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A Study of Occurrence Rates of Electromagnetic Interference (EMI) to Aircraft With a Focus on HIRF (External) High Intensity Radiated Fields

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1.0 INTRODUCTION

During the decade of the 80's, digital technology has made rapid advances in automating the command, control, and communications functions in modern commercial aircraft [Stix 1991]. The most recent advances include:

- Cockpit Automation: Advanced displays, Side-Stick Controllers, Moving-map displays, collision-avoidance, flight-management.
- Flight Control: "Fly by wire", the use of digital computers that send commands via wires to control the aircraft.
- Navigation: Satellite global positioning, Microwave landing.

These advances in electronics have made for complicated cockpits and the potential for subtle problems. Modern digital systems have been found to be more sensitive to external electromagnetic interference (EMI) than their analog predecessors. The problem is clearly summarized in Meissner 1989: "Recently, the growing concern of upset to flight-critical, fly-by-wire (FBW) control systems in military aircraft has been highlighted in technical journals and the media by reports of high-energy radio frequency (RF) (HIRF) fields insidiously inducing control-system failures that resulted in loss of aircraft and life." Currently the acronym HIRF is used, meaning high intensity radiated fields, or high intensity radio frequency interference or high intensity electromagnetic radiation fields [CKC Labs., 1991]. This study has been supported by NASA Langley to develop information on the nature of HIRF, its frequency of occurrence, and the consequences of HIRF upsets.

Since there are several sources of EMI an additional discussion of terminology is in order. A block diagram is given in Fig. 1.1 which presents the terms in a hierarchy. Modern aircraft can be affected by a variety of different Electromagnetic Interference, EMI, as shown in the top of the diagram. Three important subclasses are: on-board systems, passenger carry-on devices, and externally generated.

When on-board systems interfere with one another this is often called electromagnetic compatibility, EMC. This category also includes problems due to malfunctions within the system in question. The passenger carry-on devices include disc and tape players, computers, cellular telephones, etc.

The third class, externally generated EMI, includes lightning as well as man made high intensity radiated fields, HIRF, which is the focus of this study. HIRF incidents may result in events which have less severe consequences or those which are more severe and are called upsets.

Digital System upsets can be classified as shown in Table 1.1. Both Fig. 1.1 and Table 1.1 were developed at NASA Langley.

Much of the work on electromagnetic interference in aircraft has focused on lightning and the electromagnetic pulse generated by a nuclear explosion [Pitts, Spectrum 1988]. The work on HIRF has focused on computer models for fields within aircraft and measurement of fields within aircraft. Intuition would lead one to believe that the fuselage of an aircraft shields against HIRF. However, ample electromagnetic energy can enter the aircraft through windows, hull penetrations, and antennas. In fact, the fuselage can sometimes serve as a resonant cavity and thereby increase the HIRF fields. Furthermore, in the future the use of composite materials for aircraft will result in less shielding. Also the number of electronic and electrical systems used in aircraft design is increasing. There is even an MEA (More Electric Airplane) planning team composed of DOD, NASA, and industry representatives.

Typically, HIRF problems will occur when a modern aircraft with many Digital Systems flies too near a large powerful Radar, radio transmitter, or microwave beam. Fields are set up within the aircraft, they couple into the control electronics of the aircraft, and trigger warning lights, move control surfaces, disrupt communications, etc.

There are many reasons why HIRF data is difficult to come by. It is often hard to identify the cause of system upsets, aircraft manufactures and airlines are not too anxious to discuss HIRF problems because of liability and sometimes proprietary considerations, and events affecting military aircraft are often protected by military security. Furthermore, the cause of HIRF events may often be inadvertent effects on civilian aircraft of high powered military operations or covert drug interdiction - again events requiring secrecy. One source of information has been the Panel for Test and Analysis Methods of the Aircraft Radiated Environments Subcommittee (AE4R) of the Society of Automotive Engineers (SAE). This committee was formed in the fall of 1987 in response to the FAA's desire to draft certification guidelines for protection of aircraft against the hazards of HIRF, and has met 16 times.

As far as this author knows only one previous study similar to this research has been conducted. In 1980 Cockpit, the pilot association of west Germany published the results of a survey of "Phantom Symptoms in Complex Airborne Systems." The results showed that electronic computers in aircraft were subject to soft fails (presumably caused by Alpha-rays and cosmic rays) and that the rate increased with airplane generation (technology advances). [Taylor 1988]

Because of the problems in gathering such data, the approach taken in this study was an anonymous questionnaire distributed to experts and used to gather the necessary data. Such techniques are often called Delphi techniques (after the ancient Greek oracle) [Dalkey 1963] or Consensus Estimation [Shooman Jan., Feb., 1977]. This technique is discussed in more detail in Secs. 4 and 5. An advisory group of six knowledgeable people, (either experienced in the HIRF field or in consensus estimation), was formed to aid the author in compiling a list of experts who would be sent the form and to critique early drafts of the questionnaire. This group was extremely helpful in the conduct of the study. (See Sec. 5).

One of the objectives of this study was to be objective and have no preconceived bias, i.e. to neither believe that HIRF EMI is a rare and insignificant event nor that it is a frequent and dangerous occurrence. The objective was to develop as much information as possible on the frequency of occurrence and to let regulators, manufactures, and airlines draw their own informed conclusions.

2.0 RELATIONSHIP OF HIRF TO SAFETY

Many authorities feel that there is a need for special care as advanced technology is applied in aircraft avionics systems [Taylor 1988, Ch. 12]. Two important technologies, fly-by-wire control systems and digital avionics are being incorporated in an increasing number of modern designs. As more critical functions on advanced aircraft are automated the effect of EMI interference can be severe. Also, digital systems may be more sensitive to such interference and one can offer several hypotheses as to why this might be so:

1. A small pulse of noise in an analog system is added or mixed with the normal control signal and is generally a small effect because of the larger signal size. Quantitatively we speak of

the system signal/noise ratio. In the case of a digital signal if the noise pulse flips the least significant bit (0 to 1 or 1 to 0) this is a small effect in general. However, if the flipped bit is the most significant bit, a large error can occur.

2. If the noise tends to saturate (temporally disconnect) say the autopilot, the handing dynamics of the plane may change significantly. Commercial aircraft are dynamically stable [Anderson 1978, Blakelock, 1991], however this may not be the case in some modern high performance military or experimental aircraft such as the NASA X-29 aircraft, built by Grumman. This aircraft is dynamically unstable, and loss of the flight control computers (redundant for safety) leaves an aircraft which can not be controlled by the pilot.

3. Some digital microelectronic devices are more sensitive to unwanted noise then older analog electronics.

4. Highly automated systems automatically correct for noise or unbalance. When such systems are switched off, large and disconcerting imbalances may plague the pilot as he assumes manual control. A good example of this effect is given in Lee [1991, p. 63] "A wide body jet on route from Taipei to Los Angeles experienced a loss in power of engine #4 (outermost right side). The captain failed to notice this problem since the autopilot was compensating. When the captain switched off the autopilot the plane swung violently to the right, tumbled out of control into a diving vertical roll and dropped from 41,000 to 11,000 feet over the Pacific Ocean in two minutes before the pilot regained control. Large chunks were ripped from the tail fins and landing gear and the wings were bent, however only two minor injuries occurred".

Sometimes the effects of various radio signals produce unexpected results. If an interference signal occurs at frequency f_1 and the system will only respond to signals near frequency f_2, then we feel safe if these two frequencies are widely separated. However, there is the well known effect of intermodulation interference. Suppose a third frequency f_3 is present and signals f_1 and f_3 impinge on a nonlinearity in a device (say a multiplying effect). Then the well know trigometric identity tells us that $\cos(2\pi f_1 t) \times \cos(2\pi f_3 t) = 0.5[\cos(2\pi(f_1+f_3)t) + \cos(2\pi(f_1-f_3)t)]$. Thus, if either the sum or difference frequencies are close to f_2 unsuspected interference effects can occur.

3.0 EVIDENCE OF HIRF

3.1 Introduction

As was discussed above, the nature of HIRF EMI is such that there have been virtually no studies of the frequency and nature of occurrence. Most of the work in this area has involved modeling, simulation, and measurement of the electromagnetic fields in the airspace nearby typical emitters, the penetration of aircraft fuselages by these fields, amplification of these fields due to resonances which occur within an aircraft, and the voltages and currents induced in typical wiring or electrical and electronic circuits by the interior fields.

Most of the evidence to date of HIRF EMI occurrence is anecdotai, (short stories or accounts about a happening, usually personal). Clearly a large collection of anecdotes begins to resemble a data base from which one can draw conclusions. Unfortunately, there are only a small number of such stories and I have attempted to list and document some of the incidents which have been brought to my attention in the following section.

3.2 A Collection of Anecdotes About HIRF

The term anecdote comes from the Greek word anekdota which is the plural of anekdotos, meaning unpublished. The term has come to mean a short entertaining account of some happening, usually personal or biographical. [Webster, 1959]. In this report we will assume that the teller of the anecdote is not an eye witness but an intelligent, professionally interested person who has talked to an eyewitness or heard about the happening. If the teller were an eyewitness we would attempt to have them fill out a questionnaire and to contribute to the data collected in Sec. 6.0. It is hoped that some of the readers of this report will contact this author in the future and supply more data on these incidents, contribute documented anecdotal information on other incidents, or help to put the author in touch with eyewitnesses to such incidents. These anecdotes are typical of those which have been reported. For identification purposes, these anecdotes are numbered sequentially in their order of occurrence.

<u>Anecdote 1</u>:

An airship (blimp) lost power while flying over a Voice of America transmitter at

Greenville, NC. The event happened sometime before April 23, 1990. The company service letter responding to this incident states [Skyships 1990]:

> SERVICE LETTER
>
> SUBJECT: ELECTROMAGNETIC INTERFERENCE
>
> During a recent operation in the state of North Carolina, USA, flying in close proximity to the "Voice of America" radio transmitter, [an airship] suffered an in-flight double engine failure. The flight crew followed the appropriate emergency procedures and after a period of "balloon" flight successfully executed an unpowered landing into a suitable landing area.
>
> Preliminary investigations into the occurrence have indicated a failure of the ignition system due to extreme electromagnetic interference. It was noted that the units were Mod 1 status as opposed to Mod 2 status units. Mod 2 units have a design improvement to attenuate high frequency interference thereby giving a higher resistance to this type of electromagnetic interference.
>
> In view of this, all .... pilots have been instructed to avoid flying within a five nautical mile radius of the "Voice of America" radio transmitter and all other high, intensity radio transmitter stations. It is strongly recommended that all operators issue the same instruction to their pilots. Operators should be aware that high intensity radio transmitters are not always marked on aviation charts and therefore should make their own research to identify all such transmitters in their operating area.
>
> Mod 2 units are available .... . The units will be supplied free of charge on an exchange basis.

In "successfully executing an unpowered landing ", the pilot made an emergency landing but because of wind conditions was forced to use the emergency deflation "knife" which slices open the top of the envelope allowing all the 235,000 ft^3 of helium to escape - a major expense. A hard landing resulted with some minor damage, however, no one was hurt and the emergency deflation procedure worked as designed. The failure was due to electronic circuitry failing, (burnout of microelectronic components?), and on Feb. 28, 1991 the FAA required that all ignition control units D, Mod 1 or Mod 2 be replaced with Mod 3 units. (FAA 1991).

Anecdote 2:

There have been many reports of suspected HIRF EMI experiences involving Caribbean flights. The official position of an affected commercial carrier is stated in a short 3 page paper presented at an SAE (The Engineering Society for Advancing Mobility Land Sea Air and Space) AE4R Committee (HIRF Committee) meeting [Wright, 1990]. Since 1984 the carrier has experienced unexplained simultaneous system faults of several aircraft systems, in the Caribbean area and spreading to other areas, (around the Gulf of Mexico). The initial problems were with the Inertial Navigation System, INS, on wide body jet nonstop flights from London, arriving at dusk at Barbados, in the Caribbean Sea. The standard procedure was to power down the INS when arriving at the gate. On power up before departure, the INS would not countdown sufficiently for present position to be entered (on one or more of the three redundant units). One problem unit was returned to the manufacturer for investigation, and the memory was found to be scrambled but they could not explain why. Identical INS equipment on a supersonic airliner never reported faults. No critical systems have been affected. Flight crews sometimes replaced INS systems to cure the problem. Not all these incidents were reported since flight crews considered these nuisances. The problem has been temporarily fixed by leaving the INS running during turnarounds.

Other systems affected by unexplained faults include: pressurization outflow valves, anti-skid warning lights, window heat, cabin telephone system, air conditioning packs, heat valves. All these problems occur in the last 500 feet of final approach or on the ground, and all faults clear before or just after take-off, thus they are not considered a safety hazard.

The unofficial version of these incidents explained to this author by several knowledgeable sources sheds further light on the cause of these problems. There is a large amount of American shipboard and airborne surveillance in the Caribbean to intercept drug traffic. Most people feel that these high-power systems are responsible for most of these problems. Clearly the existence, operating schedule, frequencies, power levels, and other technical details must be kept secret and none of these are officially discussed.

Additional information is available in the notes for the CKC Labs HIRF Seminar [1991]. Effected locations are Barbados, Antigua, Bermuda, and Ascension Islands and several airlines and several types of wide body and narrow body jet aircraft have encountered these difficulties. The duration of the incidents is typically 10-15 minutes, can last up to 30-35 minutes, and one case lasted 4 hours.

<u>Anecdote 3</u>:

In 1983 a military fighter crashed in Germany. The crash occurred 1.8 miles from a Voice of

America Transmitter and the field strength has been estimated as 70 volts per meter [Lee 1991].

3.3 Evidence of HIRF in Established Data Bases

There are a number of data bases which have been established to collect potential or actual accident information involving aircraft. The best known is FAA's Aviation Safety Reporting System (ASRS) run by NASA. [Reynard 1986] This system was established in 1975 by the FAA to serve as a confidential, nonpunititive incident reporting scheme "to encourage the reporting and identification of deficiencies and discrepancies in the system before they cause accidents or incidents." On April 15, 1976 the program was modified so that a third party, NASA would receive and analyze the reports. NASA continues to run the system with the assistance of a contractor who has for several years been Battelle. With the help and cooperation of Rowena Morrison of ASRS, who served as a member of the advisory board of this study, an ASRS Search was performed.

On July 17, 1991 I visited the ASRS offices in CA and with the help of Ms. Morrison and an ASRS researcher searched the data base for evidence of HIRF induced upsets. The initial choice of key words followed by an hour of experimentation was not very productive in locating any relevant records. On July 22, 1991 ASRS Researcher Stephanie Frank conducted Search Request No. 2236. [ARCS 1991] At the time the data base contained 33,193 full-form records received since Jan. 1, 1986 which were searched. (An additional 64,037 abbreviated-form records were not searched, since the keywords chosen were not identifiable in those records.) The first part of the search uncovered 147 reports which referenced avionics interference or subsystem problems in advanced cockpit aircraft. The second part of the search uncovered 42 reports referencing lightning strikes. Part one involved "aircraft equipment problems or loss of aircraft control by an aircraft with automated navigation equipment. Each report also contained one or more of the following key words: "antenna," "international operations," "passenger electronic devices," "military airspace," or "lightning," Clearly part 1 and 2 were not mutually exclusive and some reports were located in both searches, for example Accession Number 52386 appeared in both parts.

<u>Accession Number 52386</u>:

The report involves a wide body aircraft hit by a lightning strike just south of NYC. The report is by the Copilot. A portion of the one page report follows: "... we were given instructions to 'hold at sates' ... 'hold southwest of sates on the Deer Park 221 radial, left turns'...'the Captain, disgruntled over the ambiguity of the holding instructions demanded to know the DME from Deer Park to SATES hold. I [Copilot] leaned over to my right to extract the New York (Northeast) low alt area chart from my flight bag when I heard 'PUUFF' like an air rifle shot and simultaneously winced at the white blinding flash of lightning. It took several seconds to blink away the flash while I resumed search for our specific holding pattern on the chart. At this time the Captain hollered 'what the hell happened to our altitude! Isn't anybody watching! Give me some help up here!' The autopilot had tripped off and as I glanced up from my chart the altimeter read 6600 ft., 400 ft. below our assigned altitude of 7000 ft." The Captain quickly recovered and reinstated the autopilot. [Subsequently both autopilots were used and both tripped off possibly due to gust loading and stabilizer out of trim condition, never-the-less they managed to remain within 200-300 feet of their assigned altitude.]

Other reports from part 1 are summarized below:

Accession Number 103733:

A wide body on approach to LaGuardia failed to receive normal clearance from ZDC. Captain attempted to contact ZDC with no avail. Finally they were able to contact another carrier and were eventually able to contact ZNY and Boston center who provided vectors into LaGuardia via #2 radio. On subsequent flight two days later the Captain and other carriers heard what were apparently citizens' band radio transmissions on ZDC frequency in the same area. ZDC said that citizens band interference had been occurring for the past two weeks and that the FCC was investigating.

Clearly one must understand some pilot "lingo" to fully understand the above accounts, however, the general details show several documented incidents of passenger equipment causing RFI, at least one incident of HIRF EMI (the CB radio), and several unexplained incidents. The lightning events were not studied further. The term callback is a name used by ASRS to describe selected reports which are followed up by phone calls from ASRS members to obtain further details.

Many of the respondents suggested the study of other military and civilian data bases for evidence of HIRF EMI, however, such studies were beyond the scope of this grant.

4.0 EXPERT DATA COLLECTION

4.1 Introduction

The six members of the advisory committee made substantial contributions to the conduct of this study. Gerry Fuller of CKC Labs. has conducted many HIRF studies, consults in this area, and gives several HIRF seminars each year and is a member of the SAE AE4R committee. Rowena Morrison is a Research Coordinator on the Batelle staff of the NASA Aviation Safety Reporting System Office. Felix Pitts has guided electromagnetic compatibility research for many years at NASA Langley Research center and was the research monitor for this grant. Ronald Rogers is an airline Captain and engineer, is Chairman of the Airline Pilots Association's New Aircraft Evaluation and Certification Committee, and is Chairman of the Data Accuracy Panel of the SAE AE4R committee. Joe Fragola a Vice President of SAIC and Herbert Hecht, President of SoHar Inc., have many years of experience in aircraft safety and consensus estimation.

Consensus estimation only works if one has a set of knowledgeable experts. Thus recruiting a large sample of people who know little about HIRF is of little use. Inherently such a selection produces a biased sample. The group of 230 experts who were mailed questionnaires were chosen in three ways. The members of the SAE AE4R committee were all included (engineers, engineer/pilots, and pilots) and a number of additional names were suggested by the advisory committee for a total of 187. In addition, Captain Ronald Rogers from the Airline Pilots Association (a member of the advisory committee) and Bob Hall from the Airline Pilots Association Staff were very helpful in obtaining the names of 33 airline pilots who made up the remainder of the 230 experts, (57 of whom responded).

4.2 Choice of the Sample

It was felt that the group of SAE AE4R members were all biased in the direction of having more familiarity with HIRF then an unbiased group of avionics experts or pilots. The group of 33 airline pilots were simply a group who agreed to help so they represented an unbiased sample.

The choice of bias was an advantage in that it improved the probability of receiving enough respondents who had seen HIRF EMI in such a small sample. However, it was a disadvantage in that the occurrence rates should be higher than those expected in an unbiased sample of airline pilots.

It was discussed in Sec. 3.2, that pilots in the Caribbean are likely to have seen HIRF EMI, however, it is unlikely that many of the pilots who responded had Caribbean flight experience.

During the course of this study it came to the authors attention the US military maintains an agreement with commercial airlines which allows them to "draft" commercial aircraft during a national emergency. Many pilots were "drafted" to fly in the Persian Gulf War. Donnegan & Bay [1992] cite the following information: Wide body jets were drafted in large numbers to assist in the movement of troops and equipment. Most of the troops were flown over, and most of them flew in wide bodies [op.cit. p. 209]. Three hundred wide bodies were used [op.cit. p.219]. The following quote from Schwartzkopf's Autobiography [1992, p. 341] verifies the use of commercial wide bodies: "By late August Saudi Arabia had absorbed more of our troops and military hardware than it had in its own armed forces, ... I went out to the air base at Dhahran, ... Near where I stood [a wide body had pulled up] and I watched soldiers from the 24th Mechanized Infantry Division stumbling out into the 130-degree heat".

Clearly there was a high probability that the "drafted" pilots observed HIRF EMI in the military theater of operations, however, none of them were included in this study.

5.0 DATA COLLECTION FORM

An initial draft of the data collection form was formulated by this author in July 1991 with major help and critiques by Gerry Fuller. After a number of drafts, the form was circulated to the entire advisory committee and other for review and critique. After several months and numerous written and oral changes and additions, the final form given in Appendix A was developed. Final typing, editing, and printing of the Questionnaire took place in the Spring of 1991 and the mailing began in the late Spring.

