush to share the results of their research. A joint effort is clearly needed, and in the interests of public safety, some federal money should be provided to augment airline resources. The FAA, FCC, National Transportation Safety Board, airlines, and aircraft and equipment manufacturers should form an industry-government cooperative program to evaluate, test, and promote better communication between aviation professionals and the public. All airlines operating in the United States should be required to participate. There already is a voluntary not-for-profit corporation well suited to the task—RTCA Inc., in Washington, D.C. (originally known as the Radio Technical Commission for Aeronautics)—that develops consensus-based recommendations. Its committees on PEDs have served the purpose but have convened too infrequently to be effective. Given the dynamic growth of PED use, a standing committee is needed.

2. Augment the Aviation Safety Reporting System: NASA's ASRS should once again support statistically meaningful time-series event analyses. The ASRS, a cornerstone of aviation safety, has issued more than 4000 safety alerts; outside researchers have drawn on its database to produce at least 60 safety-related reports and papers. Because the practice of including an identifiable random sample of incidents was dropped (because of budget cuts), the ASRS can no longer be used to do statistically valid studies of all types of incidents, including those involving PED interference. Congress should provide budgetary support to reinstate the random sample entries or, better yet, to enter all the received reports.

3. Continue in-flight RF spectrum measurements: Improved and ongoing characterization and analysis of the onboard RF environment will yield many benefits. Our research has been only a modest start. It would be relatively straightforward to install RF detectors in aircraft cabins that would continuously monitor and record high field strengths in several spectral bands, much as we did in our research. The data can then be stored on flight data recorders—the familiar "black boxes" that serve as tools when airplane crashes are investigated. Modern flight data recorders have hundreds of channels for recording data, and the major airlines routinely apply data-mining methods to the records from each flight to improve operational efficiency and quality assurance and to search for anomalies that could indicate problems.

4. Enable real-time monitoring by flight crews: The deployment of simple real-time tools to help flight crews detect RF emissions would help reduce risks. If flight crews or airliners had RF detectors, then they could take corrective action when they noticed strong electromagnetic emissions. The crew could more closely monitor its avionics, especially during critical flight phases such as final approach and landing. If such observations ultimately identify particular types of electronic devices that are seriously troublesome, then legal or other means should be available to keep them off airliners in the future. Currently, there is no systematic way to keep offending devices off flights.

5. Harmonize RF emissions standards: In today's world, with vast numbers of consumer electronic devices being used, either legally or illegally, on airplanes, it no longer makes sense for the FCC alone to set emission standards and policies. Clearly, the FCC and the FAA should confer in establishing electronic device emission and susceptibility standards for avionics. If the expected growth of wireless technology leads to interference problems that are sufficiently grave, then it may prove necessary to adopt more aggressive controls. For example, the FCC could require manufacturers to include override capability in wireless devices so that they could be turned off by a centrally transmitted control signal during critical phases of takeoff and final approach. Such a deactivating capability might also prove beneficial in other life-critical settings, such as hospital critical-care facilities. This type of regulation, of course, raises important questions of civil liberties and social vulnerability.

THE FCC AND THE FAA SHOULD CONFER IN ESTABLISHING ELECTRONIC EMISSION STANDARDS

PASSENGERS MUST ALSO BE INFORMED of the very real risks posed by their use of PEDs, especially on flights that use GPS approaches. Turkish Airlines' announcement is straightforward: "Mobile phones interfere with the flight instruments and have a negative effect on flight safety." The technical standards for GPS approaches could be modified to ensure that any loss of signal is immediately flagged to the crew, particularly during landings.

Taken together, the actions outlined above should enable regulators and the airline industry to better characterize and manage the risk that RF emissions from consumer electronics poses to aviation safety. In an industry that has eliminated or is effectively managing most large and obvious sources of danger, such small but persistent risks warrant serious attention. At present, we believe that passenger use of electronics on board commercial aircraft should continue to be limited and that passengers should not be allowed to operate intentionally radiating devices such as cellphones and wireless computer equipment during critical stages of flight. ■

TO PROBE FURTHER

For more about electronic devices on aircraft, see the following: "Do Portable Electronics Endanger Flight?" *IEEE Spectrum*, September 1996; Bill Strauss and M. Granger Morgan, "Everyday Threats to Aircraft Safety," *Issues in Science and Technology*, pp. 82–86, Winter 2002–03; Bill Strauss, "Portable Electronic Devices Onboard Commercial Aircraft: Assessing the Risks," Ph.D. Thesis, Carnegie Mellon University, 2005.

NASA performed a series of tests on emissions from cellphones and other PEDs. See "Wireless Phone Threat Assessment and New Wireless Technology Concerns for Aircraft Navigation Radios," NASA/TP-2003-212446, July 2003; "Portable Wireless LAN Device and Two-Way Radio Threat Assessment for Aircraft Navigation Radios," NASA/TP-2003-212438, July 2003; "Evaluation of a Mobile Phone for Aircraft GPS Interference," NASA/TM-2004-213001, March 2004.

The National Telecommunications and Information Administration has performed two studies of potential interference with GPS from ultrawideband systems: "Assessment of Compatibility Between Ultrawideband (UWB) Systems and Global Positioning System (GPS) Receivers," Special Publication 01-45, U.S. Department of Commerce, February 2001; "Measurements to Determine Potential Interference to GPS Receivers From Ultrawideband Transmission Systems," Report 01-384, U.S. Department of Commerce, February 2001.