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Personal Electronic Devices and Their Interference With Aircraft Systems

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June 2001

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ABSTRACT

A compilation of data on personal electronic devices (PEDs) attributed to having created anomalies with aircraft systems. Charts and tables display 14 years of incidents reported by pilots to the Aviation Safety Reporting System (ASRS). Affected systems, incident severity, sources of anomaly detection, and the most frequently identified PEDs are some of the more significant data. Several reports contain incidents of aircraft off course when all systems indicated on course and of critical events that occurred during landings and takeoffs. Additionally, PEDs that should receive priority in testing are identified.

TABLE OF CONTENTS

INTRODUCTION

The objective of this report is to identify and compile incidents of aircraft systems' anomalies attributed to the use of onboard personal electronic devices (PEDs). It is intended this data highlight the need for additional research to resolve these types of anomalies as a contribution to aviation safety.

NASA Langley initiated this data compilation as part of a survey activity supporting it's comprehensive program to characterize the effects on aircraft flight systems of electromagnetic (EM) disturbances which can arise from sources such as PEDs, of high intensity radiated fields (HIRF), and of lightning. The effects of lightning or HIRF on aircraft systems are not addressed in this paper.

This report is based on the Aviation Safety Reporting System's (ASRS) database.[1] The charts and tables represent the fields recorded in those reports and the year the incident was reported. Including the years in the charts and tables permits a degree of flexibility for the reader to align this report with aviation industry related events not contained in the ASRS Database.

It is beyond the scope of this report to define specific procedures for resolving the PED issue, but some suggestions are included on which devices to test. This report's intent is not to imply that any of the anomalies addressed here are unique to any specific air transport company, aircraft manufacturer, aircraft system's manufacturer, PED manufacturer or flight crewmember. Any mention of a PED by manufacturer's name and or model is directly derived from the ASRS' report narrative.

Before proceeding it is essential to understand how the ASRS program collects and manages its data and what the limitations are on using the data. Following are two quotes from the data provided by the ASRS:

Overview

> The Aviation Safety Reporting System (ASRS) was established in 1975 under a Memorandum of Agreement between the Federal Aviation Administration (FAA) and the National Aeronautics and Space Administration (NASA). FAA provides most of the program funding; NASA administers the program and sets its policies in consultation with the FAA and the aviation community. NASA has chosen to operate the program through a contractor selected via competitive bidding. The current contractor is Battelle Memorial Institute.
>
> The ASRS collects, analyzes, and responds to voluntarily submitted aviation safety incident reports in order to lessen the likelihood of aviation accidents. ASRS data are used to: identify deficiencies and discrepancies in the National Aviation System (NAS) so that these can be remedied by appropriate authorities; support policy formulation and planning for, and improvements to, the NAS; [and] strengthen the foundation of aviation human factors safety research. This is particularly important since it is generally conceded that over two-thirds of all aviation accidents and incidents have their roots in human performance errors.
>
> Pilots, air traffic controllers, flight attendants, mechanics, ground personnel, and others involved in aviation operations submit reports to the ASRS when they are involved in, or observe, an incident or situation in which aviation safety was compromised. All submissions are voluntary.

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[1] ASRS Reports: Quick Response # 271, November 30, 1994 and Search request # 5532, January 27, 1999; ASRS Office, 625 Ellis Street, Suite 305, Mountain View, California 94043; Telephone (650) 969-3969.

Reports sent to the ASRS are held in strict confidence. More than 300,000 reports have been submitted to date and no reporter's identity has ever been breached by the ASRS. ASRS de-identifies reports before entering them into the incident database. All personal and organizational names are removed. Dates, times, and related information, which could be used to infer an identity, are either generalized or eliminated.

The FAA offers ASRS reporters further guarantees and incentives to report. It has committed itself not to use ASRS information against reporters in enforcement actions. It has also chosen to waive fines and penalties, subject to certain limitations, for unintentional violations of federal aviation statutes and regulations that are reported to ASRS. The FAA's initiation, and continued support of the ASRS program and its willingness to waive penalties in qualifying cases is a measure of the value it places on the safety information gathered, and the products made possible, through incident reporting to the ASRS.

Incident reports are read and analyzed by ASRS's corps of aviation safety analysts. The analyst staff is composed entirely of experienced pilots and air traffic controllers. Their years of experience are uniformly measured in decades, and cover the full spectrum of aviation activity: air carrier, military, and general aviation; Air Traffic Control in Towers, TRACONS, Centers, and Military Facilities.

Each report received by the ASRS is read by a minimum of two analysts. Their first mission is to identify any aviation hazards that are discussed in reports and flag that information for immediate action. When such hazards are identified, an alerting message is issued to the appropriate FAA office or aviation authority. Analysts' second mission is to classify reports and diagnose the causes underlying each reported event. Their observations, and the original de-identified report, are then incorporated into the ASRS's database.

The database provides a foundation for specific products and subsequent research addressing a variety of aviation safety issues. ASRS's database includes the narratives submitted by reporters (after they have been sanitized for identifying details). These narratives provide an exceptionally rich source of information for policy development and human factors research. The database also contains coded information from the original report that is used for data retrieval and statistical analyses.[2]

Caveat Regarding Statistical Use Of ASRS Information

Certain caveats apply to the use of ASRS statistical data. All ASRS reports are voluntarily submitted, and thus cannot be considered a measured random sample of the full population of like events. For example, we receive several thousand altitude deviation reports each year. This number may comprise over half of all the altitude deviations that occur, or it may be just a small fraction of total occurrences. We have no way of knowing which.

Moreover, not all pilots, controllers, air carriers, or other participants in the aviation system, are equally aware of the ASRS or equally willing to report to us. Thus, the data reflect reporting biases. These biases, which are not fully known or measurable, distort ASRS statistics. A safety problem such as near midair collisions (NMACS) may appear to be more highly concentrated in area “A” than area “B” simply because the airmen who operate in area ‘A” are more supportive of the ASRS program and more inclined to report to us should an NMAC occur.

[2] http://asrs.arc.nasa.gov/overview.htm

Only one thing can be known for sure from ASRS statistics — **they represent the lower measure of the** true number of such events that are occurring. For example, if ASRS receives 300 reports of track deviations in 1993 (this number is purely hypothetical), then it can be known with certainty that at least 300 such events have occurred in 1993.

Because of these statistical limitations, we believe that the real power of the ASRS lies in the report narratives. Here pilots, controllers, and others, tell us about aviation safety incidents and situations in detail. They explain what happened, and more importantly, why it happened. Using report narratives effectively requires an extra measure of study; the knowledge derived is well worth the added effort.[3]

[3] ASRS Reports: Quick Response # 271, November 30, 1994 and Search request # 5532, January 27, 1999.

DEFINITIONS

CRITICAL/ACFT EQUIPMENT PROBLEM: Aircraft equipment problem that is vital to the safety of the flight.

LESS SEVERE/ACFT EQUIPMENT PROBLEM: Not qualifying as a critical aircraft equipment problem.

ANOMALY: Deviation from the common rule — irregularity; something different, abnormal, peculiar, or not easily classified.

ACCIDENT: An occurrence associated with the operation of an aircraft that takes place between the times any person boards the aircraft with the intention of flight and all such persons have disembarked, and in which any person suffers death or serious injury, or in which the aircraft receives substantial damage. (49 CFR 830)

INCIDENT: Is an occurrence other than an accident that affects or could affect the safety of operations. (49 CFR 830)

PED: Portable, Personal, or Passenger Electronic Device

CREDIBILITY OF PED EVENTS

Even though ASRS PED events are anecdotal there is one category of the database that provides supporting credibility to these events—pilot flight hours. The total mean flight time of 10,790 hours from Table 1 indicates that pilots reporting PED events are very experienced. In order to gain some appreciation of what constitutes a very experienced pilot it is helpful to consider the significance 10,790 hours converted to years of aviation experience. In today's market a typical recruiting company's hiring minimums are 3300 military hours or 5300 civilian hours for a position with a major airline. Once hired a pilot could then acquire approximately 700 to 800 hours annually. If, for example, a military pilot with 3300 hours starts flying with a major airline averaging 700 hours a year it would take that person about 11 years to reach 10,790 hours. Finally, if it took 10 years, a conservative estimate, for that pilot to accumulate the initial 3300 hours then 10,790 hours would have taken 20 years to accumulate. That amount of time is indicative of a very experienced pilot.