During the instruction with the questionnaire it was decided that rather than ask the respondents about just HIRF EMI, a broader class of RFI events would be included. This was done for two reasons. First it was felt that if only HIRF EMI events were included it was possible that respondents would include other sources of events which were not HIRF EMI. Secondly, it is sometimes easier to define something by saying what it is not, i.e. HIRF EMI is not interference caused by a passenger cellular telephone, HIRF EMI is not interference from the high frequency radio on a specific narrow body jet which is known to couple into the autopilot, HIRF EMI is not lightning effects, HIRF EMI is not effects due to equipment failures.

The data collection form was sent out to 187 participants between May 20, 1992 and May 22, 1992 and a subsequent group of 33 participants on June 30, 1992. After the second mailing approximately 10 names were suggested and mailings to these individuals were done the day received or the next. Thus, the total population contacted was 230. The survey forms were marked when received with a set of sequential numbers and the date received. Typically, the bunched forms were opened in batches a few days after receipt, except for travel periods when larger batches accumulated. If there were any uncertainty about the date received, it was estimated from the postmark. In an attempt to obtain additional returns, a second letter dated August 12, 1992 was sent to participants. (See Appendix A for a copy of this letter.)

6.0 COLLECTED DATA

6.1 Overall Features of Data Analysis

Between May 5 1992 and October 15, 1992, 57 responses were received, thus 25% of the participants replied, a high ratio for a survey. (Typically, survey forms have a response rate of a few percent.) On Nov. 25, 1992 a 58th response was received, after the first 57 had been analyzed. It was sparsely filled out and did not add much additional data, thus it has not been included in the analysis. About a month later a 59th response was received which did include data on external EMI. Since the other data had already been tabulated, it was not included. The preliminary analysis of the responses is given in Table 6.1, which lists some major features of the responses. This data is primarily derived from Secs. 1.1, 1.2, 2.1, and 6.0 as indicated in the Table heading. A bar graph of the numbers returned in each two week interval is given in Fig. 6.1. (Note that response 1 on May 5 is grouped with the June 1 responses. This was the result of a mailing to a former astronaut of the next to the last iteration of the questionnaire. He not only sent suggestions, but filled out the questionnaire himself.) One of the goals of this study was to maintain a high degree of objectivity. Thus, this chapter is devoted to reporting and preliminary analysis of the data collected and interpretation is reserved for the following chapter.

After study of each data collection form, some interpretation was required in recording the data. It was clear that most respondents were intelligent, busy, interested and cooperative. To fill out this form in detail, answer every question, and recall experiences over many years of one's professional history can take several hours. Not all respondents spent that much time, and frequently there were comments in the margins in later pages indicating that earlier sections should be changed now that they better understood the form. (They probably didn't read it through before starting to fill it out.) In one case, a respondent went back with a red pen and corrected his responses. In other cases, I made such corrections once I understood the marginal comments. Interpretation played some role in recording the responses. Some obvious cases were interpreting never observed as zero incidents, 2-3 incidents as 2.5 incidents, and 1000's as 2,000. Other interpretations are commented on later as appropriate.

6.2 Respondents Experience Base (Aircraft Types)

In Sec. 1.0 the respondents delineated their professional expertise and types of aircraft with which they were familiar. This data was accumulated for the 57 responses and is given as totals on a survey form. (See Appendix B.) In all about 144 professions were checked, thus most respondents were involved in about three professional areas over their careers, with engineers the most common (57) and pilots (29) the second most common. In addition, the respondents had experience with hundreds of different aircraft types.

In Sec. 2.2 and 2.3, Appendix B, the respondents characterized the types of aircraft affected by EMI incidents. Again a wide variety of aircraft were represented.

A goal of high importance was to obtain an estimate of frequency of occurrence of HIRF EMI events. Thus, emphasis is placed during analysis of the data on responses to questions concerning frequency of occurrence.

6.3 Number of Avionics EMI Events

In Sec. 2.0 the respondent was asked to report the number of EMI events which they were familiar with, and in Sec. 4.0 they were asked for more details on the nature of such events. The number of EMI results reported by category are listed in Table 6.2. In theory, the number of incidents reported in Sec. 2.1 should equal the sum of those reported in each category of Sec. 4.0. For example, for response 21, the 5 incidents reported were distributed as 1 external, 1 lighting, and 2 equipment failure. However, the number of incidents did not always equal the sum of those reported in each category.

To better understand how Sec. 4 was interpreted we examine two responses in detail. Respondent 20 reports 2-3 incidents but indicates 2 onboard, 1 lighting, and 3 equipment failure for a total of 6. More specifically, Sec. 4.1 was not checked and in Sec. 4.2 two checks appeared: VHF-UHF transmitter and computer. I judged that these were two separate Radio Frequency Interference, RFI, incidents rather than one which was caused by an interaction of VHF-UHF transmitter and the computer. No checks appeared in Sec. 4.3 and strike-airborne was checked in Sec. 4.4. In Sec. 4.5, intermittent transient, and hard failures were checked. I judged this to be 3 separate incidents rather than three manifestations of a single incident. No items were checked in Sec. 4.6. I feel that the explanation for this apparent inconsistency is that initially this respondent remembered 2-3 incidents, however, when asked more details in Sec. 4.0 more incidents were remembered, however, he did not go back to Sec. 2.1 and increase his total. This interpretation is corroborated since in each case where asked "how sure of you of the source (affected system)", he answered certain (10).

In the case of respondent 19, he reported some details in Sec. 4.0 on 13 of the 1530 incidents he had data on. Clearly he did not observe 1530 incidents. He reports zero incidents in the first three categories of Sec. 2.1, and estimates approximately 30 incidents from conversations, approximately 500 from data reports, and approximately 1000 anecdotal accounts. I believe the 13 incidents discussed in Sec. 4.0 are those to be focused on. Similar interpretations were made for some of the other responses.

6.4 Consistency Check

In Sec. 4.7 the respondents were asked to estimate the percent of all EMI incidents which were due to passenger RFI, onboard RFI, etc. The results of this question appear in Table 6.3. One of the purposes of this question was to provide a consistency check on the number of events in each category reported in Table 6.2. In order to compare the number of events in Table 6.2 with the percentages in Table 6.3, the data in Table 6.2 was converted into percentages in Table 6.4. For example respondent 1 reported zero passenger events in Table 6.2 and one in each of the other 5 categories. Thus, in Table 6.4, 0% were passenger incidents, and 20% were associated with each of the other categories. Because of roundoff, not all the percentages in Table 6.4 add to exactly 100%. A comparison of Tables 6.3 and 6.4 shows that 21 respondents answered the questionnaire completely enough so that the percentages in Tables 6.3 and 6.4 could be compared. The two sets of data are compared in Table 6.5.

Several methods are available for comparing the relationship between two such sets of data. Suppose we wish to check the two sets of data for consistency. In the ideal case, we assume that the respondents wrote down their observations on scrap paper and answered sections 4.0 and 4.7 by referring to that set of data. In such a case, we would expect the responses to be the same and would see identical entries in Table 6.5, indicating a linear relationship between the two sets of data. A simple test for such a linear relationship is to plot the two sets of data on a Cartesian coordinate system and examine the resulting graph. Such graphs are plotted in Fig. 6.2 for two respondents, #1 and #14. The data in Fig. 6.2 seems to approximately fit a horizontal straight line through y=20. This indicates that the y values do not increase with x but stay constant. In Fig. 6.2b we see quite a different situation where a straight line connecting the points (0,0) and (40,40) seems to fit the data well. In statistical terminology, we would say that x and y were poorly correlated in Fig. 6.2a and well (highly) correlated in Fig. 6.2b. In fact, a more objective procedure is to calculate the coefficient of correlation r which is defined in Appendix C. A correlation of r=+1 indicates a perfect linear relationship, all the points fall on a line through the origin with a slope of 45°. A correlation of r=-1 indicates a perfect linear relationship along a line through the origin with a slope of 135°. No correlation, r=0, represents a horizontal straight line. The values of r are given in the last column of Table 6.5 and were calculated using a simple PC computer program, written in BASIC, which implemented the formulas in Appendix C.

We wish to establish an objective procedure for deciding when r is large enough so that we can classify individual responses as consistent or possibly inconsistent. In Appendix C, we compare the hypothesis that the responses are uncorrelated (r is actually 0) and by chance the data exhibited some correlation with the hypothesis that a result $0<r<1$ truly represents correlation. If we use a probability of 0.1 that correlation was by chance, then chance correlation is rejected as long as $0.6 < r < 1.0$. Examining Table 6.5 we see that 13 responses qualify according to this criteria: #8, 14, 15, 16, 18, 23, 27, 30, 32, 33, 34, 55, 56.

The data in Table 6.5 was compared in another way. The values for external EMI (the HIRF data we seek) were analyzed by studying the correlation of the estimated and calculated values, for the 13 data sets where $r>0.61$ and for all the 21 data sets. The results are given in Table 6.6.

6.5 EMI Occurrence Frequencies

The consistency analysis of the previous section dealt with percentages of the various EMI events. We now discuss the occurrence rates of the various EMI events. We begin by analyzing in greater detail the data collected in Sec. 2.1. The first observation is that the pilots or pilot/engineers are in general reporting events which they have experienced or which have been reported to them, whereas the EMI Specialists and Engineers are reporting on data in a data base collected by their company, government organization, etc. Thus, we split the data into two groups for presentation and later analysis. Table 6.7 lists observational intervals (years, flights) and number of incidents of all EMI incidents as reported by pilots. The data is sparse and only the observations as a pilot seem worthy of further study. The total number of EMI incidents observed by pilots from Table 6.7, along with the calculated EMI incidents/year, EMI incidents/flight, means and standard deviations are given in Table 6.8. Examination of response number 27 reveals a relatively small number of flights, a large number of observed events, and a large frequency per flight. Applying a statistical test for outliers as described in Appendix C.3 verifies that it is wise to reject this datum, concluding it is from a different population than the other 11. Inspection of the recalculated moments, (see footnote to Table 6.8), shows that the new mean is about half the previous value and the new variance is about 1/3 as large; another validation of the advantages of dropping this one point from the other 11. If we examine the frequency per year reported by respondent number 23, we see that the value of 5 also looks a little high, and statistical analysis shows that this datum as well as the value 2 should be rejected. We conclude that these two points are from a different population than the other 14, and the means and variances decrease.

The observational intervals (years, flights) and number of incidents of HIRF EMI incidents (external EMI) observed by pilots are calculated per pilot year and per flight are calculated as are the means and standard deviations. The number of events is from column 8 of Table 6.2 and the pilot years and pilot flights from Table 6.8.

The frequency of all EMI incidents for the EMI Specialist/Engineer respondents is given in Table 6.10. The data is fragmentary for observation as a pilot or crew member, as it should be. EMI specialists and engineers can be private pilots and occasional crew members (for example on test flights), however, these are infrequent roles for this group. One could even argue that the pilot observations of respondent 19 and 33 should be grouped along with the pilot responses in Table 6.7, however, this was not done since 10 and 33 contribute little data. In the cases of conversations, reports, and anecdotes there is considerable data, however, it is unclear how to calculate rates. In all likelihood, this is from a data base constructed by adding many individual observations of incidents. Although the number of incidents should be trustworthy, it is not clear whether the years of observation and the total number of flights are as clearly defined as in the case of pilots. However, the passenger observations in Table 6.10 (and those of pilots who are passengers in Table 6.7) represent a known population and can be used to calculate occurrence frequencies. This data appears in Table 6.11. A similar table is constructed for HIRF events from the event reports in Sec. 4.3 and the interval data in Table 6.10 (see Table 6.12). In the case of HIRF, it is likely that the events in Sec. 4.3 reported by engineers were not personal observations but study of reports. In fact it is possible that more than one person is reporting on the same event.

During the study of data from Tables 6.7 and 6.10 for constructing Tables 6.11 and 6.12, I observed that many respondents left blank the section on observations of EMI incidents as a passenger. Also a few listed 0 observations. I judged the blank responses as "no opportunity to observe" and did not count them. On the other hand, a response of 0 was judged to mean: "I would have recognized upset incidents as a passenger, I didn't observe any, thus the number is zero", and these were counted. In studying the responses in Sec. 4.3, both blank responses and 0's will be counted as 0 in Table 6.12. Clearly some of these flights must have been test flights with engineers sitting with the crew, passenger pilots sitting with or talking to flight captains or crew, or "regular" pilot-passengers or engineer-passengers on regular commercial flights. No attempt was made to differentiate between these different types of observations, in this section or other sections of the questionnaire.

One can recalculate the upset data in Tables 6.8 and 6.11 for only the most consistent observers, i.e. those with $r \geq 0.6$ in Tables 6.5. The sample sizes become much smaller and the results are given in Tables 6.13 and 6.14.

6.6 Anatomy of EMI Events

In addition to the statistics presented above, there is much information of a qualitative nature which was contained in the survey. Some of this material is contained in the comments which were given in Sec. 6.0 of the questionnaire. These reports have been reproduced verbatim in Appendix D and report a wide variety of different events. There is also additional information to be gained by studying the overall picture given by the 6 pilots who reported observing HIRF (c.f. Table 6.9). A brief composite of these reports is given below:

#1 Pilot:

This military and commercial pilot who also was an astronaut and had engineering training has over 20 years of experience and has flown many different aircraft including business jets, single engine turboprop, military fighter, bomber, fighter/bomber, and tankers, and the Space Shuttle. He witnessed 5 EMI incidents as a pilot involving military fighter, bomber, fighter/bomber, and the Space Shuttle. The upsets occurred with avionics in good condition during ascent, descent, and earth orbit in clear or clouds or rain reducing visibility. Incidents of onboard RFI were caused by the VHF-UHF transmitter, radar, intercom, and navigation equipment affecting the communications and navigation equipment, and instrumentation. External RFI, HIRF, was caused by military radar, air traffic control radar, and shipboard radar transmitters which affected communication and navigation equipment as did the lightning incidents when they were observed. Also transient equipment failures and unknown failures affect the communications and navigation system. The certainty of these upsets was rated between 7 and 10. The criticality of the onboard RFI was rated as 3, the External RFI 5, those due to lightning as 6, and the equipment failure and unknown as critically 2. Additional comments appear in Appendix D.

#11 Pilot:

This corporate pilot who also has engineering training has over 20 years of experience and has flown many different aircraft including narrow body, business jets, heavy twin turboprop, light twin turboprop, single engine turboprop, and helicopters. He witnessed 5 EMI incidents as a pilot and 3 as a crew member, learned of 3 from study of reports, and others from contact with certification projects. The types of aircraft affected were business jets, single engine turboprops and piston. The EMI incidents occurred with avionics in good condition (or a design problem with a particular subsystem), during straight and level flight, descent, low-level flight, and low traffic in both clear and medium visibility. Incidents of onboard RFI caused by the high frequency transmitter affected the autopilot causing pitch oscillations. External RFI, HIRF, was caused by commercial AM or short wave transmitters which affected the autopilot and engine controls. Lightning (strike-indirect) affected the autopilot, navigation equipment, and instrumentation. Transient and electrostatic discharge equipment failures, affected navigation equipment and instrumentation. Unknown sources affected the autopilot and engine controls. The certainty of these events was rated as 10 except for lightning (6) and equipment failures 8. He rated the EMI reported of criticality 5 or 6. Additional comments appear in Appendix D.

#15 Pilot/Engineer:

This military and nonscheduled pilot and engineer with over 30 years of experience has flown many different aircraft and studied reports on upsets. The aircraft affected by HIRF included: wide body and narrow body jets, helicopters, airships, business jets, and a military fighter. He witnessed 8 incidents of EMI as a pilot and has learned of many other incidents from conversations, reports, and anecdotal accounts. The weather conditions and equipment condition were not significant, and incidents occurred during landing, takeoff, straight and level flight, taxiing, and while parked. An incident of passenger RFI due to a portable tape player affected navigation ILS and VOR receivers and the diagnosis was certain (10). Onboard RFI incidents included the instrument panel lightning circuit which affected the magnetic compass, and the high frequency transmitter affecting the autopilot on a narrowbody jet. External RFI, HIRF, included countermeasures equipment on military airplanes affecting various systems on commercial aircraft in the vicinity, Voice of America Transmitter, land and shipboard military radar, ECM and jammer equipment effecting communications equipment, helicopter flight controls, panel lights, and automated landing gear brake. Lightning was observed to affect accidental firing of sounding rockets, disrupt navigation equipment, and produced an ear splitting noise in a communications headset. Equipment failure was transient and affected communications and navigation equipment. The diagnosis of the causes and effects of all the above EMI was listed as certain (10). The criticality of the various EMI was rated at various levels; passenger RFI 4, Onboard RFI 3, External RFI 5 or 10 lightning 2, and equipment failure varying with the technology level of the effected systems. Additional comments appear in Appendix D.

#21 Pilot/Manager:

This former military pilot and manager with over 20 years of experience has flown single engine piston, military trainers, helicopters, and turboprop transports. He has witnessed about 5 incidents of EMI as a pilot, and the aircraft affected was a turboprop transport. The EMI occurred on aircraft with avionics in good condition during flight maneuvers in clouds or rain. The EMI was listed as external RFI or equipment failure and was analyzed as such by this author, however upon checking all the forms this one form was found that respondent #21 listed under External RFI incidents which caused communications equipment and instrumentation disturbances, and these may have been caused by lightning. **Thus, response 21 could be reanalyzed, shifting some upsets from external EMI to lightning.** If this were to be done the data for forms 58 and 59 would be included, and the net results would change only slightly. (See Sec. 8.0.) EMI due to equipment failure was listed as causing transient failures of communications equipment, instrumentation, and radar. Respondent #21 rated EMI caused by lightning and equipment failure of severity 2. Additional comments appear in Appendix D.

#23 Pilot/Engineer:

This commercial and corporate pilot and engineer with over 30 years of experience has flown several different aircraft including business jets, light twin turboprop, and single engine turboprop. He has witnessed about 100 incidents of EMI as a pilot, and the aircraft affected were turboprop aircraft. The EMI events occurred on aircraft with avionics in good condition during straight and level flight, ascent and descent, and weather conditions were deemed not significant. The onboard computer, radar, EFIS, FMS, and Flight Director Systems affected communications and navigation systems. Diagnosis of source was certain (10), because "on the ground we pulled circuit breakers until the interference stopped ......" and the system affected was certain (10) since "interference can be clearly heard on the VHF COM, VOR,and ADF receivers and deviations in the VOR and ADF Navigation data are also clearly evident". HIRF effects caused by a commercial FM transmitter affected communications and navigation equipment and the identification was certain (10) since the FM voice transmissions could be clearly heard in the VHF COM and the VOR/LOC receiver. An airborne lightning strike burned out the diodes in the engine driven alternator, the output went to zero and the faulty diodes were found during ground maintenance. Respondent #23 rated EMI caused by onboard and external RFI of severity 4 and the others of severity 5. Additional comments appear in Appendix D.

#40 Pilot:

This military and commercial pilot with over 30 years of experience (since 1941) has flown many different aircraft including wide body, narrow body, regional jets, heavy twin turboprop, and military fighters. He witnessed several incidents of EMI as a pilot and crew member and learned of one other by conversation and one by reading a report. The types of aircraft affected were narrow body and regional jets. The upsets occurred on aircraft with avionics in good condition during landing, straight and level flight, and descent in both clear and cloudy or rainy weather. One event involved what was thought to be unknown origin which affected the autopilot and navigation equipment. An incident of onboard RFI caused by navigation equipment affected the autopilot, spoilers, and navigation equipment. Both these events were later diagnosed on the ground. Two other events were determined with certainty when they occurred and involved a hand held walkie-talkie [HIRF] and lightning. He rated upsets caused by lightning and equipment failure of concern (criticality 4), however, he reports that he heard of a narrow body which "banked sharply and dropped 20,000 [ft.]" - [which certainly sounds like a more serious situation.] Additional comments appear in Appendix D. [Unfortunately further details on the walkie-talkie, HIRF-incident were not given].

6.7 Attributes Associated with HIRF

A large number of the questions answered by the respondents dealt with various qualitative attributes and details of their experience. For example, in question 1.1, most of the respondents had many years of experience which encompassed a number of different roles, thus out of the 57 respondents, there were 29 checks for some type of pilot experience and 57 checks for some type of engineer, physicist, or mathematician experience. Thus, the survey covered a wide variety of experience. A summary of the responses to question 1.1 appears in Appendix B.

Question 1.3 dealt with the types of aircraft with which the respondents were familiar. They covered a wide range of commercial and military aircraft. In the case of commercial aircraft 28 types were checked plus an airship, 5 types of helicopters, and 15 others were specified. Although the more popular types of aircraft were better represented, there was no predominant type. Similar results were found for business jet, turbo prop, and military/government types. In questions 2.2 an 2.3 the respondents discussed the types of aircraft affected by the various EMI incidents they were reporting on. Again popular types were more prevalent, but there was no predominant type. Detailed Summaries appear in Appendix B.

In questions 3.1 and 3.2 the respondents were asked under what conditions EMI occurs. A wide variety of flight conditions and weather conditions were reported and no consensus seemed to appear. Question 3.3 dealt with level of maintenance and most of the respondents checked either good condition [17] or design problems with a particular subsystem [9].

In section 4, the types of RFI sources and systems affected were treated and the surety of the source and affected systems were probed. In summary the results showed:

- For Passenger RFI: Sources were difficult to determine [5.3] and affected a number of different equipments, however the affected systems were easier to determine [7.6].
- For Onboard RFI: The most common sources were radio transmitters and all sources were relatively easy to determine [8.8] as were the systems affected [8.8] which were most commonly communications or navigation equipment.
- For External RFI: The most common sources were various types of radar equipment [15 reported] and various types of radio transmitters [12 reported]. All sources were relatively easy to determine [8.9] as were the systems affected [9.0] which included several types of systems.
- For Lightning: An airborne strike was most common and it was easy to determine the source [9.2] and the system affected [9.1]. The affected system was most commonly communications or navigation equipment.

- For Equipment Failure: Transient failures were most common, the source was fairly easy to determine [7.8], as was the various systems affected [7.9].
- For Unknown Sources: Only affected systems could be determined and the surety level was high [8.8]. Several different systems were affected.

Because of the small sample size and the fairly even distribution of the various sources and systems affected (except as specified above), numerical computations of the various frequencies were not attempted. The reader is referred to Appendix B for further details.

7.0 INTERPRETATION OF DATA

7.1 Introduction

This report is based on a data gathering effort which is somewhere between a survey and the creation of a data base. In the case of a survey, one would expect mainly qualitative information and much interpretation of the responses would be required. On the other hand, creation of a data base involves the collection of quantitative data and statistical interpretation. Since EMI in general and HIRF in particular is not easy to define, much of the construction of the questionnaire and its interpretation involved reading the responses in entirety and getting the sense of the respondent before using the data. In general, the respondents seemed to be a highly qualified, intelligent, and interested group and the response rate of over 25% (quite high for surveys in general) testified to these facts. However, by and large they seemed to be busy people and did not have time to study or ponder over the questions. This was evidenced by the fact that in some cases they went back over the form and corrected responses or left marginal notes regarding corrections of their responses once the import of particular questions became clearer. Several such cases where interpretation was required were discussed in Sec. 6. Statistical tests for outliers were applied to the approximately 10 samples in Table 6.8 and a few were found to be outliers, however, the means and standard deviations were reported both with and without the outliers. No attempt was made to apply such techniques to the approximately 5 samples of Table 6.9 and 6.11 or the two samples of Table 6.12. Common sense tells us that with such small populations all the data points are needed, and rejection of outliers in very small populations may be questioned regardless of the results of such statistical hypothesis testing. Thus, the interpretations in the remainder of this section will contain both qualitative and quantitative aspects.

7.2 Consistency of Data

The use of consensus estimation and expert opinion, relies on the recollections of a group of experienced experts. In some cases, the experts actually have data and reports on which to base their estimates, but because of proprietary, secrecy, privacy, or other such reasons, they can not quote the data but can provide their professional estimate (based on the data). During analysis of the 57 responses, it seemed clear that only a few of the respondents were replying based on an established data base, and that most of them were trying to recollect as best as possible actual situations they had witnessed. Anticipating that such would be the case, some questions were asked from two different viewpoints, so that subsequent analysis of the similarity of the responses could be used as a rough gauge of the consistency of the respondents recollections. The correlation coefficients of 13 of the 21 respondents in Table 6.5 (62%) had a high enough correlation > 0.6 to reject the hypothesis that they were uncorrelated. Furthermore, in Table 6.6 the means, standard deviations, and correlations of the data showed quite reasonable agreement. Thus, in general the data collected seem to be internally consistent, especially for the smaller set of 13 respondents.

7.3 Occurrence Rates - Point Estimates

A major focus of this study was to determine the occurrence rate of avionics EMI caused by HIRF. Also to help differentiate HIRF from other EMI, data was taken on several EMI sources which affect avionics operation. The occurrence rates listed in Tables 6.8 - 6.14 are reported as point estimates, (mean value used as the point estimate), in Table 7.1.

Studying Table 7.1 we see that the frequency per year of all EMI upsets observed by pilots varies between 0.25 and 1.56 depending on how we treat the data statistically. This is a range of about 6:1 and much of this variation is probably due to the small sample size. The frequency per 1000 flights varies from 2.60 to 7.93, a range of only about 3:1 which would lead one to believe that some of the large range of occurrences per year is due to fairly wide variations in the number of flights reported per year. An examination of Table 6.8 shows a mean number of flights equal to 2,691 and a standard deviation of 2,068 which reinforces the above conjecture that the number of flights per year varies considerably.

The number of all EMI events observed by passengers varies over a smaller range than that of pilots. Also we see that the number of observations per year is less for passengers than pilots, (probably because they are on fewer flights), however, The number of EMI upsets per flight varies less between pilot and passenger groups.

When we observe the HIRF occurrence frequencies in Table 7.1 we find that for pilots HIRF occurrences represent about 3.6% of all EMI events incidents per year and about 1% of the EMI incidents per flight. In the case of passengers, HIRF incidents represent about 80%, (seems unlikely that this should be so high), of all EMI occurrences per year, and about 8.4% of the incidents per flight.

The number of avionics systems which are potentially sensitive to HIRF has been increasing rapidly in recent years. Thus, the values of occurrences/flights or occurrences/year may have been increasing in recent years. The values reported in the questionnaire do not indicate the years in which the EMI incident occurred, thus only averages over the respondents experience period can be computed. Thus, the data can not be analyzed to see if occurrence rates incease with calendar years.

7.4 Occurrence Rates - Interval Estimates

Because of the wide dispersion of the data it may be more appropriate to deal with interval estimates. Interval estimates for the occurrence rate data can be computed using the statistical techniques described in Appendix C. These are computed for the most significant data, the frequency of HIRF occurrences per flight and are given in Table 7.2.

7.5 Criticality of EMI Events

In evaluating the effect of HIRF and other disturbances, it is important to study the severity of these incidents. The results of Section 5 of the study are given in Appendix B. In general, there was a significant variation in the level of concern among the respondents, as evidenced by the fairly large standard deviations in each case. Passenger RFI, Onboard RFI and Unknown Source RFI showed a critically level which averaged "Concern". In the case of Onboard Systems RFI, HIRF, and

Lightning, the average (5.7 with a standard deviation of 3.0) was closer to "Emergency Procedures".

We can learn more about HIRF criticality if we study the five pilots who reported HIRF incidents (#1,11,15,23,40) in Table 6.9. These five pilots reported HIRF criticalities of 5, 5, 5(10), 5, left blank. Respondent 40, did not list any affected systems or criticality level for HIRF. However, he reported that the external RFI he witnessed was due to a hand-held (walkie-talkie) transmitter which affected outflow values. Perhaps this was an incident which occurred when parked or taxiing and thus was not of real concern since the aircraft was not in flight. Respondent 15 listed a 10 for "Tornado due to VOA", obviously the Tornado incident discussed in Sec. 3.2. Furthermore he commented on his criticality rating of 5: " brakes, pressurization, etc., British Airways learned to live with it." Clearly this referred to the British Airways experiences discussed in Sec. 3.2. In summary, respondents (#1,11,15,23,40) were remarkably consistent in their rating of criticality, 5, which agreed well with the mean of 5.7 for all the respondents.

7.6 Comparison of HIRF Occurrence Rates with Other Occurrence Rates

As stated in the introduction this report takes a neutral attitude toward the significance and importance of HIRF. Such decisions are for policy makers. However, in interpreting the results of this study it is important to compare the results with a few other events related to transportation safety. In our comparisons we will relate the results of this study and others we use for comparison purposes to two rate metrics, frequency/flight (or frequency /trip) and frequency per hour, where one or both of these metrics is available. The results of this study and the comparative rates are given in Table 7.3. In Table 7.3 the RFI results of this study are compared with **fatality** rates for various modes of transportation and other events. These rates were chosen because they are transportation related, and are available. We must remember that RFI does not in general cause fatalities, (remember the criticality ratings of Sec. 7.5), thus the RFI values should be multiplied by the percentage of RFI event which result in fatalities for direct comparison. Unfortunately this value is not available. An alternative would be to compare the RFI values with other similar events such as aircraft collision near misses, automobile severe skids or steering and braking system failures. Again these values are not readily available. The reader should be reminded that this was a biased sample (c.f. Sec. 4.2).

Comparing the events of Table 7.3 we see that the number of RFI events per hour varies between 10^{-3} and 10^{-4} per hour, and the number of HIRF EMI events per hour varies between 10^{-4} and 10^{-5} per hour. Depending on which values we compare, the HIRF EMI rates vary from roughly equal to all RFI values to about 1/65 of the RFI total. For comparison the fatality rates per hour for other modes of transportation, (and also disease), range from 10^{-6} to 10^{-7} (except for general aviation which is 10^{-5}). Thus, HIRF EMI events occur about 100 times as frequently as transportation fatalities. Comparison of the frequencies per hour with the frequencies per trip shows that the rates per trip are 3-30 times greater than those per hour, and much of this is due to average trip length in hours.

8.0 SUMMARY AND CONCLUSIONS

The technique of consensus estimation, the use of an anonymous questionnaire to solicit the opinion and estimates of experts, has been used to develop data on HIRF EMI. Although HIRF EMI is an uncommon event, difficult to define, and sometimes shrouded in secrecy for various reasons, the methodology has worked and revealed basic information about HIRF EMI. Out of the sample of 57 respondents, 5 clearly experienced some form of HIRF EMI (the pilots), and two observed it as passengers (the engineers). Though the sample is small, the descriptions of the HIRF EMI events are clear, and along with the anecdotal evidence cited we can conclude that HIRF EMI does occur. The significance, risk, importance, means of reduction, and other related matters are the purview of policy makers.

Much can be done to continue the study of HIRF EMI:

- The computations can be repeated to correct for the effects of respondents 21, 57, and 58.
- A bigger sample can be questioned to increase the number of respondents who have experienced HIRF EMI.
- One can focus future studies on "high risk" HIRF EMI groups, such as Caribbean Pilots, Drafted Desert Storm Commercial Pilots, and military pilots.
- Contact can be made with pilots in other countries who may have HIRF EMI experience.
- Relate, through the creation of a larger data base (as suggested above) or via a focused study, the frequency and consequences of HIRF EMI as a function of the amount of digital

automation in various aircraft.

- Study the potential for and mechanisms of HIRF EMI induced safety problems such as those discussed in Sec. 2.
- The various trade-offs involved in shielding fly-by-wire systems compared with using fly-by-light systems to reduce avionics upsets can be studied [Baker and Pitts, 1992].

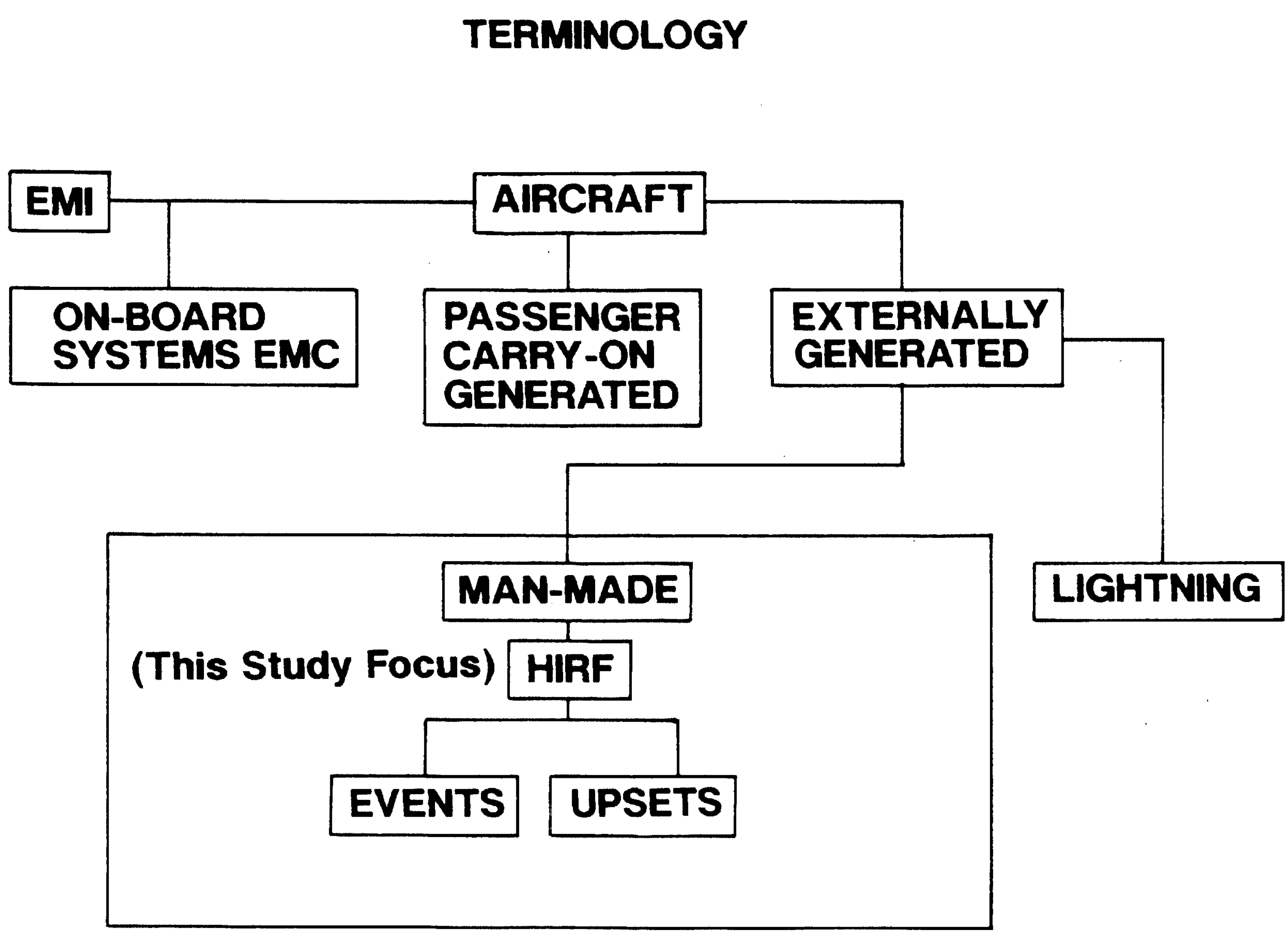

Fig. 1.1 Electromagnetic Interference Terminology

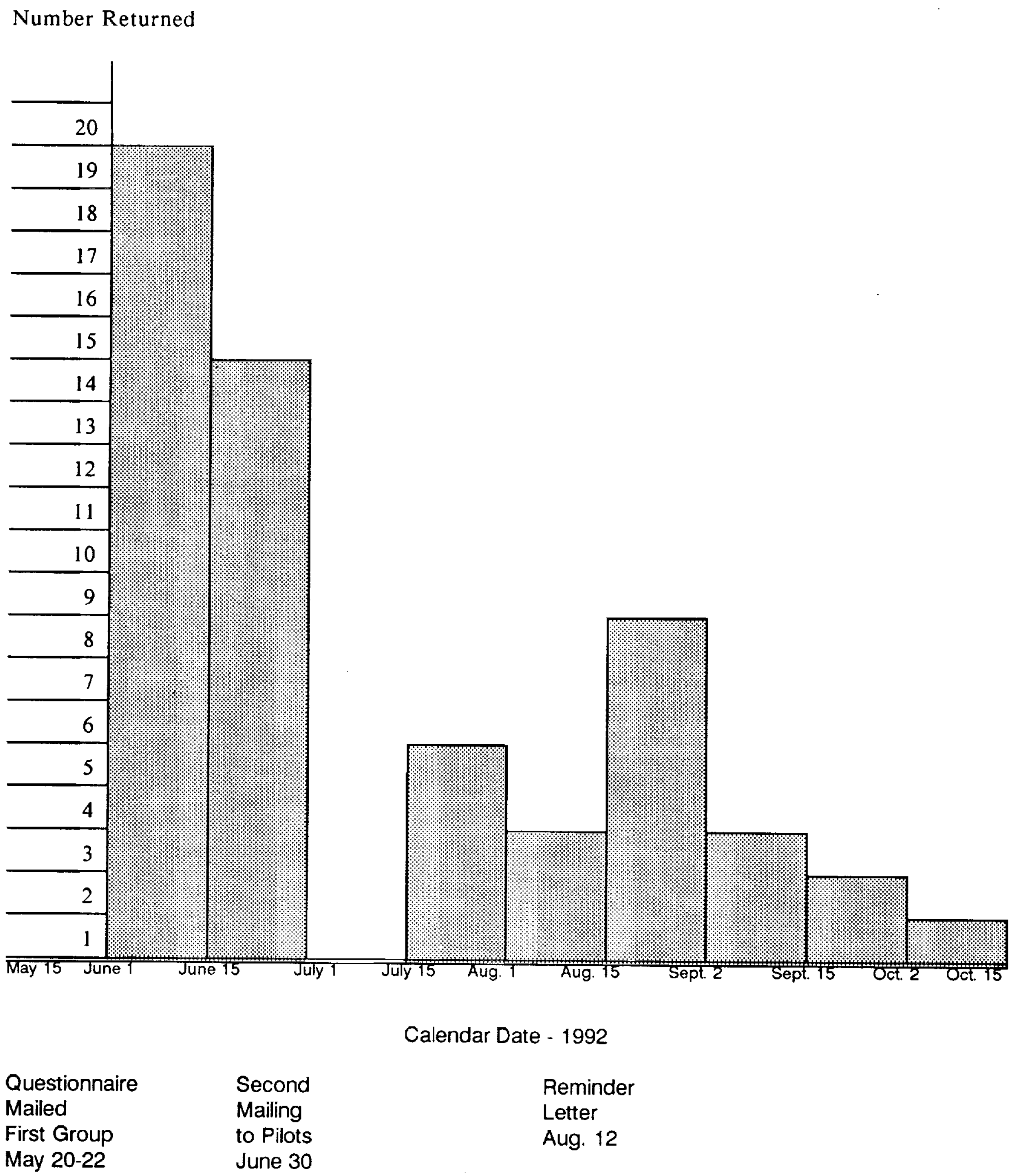

Fig. 6.1 Return rate of the questionnaires.

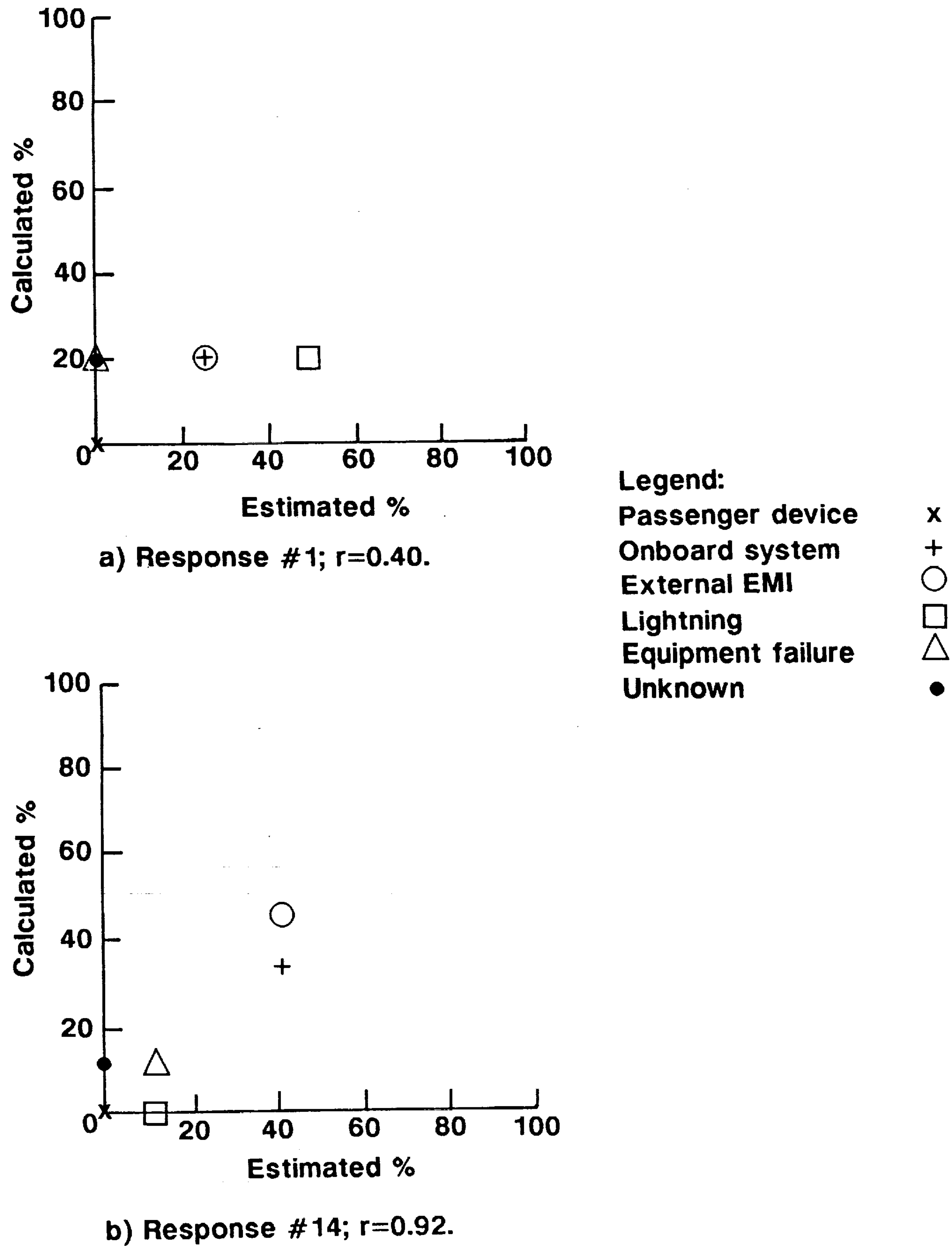

Fig. 6.2. Comparison of Two Sets of Data from Table 6.5.