Chart 1. Pilot flight time

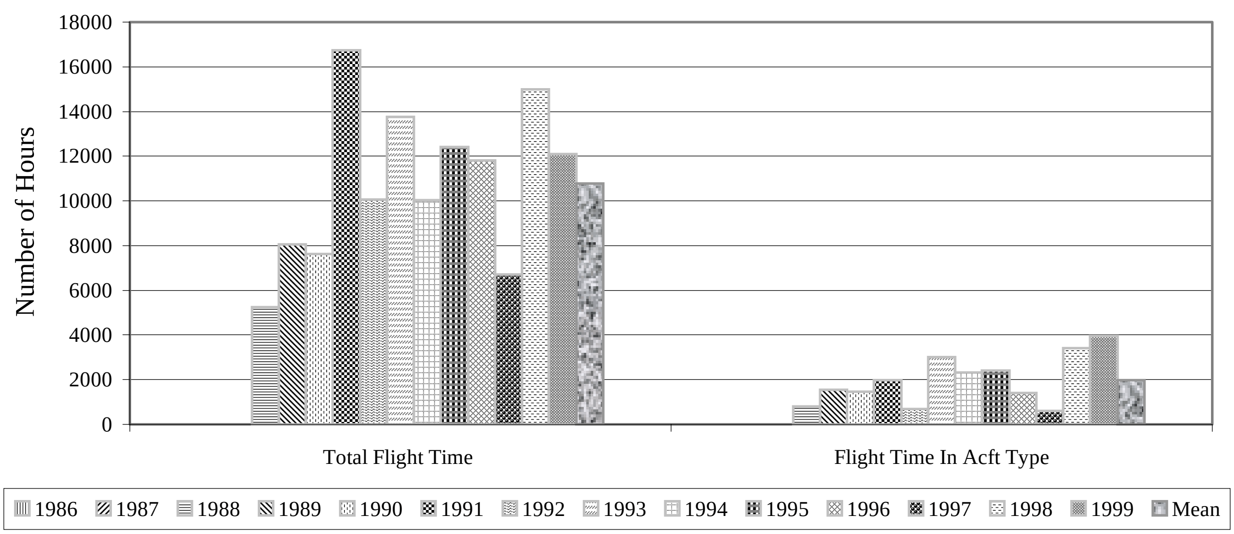

Table 1. Pilot flight time

	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	Mean
Total Flight Time	No data	No data	5250	8046	7630	16728	10055	13771	10020	12400	11800	6700	15000	12083	10790
Flight Time In ACFT Type			800	1754	1516	1970	696	3038	4239	2588	1150	610	5067	4243	2306

Note: Total Flight Time: Highest 25000 to Lowest 600; Flight Time In Aircraft Type: Highest 15000 to Lowest 175

In Table 1 the hours for each crewmember reporting an incident were summed and divided by the total number of incidents for that year resulting in the annual totals. The mean was derived by summing the annual totals and then dividing by the span of years in the table. Only one pilot's hours were used from each report. The next chart introduces what has happened regarding PEDs.

RECORDED PED EVENTS

Chart 2. Annual PED incidents

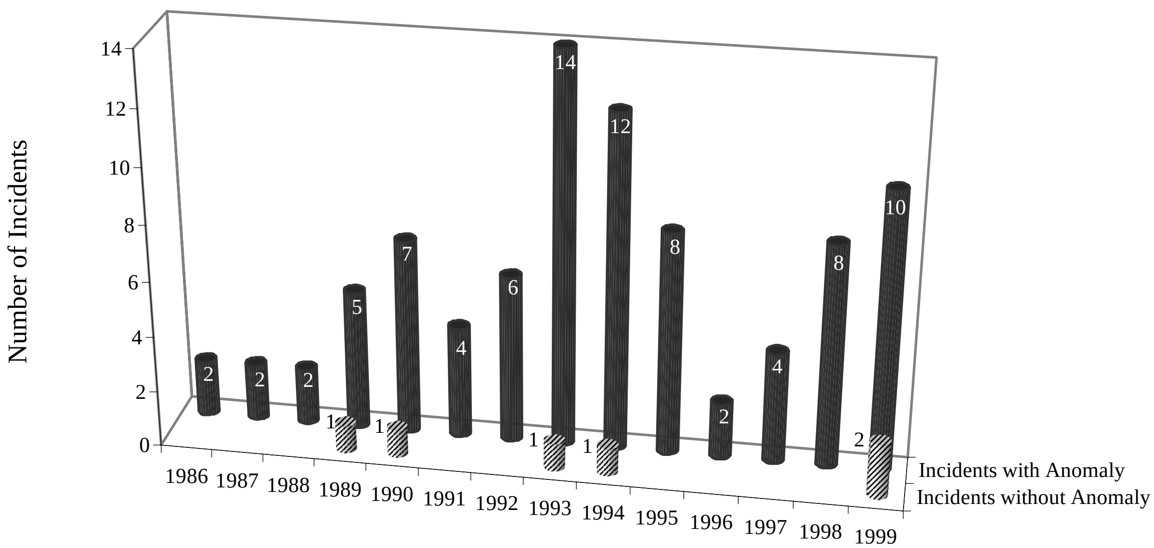

Table 2. Annual PED incidents

	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	Total
Incidents with Anomaly	2	2	2	4	7	4	6	14	12	8	2	4	8	10	85
Incidents without Anomaly				1	1			1	1						4
Totals	2	2	2	5	8	4	6	15	13	8	2	4	8	10	89

It is important to establish just what has happened regarding onboard PED use. Chart 2, the initial chart for documenting what has happened, presents all ASRS reports attributed to PEDs. Additionally, it points out that not every incident of PED use has created an anomaly. Non-anomaly events are charted here in the interest of objectivity and are not included in any other charts or tables.[4] Obviously, non-anomaly events represent a low safety risk, however other charts will identify events of significantly greater risk.

Throughout the entire ASRS Database there were no reports, following a PED anomaly event, where aircraft systems were found faulty when checked by maintenance personnel. Two incidents were reported where a navigation line replaceable unit (LRU) was replaced for precautionary reasons, but no faults were found with either piece of equipment. This would seem to indicate that equipment has functioned correctly prior to and after exposure to an external source such as a PED. Not only have anomalies happened, but they have also been associated with critical system's interference.

[4] Out of the four non-anomaly events one happened in the air and three on the ground.

Chart 3. Annual PED incidents by severity

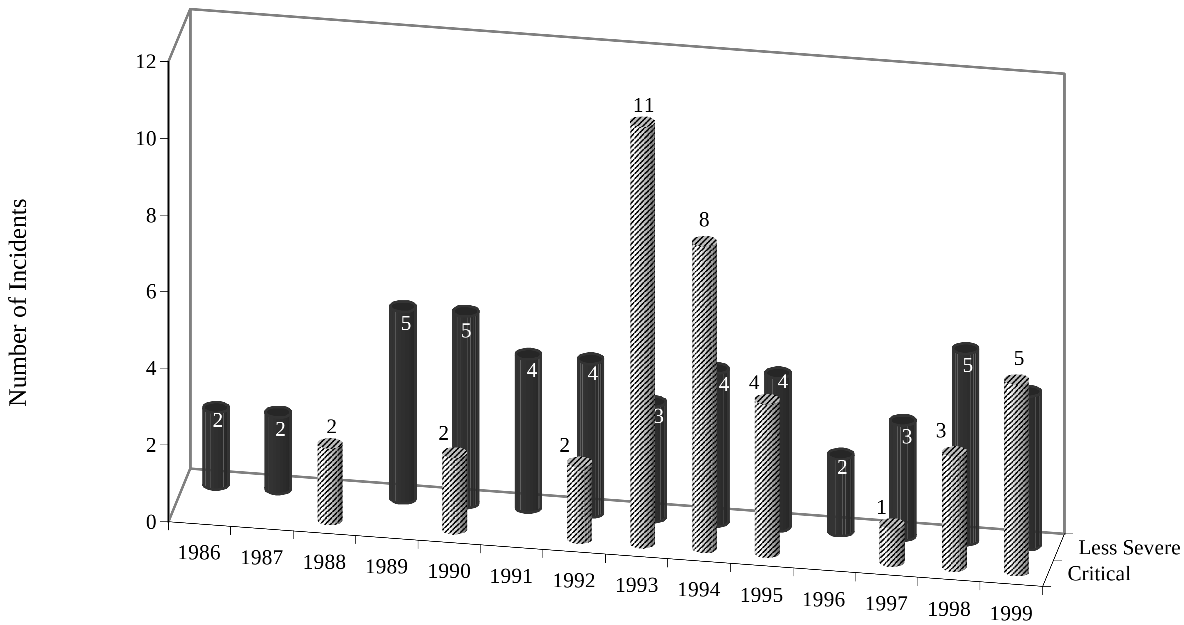

Table 3. Annual PED incidents by severity

	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	Totals
Less Severe	2	2		4	3	3	3	2	3	4	2	3	5	4	40
Critical			2		1		2	11	9	4	1	1	3	5	39
Not Rated					3	1	1	1						1	7
Totals	2	2	2	4	7	4	6	14	12	8	3	4	8	10	86

Chart 3 represents anomalies that were designated as critical or less severe. These two categories represent a flight crew’s evaluation of the degree of system interference in relation to safety of flight. A greater awareness for the safety risks of PED incidents can be gained by viewing Chart 6’s depiction of anomalies that happened during landings and takeoffs.

The third data area of what has happened is contained in table 4, page 9, and it identifies the number of PEDs associated with each anomaly event. The category *Single* represents events where only one PED was observed to be in use at the time an anomaly occurred in contrast to the categories *Multiple Similar* and *Multiple Dissimilar* where two or more PEDs were observed to be in use. This data illustrates the need to separately evaluate the potential for interference of a single PED and multiple PEDs. Additionally, multiple PEDs may need to be evaluated as groups of similar and dissimilar devices. It is interesting to note that there was one report where 24 PEDs were observed to have been in use at one time. However, the important point is anomalies have been created by a single PED.

Chart 4. Incidents involving single VS multiple PED usage

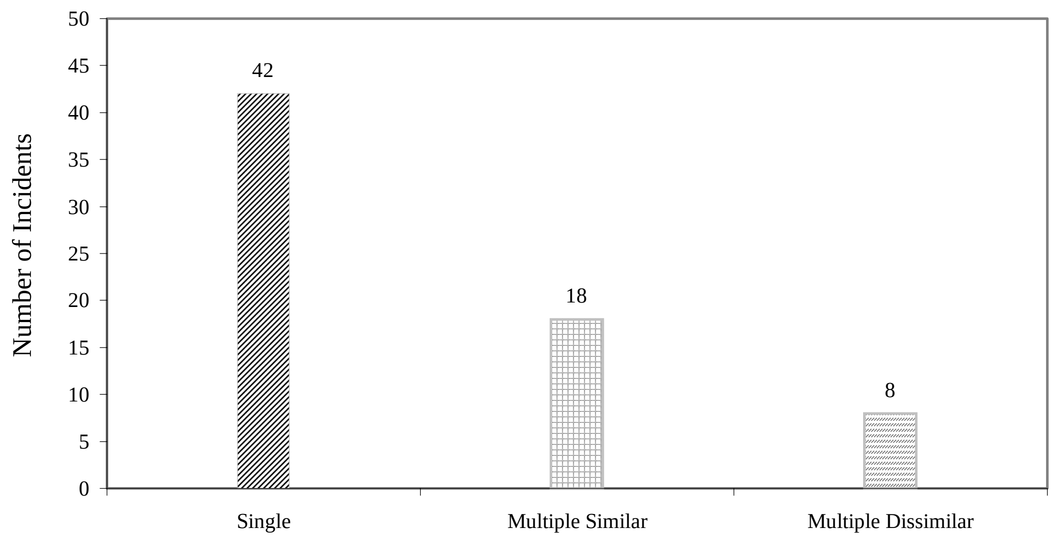

Table 4. Incidents involving single VS multiple PED usage

	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	Totals
Single	1		1	4	3	3	3	7	6	1	1	1	4	7	42
Multiple Similar				1		1		2	2			1		1	8
Multiple Dissimilar	1	1	1		2		2	4	1			1	2	3	18
Totals	2	1	2	5	5	4	5	13	9	1	1	3	6	11	68

PED EVENTS AND THE ENVIRONMENT IN WHICH THEY TOOK PLACE

The next three charts identify where incidents have occurred relative to aircraft specifics and phase of flight. One would expect the first chart to address aircraft type, but the ASRS data system did not track aircraft types until 1994. Instead, it tracked aircraft size (wide body, large transport, etc.) based on weight. The combined analysis of aircraft weights and types yielded only one supportable observation—PED occurrences have happened to a wide variety of aircraft regardless of manufacturer or weight. Nonetheless, the database contained one field worthy of note—cockpit design.

Between 1986 and 1999 there have been significant changes in cockpit design from basic analog to advanced glass. The ASRS defines advanced cockpits as those fitted with one or any combination of the following: integrated navigation (NAV), electronic flight instrument system (EFIS), flat panel liquid crystal display (LCD), cathode ray tube (CRT), flight management system (FMS) and heads up display (HUD).

Chart 5. Aircraft cockpit type

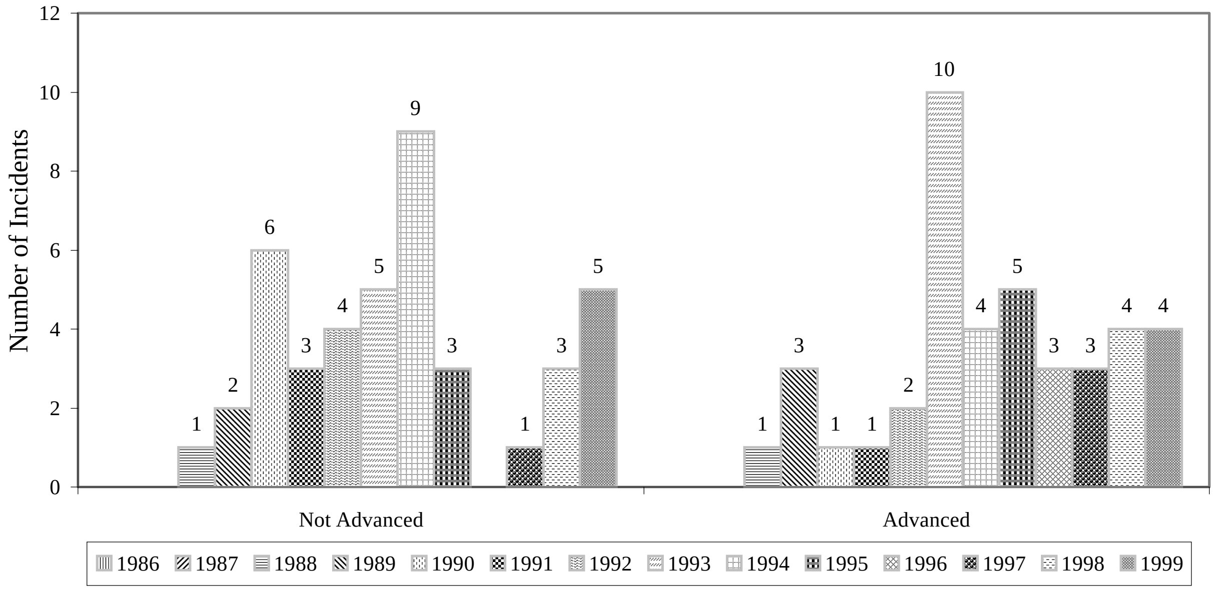

Table 5. Aircraft cockpit type

	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	Totals
Not Advanced			1	2	6	3	4	5	9	3		1	3	5	42
Advanced			1	3	1	1	2	10	4	5	3	3	4	4	41
Totals			2	5	7	4	6	15	13	8	3	4	7	9	83

Although the data in Chart 5 appears to indicate that advanced cockpit system's increased fault tolerant characteristic accounted for fewer incidents, without knowing the total number of aircraft equipped with an advanced cockpit this conclusion is not supportable.[5] The fact remains that PED related anomalies have happened in aircraft with advanced cockpits, and they have happened at less than desirable moments.