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TABLE 1.1
Digital System Upset

- **Functional Error Mode**
  - System/Subsystem Level
  - Caused by Electrical Transient
    - Lightning
    - HIRF
  - No Component Damage

- **Requires Corrective Action**
  - Reset/Reload Software
  - Internal Recovery Mechanism (Hardware/Software)

TABLE 6.1

Preliminary Analysis of Completed Questionnaire (Sections 1.1, 1.2, 2.1, 6.0)

Response Number	Date Received	Work	Experience >Years	Degree of Completion	Number of Incidents	Event Description	Comments
1	May 05	Pilot	20	Detailed	5	Yes	Astronaut
2	Jun 01	EMI Specialist	10	Medium	0	No	No opportunity
3	Jun 01	Manager/Engr.	30	Nil	--	No	No Knowledge
4	Jun 01	EMI Specialist	5	Detailed	102	No	--
5	Jun 01	Engineer	20	Some	0	No	--
6	Jun 01	EMI Specialist	10	Detailed	4	Yes	--
7	Jun 01	EMI Specialist	30	Medium	5	No	--
8	Jun 02	EMI/Pilot	30	Detailed	12.5	No	Don't Remember
9	Jun 04	Psy/Manager	10	Medium	0	No	--
10	Jun 08	EMI Specialist	30	Some	0	No	--
11	Jun 08	Pilot/Engineer	20	Detailed	11	Yes	--
12	Jun 08	Engineer	30	Some	1	No	--
13	Jun 08	EMI Specialist	30	Detailed	3	Yes	--
14	Jun 08	EMI Specialist	38	Detailed	32	Yes	--
15	Jun 08	Pilot/Engineer	30	Detailed	28.+	Yes	Also Government
16	Jun 08	EMI Specialist	20	Detailed	10	Yes	--
17	Jun 08	EMI Specialist	30	Detailed	1	Yes	--
18	Jun 08	EMI Specialist	30	Detailed	13	Yes	--
19	Jun 10	Engineer	30	Detailed	1530	No	--
20	Jun 15	Engineer/Mgr.	20	Detailed	2.5	No	--
21	Jun 15	Pilot/Manager	20	Detailed	5	Yes	--
22	Jun 15	EMI Specialist	30	Detailed	3	Yes	--
23	Jun 15	Pilot/Engineer	30	Detailed	100	Yes	--
24	Jun 15	Pilot/Engineer	10	Detailed	3	Yes	--
25	Jun 15	Pilot	10	Some	0	No	--
26	Jun 15	Pilot/Engineer	20	Some	0	No	--
27	Jun 15	Pilot/Engineer	10	Some	24	Yes	--
28	Jun 19	EMI Specialist	20	Some	0	No	--
29	Jun 19	Manager	30	Medium	2	No	--
30	Jun 22	EMI Specialist	20	Detailed	30	Yes	--

TABLE 6.1 (Continued)
Preliminary Analysis of Completed Questionnaire (Sections 1.1, 1.2, 2.1, 6.0)

Response Number	Date Received	Work	Experience >Years	Degree of Completion	Number of Incidents	Event Description	Comments
31	Jun 22	EMI Specialist	20	Detailed	10	No	--
32	Jun 27	EMI Specialist	20	Medium	0	Yes	--
33	Jun 30	EMI Specialist	30	Detailed	5	Yes	Cell Phone
34	Jul 23	Pilot/Engineer	30	Detailed	14	Yes	--
35	Jul 24	Pilot	30	Some	2	No	--
36	Jul 27	Pilot	20	Some	0	No	--
37	Jul 28	Pilot	30	Medium	0	Yes	No Problems
38	Jul 29	Pilot	30	Detailed	1	Yes	--
39	Aug 07	Pilot	30	Medium	3	No	--
40	Aug 07	Pilot	30	Medium	8	Yes	--
41	Aug 12	--	--	--	--	No	Returned unanswered
42	Aug 16	EMI Specialist	20	Some	1	No	--
43	Aug 17	Engineer/Mgr.	30	Some	0	No	--
44	Aug 20	Pilot	30	Some	0	No	--
45	Aug 24	Gov't. Admin.	30	Some	0	No	--
46	Aug 24	Engineer	--	--	--	--	Military Security
47	Aug 28	Engineer/Mgr.	10	Some	8	No	Form Not Clear
48	Aug 28	EMI/Manager	20	Some	5	No	--
49	Aug 28	EMI/Engineer	30	Medium	4	No	--
50	Aug 31	EMI Specialist	10	Medium	7	No	--
51	Sep 03	Gov't. Admin.	5	Detailed	8	No	--
52	Sep 03	Engineer	20	Some	0	No	--
53	Sep 09	EMI/Manager	20	Some	--	No	Confidential
54	Sep 14	EMI Specialist	--	Detailed	63	Yes	--
55	Sep 16	Pilot	10	Detailed	2	Yes	--
56	Sep 22	EMI Specialist	20	Detailed	Many	Yes	--
57	Oct 15	EMI Specialist	10	Medium	Several	No	Military Security

TABLE 6.2
Number of EMI Events Reported by Category (Sections 2.1, 4.0)

Response Number	Work	Experience > Years	Degree of Completion	Number of Incidents	Pass	Onboard	External	Lighting	Equipment Failure	Unknown
1	Pilot	20	Detailed	5	0	1	1	1	1	1
2	EMI Specialist	10	Medium	0	0	0	0	0	0	0
3	Manager/Engr.	30	Nil	--	--	--	--	--	--	--
4	EMI Specialist	5	Detailed	102	0	102	0	0	0	0
5	Engineer	20	Some	0	0	0	0	0	0	0
6	EMI Specialist	10	Detailed	4	0	3	0	0	0	1
7	EMI Specialist	30	Medium	5	--	--	--	--	--	--
8	EMI/Pilot	30	Detailed	12.5	1	3	0	2	2	0
9	Psy/Manager	10	Medium	0	0	0	0	0	0	0
10	EMI Specialist	30	Some	0	0	0	0	0	0	0
11	Pilot/Engineer	20	Detailed	11	0	1	2	1	2	2
12	Engineer	30	Some	1	0	0	0	0	0	0
13	EMI Specialist	30	Detailed	3	0	1	1	1	0	0
14	EMI Specialist	38	Detailed	32	3	4	0	1	1	0
15	Pilot/Engineer	30	Detailed	28.+	3	3	4	3	2	0
16	EMI Specialist	20	Detailed	10	0	3	1	1	1	0
17	EMI Specialist	30	Detailed	1	1	0	0	0	0	0
18	EMI Specialist	30	Detailed	13	0	1	0	0	1	0
19	Engineer	30	Detailed	1530	0	0	1	2	2	8
20	Engineer/Mgr.	20	Detailed	2.5	0	2	0	1	3	0
21	Pilot/Manager	20	Detailed	5	0	0	1	1	3	0
22	EMI Specialist	30	Detailed	3	0	4	0	2	0	0
23	Pilot/Engineer	30	Detailed	100	0	5	1	1	0	0
24	Pilot/Engineer	10	Detailed	3	0	2	0	0	0	0
25	Pilot	10	Some	0	0	0	0	0	0	0
26	Pilot/Engineer	20	Some	0	0	0	0	0	0	0
27	Pilot/Engineer	10	Some	24	0	3	0	0	21	1
28	EMI Specialist	20	Some	0	0	0	0	0	0	0
29	Manager	30	Medium	2	0	0	0	0	0	0
30	EMI Specialist	20	Detailed	30	0	0	0	1	1	0

TABLE 6.2 (Continued)
Number of EMI Events Reported by Category (Sections 2.1, 4.0)

Response Number	Work	Experience > Years	Degree of Completion	Number of Incidents	Pass	Onboard	External	Lighting	Equipment Failure	Unknown
32	EMI Specialist	20	Detailed	10	0	4	3	3	3	3
33	EMI Specialist	20	Medium	0,(15)	0	10	2	1	1	1
34	EMI Specialist	30	Detailed	5	1	2	0	5	Many	0
35	Pilot/Engineer	30	Detailed	14	0	0	0	1	1	0
36	Pilot	30	Some	2	0	0	0	0	0	0
37	Pilot	20	Some	0	0	0	0	0	0	0
38	Pilot	30	Medium	0	0	0	0	0	0	0
39	Pilot	30	Detailed	1,(1)	0	1	0	0	0	0
40	Pilot	30	Medium	4	0	0	0	0	0	0
41	Pilot	30	Medium	8	1	2	1	2	0	1
42	--	--	--	--	--	--	--	--	--	--
43	EMI Specialist	20	Some	1	0	0	0	0	0	0
44	Engineer/Mgr.	30	Some	0	0	0	0	0	0	0
45	Pilot	30	Some	0	0	0	0	0	0	0
46	Gov't. Admin.	30	Some	0	0	0	0	0	0	0
47	Engineer	--	--	--	--	--	--	--	--	--
48	Engineer/Mgr.	10	Some	0,(14)	1	1	4	1	1	6
49	EMI/Manager	20	Some	5	0	0	0	0	0	0
50	EMI/Engineer	30	Medium	4	0	0	0	0	0	0
51	EMI Specialist	10	Medium	7	0	0	0	0	0	0
52	Gov't. Admin.	5	Detailed	8	1	2	1	1	1	1
53	Engineer	20	Some	0	0	0	0	0	0	0
54	EMI/Manager	20	Some	--	0	0	0	0	0	0
55	EMI Specialist	--	Detailed	63	0	2	1	2	0	0
56	Pilot	10	Detailed	2	0(2)	0	0	1	1	2
57	EMI Specialist	20	Detailed	Many	0	7	4	4	2	0
	EMI Specialist	10	Medium	Several	0	2	1	1	0	0

TABLE 6.3
Estimated Cause of EMI Events - Percentages (Section 4.7)

Response Number	Work	Experience > Years	Degree of Completion	Pass	Onboard	External	Lighting	Equipment Failure	Unknown
1	Pilot	20	Detailed	0	25	25	50	0	0
2	EMI Specialist	10	Medium	-	-	-	-	-	-
3	Manager/Engr.	30	Nil	-	-	-	-	-	-
4	EMI Specialist	5	Detailed	-	-	-	-	-	-
5	Engineer	20	Some	-	-	-	-	-	-
6	EMI Specialist	10	Detailed	-	-	-	-	-	-
7	EMI Specialist	30	Medium	-	-	-	-	-	-
8	EMI/Pilot	30	Detailed	5	75	5	5	5	5[1]
9	Psy/Manager	10	Medium	-	-	-	-	-	-
10	EMI Specialist	30	Some	-	-	-	-	-	-
11	Pilot/Engineer	20	Detailed	0	20	35	35	0	10
12	Engineer	30	Some	-	-	-	-	-	-
13	EMI Specialist	30	Detailed	-	-	-	-	-	-
14	EMI Specialist	38	Detailed	0	40	40	10	10	0
15	Pilot/Engineer	30	Detailed	5	5	50	40	0	0
16	EMI Specialist	20	Detailed	0	25	25	25	25	0
17	EMI Specialist	30	Detailed	0	0	0	0	0	100
18	EMI Specialist	30	Detailed	0	100	0	0	0	0
19	Engineer	30	Detailed	0	1	0	1	88	1[2]
20	Engineer/Mgr.	20	Detailed	-	-	-	-	-	-
21	Pilot/Manager	20	Detailed	0	0	25	75	0	0
22	EMI Specialist	30	Detailed	2.5	20	2.5	10	65	0[3]
23	Pilot/Engineer	30	Detailed	0	99	0	1	0	0
24	Pilot/Engineer	10	Detailed	-	-	-	-	-	-
25	Pilot	10	Some	-	-	-	-	-	-
26	Pilot/Engineer	20	Some	-	-	-	-	-	-
27	Pilot/Engineer	10	Some	0	20	0	0	65	10[4]
28	EMI Specialist	20	Some	-	-	-	-	-	-
29	Manager	30	Medium	-	-	-	-	-	-
30	EMI Specialist	20	Detailed	0	0	0	10	80	10

TABLE 6.3 (Continued)
Estimated Cause of EMI Events - Percentages (Section 4.7)

Response Number	Work	Experience > Years	Degree of Completion	Pass	Onboard	External	Lighting	Equipment Failure	Unknown
31	EMI Specialist	20	Detailed	0	49	1	50	0	0
32	EMI Specialist	20	Medium	0	80	10	10	0	0
33	EMI Specialist	30	Detailed	0	1	0	1	99	0
34	Pilot/Engineer	30	Detailed	0	0	0	5	95	0
35	Pilot	30	Some	-	-	-	-	-	-
36	Pilot	20	Some	-	-	-	-	-	-
37	Pilot	30	Medium	-	-	-	-	-	-
38	Pilot	30	Detailed	-	-	-	-	-	-
39	Pilot	30	Medium	-	-	-	-	-	-
40	Pilot	30	Medium	-	-	-	-	-	-
41	--	--	--	-	-	-	-	-	-
42	EMI Specialist	20	Some	-	-	-	-	-	-
43	Engineer/Mgr.	30	Some	-	-	-	-	-	-
44	Pilot	30	Some	-	-	-	-	-	-
45	Gov't. Admin.	30	Some	-	-	-	-	-	-
46	Engineer	--	--	-	-	-	-	-	-
47	Engineer/Mgr.	10	Some	-	-	-	-	-	-
48	EMI/Manager	20	Some	-	-	-	-	-	-
49	EMI/Engineer	30	Medium	-	-	-	-	-	-
50	EMI Specialist	10	Medium	-	-	-	-	-	-
51	Gov't. Admin.	5	Detailed	-	-	-	-	-	-
52	Engineer	20	Some	-	-	-	-	-	-
53	EMI/Manager	20	Some	-	-	-	-	-	-
54	EMI Specialist	--	Detailed	0	90	3	3	2	2
55	Pilot	10	Detailed	0	0	0	50	0	50
56	EMI Specialist	20	Detailed	0	90	7	3	0	0
57	EMI Specialist	10	Medium	-	-	-	-	-	-

1 Most = 75, Small = 5
2 Other: Pilot & Crew Mistakes - 10%
3 To normalize to 100% <5% = 2.5%, 70% = 65%
4 Other: Pilot Induced - 5%

TABLE 6.4
Cause of EMI Events - Calculated Percentages (From Data in Table 6.2)

Response Number	Work	Experience > Years	Degree of Completion	Pass	Onboard	External	Lighting	Equipment Failure	Unknown
1	Pilot	20	Detailed	0	20	20	20	20	20
2	EMI Specialist	10	Medium	-	-	-	-	-	-
3	Manager/Engr.	30	Nil	-	-	-	-	-	-
4	EMI Specialist	5	Detailed	0	100	0	0	0	0
5	Engineer	20	Some	-	-	-	-	-	-
6	EMI Specialist	10	Detailed	0	75	0	0	0	25
7	EMI Specialist	30	Medium	-	-	-	-	-	-
8	EMI/Pilot	30	Detailed	12.5	37.5	0	25	25	0
9	Psy/Manager	10	Medium	-	-	-	-	-	-
10	EMI Specialist	30	Some	-	-	-	-	-	-
11	Pilot/Engineer	20	Detailed	0	12.5	25	12.5	25	25
12	Engineer	30	Some	-	-	-	-	-	-
13	EMI Specialist	30	Detailed	0	33	33	33	0	0
14	EMI Specialist	38	Detailed	0	33	44	0	11	11
15	Pilot/Engineer	30	Detailed	20	20	27	20	13	0
16	EMI Specialist	20	Detailed	0	50	17	17	17	0
17	EMI Specialist	30	Detailed	100	0	0	0	0	0
18	EMI Specialist	30	Detailed	0	50	0	0	50	0
19	Engineer	30	Detailed	0	0	8	15	15	62
20	Engineer/Mgr.	20	Detailed	0	33	0	17	50	0
21	Pilot/Manager	20	Detailed	0	0	20	20	60	0
22	EMI Specialist	30	Detailed	0	67	0	33	0	0
23	Pilot/Engineer	30	Detailed	0	71	14	14	0	0
24	Pilot/Engineer	10	Detailed	0	100	0	0	0	0
25	Pilot	10	Some	-	-	-	-	-	-
26	Pilot/Engineer	20	Some	-	-	-	-	-	-
27	Pilot/Engineer	10	Some	0	12	0	0	81	8
28	EMI Specialist	20	Some	-	-	-	-	-	-
29	Manager	30	Medium	-	-	-	-	-	-
30	EMI Specialist	20	Detailed	0	0	0	50	50	0

TABLE 6.4 (Continued)
Cause of EMI Events - Calculated Percentages (From Data in Table 6.2)

Response Number	Work	Experience > Years	Degree of Completion	Pass	Onboard	External	Lighting	Equipment Failure	Unknown
31	EMI Specialist	20	Detailed	0	25	19	19	19	19
32	EMI Specialist	20	Medium	0	67	13	6	6	6
33	EMI Specialist	30	Detailed	4	7	0	18	71	0
34	Pilot/Engineer	30	Detailed	0	0	0	50	50	0
35	Pilot	30	Some	-	-	-	-	-	-
36	Pilot	20	Some	-	-	-	-	-	-
37	Pilot	30	Medium	-	-	-	-	-	-
38	Pilot	30	Detailed	0	100	0	0	0	0
39	Pilot	30	Medium	-	-	-	-	-	-
40	Pilot	30	Medium	17	33	17	33	0	0
41	--	--	--	-	-	-	-	-	-
42	EMI Specialist	20	Some	-	-	-	-	-	-
43	Engineer/Mgr.	30	Some	-	-	-	-	-	-
44	Pilot	30	Some	-	-	-	-	-	-
45	Gov't. Admin.	30	Some	-	-	-	-	-	-
46	Engineer	--	--	-	-	-	-	-	-
47	Engineer/Mgr.	10	Some	7	7	29	7	7	43
48	EMI/Manager	20	Some	-	-	-	-	-	-
49	EMI/Engineer	30	Medium	-	-	-	-	-	-
50	EMI Specialist	10	Medium	-	-	-	-	-	-
51	Gov't. Admin.	5	Detailed	14	29	14	14	14	14
52	Engineer	20	Some	-	-	-	-	-	-
53	EMI/Manager	20	Some	-	-	-	-	-	-
54	EMI Specialist	--	Detailed	0	40	20	40	0	0
55	Pilot	10	Detailed	0	0	0	25	25	50
56	EMI Specialist	20	Detailed	0	41	24	24	0	0
57	EMI Specialist	10	Medium	-	-	-	-	-	-

TABLE 6.5
Comparison of Estimated Percentages vs. Calculated Percentages (From Tables 6.3 and 6.4)

Response Number	Work	Experience > Years	Degree of Completion	Estimated/ Calculated	Pass	Onboard	External	Lighting	Equipment Failure	Unknown	Correlation Coeficient-r
1	Pilot	20	Detailed	E	0	25	25	50	0	0	0.40
				C	0	20	20	20	20	20	
8	EMI/Pilot	30	Detailed	E	5	75	5	5	5	5[1]	0.67
				C	12.5	37.5	0	25	25	0	
11	Pilot/Engineer	20	Detailed	E	0	20	35	35	0	10	0.18
				C	0	12.5	25	12.5	25	25	
14	EMI Specialist	38	Detailed	E	0	40	40	10	10	0	0.92
				C	0	33	44	0	11	11	
15	Pilot/Engineer	30	Detailed	E	5	5	50	40	0	0	0.66
				C	20	20	27	20	13	20	
16	EMI Specialist	20	Detailed	E	0	25	25	25	25	0	0.71
				C	0	50	17	17	17	0	
17	EMI Specialist	30	Detailed	E	0	0	0	0	0	100	-0.20
				C	100	0	0	0	0	0	
18	EMI Specialist	30	Detailed	E	0	100	0	0	0	0	0.63
				C	0	50	0	0	50	0	
19	Engineer	30	Detailed	E	0	1	0	1	88	1[2]	-0.03
				C	0	0	8	15	15	62	
21	Pilot/Manager	20	Detailed	E	0	0	25	75	0	0	-0.09
				C	0	0	20	20	60	0	
22	EMI Specialist	30	Detailed	E	2.5	20	2.5	10	65	0[3]	-0.001
				C	0	67	0	33	0	0	
23	Pilot/Engineer	30	Detailed	E	0	99	0	1	0	0	0.97
				C	0	71	14	14	0	0	
27	Pilot/Engineer	10	Some	E	0	20	0	0	65	10[4]	0.99
				C	0	12	0	0	81	8	
30	EMI Specialist	20	Detailed	E	0	0	0	10	80	10	0.70
				C	0	0	0	50	50	0	