[5] At the time of this report, data reflecting the number of aircraft fitted with a particular type of cockpit for any given year was not obtainable.

Specifically, these were moments when flight crews were already busy with the multiple tasks involved in landing or taking off. Clearly, Chart 6 on page 11 documents that PED anomalies have occurred during critical phases of flight.[6] Each phase, approach and landing or takeoff and climb, accounted for approximately 22 percent of all anomalies. Therefore, about 44 percent of all reported incidents occurred during a critical phase of flight.[7]

Chart 6. Phase of flight when incident occurred

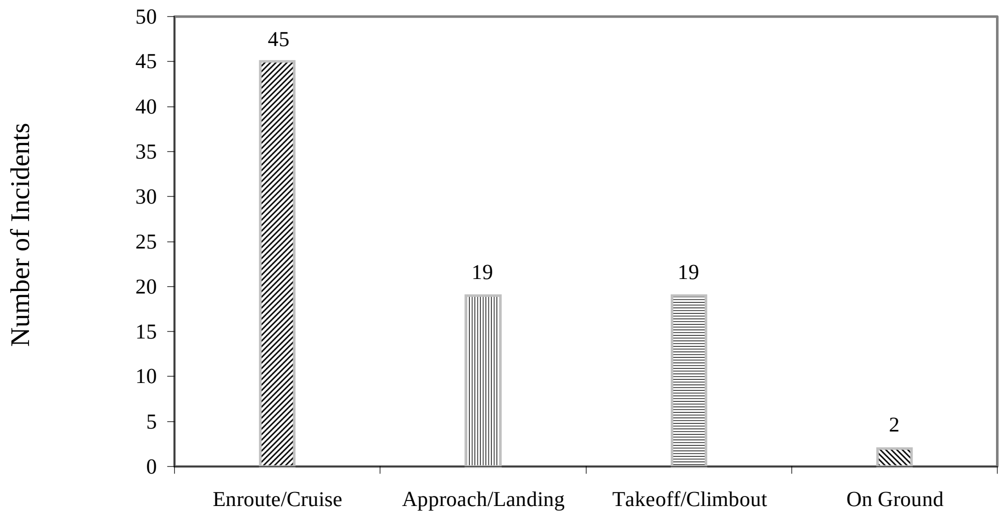

Table 6. Phase of flight when incident occurred

	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	Totals
Enroute/Cruise	2	2	2	3	6	3	3	9	5	1			5	6	47
Approach/Landing					1		1	3	4	7	3		2	2	23
Takeoff/Climbout				1		1	2	2	2	1		4	1	2	16
On Ground				1					1						2
Totals	2	2	2	5	7	4	6	14	12	9	3	4	8	10	88

A broader significance of Chart 6 can be determined by associating its data with the aviation statistic that 68 percent of all fatal aviation accidents have occurred during a critical phase of flight.[8] Clearly there is a need to reduce or eliminate critical system anomalies from occurring during these significant flight phases. Additional support for this matter is contained in the next chart's data.

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[6] Critical phases of flight are defined, in accordance with FAR 121.542 and FAR 135.100, as "…takeoffs and landings, all ground operations involving taxiing, and all other flight operations conducted below 10,000 feet, except cruise flight."

[7] For detailed examples see line items 33, 46, 48, 50, 53, 55, 59, 61, 62, and 68 in Table 11.

[8] (Boe96): Boeing Commercial Airplane Group, *Statistical Summary of Commercial Jet Aircraft Accidents: worldwide operations 1959-95*, 1996.

Chart 7. Altitude of flight when incident occurred

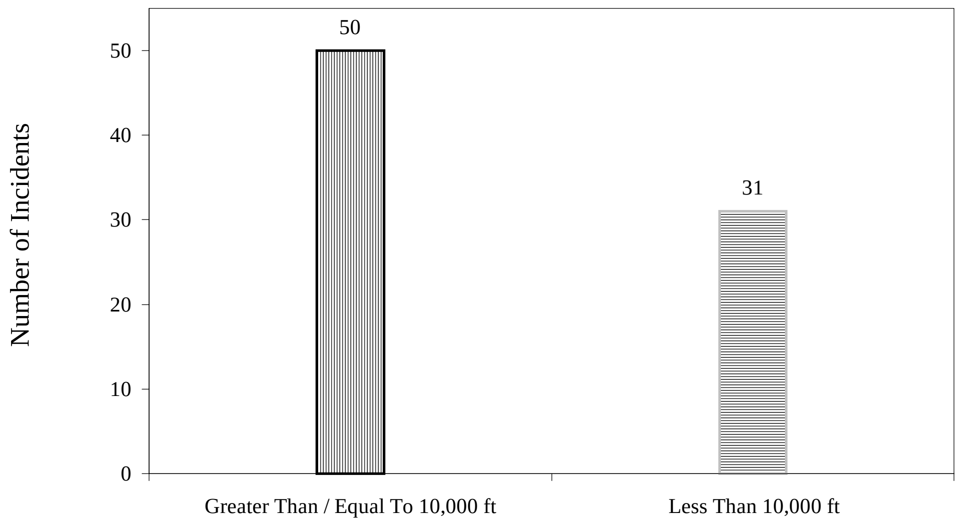


Table 7. Altitude of flight when incident occurred

	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	Totals
Greater Than / = To 10,000 ft	1	2	2	2	5	2	2	9	6	5	1	2	5	6	50
Less Than 10,000 ft	1			2	1	1	4	5	6	3	1	1	3	3	31
Totals	2	2	2	4	6	3	6	14	12	8	2	3	8	9	81

Where as the previous chart is based on flight phases, Chart 7 is predicated on altitude and indicates that approximately 38 percent of all PED incidents happened at altitudes where the flight crew was required to maintain Sterile Cockpit Rules.[9] These rules restrict flight crew actions to those considered essential to safe operation of the aircraft. They are applicable at and below 10,000 feet where landings and takeoffs are typically conducted. The difference between the 44 percent in the previous chart and the 38 percent of Chart 7 is attributable to the exclusion, in Chart 7, of approach and climb incidents that happened above 10,000 feet. For clarification, climb is the extended portion of a takeoff that begins once an aircraft is airborne and ends when it reaches cruise altitude. Approach is the initial portion of landing that commences when cruise is departed and continues to runway touchdown. Regardless of the difference, either figure is sufficient cause for concern.

[9] Sterile Cockpit Rules are defined by two regulations. “FAR 121.542/FAR 135.100 stipulate flight crew member duties as: (a) “No certificate holder shall require, nor may any flight crew member perform any duties during a critical phase of flight except those duties required for the safe operation of the aircraft….”(c) “for the purposes of this section, critical phase of flight involves all ground operations involving taxi, takeoff and landing, and all other flight operations conducted below 10,000 feet, except cruise flight.

ANOMALY DISCOVERY SOURCES

Chart 8. Sources of anomaly detection

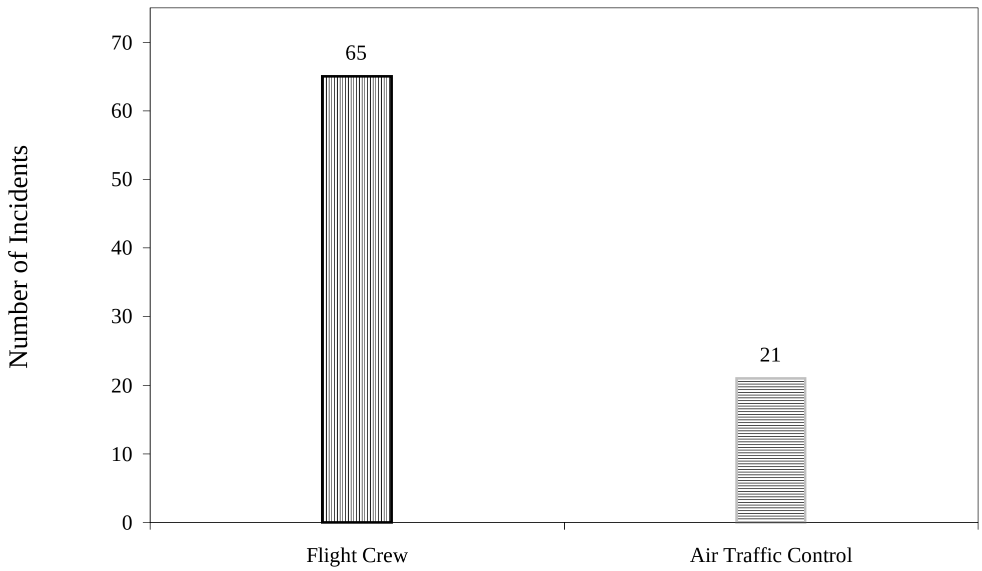


Table 8. Sources of anomaly detection

	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	Totals
Flight Crew		2	2	2	5	1	4	9	9	8	2	3	8	10	65
Air Traffic Control	2			1	3	3	2	5	3		1	1			21
Totals	2	2	2	3	8	4	6	14	12	8	3	4	8	10	86

The next significant ASRS data fields are those that address how anomalies have been discovered. In Chart 8 data has been graphed of air traffic control (ATC) radar plots that were the basis for notification from ATC to the flight crew their aircraft was off course. At the time of notification the flight crew had no idea based on display panel data that the aircraft was not where the panel data indicated. All navigation systems showed on course and displayed no flags, warnings, or other abnormalities. The major point here is that ATC has initially discovered almost one fourth of the PED anomalies. These radar plots also represent an independent resource for confirmation of anomalies. Anomalies were also detected by aircraft systems as is reflected in the next chart.

Chart 9. NAV Systems' responses to onboard PED operations

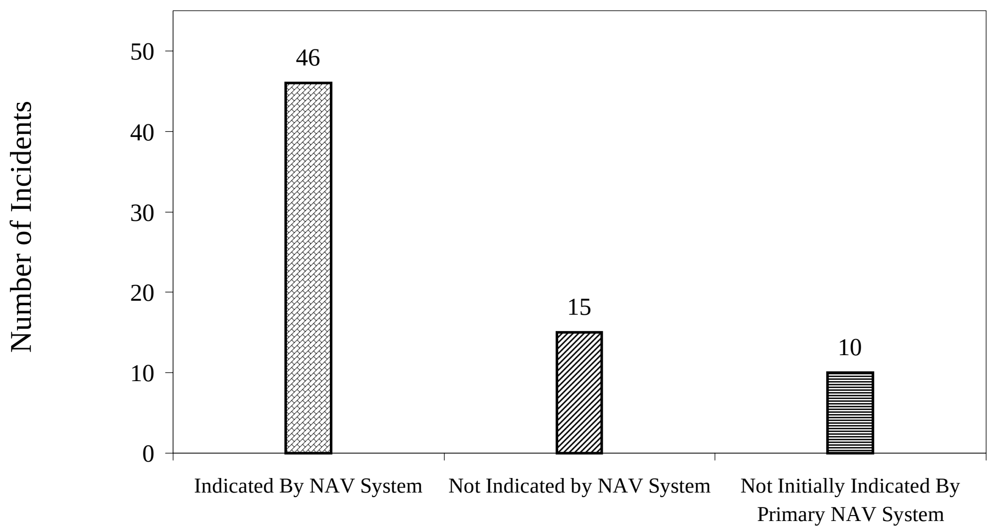


Table 9. NAV Systems' responses to onboard PED operations

	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	Totals
Indicated By NAV System		2	2	2	5		1	7	4	6	1	3	6	7	46
Not Indicated by NAV System				1	3	1	1	4	3	1		1			15
Not Initially Indicated By Primary NAV System				1		3	1	3	1		1				10
Totals		2	2	4	8	4	3	14	8	7	2	4	6	7	71

NOTE: Indicated By NAV System - off flag, warning signal, data display inconsistency etc.
Not Indicated By NAV System - the opposite of indicated by NAV system
Not Initially Indicated By Primary NAV System - anomaly discovered upon reverting to raw (analog) data

The data for Table 9 was selected from the flightcrew's comments contained in the narrative of each incident report. Row one is self-explanatory, but rows two and three suggest the possibility of data transfer problems from analog to digital or the processing of the digital data respectively.

Two significant questions about PEDs remain—which systems have been affected and which PEDs have been associated with anomalies. The first question is addressed in the next chart and in Table 11.

SYSTEMS THAT WERE AFFECTED

Chart 10. Aircraft systems affected by PEDs

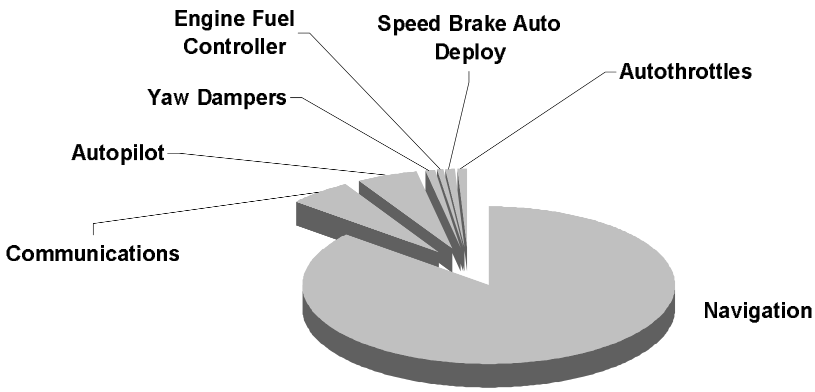


Table 10. Aircraft systems affected by PEDs

	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	Totals
Navigation	2	2	4	6	13	7	3	20	14	11	2	6	13	9	112
Communications							3	1	2	1					7
Autopilot			1						1	4				1	7
Yaw Dampers			1												1
Engine Fuel Controller									1						1
Speed Brake Auto Deploy										1					1
Autothrottles										1					1
Totals	2	2	6	6	13	7	6	21	18	18	2	6	13	10	130

Chart 10's significance is the order of magnitude higher that navigation systems above all other systems were affected by PED anomalies. The systems in this chart and table were identified in ASRS report narratives and in some cases reflect incidents where more than one system had an anomaly. Multiple anomalies explain why the total number of affected systems in this chart exceeds the total number of incidents reported in Chart 1. Greater detail on affected systems is provided in the following table.

Table 11, page 17 and 18, not only lists each system affected by an anomaly, but also lists that system's corresponding responses. Each line item, 1-86, represents one incident report. This table's significance is its side-by-side comparison of systems responses with incident severity and phase of flight.