TABLE 6.5 (Continued)
Comparison of Estimated Percentages vs. Calculated Percentages (From Tables 6.3 and 6.4)

Response Number	Work	Experience > Years	Degree of Completion	Estimated/ Calculated	Pass	Onboard	External	Lighting	Equipment Failure	Unknown	Correlation Coeficient-r
31	EMI Specialist	20	Detailed	E	0	49	1	50	0	0	0.47
				C	0	25	19	19	19	19	
32	EMI Specialist	20	Medium	E	0	80	10	10	0	0	0.99
				C	0	67	13	6	6	6	
33	EMI Specialist	30	Detailed	E	0	1	0	1	99	0	0.97
				C	4	7	0	18	71	0	
34	Pilot/Engineer	30	Detailed	E	0	0	0	5	95	0	0.67
				C	0	0	0	50	50	0	
54	EMI Specialist	--	Detailed	E	0	40	20	40	0	0	0.60
				C	0	90	3	3	2	2	
55	Pilot	10	Detailed	E	0	0	0	25	25	50	0.79
				C	0	0	0	50	0	50	
56	EMI Specialist	20	Detailed	E	0	41	24	24	0	0	0.78
				C	0	90	7	3	0	0	

(1) Most = 75, Small = 5
(2) Other: Pilot & Crew Mistakes - 10%
(3) To normalize to 100% <5% = 2.5%, 70% = 65%
(4) Other: Pilot Induced - 5%

TABLE 6.6
Comparison of Estimated and Calculated Percentages for External EMI

	21 Data Sets in Table 6.5	13 Data Sets with r>0.61 in Table 6.5
Mean Estimated	12.5	12.1
Mean Calculated	10.3	9.4
Standard Deviation Estimated	15.9	17.5
Standard Deviation Calculated	12.2	13.6
Correlation Between Estimated and Calculated	0.79	0.83

TABLE 6.7
Observation Intervals and Number of Incidents for All Upsets - Pilots (Sections 2.1)

Response #	Work	Observation as Pilot			Observation as Crew			Observation as Passenger			Conversations			Reports			Anecdotes			Other
		#	Years	Flights	#	Years	Flights	#	Years	Flights	#	Years	Flights	#	Years	Flights	#	Years	Flights	
1	Pilot	5	25	4000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8	Pilot	13	13	6000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
11	Pilot/Engineer	5	10	500	3	10	700	-	-	-	-	-	-	3	5	?	-	-	-	(1)
15	Pilot/Engineer	8	38	1800	0	-	-	0	-	-	N	?	VG	20	1/4	90	N	10	VG	(2)
21	Pilot/Manager	5	3	5	-	-	-	-	-	-	-	-	-	5	3	5	-	-	-	-
23	Pilot/Engineer	100	20	1500	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
24	Pilot/Engineer	3	20	1400	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
25	Pilot/Engineer	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
26	Pilot/Engineer	0	26	3000	-	-	-	-	-	-	1	26	?	-	-	-	-	-	-	-
27	Pilot/Engineer	12	6	370	-	-	-	4	4	120	-	-	-	8	2	1000	-	-	-	-
34	Pilot/Engineer	4	25	6500	-	-	-	-	-	-	10	25	?	-	-	-	-	-	-	-
35	Pilot	0	31	?	-	-	-	0	31	?	-	-	-	-	-	-	-	-	-	-
36	Pilot	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-
37	Pilot	0	26	25,000/hrs	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	(3)
38	Pilot	0	37	3000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
39	Pilot	4	30	?	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
40	Pilot	5	25	?	5	25	?	-	-	-	-	-	-	-	-	-	-	-	-	-
44	Pilot	0	28	?	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
55	Pilot	2	2	1536	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

(1) Certification Projects.
(2) Reports of British Airways. N = Numerous, VG = Very Great
(3) Hours of flight time.

TABLE 6.8 Frequency of All Upsets as Observed by Pilots		
Response #	Upsets/Year	Upsets/Flight
1	0.20	1.25×10^{-3}
8	1.00	2.17×10^{-3}
11	0.50	10×10^{-3}
15	0.21	4.4×10^{-3}
23	5.00	66×10^{-3}
24	0.15	2.1×10^{-3}
26	0	0
27	2.0	32×10^{-3}
34	0.16	0.6×10^{-3}
35	0	-
37	0	0
38	0	0
39	0.13	-
40	0.20	-
44	0	-
55	1.0	1.3×10^{-3}
Mean	0.63	10.7×10^{-3}
Standard Deviation	1.32	20.6×10^{-3}

TABLE 6.9 Frequency of HIRF Events - As Observed by Pilots (Tables 6.2 and 6.8)						
Response #	Work	External EMI Observation as Pilot			Frequency Per Year	Frequency Per Flight
		#	Years	Flights		
1	Pilot	1	25	4000	.04	$.25\times10^{-3}$
8	Pilot/Engineer	0	13	6000	0	0
11	Pilot	2	10	500	.20	4×10^{-3}
15	Pilot/Engineer	4	38	1800	.11	2.2×10^{-3}
21	Pilot/Manager	1	-	-	-	-
23	Pilot/Engineer	1	20	1500	.05	$.67\times10^{-3}$
24	Pilot/Engineer	0	20	1400	0	0
25	Pilot/Engineer	0	-	-	0	0
26	Pilot/Engineer	0	26	3000	0	0
27	Pilot/Engineer	0	6	370	0	0
34	Pilot/Engineer	0	25	6500	0	0
35	Pilot	0	31	?	0	0
36	Pilot	0	-	-	0	-
37	Pilot	0	26	25,000 hrs.	0	0
38	Pilot	0	37	3000	0	0
39	Pilot	0	30	?	0	0
40	Pilot	1	25	?	.04	-
44	Pilot	0	28	?	0	0
55	Pilot	0	2	1536	0	0
Mean					.024	0.45×10^{-3}
Standard Deviation					.053	1.07×10^{-3}

TABLE 6.10
Frequency of All Upsets - Engineers (Sections 2.1)

Response #	Work	Observation as Pilot			Observation as Crew			Observation as Passenger			Conversations			Reports			Anecdotes			Other
		#	Years	Flights	#	Years	Flights	#	Years	Flights	#	Years	Flights	#	Years	Flights	#	Years	Flights	
2,3,5,9,12, 20,28,32,41, 43,45,46,47, 52,53,56,57	EMI Specialist or Engineer	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	(1)
4	"	-	-	-	-	-	-	2	7	100	-	-	-	100	40	?	-	-	-	-
6	"	-	-	-	-	-	-	-	-	-	-	-	-	4	19	?	-	-	-	-
7	"	-	-	-	-	-	-	0	30	100	5	30	?	-	-	-	-	-	-	-
10	"	-	-	-	-	-	-	0	30	500	-	-	-	-	-	-	-	-	-	-
13	"	-	-	-	3	15	?	-	-	-	-	-	-	-	-	-	-	-	-	-
14	"	-	-	-	-	-	-	2	20	2000	6	20	-	10	30	-	20	35	-	-
16	"	-	-	-	-	-	-	-	-	-	-	-	-	10	10	?	-	-	-	-
17	"	-	-	-	-	-	-	1	25	120	-	-	-	-	-	-	-	-	-	-
18	"	-	-	-	-	-	-	-	-	-	10	1	10	-	-	-	-	-	-	-
19	"	0	5	300	-	-	-	0	30	-	30	30	25	500	30	6000	1000	30	3000	-
22	"	-	-	-	-	-	-	3	35	200	?	35	1000	?	35	100,000	-	-	-	-
29	"	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	5	10	-
30	"	-	-	-	-	-	-	10	25	1000	-	-	-	10	25	1000 2000	10	25	1000	-
31	"	-	-	-	-	-	-	0	25	450	-	-	-	10	25	-	-	-	-	-
33	"	5	30	-	-	-	-	-	-	-	-	-	-	-	-	-	?	30	-	-
42	"	-	-	-	-	-	-	0	8	200	1	20	?	-	-	-	-	-	-	-
48	"	-	-	-	-	-	-	0	23	1500	1	2	?	-	-	-	4	5	?	-
49	"	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5	30	200	-
50	"	-	-	-	-	-	-	-	-	-	-	-	-	4	10	-	3	10	-	-
51	"	-	-	-	-	-	-	-	-	-	8	5	-	-	-	-	-	-	-	-
54	"	-	-	-	10	4	30	-	-	-	-	-	-	50	5		3	-	3	-

(1) No opportunity to observe or no ontact with aircraft, or confidential, or incomplete.

TABLE 6.11
Frequency of All Events as Observed by Passengers
(From Tables 6.7 and 6.10)

Response #	Work	External Observation as Passenger			Frequency Per Year	Frequency Per Flight
		#	Years	Flights		
4	EMI Specialist or Engineer	2	7	100	0.28	20×10^{-3}
7	"	0	30	100	0	0
10	"	0	30	500	0	0
14	"	2	20	2000	0.10	1×10^{-3}
17	"	1	25	120	0.04	8.3×10^{-3}
19	"	0	30	-	0	0
22	"	3	35	200	0.086	15×10^{-3}
27	Pilot/Engineer	4	4	120	1.0	33.3×10^{-3}
30	EMI Specialist or Engineer	10	25	1000	0.4	10×10^{-3}
31	"	0	25	450	0	0
35	Pilot	0	31	?	0	0
42	EMI Specialist or Engineer	0	8	200	0	0
48	"	0	23	1500	0	0
Mean					0.15	6.7×10^{-3}
Standard Deviation					0.29	10.5×10^{-3}

TABLE 6.12
Frequency of HIRF Events as Reported by Passengers
(From Sec. 4.3 and Table 6.11)

Response #	Work	External Observation as Passenger			Frequency Per Year	Frequency Per Flight
		#	Years	Flights		
4	EMI Specialist or Engineer	0	7	100	0	0
7	"	0	30	100	0	0
10	"	0	30	500	0	0
14	"	0	20	2000	0	0
17	"	0	25	120	0	0
19	"	1	30	-	0.033	-
22	"	0	35	200	0	0
27	Pilot/Engineer	0	4	120	0	0
30	EMI Specialist or Engineer	0	25	1000	0	0
31	"	3	25	450	0.12	6.7×10-3
35	Pilot	0	31	?	0	0
42	EMI Specialist or Engineer	0	8	200	0	0
48	"	0	23	1500	0	0
Mean					0.12	0.56×10^{-3}
Standard Deviation					0.34	1.93×10^{-3}

TABLE 6.13 Frequency of All Events as Observed by Pilots (with r ≥ 0.60 in Table 6.5) (From Table 6.8)		
Response #	Upsets/Year	Upsets/Flight
8	1.00	2.17×10^{-3}
15	0.21	4.4×10^{-3}
23	5.00	6.7×10^{-3}
27	2.0	32.4×10^{-3}
34	0.16	0.61×10^{-3}
55	1.0	1.3×10^{-3}
Mean	1.56	7.93×10^{-3}
Standard Deviation	1.81	12.2×10^{-3}

TABLE 6.14 Frequency of All Events as Reported by Passengers (with r ≥ 0.6 in Table 6.5) (From Table 6.11)			
Response #	Work	Upsets/Year	Upsets/Flight
14	"	0.10	1×10^{-3}
27	Pilot/Engineer	1.0	33.3×10^{-3}
30	EMI Specialist or Engineer	0.4	10×10^{-3}
Mean		0.5	14.8×10^{-3}
Standard Deviation		0.4	16.67×10^{-3}

TABLE 7.1 Mean Occurrence Rates of Various Events		
Quantity	Frequency/Year	Frequency/1000 Flights
All EMI Upsets Observed by Pilots	0.66 0.25* 1.56**	5.08 2.60* 7.93**
HIRF Upsets Observed by Pilots	0.024	0.45
All EMI Upsets Observed by Passengers	0.15 0.5**	6.7 14.8**
HIRF Upsets Observed by Passengers	0.12	0.56

* With outliers removed.
** Only responses with $r > 0.61$ considered

TABLE 7.2 Interval Estimates of Occurrence Rates for Various Events	
Quantity	Frequency/1000 Flights 80% Confidence Interval
HIRF Upsets Observed by Pilots	0.31 - 0.76
HIRF Upsets Observed by Passengers	0.25 - 0.93

TABLE 7.3
Occurrence Rates from This Study and Other Comparative Studies

Event	Frequency/Hour	Frequency/Flight or Trip
All Upsets Pilots[1] (Point Estimates)	0.25×10^{-3} 0.66×10^{-3} 1.56×10^{-3}	2.60×10^{-3} 5.08×10^{-3} 7.93×10^{-3}
All Upsets Passengers[2] (Point Estimates)	0.15×10^{-3} 0.5×10^{-3}	6.7×10^{-3} 14.8×10^{-3}
HIRF Upsets Pilots[3] (Point Estimates) (Interval Estimates)	0.024×10^{-3} ----	0.45×10^{-3} $0.31\text{-}0.76 \times 10^{-3}$
HIRF Upsets Passengers[4] (Point Estimates) (Interval Estimates)	0.12×10^{-3} ----	0.56×10^{-3} $0.25\text{-}0.93 \times 10^{-3}$
Rail Fatalities[5] (Point Estimates)	0.007×10^{-5}	0.014×10^{-5}
Bus Fatalities[5] (Point Estimates)	0.384×10^{-5}	0.768×10^{-5}
Scheduled Air Fatalities[5] (Point Estimates)	0.209×10^{-5}	0.627×10^{-5}
Auto Fatalities[5] (Point Estimates)[6]	0.166×10^{-5} 0.055×10^{-5}	0.111×10^{-5} ----
General Aviation Fatalities[5] (Point Estimates)	3.1×10^{-5}	9.3×10^{-5}
Average Due to Disease[7] (Point Estimates)	1×10^{-6}	----
Airline Crashes into Mountain in Good Weather and Mechanical Condition[8]	----	$1.25\text{-}5.6 \times 10^{-7}$

1 Table 7.1, assume 1000 exposure hours/year
2 Table 7.1, assume 1000 exposure hours/year
3 Table 7.1, 7.2, assume 1000 exposure hours/year
4 Table 7.1, 7.2, assume 1000 exposure hours/year
5 Shooman, Table J-3, p. 630, based on a NYC to Washington DC "average trip"
6 Department of Transportation, May 1988, assume 10,000 miles driven/year and an average of 25 mph. = 400 hr./year
7 Shooman, Fig. J-1, p. 624 "average trip"
8 Fragola and Shooman, 1992

APPENDIX A

QUESTIONNAIRE AND MAILING TO THE PARTICIPANTS

The following 16 page questionnaire was sent to the respondents along with the cover letter dated on May 4, 1992.

A copy of the reminder letter, dated August 12, 1992, and sent to participants to encourage additional responses is included.

Route 110, Farmingdale, New York 11735 516-755-4400/FAX 5167554404

SCHOOL OF
ELECTRICAL ENGINEERING
AND COMPUTER SCIENCE

516-755-4290

Polytechnic UNIVERSITY

Dr. Martin L. Shooman
Professor of Electrical Engineering and Computer Science
Polytechnic University - Long Island Campus
Route 110
Farmingdale, NY 11735

May 4, 1992

UNEXPLAINED AIRCRAFT UPSET QUESTIONNAIRE

INTRODUCTION:

Dear Professional:

Your are being asked to participate in an important data collection effort on Aircraft Safety. In recent years, many anecdotal reports (stories) have appeared regarding the upset (disruption) of avionics systems. I am presently working to collect data on the frequency, nature, and severity of such interrupt events under a NASA Grant. This data will be used to help determine if further study is needed and to assign research priorities. Some of these events have been previously studied or are well known, e.g. lightning, interference of passenger electronics equipment. However, the effects and importance of system failures due to malfunctions and external radio interference (sometimes called High Intensity Radio Frequency Interference, HIRF) are less well studied.

I am sure you appreciate that some of this information is considered sensitive or proprietary by manufacturers, airlines, and others. In addition some of the suspected sources of interference are military or covert activities. Thus, it was decided to use an "Anonymous Expert Questionnaire" to develop some of this data. No names will appear in the reporting of this data and the sources will only be described as to the numbers or percentages of airline captains, avionics engineers, airline maintenance personnel, etc. who responded to the questionnaire.

I would like to acknowledge the help of the following individuals who critiqued this questionnaire and supplied the names of most of the professionals to whom this was sent:

Joe Fragola, SAIC	Rowena Morrison, NASA Aviation Safety Reporting System
Gerry Fuller, CKC Labs	Felix Pitts, NASA Langley
Herbert Hecht, SoHar Inc.	Ronald Rogers, Airline Pilots Association

Before completing this questionnaire, please suggest or send copies to other knowledgeable colleagues who should also complete this questionnaire. (Please read question 8 and make copies if appropriate). Complete and return this questionnaire even if you know of zero incidents of upsets since this is also valid data. Your cooperation, help, time and suggestions are much appreciated.

Please send the completed questionnaire to my Secretary, JoAnn McDonald, in the enclosed stamped, self-addressed envelope, (within two weeks of receipt if possible).

Sincerely,

Martin L. Shooman

New York City:
333 Jay Street
Brooklyn, NY 11201
718-260-3600
FAX 7182603136

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Route 110
Farmingdale, NY 11735
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FAX 5167554404

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36 Saw Mill River Road
Hawthorne, NY 10532
914-347-6940
FAX 9143476939

1.0 YOUR FIELD OF EXPERTISE

1.1 Your Profession and Employment (Check all that apply)

☐ Military Pilot	☐ Military Crew Member	☐ Military Aircraft Maintenance
☐ Commercial Pilot	☐ Commercial Crew Member	☐ Commercial Aircraft Maintenance
☐ NonSched Pilot	☐ NonSched Crew Member	☐ NonSched Aircraft Maintenance
☐ Corporate Pilot	☐ Corporate Crew Member	☐ Corporate Aircraft Maintenance
☐ Aerospace Engineer	☐ Electrical Engineer	☐ Airframe manufacturer (military)
☐ Physicist	☐ Mathematician	☐ Airframe manufacturer (commercial)
☐ Manager	☐ Mechanical Engineer	☐ Avionics* manufacturer (military)
☐ EMI Specialist	☐ Government Administrator	☐ Avionics* manufacturer (commercial)

☐ Other (specify) ____

* Avionics includes instrumentation, navigation, control, etc.

1.2 Total Years of Experience in Your Field:

☐ > 30 years ☐ > 20 years ☐ > 10 years ☐ > 5 years ☐ > 1 year

☐ Other (specify)____

1.3 Types of Aircraft Associated with Your Professional Experience:

Commercial

☐ Wide Body	☐ Narrow Body	☐ Feeder Jets	☐ Regional Jets
☐ Business Jets	☐ Heavy Twin Turboprop	☐ Light Twin Turboprop	
☐ Airship	☐ Single Engine Turboprop	☐ Helicopter	

☐ Other (specify)____

Military

☐ Fighter	☐ Recon	☐ Bomber	☐ Fighter/Bomber
☐ Transport	☐ Tanker	☐ Airship	☐ Helicopter

☐ Other (specify)____

Commercial

☐ A300 ☐ A310 ☐ A320 ☐ A330 ☐ A340 ☐ A300-600
☐ 747-100 ☐ 707-720 ☐ 747-200,300 ☐ 747-SP ☐ 747-400 ☐ 757
☐ 767 ☐ 777 ☐ 737-200,300 ☐ 737-400 ☐ 737-500 ☐ 727-STD
☐ 727-LONG ☐ MD-80 ☐ MD-11 ☐ MD-90 ☐ DC-8 ☐ DC-10
☐ DC-60 ☐ DC-SUPER 70 ☐ DC-9,10,20 ☐ DC-30,40 ☐ L1011
☐ Airship_______________ ☐ Helicopter_______________
☐ Other (specify)____

Business Jet

☐ Cessna Citation I ☐ Cessna Citation II ☐ Cessna Citation III
☐ Gates Learjet 25D,256 ☐ Gates Learjet 35,36A ☐ Gates Learjet 55
☐ Gulfstream II ☐ Gulfstream IIB ☐ Gulfstream III
☐ Gulfstream IV ☐ Beech Jet 400 II ☐ Beech Jet 400 III
☐ Other (specify)____

Turbo Prop

☐ Beech Airliner C-99 ☐ Beech 1900C ☐ Fairchild Metro III & V
☐ Beech King Air F90-1 ☐ Beech Super 200,B200 ☐ Piper Chieftain
☐ Piper Mojave ☐ Piper 400LS CLEY IIIA ☐ Piper Seneca
☐ Piper T-1020 ☐ Piper T-1040 ☐ Cessna Twin Conquest II
☐ Cessna Twin Utiliner 402C ☐ Cessna-Chancellor ☐ Cessna 421
☐ Other (specify)____

Military/Government

☐ F-111 ☐ F-14 ☐ F-18 ☐ Helicopter_______________
☐ C-5A1B ☐ B-52 ☐ B-1 ☐ Airship_______________
☐ Other (specify) ____

2.0 FREQUENCY OF AVIONICS UPSETS* (Check all that apply)

* The term upset is defined to mean any significant deviation from expected behavior which is more than a nuisance and might compromise aspects of the flight.