Table 11. Detailed system responses to onboard PED operations

	Anomaly Event	Year	Degree of Severity	Phase of Flight
1	OMEGA NAV on autopilot 5 nm off course;	1986	LS	Cru
2	VOR, DME, RNAV showed on course; ATC radar showed 12 mi off course;	1986	LS	Cru
3	VOR repetitive full scale right deflections;	1987	LS	Cru
4	VOR both displayed fail flag; squeal for ident;	1987	LS	Cru
5	VOR CDI 3 - 4 degree split with Capt.’s left & FO's right; ATC radar showed 4 mi right of course;	1988	C	Cru
6	autopilot & yaw dampers uncommanded disengagement; FMGC & air data computer displays lost;	1988	C	Cru
7	CDI frequent needle swings; ATC radar showed 3 mi off course;	1989	LS	T/O
8	VOR needle swings;	1989	LS	Cru
9	VOR track off 23 degrees by ATC radar; magnetic compass 40 degree swings;	1989	LS	Cru
10	VOR severe deflection to right;	1989	LS	Cru
11	VOR intermittent to complete loss of signal;	1990	LS	Cru
12	VOR very erratic needle swings left & right; intermittent flag on / off;	1990	N/R	Cru
13	NAV CDIs erratic;	1990	N/R	Cru
14	VOR indicated incorrect station passage; fluctuation to / from flag;	1990	LS	Cru
15	HSI & RMI indicate on course; false lock onto VOR causes 80 nm error in NAVAID location; ATC radar shows 90 deg off course;	1990	N/R	Cru
16	EFIS HSI discrepancy right & left sides;	1990	C	Ldg
17	CDI & compass 5 - 10 swings left & right; 8 nm off course;	1990	LS	Cru
18	VOR & RNAV (OMEGA) unreliable;	1991	N/R	Cru
19	VOR & OMEGA unreliable; ATC radar showed off course several miles;	1991	LS	Cru
20	HSI indicated 60 degree difference from whiskey (magnetic) compass;	1991	LS	T/O
21	cockpit indicated on course; course indicator bar left & right two needle widths; ATC radar shows 3 - 5 mi off course;	1991	LS	Cru
22	Capt.’s & FO’s ILS needles fluctuated 1 1/2 dots opposite of each other;	1992	C	Ldg
23	heard same music on 132.95 all radios;	1992	LS	Cru
24	heard static on 124.5; 2nd acft heard same;	1992	N/R	Cru
25	com 2 loud squeal; couldn't receive; ultimately lost com 1 & 2; couldn't xmit or receive;	1992	C	T/G
26	VOR indicated on course; ATC radar showed off course;	1992	LS	Cru
27	HSI & compass 55 degree difference;	1992	LS	T/O
28	HSI indicated on course; ATC radar showed 7 mi off course;	1993	C	Cru
29	VORs loss of both with fail flag & full needle deflection; no audio signal;	1993	C	Cru
30	lost all directional gyros except whiskey (magnetic) compass; then VORs & RMIs lost;	1993	C	Cru
31	VOR indicated on course; ATC said off course by 7 nm; # 1 compass 10 - 15 degrees in error;	1993	C	Cru
32	both sets of LOC & GS (ILS) flags appeared in Capt.’s & FO's displays; during 2nd approach flags were intermittent; audio ident had interference on both missed approaches;	1993	C	Ldg
33	EFIS displays blanked; indicated “missed approach fail”; loss of all automatic NAV functions;	1993	C	T/O
34	LOC erratic with full left deflection;	1993	C	Ldg
35	compass precessed 10 degrees right;	1993	C	Cru
36	OMEGA NAV off course;	1993	C	Cru
37	HDG flag & AHRS warning on both EHSIs; 20 degree error between Capt.’s & FO's EHSIs;	1993	C	T/O
38	VOR indicated on course; ATC radar showed off course; INS in use; both NAV compasses differed by 40 degrees with the wet (magnetic) compass;	1993	C	Cru
39	radio communications lost temporarily due to interference;	1993	LS	Ldg
40	FMS showed on course; ATC radar showed off course 13 mi; next NAVAID FMS indicated 7 mi off course and # 1 and # 2 INSs agreed; # 3 INS agreed with NAV radios as on course;	1993	LS	Cru
41	EHSI indicated on course; ATC showed 7 mi off course;	1993	N/R	Cru
42	VORs indicated on course; ATC showed off course;	1994	LS	Cru
43	left engine uncommanded roll back to less than idle;	1994	C	Gnd
44	both pilot's cockpit displays indicated on course; ATC radar showed off course by 10 mi; event happened a second time;	1994	LS	Cru
45	radar altimeter off flag displayed; both pilots heard static on com radios;	1994	C	T/O
46	LOC & GS showed on course, but visual observation by flightcrew showed well left of course;	1994	C	Ldg
47	VOR (CDI) erratic deviations left & right;	1994	C	Cru
48	autopilot uncommanded 30 degree right turn twice;	1994	C	Ldg
49	HSIs indicated on course; ATC showed 15 degrees left of course;	1994	C	Cru

50	during ILS apch with CDI centered acft is right of course; correction made; at breakout with LOC & GS centered acft appears high; then noted erratic CDI and GS;	1994	C	Ldg
51	compass # 1 & # 2 differed by 15 degrees twice;	1994	C	Cru
52	radio altimeter indicated 900 ft when aircraft was at 13,000 ft; GPWS sounded 'too low';	1994	LS	T/O
53	loss of ILS signal with LOC & GS off flags displayed; go around;	1994	C	Ldg
54	LOC erratic with left & right drifts from course; go around performed followed by uneventful landing;	1995	LS	Ldg
55	ADI display disappeared; “ATT fail” displayed on CRT; FLT director bars crossed and centered; RDMI displayed all 3 off flags; FO's ND displayed “ATT and HDG fail”; FMA displayed “no autoland”;	1995	C	Ldg
56	uncommanded 15 degree left then right turns; FO's HSI and RMI slewing left and right 70 degrees of HDG; additional shallow left and right turns; Capt.’s instruments unaffected;	1995	LS	Ldg
57	LOC # 1 selected ADI & HSI full left and right deflections; LOC # 2 operated normally;	1995	LS	Ldg
58	autopilot uncommanded descent 300 ft; speedbrake uncommanded extension 3/4 full & cycled 1/2 to 3/4; resistance felt during manual retract; control gained with electronic yoke trim; ACFT manually flown at descent; during manual retraction of speedbrake noisy thump as lever passed auto armed detent; speedbrake is fly by wire;	1995	C	Cru
59	alternating flashing amber HDG and horizon lights; lost autopilot and autothrottles; CAPT no FLT director bars or RDMI; FO no primary flight display, but had flight director bars;	1995	C	Ldg
60	Capt.’s and FO's VOR signal incorrect; intermittent red flag; CDI needle left and right swings 20 - 30 degrees off course; audible signal interference;	1995	LS	T/L
61	during coupled autopilot approach using all 3 autopilots FLC noticed ACFT left of RNWY; autopilots disconnected even though they indicated aircraft was centered on course;	1995	C	Ldg
62	uncommanded FLT mgmt annunciator went from “pitch = vertical speed” & “autothrottles = speed” to “ALT hold” and “vertical speed arm in pitch”; aircraft pitched down 10 degrees; lost 500 ft;	1996	C	Ldg
63	FMSs went independent of each other; upon landing maintenance check found 20 mi FMS error in spite of FLC's updating FMS when ever .05 - .07 error was noticed;	1996	LS	Ldg
64	difficulty centering HSI; 8 degree needle split HSI between CAPT & FO; split increased to 15 degrees;	1996	LS	Ldg
65	EICAS displayed caution message 'EFIS COMP MON' due to disagreement of HDG indicators; 'EFIS COMP MON' displayed due to airspeed indicator’s 10 knots difference; message displayed again due to difference in altimeters and airspeed indicators; FO's instruments reliable in each case;	1997	LS	T/O
66	cockpit instruments indicated on course; ATC radar showed 7 mi off course;	1997	LS	T/O
67	erroneous VOR / CDI readings;	1997	LS	T/O
68	Capt.’s ILS, radio altimeter, and PFD went out;	1997	C	T/O
69	FO's CDI fluctuating on all VORTAC stations used; CAPT using FMC for NAV had no problems;	1998	C	Cru
70	NAV CDI fluctuations;	1998	LS	Cru
71	both VORs erratic;	1998	LS	Ldg
72	during takeoff GPWS low terrain alert followed by major FMS map shift of about 30mi;	1998	C	T/O
73	both ADF needles either didn't move or were 40 - 50 degrees in error;	1998	C	Cru
74	CDI full deflection left; corrected; drifted left again; CDI & flight director fluctuating right 8 - 10 degrees;	1998	LS	Cru
75	TCAS II false TA;	1998	LS	Cru
76	Capt.’s radar altimeter flag intermittently displayed; TCAS II annunciated 'TCAS II fail';	1998	LS	Ldg
77	tone in headsets (confirmed NOKIA mobile phone); NAV and SPD modes disengaged; FLT director command bars removed; FMS and short range NAV systems not reliable;	1999	N/R	Ldg
78	FLT mode annunciator displayed “HDG error” and “no Autoland” messages; 30 degree split between left and right HDG systems using # 2 CADC; # 1 CADC agreed with standby compass;	1999	C	T/O
79	# 1 NAV receiver erratic with intermittent display of to / from flag;	1999	LS	Cru
80	VOR CDI erratic + / - 5 degrees;	1999	C	Cru
81	FMS locked up; NAV display & PFD flickered then went blank; RTE and performance data dumped; # 1 MCDU inop;	1999	LS	Cru
82	uncommanded right turn; autopilot tripped with alarm; ILS flag; command bars lost; LOC signal lost;	1999	LS	Ldg
83	radar altimeter flag displayed; GPWS & TCAS II annunciated 'fail'; VORs flagged;	1999	C	Cru
84	VOR 30 degree needle difference between # 1 and # 2; DME and CDI Capt and FO agreed with GFMS and # 1 VOR;	1999	C	T/O
85	radar altimeter flagged; TCAS II & GPWS annunciated 'fail';	1999	C	Cru
86	FO's VOR receiver no signal or ident; Capt.’s VOR okay; both tuned to same VOR;	1999	LS	Cru