2.1 Frequency of Upsets:

Estimate the number of incidents, and the numbers of years and flights to the best of your ability. If you have not observed any such upsets enter 0 as the number of incidents since 0 incidents is important data.

☐ Personal Observation as a pilot

☐ Number of incidents ______ ☐ Over ______ years ☐ Covering ______ flights

☐ Personal observation as a crew member

☐ Number of incidents ______ ☐ Over ______ years ☐ Covering ______ flights

☐ Personal observation as a passenger

☐ Number of incidents ______ ☐ Over ______ years ☐ Covering ______ flights

☐ Conversations with others who were personal observers

☐ Number of incidents ______ ☐ Over ______ years ☐ Covering ______ flights

☐ Study of data or reports

☐ Number of incidents ______ ☐ Over ______ years ☐ Covering ______ flights

☐ Study of anecdotal (stories) accounts

☐ Number of incidents ______ ☐ Over ______ years ☐ Covering ______ flights

☐ Other____

2.2 Types of Aircraft Affected by Upset Incidents (Check all that apply):

Commercial

☐ Wide Body ☐ Narrow Body ☐ Feeder Jets ☐ Regional Jets

☐ Business Jets ☐ Heavy Twin Turboprop ☐ Light Twin Turboprop

☐ Airship ☐ Helicopter ☐ Single Engine Turboprop

☐ Other (specify)____

Military

- ☐ Fighter
- ☐ Recon
- ☐ Bomber
- ☐ Fighter/Bomber
- ☐ Transport
- ☐ Tanker
- ☐ Helicopter
- ☐ Airship
- ☐ Other (specify)____

2.3 **Specific Aircraft Affected by Upset Incidents (Check all that apply):**

Commercial

- ☐ A300
- ☐ A310
- ☐ A320
- ☐ A330
- ☐ A340
- ☐ A300-600
- ☐ 747-100
- ☐ 707-720
- ☐ 747-200,300
- ☐ 747-SP
- ☐ 747-400
- ☐ 757
- ☐ 767
- ☐ 777
- ☐ 737-200,300
- ☐ 737-400
- ☐ 737-500
- ☐ 727-STD
- ☐ 727-LONG
- ☐ MD-80
- ☐ MD-11
- ☐ MD-90
- ☐ DC-8
- ☐ DC-10
- ☐ DC-60
- ☐ DC-SUPER 70
- ☐ DC-9,10,20
- ☐ DC-30,40
- ☐ L1011
- ☐ Airship____________________
- ☐ Helicopter____________________
- ☐ Other (specify)____

Business Jet

- ☐ Cessna Citation I
- ☐ Cessna Citation II
- ☐ Cessna Citation III
- ☐ Gates Learjet 25D,256
- ☐ Gates Learjet 35,36A
- ☐ Gates Learjet 55
- ☐ Gulfstream II
- ☐ Gulfstream IIB
- ☐ Gulfstream III
- ☐ Gulfstream IV
- ☐ Beech Jet 400 II
- ☐ Beech Jet 400 III
- ☐ Other (specify)____

Turbo Prop

- ☐ Beech Airliner C-99
- ☐ Beech 1900C
- ☐ Fairchild Metro III & V
- ☐ Beech King Air F90-1
- ☐ Beech Super 200,B200
- ☐ Piper Chieftain
- ☐ Piper Mojave
- ☐ Piper 400LS CLEY IIIA
- ☐ Piper Seneca
- ☐ Piper T-1020
- ☐ Piper T-1040
- ☐ Cessna Twin Conquest II
- ☐ Cessna Twin Utiliner 402C
- ☐ Cessna-Chancellor
- ☐ Cessna 421
- ☐ Other (specify)____

Military/Government

☐ F-111 ☐ F-14 ☐ F-18 ☐ Helicopter________________
☐ C-5A1B ☐ B-52 ☐ B-1 ☐ Airship________________
☐ Other (specify) ________________________________

IF YOU HAVE EXPERIENCED 0 UPSETS OF ANY KIND PLEASE SKIP TO QUESTION 7.

3.0 CONDITION UNDER WHICH UPSETS OCCUR

3.1 **Do Such Upsets Occur on:**

☐ Landing ☐ Takeoff ☐ Straight and level Flight ☐ Ascent ☐ Descent
☐ Taxing ☐ Parked ☐ Don't know ☐ Formation Flight
☐ Low-level Flight ☐ Flight Maneuvers ☐ Low Traffic ☐ High Traffic
☐ Other (specify)________________________________

3.2 **Under What Weather Conditions:**

☐ Clear, good visibility ☐ Cloudy, medium visibility ☐ Rain*, medium visibility
☐ Clouds or Rain*, Poor Visibility ☐ Not significant ☐ Don't know
☐ Hot ☐ Cold
☐ Other (specify)________________________________

* Or other precipitation

3.3 **Level of Avionics Maintenance When Upsets Occurred:**

☐ Good condition ☐ Needed servicing ☐ Under service ☐ Problems with a particular unit
☐ Not significant ☐ Don't know ☐ Design problem with a particular subsystem

WE WISH MORE DETAILS ON THE NATURE OF THE UPSETS YOU REPORTED IN QUESTION 2.0. PLEASE COMPLETE QUESTIONS 4 AND 5 TO THE BEST OF YOUR ABILITY FOR ALL THE INCIDENTS YOU REMEMBER.

4.0 CAUSE AND EFFECT OF UPSET

4.1 Passenger RFI*

*Radio frequency interference affecting an aircraft system caused by passenger equipment operating inside the aircraft.

Source:

☐ AM Radio ☐ FM Radio ☐ Short Wave Radio ☐ Transmitter

☐ Computer ☐ Tape player/recorder ☐ CD Player ☐ Air to Ground Phone

☐ Unknown or difficult to determine source

☐ Other (specify) ____________________

How sure are you of the source of upset? Circle appropriate number:

No Idea			Maybe		Possibly		Probably			Certain
0	1	2	3	4	5	6	7	8	9	10

How do you know the source?____________________

System or subsystem affected:

☐ Autopilot ☐ Panel Lights ☐ Cabin Lights ☐ Communications Equipment

☐ Navigation equipment ☐ Flaps ☐ Spoilers ☐ Landing Gear (Auto Braking/Anti Skid)

☐ Engine Controls ☐ Rotor Controls ☐ Instrumentation ☐ Airship Gas Lift Controls

☐ Window Heat ☐ Intercom ☐ Ailerons ☐ Cabin Pressure & Temperature

☐ Rudder ☐ Elevators ☐ Nose Wheel Steering

☐ Other (specify)____________________

How sure are you of the affected system or subsystem? Circle appropriate number:

No Idea			Maybe		Possibly		Probably			Certain
0	1	2	3	4	5	6	7	8	9	10

How do you know the system/subsystem?____________________

4.2 Onboard RFI**

** Radio frequency interference caused by one on board system affecting the operation of another on board system.

Source:

- ☐ VHF-UHF Transmitter
- ☐ High Frequency Transmitter
- ☐ Radar
- ☐ Countermeasures Equipment
- ☐ Power Source
- ☐ Intercom
- ☐ Navigation Equipment
- ☐ Computer
- ☐ Unknown
- ☐ Other (specify)______________________________

How sure are you of the source of upset? Circle appropriate number:

No Idea			Maybe		Possibly		Probably			Certain
0	1	2	3	4	5	6	7	8	9	10

How do you know the source?______________________________

System or subsystem affected:

- ☐ Autopilot
- ☐ Panel Lights
- ☐ Cabin Lights
- ☐ Communications Equipment
- ☐ Navigation equipment
- ☐ Flaps
- ☐ Spoilers
- ☐ Automated Landing Gear
- ☐ Engine Controls
- ☐ Helicopter Rotor Controls
- ☐ Airship Gas Lift controls
- ☐ Instrumentation
- ☐ Other (specify)______________________________

How sure are you of the affected system or subsystem? Circle appropriate number:

No Idea			Maybe		Possibly		Probably			Certain
0	1	2	3	4	5	6	7	8	9	10

How do you know the system/subsystem?______________________________

4.3 <u>External RFI</u>***

*** Radio frequency interference from a source outside the aircraft (another aircraft, a ship, a ground installation, etc.) which affects systems within the aircraft (often called HIRF).

Source:

☐ Commercial AM Transmitter
☐ Commercial FM Transmitter
☐ Commercial Short Wave Transmitter
☐ Voice of America Transmitter
☐ Air Traffic Control Radar
☐ Weather Radar
☐ Military Radar
☐ Shipboard military radar
☐ Airborne military radar
☐ Landbased military radar
☐ Unknown
☐ VLF/LF Transmitter
☐ Hand-held (Walkie-Talkies)
☐ Airport Fixed Transmitter
☐ Car Mobile Transmitter
☐ Air Mobile Transmitter
☐ Other (specify)____________________

How sure are you of the source of upset? Circle appropriate number:

No Idea			Maybe		Possibly		Probably			Certain
0	1	2	3	4	5	6	7	8	9	10

How do you know the source?____________________

System or subsystem affected:

☐ Autopilot
☐ Panel Lights
☐ Cabin Lights
☐ Communications Equipment
☐ Navigation equipment
☐ Flaps
☐ Spoilers
☐ Automated Landing Gear
☐ Engine Controls
☐ Helicopter Rotor Controls
☐ Airship Gas Lift controls
☐ Instrumentation
☐ Other____________________

How sure are you of the affected system or subsystem? Circle the appropriate number:

No Idea			Maybe		Possibly		Probably			Certain
0	1	2	3	4	5	6	7	8	9	10

How do you know the system/subsystem?____________________

4.4 Lightning

Source:

- ☐ Electrostatic Discharge (ESD)
- ☐ Strike-Airborne
- ☐ Strike-Ground
- ☐ Strike-Indirect
- ☐ St. Elmo's Fire
- ☐ Other (specify)________________

How sure are you of the source of upset? Circle the appropriate number:

No Idea			Maybe		Possibly		Probably			Certain
0	1	2	3	4	5	6	7	8	9	10

How do you know the source?________________

System or subsystem affected:

- ☐ Autopilot
- ☐ Panel Lights
- ☐ Cabin Lights
- ☐ Communications Equipment
- ☐ Navigation equipment
- ☐ Flaps
- ☐ Spoilers
- ☐ Automated Landing Gear
- ☐ Engine Controls
- ☐ Helicopter Rotor Controls
- ☐ Airship Gas Lift controls
- ☐ Instrumentation
- ☐ Other (specify)________________

How sure are you of the affected system or subsystem? Circle the appropriate number:

No Idea			Maybe		Possibly		Probably			Certain
0	1	2	3	4	5	6	7	8	9	10

How do you know the system/subsystem?________________

4.5 Equipment Failure

Source:

- ☐ Intermittent
- ☐ Transient
- ☐ Hard Failures
- ☐ Electrostatic Discharge
- ☐ Other________________

How sure are you of the sources? Circle the appropriate number:

No Idea			Maybe		Possibly		Probably			Certain
0	1	2	3	4	5	6	7	8	9	10

How do you know the source?____

System or subsystem affected:

- ☐ Autopilot
- ☐ Panel Lights
- ☐ Cabin Lights
- ☐ Communications Equipment
- ☐ Navigation equipment
- ☐ Flaps
- ☐ Spoilers
- ☐ Automated Landing Gear
- ☐ Engine Controls
- ☐ Helicopter Rotor Controls
- ☐ Airship Gas Lift controls
- ☐ Instrumentation
- ☐ Other (specify)____

How sure are you of the affected system or subsystem? Circle the appropriate number:

No Idea			Maybe		Possibly		Probably			Certain
0	1	2	3	4	5	6	7	8	9	10

How do you know the system/subsystem?____

4.6 Unknown Source

System or subsystem affected:

- ☐ Autopilot
- ☐ Panel Lights
- ☐ Cabin Lights
- ☐ Communications Equipment
- ☐ Navigation equipment
- ☐ Flaps
- ☐ Spoilers
- ☐ Automated Landing Gear
- ☐ Engine Controls
- ☐ Helicopter Rotor Controls
- ☐ Airship Gas Lift controls
- ☐ Instrumentation
- ☐ Other (specify)____

How sure are you of the affected system or subsystem? Circle the appropriate number:

No Idea			Maybe		Possibly		Probably			Certain
0	1	2	3	4	5	6	7	8	9	10

How do you know the system/subsystem?____

4.7 Cause of Upset

Estimate What Percentage of All the Upsets are Due to:

Passenger RFI_______________
Onboard RFI_______________
External RFI_______________
Lighting_______________
Equipment Failure__________
Unknown Source__________
Other (specify)____

5.0 CRITICALLY OF UPSETS

5.1 Passenger RFI

How Critical Are The Upsets Due to Passenger RFI:

Normal		Nuisance		Concern		Emergency Procedures		Injuries Damage		Catastrophic Total Loss
0	1	2	3	4	5	6	7	8	9	10

5.2 Onboard Systems RFI

How Critical Are The Upsets Due to Onboard RFI:

Normal		Nuisance		Concern		Emergency Procedures		Injuries Damage		Catastrophic Total Loss
0	1	2	3	4	5	6	7	8	9	10

5.3 External RFI (HIRF)

How Critical Are The Upsets Due to External RFI (HIRF):

Normal		Nuisance		Concern		Emergency Procedures		Injuries Damage		Catastrophic Total Loss
0	1	2	3	4	5	6	7	8	9	10

5.4 Lightning

How Critical Are The Upsets Due to Lighting:

Normal		Nuisance		Concern		Emergency Procedures		Injuries Damage		Catastrophic Total Loss
0	1	2	3	4	5	6	7	8	9	10

5.5 Avionics Equipment Failure

How Critical Are The Upsets Due to Avionics Equipment Failure:

Normal		Nuisance		Concern		Emergency Procedures		Injuries Damage		Catastrophic Total Loss
0	1	2	3	4	5	6	7	8	9	10

5.6 Unknown Source

How Critical Are The Upsets Due to Unknown Sources:

Normal		Nuisance		Concern		Emergency Procedures		Injuries Damage		Catastrophic Total Loss
0	1	2	3	4	5	6	7	8	9	10

6.0 DESCRIPTION OF EVENTS

Now that you have reported on overall aspects of avionics upsets you are asked to give more specific details of such incidents. Please focus on those you think were most significant.

6.1 <u>If you have detailed knowledge of any upset events please describe them below</u>:

My descriptions are based on:

- ☐ Personal Observation
- ☐ Reliable and detailed report from a second party
- ☐ Study of data based on reliable reports of observers
- ☐ Other (specify)______________________________
- ☐ Don't have detailed information

6.2 <u>Please give a brief description of the events, including aircraft, flight condition, airport or location, weather, maintenance conditions, source of upset, how determined, effect, severity, criticality, etc.)</u>:

Event 1:______________________________

____

____

____

____

____

____

Event 2:______________________________

____

____

____

____

____

____

____

____

Event 3:

(Please use additional sheets if more room is needed for more details or additional events.)

☐ **Additional sheets attached.**

WE ARE ATTEMPTING TO COMPILE A LIST OF PUBLISHED REPORTS AND ARTICLES ABOUT UPSETS

7.0 HAVE YOU SEEN FREQUENCY OR SEVERITY DATA REPORTED ON UPSET EVENTS DUE TO?

7.1 Passenger RFI

Source of data:

Person/Organization to Contact for more details:

Articles/Reports in the literature with data:

7.2 Onboard RFI

Source of data:

Person/Organization to Contact for more details:

Articles/Reports in the literature with data:

7.3 External RFI

Source of data:

Person/Organization to Contact for more details:

Articles/Reports in the literature with data:

7.4 Lightning

Source of data:

Person/Organization to Contact for more details:

Articles/Reports in the literature with data:

7.5 Avionics Equipment Failure

Source of data:____________________

Person/Organization to Contact for more details:____________________

Articles/Reports in the literature with data:____________________

8.0 ADDITIONAL INFORMATION

8.1 Who else has information on avionics upsets and should be sent a copy of this form and asked to respond?

☐ I have made copies of this form and sent it to ________ colleagues for their completion.

☐ Shooman please send copies to the following individuals:

Contact 1: ____________________

Contact 2: ____________________

Contact 3:____________________

(Please use additional sheets if more room is needed for more details or additional events.)

☐ **Additional sheets attached.**

8.2 Additional Comments

THANK YOU FOR YOUR TIME AND HELP IN CONTRIBUTING TO THIS IMPORTANT STUDY OF AIRCRAFT SAFETY

Route 110, Farmingdale, New York 11735 516-755-4400 / FAX5167554404

SCHOOL OF
ELECTRICAL ENGINEERING
AND COMPUTER SCIENCE

Computer Science Department
516/755-4290

Polytechnic
UNIVERSITY

E-MAIL: shooman@prism.poly.edu

August 12, 1992

Dear Participant:

Some time ago I sent you a copy of a questionnaire requesting your experiences concerning the frequency and effects of radio frequency interference on aircraft systems.

If you have not filled out the form and responded, I would appreciate it if you could take some time to complete and return the form. Your response would be much appreciated, even if you have never observed this phenomena.

Very truly yours,

Martin L. Shooman

Martin L. Shooman
Professor of Electrical Engineering
and Computer Science

MLS/jam

New York City:
333 Jay Street
Brooklyn, NY 11201
718-260-3600
FAX 7182603136

Long Island:
Route 110
Farmingdale, NY 11735
516-755-4400
FAX 5167554404

Westchester:
36 Saw Mill River Road
Hawthorne, NY 10532
914-347-6940
FAX 9143476939

APPENDIX B

EXPERIENCE DATA

The information for many of the questions on the questionnaire can be summarized by adding all the responses for the 57 respondents. Rather than create a large set of tables, the data was listed on a copy of the response form which follows in this appendix. The total number of responses are listed to the left of each item. Clearly, there are more responses than 57. For example respondent #1 checked: military pilot, commercial pilot, aerospace engineer, manager, and mechanical engineer in response to question 1.1.

For question 1.1, seven "other" responses were received and are listed on the last line for this section. The notation FAA [2] means that two respondents said they worked for the FAA during some portion of their career. Brackets were used to indicate multiple responses for other questions as well.

In section 4.1 twelve sources were checked, with unknown accounting for five of these responses. Only eight respondents checked a number under "how sure are you of the source of upset": 7,10,7,10,0,0,1,7. The average was 5.3 and the standard deviation 4.3. In some cases respondents checked more than one source and circled an "average surety" or checked one or more sources but left blank the question on surety. Similar comments hold for the other subsections of Sec. 4.0 and 5.0.

1.0 YOUR FIELD OF EXPERTISE

1.1 Your Profession and Employment (Check all that apply)

10	Military Pilot	0	Military Crew Member	0	Military Aircraft Maintenance
13	Commercial Pilot	2	Commercial Crew Member	1	Commercial Aircraft Maintenance
2	NonSched Pilot	0	NonSched Crew Member	1	NonSched Aircraft Maintenance
4	Corporate Pilot	0	Corporate Crew Member	2	Corporate Aircraft Maintenance
10	Aerospace Engineer	22	Electrical Engineer	4	Airframe manufacturer (military)
4	Physicist	1	Mathematician	7	Airframe manufacturer (commercial)
15	Manager	5	Mechanical Engineer	5	Avionics* manufacturer (military)
15	EMI Specialist	4	Government Administrator	10	Avionics* manufacturer (commercial)

7 Other: Aircraft Components Manufacturer
EMC Consultant
Pilot/Crew Member Flight Testing
NASA
FAA [2]
General Aviation Pilot

* Avionics includes instrumentation, navigation, control, etc.