NOTE: See page 19 for applicable abbreviations and acronyms

Abbreviations for Table 11

acft – aircraft; **ALT –** altitude; **apch** – approach; auto – automatic; C – critical; **Capt** – Captain; **com** – communications; **COMP –** computer; **cru** – cruise; **FLC** – Flightcrew; **FO** - First Officer; **gnd –** ground; **HDG –** heading; **ident –** Identification; **inop** – inoperative; **ldg –** landing: **L/S –** less severe; **MAG –** magnetic; **MON –** monitor; **N/R –** not reported; **nm** - nautical miles; **rnwy** – runway; **rte** – route; **spd –** speed; **T/G –** takeoff / ground; **T/O –** takeoff; **xmit –** transmit;

Acronyms for Table 11

ADI - Attitude direction indicator
AHRS - Attitude-heading reference system
ATC - Air Traffic Control
CADC - Central Air Data Computer
CDI - Course Deviation Indicator
DME - Distance Measuring Equipment
EFIS - Electronic Flight Instrument System
EHSI - Electronic horizontal situation indicator
EICAS - Engine indicating and crew alerting system
FMA - Flight mode annunciation: speed, roll and altitude are the major control functions;
FMGC - Flight management and guidance computer
FMS - Flight management system
GFMS - GPS Flight Management System
GPWS - Ground Proximity Warning System
GS - Glide Slope
HSI - Horizontal Situation Indicator
ILS - Instrument Landing System
INS - Inertial Navigation System
LOC - Localizer receiver and indicator
MCDU - Multifunction control display unit: entry of flight plan, monitoring and revision
NAV - Navigation Receivers
NAVAID - Navigational Aid
OMEGA - A very-low-frequency navigation system
PFD - Primary flight display
RDMI - Radio Distance Magnetic Indicator
RMI - Radio Magnetic Indicator
RNAV - aRea NAVigation
TCAS - Traffic Alert and Collision Avoidance System
TA - Traffic advisory (TCAS)
VOR - VHF Omni directional Receiver

The remaining charts, beginning with Chart 12, identify which PEDs have been associated with anomalies.

PEDs THAT AFFECTED AIRCRAFT SYSTEMS

Chart 12. PEDs affecting aircraft systems

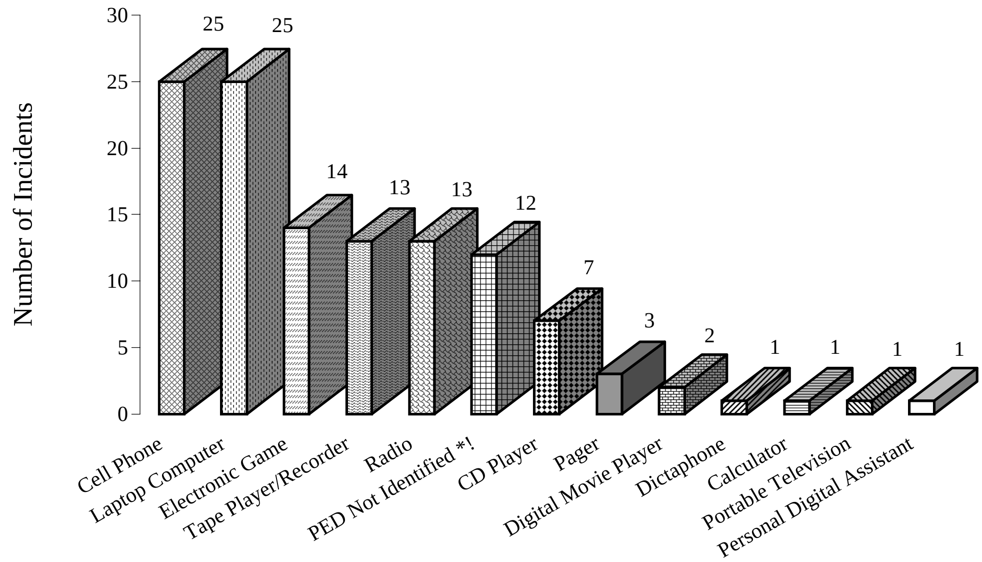


Table 12. PEDs affecting aircraft systems

	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	Totals
Cell Phone					2	1	3	5	5	1		2	2	4	25
Laptop Computer	1				2	1	2	6	3	2		1	3	4	25
PED Not Identified *!		1			1				2	5	2	1		2	14
Electronic Game				1	1		1	4	4				2		13
Tape Player/Recorder	3	2	1	1	1	2	1	1					1		13
Radio	1	1	2	1	2	1	1	3							12
CD Player			1					1	1	1		1	1	1	7
Pager													2	1	3
Digital Movie Player														2	2
Dictaphone				1											1
Calculator								1							1
Portable Television								1							1
Personal Digital Assistant														1	1
Totals	5	4	4	4	9	5	8	21	15	9	2	5	11	15	118

* Incident reports where a general passenger cabin announcement was made requesting all electronic devices be turned off and resulted in aircraft systems returned to normal

! PED Not Identified Category is similar to suspected PED interference events in Bruce Donham's article. All other categories on this sheet correspond to apparent and strong PED correlation events in Mr. Donham's article. Reference for article is: **Electronic Interference from Passenger – Carried Portable Electronic Devices** by Bruce Donham, Principal Engineer and Designated Engineering Representative, Electromagnetic Effects and Antennas, Boeing Commercial Airplanes Group; http://www.aerospaceonline.com/content/news/article.asp?DocID={64E8CA11-0708 -11D4-8C31-009027DE0829}&Bucket=Current+Features

Chart 12 specifically reflects all PEDs identified in the ASRS database. Clearly, based on their frequent association with anomalies, cell phones and laptops are prime candidates for PED testing. This observation also holds true for the next two charts.

Chart 13. PEDs associated with critical anomalies on aircraft systems

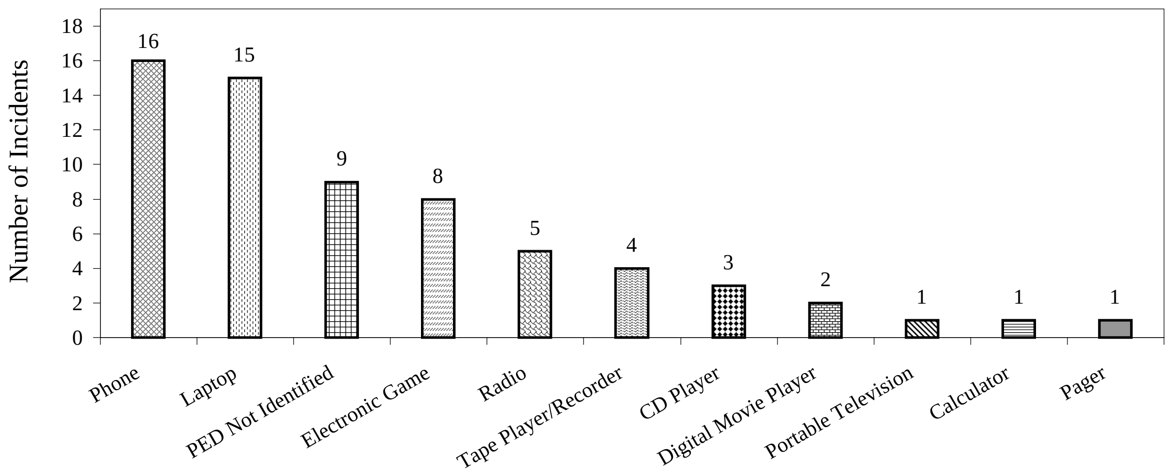
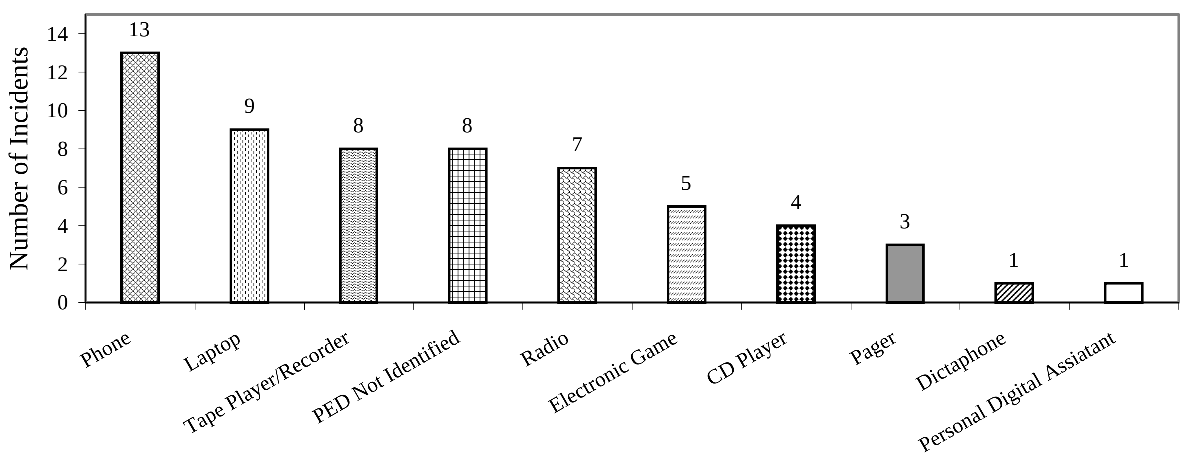


Chart 14. PEDs associated with less severe anomalies on aircraft systems



With very few exceptions, it is evident from Charts 13 and 14 that PEDs associated with critical events were also associated with less severe events and visa versa. The only exceptions were digital movie players, Dictaphones, and palm pilots. Although cell phones and laptops were most frequently identified throughout the charts, as a minimum all PEDs associated with critical events need to be thoroughly evaluated in order to determine their part in aircraft system's anomalies.

Table 13. PEDs associated with critical anomalies on aircraft systems

	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	Totals
Phone					1		2	6	3	2		1		15
Laptop							2	5	3	2			2	14
Electronic Game							2	2	3				1	8
PED Not Identified								1	3	3	1			8
Radio			2					3						5
Tape Player/Recorder			1				1	1					1	4
CD Player			1						1				1	3
Portable Television								1						1
Calculator								1						1
Totals	0	0	4	0	1	0	7	20	13	7	1	1	5	59

Table 14. PEDs associated with less severe anomalies on aircraft systems

	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	Totals
Phone				1	2	1	1	1	2	1		1	2	1	13
Laptop	1				2	1		1	1			1	1	1	9
Tape Player/Recorder	1	1	1	2	1	2									8
PED Not Identified		1			1					1	2	1		2	8
Radio	1	1		1	3		1								7
Electronic Game				1	1			1		1			1		5
CD Player			1					1		1		1			4
Pager													3		3
Dictaphone				1											1
Personal Digital Assistant														1	1
Totals	3	3	2	6	10	4	2	4	3	4	2	4	7	5	59

It is also obvious in Charts 13 and 14 how significantly each anomaly event affected aircraft equipment in regards to safety of flight. Severity of an event is defined on page 5.

The remaining charts, 15 through 21, are detailed breakdowns of the PED categories in Chart 12 and reflect any PEDs specifically identified by model or manufacturer. Specifically identified devices may be prime starting points for testing.

NOTE: All specific manufacturer's names and models of PEDs in Tables 15-21 are as recorded in ASRS Reports. This information should not be construed to imply these devices have been tested by NASA and found to be in any way problematic.

Table 15. PED – phone

	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	Totals
Cellular Phone					2	1	3	5	5	1		2	2	3	24
Nokia														1	1
Totals					2	1	3	5	5	1		2	2	4	25

Table 16. PED - Laptop

	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	Totals
Laptop	1				2	1	2	5	2	2		1	3	4	23
Imported Clone								1							1
Toshiba Model 1060 CT									1						1
Totals	1				2	1	2	6	3	2		1	3	4	25

NOTE: All specific manufacturer's names and models of PEDs in Tables 15-21 are as recorded in ASRS Reports. This information should not be construed to imply these devices have been tested by NASA and found to be in any way problematic.

Table 17. PED – Electronic games

	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	Totals
Game Boy							1	1	2				1		5
Video Game								2					1		3
Nintendo Electronic Game					1		1								2
Electronic Chess Player				1											1
Game Boys w/ Cable									1						1
Electronic Game									1						1
Totals				1			1	3	4				2		13

Table 18. PED - Radios

	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	Totals
FM Radio	1						1	2							4
AM/FM/Cassette Walkman					1	1		1							3
AM-FM Recorder			1	1											2
AM Radio		1													1
HF Marine Radio			1												1
Radio					1										1
Totals	1	1	2	1	2	1	1	3							12

Table 19. PED – Tape players

	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	Totals
Tape Recorder	3	2													5
Tape Player				1		1	1						1		4
Walkman Cassette			1		1	1		1							4
Totals	3	2	1	1	1	2	1	1					1		13

Table 20. PED – CD players

	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	Totals
CD Player			1						1	1		1	1	1	6
Kenwood CD								1							1
Totals			1					1	1	1		1	1	1	7

NOTE: All specific manufacturer’s names and models of PEDs in Tables 15-21 are as recorded in ASRS Reports. This information should not be construed to imply these devices have been tested by NASA and found to be in any way problematic.

Table 21. PED – Pagers, Dictaphone, Calculator, Portable Television

	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	Totals
Digital Movie Player														2	2
Pager													1	1	2
Pager, Pronet													1		1
Dictaphone				1											1
Calculator								1							1
Portable Television								1							1
Palm Pilot														1	1
Totals				1				2					2	2	9

CONCLUSIONS

The data shows that a wide variety of PEDs are suspected of having caused anomalies with aircraft systems. Although resolving the issue of PEDs interference is a complex task, the data indicates that cell phones and laptops should be prime candidates for evaluation of their part in anomalies. Additionally, the anomalies affected navigation systems 86 percent more often than any other system on the aircraft. If these events were happening at cruise altitudes where a pilot’s workload is lower than for any other flight phase, they might not be cause for concern, but that is not the case. The data clearly indicates that not only were some events judged as having had a critical effect on a system, but they also happened during critical stages of flight specifically landings and takeoffs. Research on single, multiple similar and multiple dissimilar devices and their interaction with their environment may provide useful data on PEDs interference.

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13. ABSTRACT (Maximum 200 words)

A compilation of data on personal electronic devices (PEDs) attributed to having created anomalies with aircraft systems. Charts and tables display 14 years of incidents reported by pilots to the Aviation Safety Reporting System (ASRS). Affected systems, incident severity, sources of anomaly detection, and the most frequently identified PEDs are some of the more significant data. Several reports contain incidents of aircraft off course when all systems indicated on course and of critical events that occurred during landings and takeoffs. Additionally, PEDs that should receive priority in testing are identified.

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