1.2 Total Years of Experience in Your Field:

☐ > 30 years ☐ > 20 years ☐ > 10 years ☐ > 5 years ☐ > 1 year

☐ Other (specify)________________________________

1.3 Types of Aircraft Associated with Your Professional Experience:

Commercial

27	Wide Body	21	Narrow Body	4	Feeder Jets	7	Regional Jets
19	Business Jets	10	Heavy Twin Turboprop	9	Light Twin Turboprop		
0	Airship	7	Single Engine Turboprop	10	Helicopter		

8 Other: IC Engine Prop. Driven
Single Engine Piston
CV 440
L-188 (Electra)
DC-9
B727
Cessna 310
Cessna Aero Commander

Military

20	Fighter	10	Recon	13	Bomber	14	Fighter/Bomber
17	Transport	8	Tanker	0	Airship	10	Helicopter

3 Other: Trainer [2]
PPV

Commercial

6 A300	5 A310	5 A320	4 A330	3 A340	2 A300-600
11 747-100	9 707-720	10 747-200,300	8 747-SP	5 747-400	4 757
12 767	6 777	4 737-200,300	4 737-400	4 737-500	11 727-STD
12 727-LONG	8 MD-80	7 MD-11	2 MD-90	1 DC-8	4 DC-10
0 DC-60	1 DC-SUPER 70	9 DC-9,10,20	2 DC-30,40	12 L1011	

2 Airship 600 [2] 7 Helicopter MBX,206,212,412,214, helicopter [2]

15 Other (specify)__________

Business Jet

5 Cessna Citation I	7 Cessna Citation II	9 Cessna Citation III
5 Gates Learjet 25D,256	6 Gates Learjet 35,36A	3 Gates Learjet 55
4 Gulfstream II	2 Gulfstream IIB	3 Gulfstream III
7 Gulfstream IV	5 Beech Jet 400 II	5 Beech Jet 400 III

18 Other (specify)__________

Turbo Prop

3 Beech Airliner C-99	4 Beech 1900C	4 Fairchild Metro III & V
3 Beech King Air F90-1	7 Beech Super 200,B200	2 Piper Chieftain
2 Piper Mojave	3 Piper 400LS CLEY IIIA	3 Piper Seneca
2 Piper T-1020	3 Piper T-1040	2 Cessna Twin Conquest II
2 Cessna Twin Utiliner 402C	3 Cessna-Chancellor	2 Cessna 421

21 Other (specify)__________

Military/Government

3 F-111	5 F-14	8 F-18	9 Helicopter__________
2 C-5A1B	2 B-52	5 B-1	0 Airship__________

69 Other (specify) __________

2.0 FREQUENCY OF AVIONICS UPSETS* (Check all that apply)

* The term upset is defined to mean any significant deviation from expected behavior which is more than a nuisance and might compromise aspects of the flight.

2.1 Frequency of Upsets:

Estimate the number of incidents, and the numbers of years and flights to the best of your ability. If you have not observed any such upsets enter 0 as the number of incidents since 0 incidents is important data.

☐ Personal Observation as a pilot

☐ Number of incidents _____ ☐ Over _____ years ☐ Covering _____ flights

☐ Personal observation as a crew member

☐ Number of incidents _____ ☐ Over _____ years ☐ Covering _____ flights

☐ Personal observation as a passenger

☐ Number of incidents _____ ☐ Over _____ years ☐ Covering _____ flights

☐ Conversations with others who were personal observers

☐ Number of incidents _____ ☐ Over _____ years ☐ Covering _____ flights

☐ Study of data or reports

☐ Number of incidents _____ ☐ Over _____ years ☐ Covering _____ flights

☐ Study of anecdotal (stories) accounts

☐ Number of incidents _____ ☐ Over _____ years ☐ Covering _____ flights

☐ Other____

2.2 Types of Aircraft Affected by Upset Incidents (Check all that apply):

Commercial

15 Wide Body	14 Narrow Body	2 Feeder Jets	4 Regional Jets
7 Business Jets	8 Heavy Twin Turboprop	3 Light Twin Turboprop	
2 Airship	5 Helicopter	3 Single Engine Turboprop	

3 Other Single Engine Piston [2], Confidential

Military

9 Fighter	2 Recon	3 Bomber	5 Fighter/Bomber
5 Transport	2 Tanker	5 Helicopter	0 Airship

3 Other: Space Shuttle, Special Purpose Transport, Trainer

2.3 Specific Aircraft Affected by Upset Incidents (Check all that apply):

Commercial

2 A300	1 A310	1 A320	0 A330	0 A340	0 A300-600
6 747-100	3 707-720	4 747-200,300	1 747-SP	0 747-400	2 757
3 767	0 777	2 737-200,300	0 737-400	0 737-500	4 727-STD
5 727-LONG	6 MD-80	1 MD-11	0 MD-90	2 DC-8	3 DC-10
0 DC-60	0 DC-SUPER 70	5 DC-9,10,20	0 DC-30,40	7 L1011	
2 Airship________________		3 Helicopter________________			

5 Other: CV580, CV440, Fan Trainer, Diamona, SF-25C

Business Jet

1 Cessna Citation I	1 Cessna Citation II	3 Cessna Citation III
1 Gates Learjet 25D,256	1 Gates Learjet 35,36A	0 Gates Learjet 55
2 Gulfstream II	0 Gulfstream IIB	0 Gulfstream III
0 Gulfstream IV	0 Beech Jet 400 II	0 Beech Jet 400 III

3 Other: Cessna Citation V, BA-125-800, Falcon 900

Turbo Prop

1 Beech Airliner C-99	0 Beech 1900C	1 Fairchild Metro III & V
1 Beech King Air F90-1	0 Beech Super 200,B200	1 Piper Chieftain
1 Piper Mojave	0 Piper 400LS CLEY IIIA	0 Piper Seneca
0 Piper T-1020	0 Piper T-1040	1 Cessna Twin Conquest II
0 Cessna Twin Utiliner 402C	0 Cessna-Chancellor	0 Cessna 421

7 Other: Pilatus PC-9, Piper Malibu (Piston), Beechcraft Bonanza, CU580, ATR43, Dash8, 5340

Military/Government

2 F-111   1 F-14   4 F-18   7 Helicopter Blackhawk, Appache, helicopter [5]
1 C-5A1B   2 B-52   3 B-1   0 Airship________________________
15 Other: A-7, C-130 [2], Army RC-12 Series, Tornado [3], F-15, OV-1D, T-37, T-38, C-17, Classified, F-16, F-4

IF YOU HAVE EXPERIENCED 0 UPSETS OF ANY KIND PLEASE SKIP TO QUESTION 7.

3.0 CONDITION UNDER WHICH UPSETS OCCUR

3.1 Do Such Upsets Occur on:

6 Landing   7 Takeoff   18 Straight and level Flight   8 Ascent   11 Descent
4 Taxing   7 Parked   0 Don't know   0 Formation Flight
5 Low-level Flight   4 Flight Maneuvers   2 Low Traffic   1 High Traffic

8 Other   Earth orbit, ground checkout, EMC test program, cloud penetrations, any condition [2], helicopter ground run [2]

3.2 Under What Weather Conditions:

16 Clear, good visibility   3 Cloudy, medium visibility   5 Rain*, medium visibility
9 Clouds or Rain*, Poor Visibility   11 Not significant   2 Don't know
1 Hot   1 Cold

2 Other: ENC Test program, not important except for lightening

* Or other precipitation

3.3 Level of Avionics Maintenance When Upsets Occurred:

17 Good condition   0 Needed servicing   0 Under service   3 Problems with a particular unit
3 Not significant   3 Don't know   9 Design problem with a particular subsystem

WE WISH MORE DETAILS ON THE NATURE OF THE UPSETS YOU REPORTED IN QUESTION 2.0. PLEASE COMPLETE QUESTIONS 4 AND 5 TO THE BEST OF YOUR ABILITY FOR ALL THE INCIDENTS YOU REMEMBER.

4.0 CAUSE AND EFFECT OF UPSET

4.1 Passenger RFI*

*Radio frequency interference affecting an aircraft system caused by passenger equipment operating inside the aircraft.

Source:

1 AM Radio	0 FM Radio	1 Short Wave Radio	1 Transmitter
1 Computer	0 Tape player/recorder	0 CD Player	2 Air to Ground Phone
5 Unknown or difficult to determine source			

1 Other: Ground Sources

How sure are you of the source of upset? Circle appropriate number: 7,10,7,10,0,0,1,7:
Average = 5.3
Standard Deviation = 4.3

No Idea			Maybe		Possibly		Probably			Certain
0	1	2	3	4	5	6	7	8	9	10

How do you know the source?____

System or subsystem affected:

3 Autopilot	0 Panel Lights	0 Cabin Lights	2 Communications Equipment
4 Navigation equipment	0 Flaps	0 Spoilers	0 Landing Gear (Auto Braking/Anti Skid)
0 Engine Controls	0 Rotor Controls	2 Instrumentation	0 Airship Gas Lift Controls
0 Window Heat	1 Intercom	0 Ailerons	1 Cabin Pressure & Temperature
0 Rudder	0 Elevators	0 Nose Wheel Steering	
1 Other: Radio			

How sure are you of the affected system or subsystem? Circle appropriate number: 10,10,9,10,10,0,2,10:
Average = 7.6
Standard Deviation = 4.1

No Idea			Maybe		Possibly		Probably			Certain
0	1	2	3	4	5	6	7	8	9	10

How do you know the system/subsystem? Saw and heard oxygen masks deployed

4.2 Onboard RFI**

** Radio frequency interference caused by one on board system affecting the operation of another on board system.

Source:

14 VHF-UHF Transmitter	13 High Frequency Transmitter	9 Radar
7 Countermeasures Equipment	5 Power Source	2 Intercom
5 Navigation Equipment	4 Computer	4 Unknown

7 Other (specify)____

How sure are you of the source of upset? Circle appropriate number: 9,10,10,10,10,7,10,10,7,10,9,10,10, 10,6,10,10,10,9,10,10,10,0,3,9,9,10,10,

Average = 8.8
Standard Deviation = 2.4

No Idea			Maybe		Possibly		Probably			Certain
0	1	2	3	4	5	6	7	8	9	10

How do you know the source?____

System or subsystem affected:

9 Autopilot	0 Panel Lights	0 Cabin Lights
19 Communications Equipment	14 Navigation equipment	0 Flaps
0 Spoilers	0 Automated Landing Gear	2 Engine Controls
1 Helicopter Rotor Controls	0 Airship Gas Lift controls	10 Instrumentation

7 Other (specify)____

How sure are you of the affected system or subsystem? Circle appropriate number: 9,9,10,6,10,10,9,10,9,10,10,6, 10,10,10,10,10,10,0,3,9,10,10,10:

Average = 8.8
Standard Deviation = 2.5

No Idea			Maybe		Possibly		Probably			Certain
0	1	2	3	4	5	6	7	8	9	10

How do you know the system/subsystem?____

4.3 External RFI***

*** Radio frequency interference from a source outside the aircraft (another aircraft, a ship, a ground installation, etc.) which affects systems within the aircraft (often called HIRF).

Source:

1 Commercial AM Transmitter
6 Voice of America Transmitter
6 Military Radar
2 Landbased military radar
2 Hand-held (Walkie-Talkies)
0 Air Mobile Transmitter
3 Commercial FM Transmitter
1 Air Traffic Control Radar
5 Shipboard military radar
0 Unknown
0 Airport Fixed Transmitter
2 Commercial Short Wave Transmitter
0 Weather Radar
1 Airborne military radar
0 VLF/LF Transmitter
0 Car Mobile Transmitter

3 Other: ECM and Jammer Equipment, Confidential reports

How sure are you of the source of upset? Circle appropriate number: 7,10,10,10,4,8,10,10,10,10,6,9,10,10:
Average = 8.9
Standard Deviation = 1.9

No Idea			Maybe		Possibly		Probably			Certain
0	1	2	3	4	5	6	7	8	9	10

How do you know the source?______________________________

System or subsystem affected:

4 Autopilot
6 Communications Equipment
0 Spoilers
3 Helicopter Rotor Controls
1 Panel Lights
4 Navigation equipment
2 Automated Landing Gear
0 Airship Gas Lift controls
0 Cabin Lights
0 Flaps
4 Engine Controls
4 Instrumentation
0 Other______________________________

How sure are you of the affected system or subsystem? Circle the appropriate number: 10,10,10,3,10,10,10,6,10,10,10:
Average = 9.0
Standard Deviation = 2.3

No Idea			Maybe		Possibly		Probably			Certain
0	1	2	3	4	5	6	7	8	9	10

How do you know the system/subsystem?______________________________

4.4 Lightning

Source:

5 Electrostatic Discharge (ESD)
14 Strike-Airborne
3 Strike-Ground
6 Strike-Indirect
5 St. Elmo's Fire

Other (specify)________________________________

How sure are you of the source of upset? Circle the appropriate number: 10,7,6,10,10,9,10,10,7,10,7,10,10,10,10,10, 7,10,10,9,10,10,8,10:
Average = 9.2
Standard Deviation = 1.3

No Idea			Maybe		Possibly		Probably			Certain
0	1	2	3	4	5	6	7	8	9	10

How do you know the source?________________________________

System or subsystem affected:

7 Autopilot
0 Panel Lights
2 Cabin Lights
10 Communications Equipment
11 Navigation equipment
0 Flaps
0 Spoilers
0 Automated Landing Gear
2 Engine Controls
0 Helicopter Rotor Controls
0 Airship Gas Lift controls
9 Instrumentation
0 Other (specify)________________________________

How sure are you of the affected system or subsystem? Circle the appropriate number: 10,6,10,10,7,10,8,10,10,7,9, 10,10,10,10,7,10,10,10,8:
Average = 9.1
Standard Deviation = 1.4

No Idea			Maybe		Possibly		Probably			Certain
0	1	2	3	4	5	6	7	8	9	10

How do you know the system/subsystem?________________________________

4.5 Equipment Failure

Source:

9 Intermittent
12 Transient
8 Hard Failures
0Electrostatic Discharge
0 Other________________________________

How sure are you of the sources? Circle the appropriate number: 7,5,8,7,9,10,7,10,10,0,10,8,10,10,3,10,4,7,10,10,6, 10: Average = 7.8
Standard Deviation = 2.8

No Idea			Maybe		Possibly		Probably			Certain
0	1	2	3	4	5	6	7	8	9	10

How do you know the source?____

System or subsystem affected:

6 Autopilot	1 Panel Lights	0 Cabin Lights
6 Communications Equipment	7 Navigation equipment	0 Flaps
0 Spoilers	0 Automated Landing Gear	7 Engine Controls
1 Helicopter Rotor Controls	0 Airship Gas Lift controls	9 Instrumentation

Other (specify)____

How sure are you of the affected system or subsystem? Circle the appropriate number: 7,5,10,7,10,6,10,8,10,10,7,3, 10,6,10:

Average = 7.9
Standard Deviation = 2.3

No Idea			Maybe		Possibly		Probably			Certain
0	1	2	3	4	5	6	7	8	9	10

How do you know the system/subsystem?____________________________________

4.6 Unknown Source

System or subsystem affected:

5 Autopilot	2 Panel Lights	0 Cabin Lights
5 Communications Equipment	4 Navigation equipment	2 Flaps
0 Spoilers	2 Automated Landing Gear	3 Engine Controls
0 Helicopter Rotor Controls	0 Airship Gas Lift controls	3 Instrumentation
1 Other: Flight Controls		

How sure are you of the affected system or subsystem? Circle the appropriate number: 9,10,8,9,8,10,6,10:

Average = 8.8
Standard Deviation = 1.4

No Idea			Maybe		Possibly		Probably			Certain
0	1	2	3	4	5	6	7	8	9	10

How do you know the system/subsystem?____________________________________

4.7 Cause of Upset

Estimate What Percentage of All the Upsets are Due to:

Passenger RFI__________	Lighting__________
Onboard RFI__________	Equipment Failure__________
External RFI__________	Unknown Source__________

Other (specify)____

5.0 CRITICALLY OF UPSETS

5.1 Passenger RFI

How Critical Are The Upsets Due to Passenger RFI: 4,2,4,3,2,5,2,2,5,4,2:
Average = 3.2
Standard Deviation = 1.3

Normal		Nuisance		Concern		Emergency Procedures		Injuries Damage		Catastrophic Total Loss
0	1	2	3	4	5	6	7	8	9	10

Comment: Could be a 10 on a CAT III approach.

5.2 Onboard Systems RFI

How Critical Are The Upsets Due to Onboard RFI: 3,6,3,2,5,2,5,3,5,4,2,4,3,4,2,4,5,2,10,10,2,2,4,5,10,7,5,4,0,10,6:
Average = 4.5
Standard Deviation = 2.6

Normal		Nuisance		Concern		Emergency Procedures		Injuries Damage		Catastrophic Total Loss
0	1	2	3	4	5	6	7	8	9	10

5.3 External RFI (HIRF)

How Critical Are The Upsets Due to External RFI (HIRF): 5,6,5,2,8,5,10,7,2,4,1,10,1,5,10,8,4,10,4,4,10,4:
Average = 5.7
Standard Deviation = 3.0

Normal		Nuisance		Concern		Emergency Procedures		Injuries Damage		Catastrophic Total Loss
0	1	2	3	4	5	6	7	8	9	10

5.4 Lightning

How Critical Are The Upsets Due to Lighting: 6,5,6,2,6,2,6,4,6,6,2,3,5,6,10,8,4,4,4,5,10,8,10,5,4,5,10,7:
Average = 5.7
Standard Deviation = 2.4

Normal		Nuisance		Concern		Emergency Procedures		Injuries Damage		Catastrophic Total Loss
0	1	2	3	4	5	6	7	8	9	10

5.5 Avionics Equipment Failure

How Critical Are The Upsets Due to Avionics Equipment Failure: 2,6,5,6,5,4,6,5,8,5,2,3,5,1,4,6,2,2,6,4,5,10,8,4,5,10: Average = 5.0
Standard Deviation = 2.3

Normal		Nuisance		Concern		Emergency Procedures		Injuries Damage		Catastrophic Total Loss
0	1	2	3	4	5	6	7	8	9	10

5.6 Unknown Source

How Critical Are The Upsets Due to Unknown Sources: 2,4,6,4,6,4,10,3,5,4,5,2,5,10,4,4,3,4,2,6:
Average = 4.7
Standard Deviation = 2.2

Normal		Nuisance		Concern		Emergency Procedures		Injuries Damage		Catastrophic Total Loss
0	1	2	3	4	5	6	7	8	9	10

APPENDIX C

STATISTICAL RELATIONSHIPS

C.1 Introduction

In the case of large samples, $(n > 100)$, simple computations of means and standard deviations are probably sufficient for the objectives of this study. If the sample size is small, $(n < 10)$, means and deviations suffice, however, there will probably be considerable dispersion of the data. When the sample size is between these two extremes, some additional sophistication in statistical analysis is warranted. Two such statistical tools will be used in a few cases in this report, correlation and rejection of outliers. These methods are briefly introduced in the following two sections.

C.2 Correlation Calculations

Sometimes two sets of data are assumed to be related (based on hypothesis, prior results, etc.) and we wish to study the validity of the assumption. For example, suppose we wish to study the relationship between the grades of a group of n students on the midterm exam $(x_1, x_2, \ldots x_n)$ and the grades on the final exam $(y_1, y_2, \ldots y_n)$ in a course. If we plot the grades for each student on a set of Cartesian coordinates, we can study the degree of correlation. If the grades are highly correlated, then they would approximately fall on a straight line through the origin at 45 degrees. The degree of correlation can be measured by computing the sample correlation coefficient r. Perfect correlation is $r = 1$, where the points all fall on the 45 degree line. If $r = 0$, there is no correlation and the points fall on a horizontal straight line. We can develop a formula for r in terms of various moments of x and y, [Crow 1960, Freund 1973].

We begin by listing the following well known moment formulas:

$$\text{mean of } x = \overline{x} = \frac{1}{n}\sum_{i=1}^{n} x_i \tag{C.1}$$

$$\text{mean of } y = \overline{y} = \frac{1}{n}\sum_{i=1}^{n} y_i \tag{C.2}$$

standard deviation of x = S_x =

$$\sqrt{\sum_{i=1}^{n} (x_i - \overline{x})^2/n^2} \qquad \text{(C.3)}$$

Expansion of Eq. (C.3) and simplification leads to another form which is computationally simpler:

$$S_x = \sqrt{\left[n\sum_{i=1}^{n} x_i^2 - \left(\sum_{i=1}^{n} x_i\right)^2\right] \Big/ n^2} \qquad \text{(C.4)}$$

And similarly for y

$$S_y = \sqrt{\left[n\sum_{i=1}^{n} y_i^2 - \left(\sum_{i=1}^{n} y_i\right)^2\right] \Big/ n^2} \qquad \text{(C.5)}$$

The covariance of x and y is defined as

$$\text{cov}(x,y) = \left[\sum_{i=1}^{n} (x_i - \overline{x})(y_i - \overline{y})\right] \Big/ n^2 \qquad \text{(C.6)}$$

If the formulas are corrected for bias [see Shooman 1990, p.83, Crow 1960, p. 12], the denominators in Eqs. C.4,5,6 become (n)(n-1) instead of n^2, which is an important correction for small sample sizes. The sample correlation coefficient is defined as the ratio of the covariance to the product of the standard deviations.

$$r = \text{cov}(x,y)/S_x S_y \qquad \text{(C.7)}$$

A BASIC program was written based on these formulas to compute the means, standard deviations, and correlation coefficient for the data in this report.

Clearly, correlations of 0.98 and 0.99 represent high correlations and those of 0.05 and 0.1 represent very low correlation. However, how are we to interpret values in between. Freund [p. 427] gives a useful test of the hypothesis that samples are correlated vs. the null hypothesis that they are uncorrelated. It can be shown that acceptance of the null hypothesis is governed by the t distribution where:

$$t = r\sqrt{n-2} \Big/ \sqrt{1-r^2} \tag{C.8}$$

and the t distribution has n-2 degrees of freedom. The quantity n is the number of samples in the correlation analysis. For the correlation calculations in Table 6.5, n = 6 and solving Eq. (C.8) for r yields:

$$r = t/\sqrt{4+r^2} \tag{C.9}$$

From the t distribution table [Freund, p.], for n - 2 = 4 degrees of freedom and a confidence level of 10%, the value of t = 1.533. Substitution in Eq. (C.9) yields a value for r of 0.608. The conclusion is that responses in Table 6.5 with a value of r >= 0.608 have a probability of 0.1 or less of having occurred by chance from uncorrelated data. Thus, we will consider responses with r >= 0.608 as significantly correlated.

C.3 Statistical Rejection of Outliers

In many cases one value in a set of n data values (x_1, x_2, ...,x_n) seems to be too large (small) as compared with the remaining body of data. Of course there is always a probability that the point in question does belong to the distribution represented by the other (n-1) values, and is only an extreme data point. Thus, it is useful to devise statistical tests which determine the probability that all the n values belong to the same distribution (the working hypothesis, H) as opposed to the probability that the one large value belongs to a different distribution then the other (n-1) values (the alternate hypothesis, $\overline{H}$).

The test statistic which is used in many such tests is best explained by assuming that the n observations are arranged in ascending order, where x_1 is the smallest and x_n the largest (i.e. the value in question). [Barnett, p. 52] We then compute a test statistic T = (numerator)/(denominator) = N/D. The numerator is a measure of the separation of the n'th observation from the remainder of the sample, and the denominator is a measure of the spread of the sample. As an example, for N one might consider the separation between samples n and (n-1), i.e. x_n - x_{n-1}, and for D the range of the group, x_n - x_1. This is only illustrative, and other choices for N and D are possible.

In Barnett [Sec. 3.4.2], 16 tests for outliers (also called discordancy) in a set of gamma (including exponential) samples are presented. If we assume that the time of occurrence of an EMI event is exponentially distributed, then Epstein [1953] has shown that the sampling distribution of the occurrence rate (occurrences/hour) is chi-square. This result should also apply to the frequency/year and the frequency/flight values given in Table 6.8. It is also true that the gamma distribution becomes the chi-square distribution when the gamma parameter β = 2. Thus we can use one of Barnett's gamma tests with β = 2 to test the data of Table 6.8 for outliers.

The outlier test we will use from Barnett sets T = outlier value/sum of observations,

$$T = x_n \Big/ \sum_{i=1}^{n} x_i$$

The test leads to a procedure where the test statistic is compared with values from an F distribution table. We illustrate the procedure by testing the data in Table 6.8. Suppose that we suspect that the value of 32.4 for respondent #27 is an outlier among the other values of frequency of occurrence given in the table. Computing T we obtain

$$T = 32.4/(0+0+0+0.61+....+10+32.4)$$

$$T = 32.4/60.93 = 0.5318$$

The critical value for 99% probability of an outlier (1% critical value) is given on page 290 of Barnett for β =2 and n = 12 is 0.3428 < 0.5318. Thus, 32.4 is much too high to be considered from the same distribution as the other 11 respondents and should be dropped. We can now test the next largest value, 10, to see if it should be included with the other 10 values. Calculating our new T = 10/(60.93 - 32.4) = 0.3505 we see that this is less than 0.3681, the 1% critical value obtained by interpolation from the table, thus we accept the value of 10.

We can use this same test on the data in the frequency per year column of Table 6.8 to test weather respondent #23's value of 5.0 is an outlier.

$$T = 5/(0+0 + ... + 2.0+5.0) = 5/10.55 = 0.4739$$

The value given in the table for n= 15 is 0.2882. (The correct value for n = 16 could be obtained by interpolation values in the table and would be slightly smaller). Thus, the value of 5 should be rejected. Continuing as before, we now test the next value which is 2. The new value of T = 2/(10.55 - 5) = 0.3604 > 0.2882, thus 2 is also rejected. Testing the third value, 1, we have T = 1/(5.55 - 2) = 0.2817 < 0.2882, (the correct value for n = 14 could be obtained by interpolation values in the table and would be slightly larger), thus this value should be accepted. The means and standard deviations are recalculated after dropping the rejected values and the results appear in the footnotes to Table 6.8.

C.4 Interval Estimates

To establish an interval estimate on statistical data one must first know the probability distribution of the estimate. We have assumed that all the occurrence rates were constant. (There is no reason to believe otherwise, and there is insufficient data to support models with a varying occurrence rate). It has been shown by Epstein [1953] that the sample distribution for a constant occurrence rate has a chi-square (χ^2) distribution. Specifically $2r = 2nT\lambda$ has a chi-square distribution, where r is the number of observed occurrences, n is the size of the observed population, T is the length of the observation period, and λ is the occurrence rate, where the lower confidence band has 2r degrees of freedom and the upper confidence bound has 2r + 2 degrees of freedom. Simple charts have been computed where the multiplier of the mean time between occurrences at the upper and lower conficence levels is plotted versus r for various confidence levels, [see Shooman 1990]. From these charts we find that for 10 occurrences of HIRF for pilots, the 80% confidence interval for the mean time between occurrences is 0.7 × mean to 1.7 × mean. Since the occurrence rates are the reciprocal of the mean time between occurrences, the required multipliers are the reciprocals of 0.7 and 1.7, ie. 0.59 and 1.43. Thus for pilot HIRF occurrence rate of 0.53/thousand, the interval estimate becomes 0.53/1.7 = 0.31 and 0.53/0.7 = 0.76. Similarly for the 4 occurrences of HIRF for passengers, the occurrence rates become 0.56/2.2 = 0.25 to 0.56/0.6 = 0.93.

APPENDIX D - DESCRIPTION OF EVENTS

If we examine Table D.1 we see that 24 of the 57 respondents provided event descriptions in Sec. 6.0. I have reproduced these descriptions verbatim in Table D.1. Note that if a respondent described three events they are listed as Event 1, Event 2, Event 3.

TABLE D.1 DESCRIPTION OF EVENTS (see Sec. 6)

Response #	Source [1]	Description
1	PO	Event 1: Space shuttle. Intermittent static on air-to-ground communications channels over certain parts of the earth. Occurs particularly over eastern Europe and parts of the former Soviet Union. Event 2: Minor interference from shipboard radar on aircraft carrier flight deck. Manifested by noise in communications systems. No system degradation. Event 3: Lightning strike associated with flight near thunderstorms. Temporary loss of comm/nav equipment. All equipment recovered following initial surge.
6		Event 1: CRT screen ripple, caused by using cargo aircraft (modified) hull as neutral (return) for 115VAC L-N 30 4wire 400HZ power. Event 2: DC BUS noise due to DC toilet pump motor on a bomber. Event 3: Headset noise due to DC motor for turret of Chaff dispenser of a fighter. Not really a problem.
11	PO, SP	Event 1: Narrow body jet ELU failure; several events: passing tangential at ~20km a commercial HF transmitter (12-20 MHz) on different sides, as well in low altitude as on the airway at FL 90 in VMC the ELU failed and the related C/B tripped. Inflight reset. Action: detailed evaluation; system and installation hardened. Event 2: Autopilot malfunction commuter airliner: (Gander frequency) Transmitting of onboard HF equipment resulted in severe A/P oscillations. Evaluation showed entry of RF through installed broadcast radio receiver to interfere with A/P system. Action: A/C manufacturers modifications resulted in reduction of the effect to slight rumbling. Event 3: ILS equipment malfunction; business transport in IMC, rain, thunderstorms in vicinity: established on ILS, A/P coupled system 1+2 showed zero track deviation, no flag, static noise in VHF COM intermittent. Becoming VMC at ~ LOC only minimum vis. reference show ~80-100 ft. below GS and on LOC followed by a quick LOC/GS flag on 1 system. Manual A/P disconnect, all indications normal at landing. Event 4: Flying around an embedded build up in heavy rain with a business transport. the fuel flow (electrical) indication failed (zero reading). no effect on engine function or sound. Emg. fuel pump procedure show no effect, fuel flow remain zero for approx. >10 min. Event 5: Engine failure, business transport: ~10 min after Event 4, IMC, established on the ILS for GVA airport a ~6500 ft, the engine quit, windmilling propeller, zero thrust, no sound beside airflow, ff still zero. Restarting emg. procedure unsuccessful. At ~4000 ft in VMC, during emg. landing procedure sudden restart of the engine, normal performance, all readings incl. FF normal. Evaluations of engine, fuel system, instr. systems show no abnormalities. Event 6: Unmotivated A/P disconnect, business transport: 2 events VMC, Cu's ~5km in 1 case, cruise at FL80. Both events in the same area, about 10km inbetween locations, timely interval ~6 int. Locations ~30 km from commercial HF transmitter (10-20 MHz). In stable cruise, sudden A/P disconnect resulting in ~5° pitch down. (alt. hold mode). Inflight reset successful, not reproducible.
13	PO (During EMC Ground & flight Testing)	Event 1: When the HF transmitter was keyed during EMC testing the autopilot would indicate a rolling dive. Traced to electrical grounding problem of the HF power amplifier. Recommend use of SAE ARC-1870 grounding and Bonding, Electrical for Aircraft. Event 2: Intermodulation problem - commercial FM station and on board VHF transmitter - mixing in another VHF receiver. The problem was traced to oxidized exhaust parts forming a non-linear detector/mixer.
14	PO, SP, SD	Event 1: Wide body descending ~10,000 ft. through thunderstorm received lightning strike in Port wing. Cabin lights and 1 engine shut down. Pilot took action to reset auto pilot. All damage appeared initially to be temporary. Near Atlanta, GA. Event 2: Helicopter reported interference to Auto Pilot and rotor controls in vicinity of Navy Ship with high power. Problem associated with cable pick up of R.F. Same problem identified several times.

TABLE D.1 DESCRIPTION OF EVENTS (see Sec. 6)

Response #	Source [1]	Description
15	PO, SP, SD, O	Event 1: Wide and narrow bodies - Threats were from military aircraft outside U.S. airspace. Event 2: Helicopter, threats were Russian ship radar in open sea and illegal CB radio (high power) in Southern U.S. Event 3: Airship (blimp), ignition on the ponsch engine used for pwn. Event 4: Light transport, TV station interference with radios over Oakland, CA. Freq. 108.2 MHz. Event 5: Combat aircraft, threat was VOA on border between Russia and W. Germany Event 6: Portable tape player/upset duplicated in aircraft manufacturer's labs. ILS Receiver. Radio frequency interference effecting an aircraft system caused by passenger equipment operating inside the aircraft. Event 7: Countermeasures Equipment on military airplanes effecting systems on commercial aircraft in vicinity. Event 8: High frequency transmitter effects autopilot on a narrowbody. Event 9: Instrument panel light circuit affecting magnetic compass. Fix was to reroute supply wires and place aluminum foil around glare shield and shield supply wires. Event 10: Sources: Voice of America transmitter, military radar, shipboard military radar, ECM & jammer equipment. Effects: communications equipment in headset from VOA, Helicopter flight controls, Panel lights - brake warning, windshield heat, automated landing gear-brake, ECM equipment. Event 11: Lightning on ground strike ADF & VOR effected. There is an Air Force report of a missle being fired due to lightning; there is a NASA report of sounding rocket being launched due to lightning.
16		Event 1: Aircraft modified to install HF transceiver. When transmitter keyed control surfaces moved. Modulation on the HF carrier coupled to flight control wiring. Found during pre-flight safety checks. Event 2: Aircraft struck by lightning. Pitol static probe heater wiring carried current to main structure. Heater wire burned in to causing radar radome to burst. Aircraft landed safely. Event 3: Promity switches failed on landings. Landing gear prox switches were susceptible to HIRF (field levels 1700 v/m). Switch qualified to 200 v/m.
17	PO	Event 1: Within 10 min of take-off the passenger cabin oxygen masks deployed, estimated altitude ~ 10-11,000 ft. Pilot opted to return to airport and passengers were transferred to another flight. No injuries or trauma resulted as the aircraft was approximately on 25% occupied during the event.
18	PO	Event 1: Pilot complaint: when keyed UHF radio radar antenna slued violently making A/C difficult to handle. I observed the problem by operating the UHF whenthe radar system and antenna was active. It was discovered the antenna syncros were susceptible to the UHF radio. A fix was installed. The incidents have not recurred in the last 10 years.
21	PO, SP, SD	Event 2: During 8.4,5,6,7, used experimental aircraft to make lightning cloud penetrations into thunderstorms. When struck wx radar normally went blank and in 1 or 2 sweeps, returned to normal oper. during exercise, normally had radio static.
22	PO. SP	Event 1: ~60% of the problems we have experienced at Boeing have been due to coupling of the HF communications transmitted signal into unshielded signal lines on the vehicle. This results in digital signal upset and noise in audio circuits. This is basically due to the aircraft and its cabling being resonant at these frequencies. Event 2: ~35% of the problems we have experienced have been due to low frequency (i.e. 400 Hz) coupling into audio circuits. Again primarily due to poor wiring practices (twisting, shielding, roofing, etc.). With the use of modern digital audio systems these problems have diminished considerably. Event 3: Most passenger accommodation systems (i.e. cabin lights, call buttons, intercom, etc.) are not designed to withstand lightning strike transient without malfunction. In fact on most aircraft only flight essential avionics will survive a lightning strike without a transient performance interruption. This is probably proper cost-effective design.

TABLE D.1 DESCRIPTION OF EVENTS (see Sec. 6)

Response #	Source [1]	Description
23	PO	Event 1: In over 20 years of flying flight tests of avionics I have observed many cases of interference to many different radio systems from other on-board equipment and external RFI from AM, FM, and television stations.
		Event 2: While flying in southeastern Georgia in IFR conditions in an aircraft without weather radar, I got into an embedded thunderstorm with nearly continuous lightning discharges all around the aircraft. At this time the engine driven alternator quit, the ammeter went to zero. In about 2 minutes (it seemed much longer) I had passed through the thunderstorm cell and broke out into clear air. I landed to get the alternator fixed and maintenance found all the diodes in the alternator burned out.
24	PO	Event 1: (All 3 incidents were basically the same and as described as Event 1 below): light transport in normal cruise at +30,000' alt. Weather radar was turned on and working properly. Whenever an in-flight phone call was made, weather radar would either blank it's display or paint the entire display a solid color. As soon as the phone call was completed, radar display would return to normal.
27	PO. SP, SD	Event 1: Turbo fan transport/rotation at takeoff/Teterboro, NJ/daytime low overcast/ maint. assumed good - new a/c unreliable symbol generator source-to-display tube select logic/condition reproduced on bench and analyzed/effect was total loss of all primary displays in critical flight regime/a/c entered IFR in this condition - crew had to return for landing on standbys - did not think or know to cycle breakers which clears problem.
		Event 2: Turbo fan transport/level cruise/(other than cruise) unknown flt. conditions/ unknown location/unknown weather/assumed good maint. - new a/c/two different avionics units connected to central comm. data bus went unstable in their bus interface hardware and caused bus to be "blinded"/faulty units were returned and tested/analyzed/effect was rapid and intermittent loss of displayed parameters, air data parameters, loss of auto pilot, multiple and rapid data fail flag oscillations/pilot loss of confidence in primary displays while bus is blinded - had to resort to standbys, essential level no no .
		Event 3: Bomber/level cruise/ northern US/ clear wx/ assumed good maint/ YAW damper channel induced rudder kicks/ YD replaced which solved problem/effect was intermittent and sometimes severe kicks of rudder (and pedals). YAW damper had to be powered down/criticality...? Maybe could have damaged vert stab, rudder or fuselage, but kicking pedal liked to smash knees into the yoke!
30	SP. SD	Event 1: Twin-turbo prop transport, take-off, Puerto Rico, good weather, good maintenance, trim out of whack on aileron caused by pilot error, caused severe roll and loss of altitude. Pilot was able to regain control, but a crash was certain!
32	PO	Event 1: Many examples of intrasystem and intersystem EMI during EMC and EMV tests.
33	PO	Event 1: Too difficult a task for 15,000 flight hours.
34	PO	Event 1: Lightning strike narrowbody knocked out all F/O instruments plus several electrical busses. Aircraft near thunderstorm in Kansas. Most instruments eventually restored.
		Event 2: Failure of all navigation instruments. Electrical bus failures at night in level light. Cockpit near totally dark. Some instruments later restored. Fortunate this was night VFR.
		Event 3: Auto land in narrowbody. A/C pitched down violently (nose down) just as flare initiated. Day VFR. PHL airport.
37	PO	Event 1: Had White House Secret Service agents on board w/special telephone. They called White House after notifying me - no problems with any instruments on board my aircraft during telephone usage.
		Event 2: I've had lightning strikes on a few occasions - no troubles of any kind after strikes.
38	PO	Event 1: 4.2 RFI incident: wide body a/c. Happened about 4:30 in to an 8:00 flt., when using #1 HF to make enroute position report. Tried other HF - did not occur. I attributed it to shielding on #1 HF transmitter lead to common antenna breaking down, after use for several hours. This happened just last month, Ist of my experience.
40	SP	Event 1: Narrowbody banked sharply and dropped 20,000'.

TABLE D.1 DESCRIPTION OF EVENTS (see Sec. 6)

Response #	Source [1]	Description
54	PO, SP	Event 1: HF transmissions corrupted engine oil pressure sensor output data (weather & flight conditions were irrelevant). Established cause: oil pressure sensor susceptible to HF RF-fields. The problem led to an imposed operational limitation on the use of HF-comm. Pending a final solution. The problem has highlighted a potential HIRF problem if left unsolved. Solution has been to implement interface filtering at sensor.
		Event 2: Ground maintenance crew using hand-held UHF-comm. transmitters caused upset to elevator feel control system. EFC showed susceptible to UHF RF-fields. These could cause nuisance fault status-indication and reposition the system. This would lead to flight deck annunciated alerts. Solution was to implement interface filtering at connector.
		Event 3: Airflow in engine air intake duct (a plastic part) led to ESD discharges, caused by air and/or rain particles impacting on/in the duct. Subsequent ESD discharges caused upset to engine anti-ice system sensors in the duct, leading to occasional degraded functioning of the engine anti-ice system. Consequently in accordance with flight procedures aircraft must evade icing conditions upon a deicing fault annunciation. Problem was solved by an improved bonding of the air duct, which prevents a charge build up.
55	PO	Event 1: During descent into a very busy airport (ORD) all electronic displays onboard abruptly dumped! The aircraft twin-turbofan airliner has extensive electronics and all of them died except for backup controls and indicators. The aircraft remained controllable due to redundancy and the weather was clear. Had the weather been bad and had we been in the transition phase of flight (from approach to landing) the situation would've become dangerous.
		Event 2: During descent phase into an airport heavy thunderstorm activity surrounded the aircraft. We were penetrating an area of little or no activity but had cells in close proximity. The area had nearly continuous discharge but no affect was observed on the aircraft. Suddenly we were subjected to a discharge very nearby. The lightning did not strike the aircraft but our weather radar blanked it's current sweep, then resumed but left the first portion of it's screen blank until the return sweep. Subsequent operation was normal.
56	PO	Event 1: HF transmitter interference into autopilot caused up to 75% travel of collective varied with pitch of modulating voice and transmit frequency caused by poor design which installed autopilot junction block in vicinity of HF antenna coupler on UH-IN - potentially very dangerous.
		Event 2: HF transmitter interference with analog engine governor controls caused engine to surge. Varied with frequency, unaffected by extra modulation. UHF common interference with instruments, erp fuel qty. Panel lights interfere with instr, due to common ground.
		Event 3: P-STATIC buildup (esp during operation in snow or sand) has caused loss of comm and nav capability per several reliable operator reports.

1. PO = Personal Observation; SP = Report from a Second Party; SD = Study of Data; O = Other.

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13. ABSTRACT *(Maximum 200 words)*

This report presents the methodology and results of a subjective study done by Polytechnic University to investigate Electromagnetic Interference (EMI) events on aircraft. The results cover various types of EMI from on-board aircraft systems, passenger carry-on devices, and externally generated disturbances. The focus of the study, however, was on externally generated EMI, termed High Intensity Radiated Fields (HIRF), from radars, radio and television transmitters, and other man-made emitters of electromagnetic energy. The study methodology used an anonymous questionnaire distributed to experts to gather the data. This method is known as the Delphi or Consensus Estimation technique. The questionnaire was sent to an expert population of 230 and there were 57 respondents. Details of the questionnaire, a few anecdotes, and the statistical results of the study are presented.

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