General Aviation Maintenance-Related Accidents:

A Review of 10 Years of NTSB Data

Providing adequate maintenance for general aviation (GA) aircraft is essential for ensuring human safety and the structural integrity of aircraft. Unlike commercial air carriers, which usually have their own maintenance shops, GA operators and owners obtain their maintenance work from a variety of privately owned, certified maintenance shops. GA maintenance shops provide a wide range of services. Services include repairs, installations, inspections, and even modifications of such critical aircraft structures and systems as the airframe, powerplants, propellers, instruments and avionics equipment. Errors committed by management, technicians and inspectors while aircraft are on the maintenance line can develop into problems with disastrous consequences. Maintenance-related errors have been associated with up to 15% of major aircraft accidents (Murray, 1998) and with 16% of Naval Aviation Class A Flight Mishaps (Schmidt, Schmorrow, & Hardee, 1998). Though it may be impossible to completely eliminate human error in aviation maintenance, Reason (1990, p.148) suggests that "…we must discover more effective ways of mitigating their consequences in unforgiving situations."

Studies seeking to classify maintenance error based on the process or activity involved can provide tangible benefits for ensuring safety in GA operations. Dorn (1996) reviewed 101 maintenance-related accidents involving aircraft flown by U.S. civilian charter operations, airline operators, and the U.S. Air Force and found that most failures in the maintenance environment occurred because of problems at the process level. The Australian Transportation Safety Board (Hobbs & Williamson, 2000) conducted a survey of Licensed Aircraft Maintenance Engineers to determine what they thought were the causal factors in accidents. More than 95% of the survey respondents indicated that memory lapses were the most commonly reported unsafe factor preceding a safety occurrence.

From 1988 to 1996, GA in the United States has experienced a relatively stable accident rate per 100,000 aircraft hours flown, fluctuating from 8.69 in 1988 to 9.11 in 1994 and back to 8.06 in 1996, with an average of 8.45 (U.S. Department of Transportation, 1999). Research efforts focused on identifying, managing and reducing human error in GA maintenance will help further reduce the economic and human costs associated with GA accidents and fatalities. Before determining the efficacy of any given theoretical model or intervention program for human error in GA maintenance, one needs to describe the nature of the problem. The purpose of the current study was to provide a descriptive summary of maintenance safety errors associated with GA accidents, based on classification of maintenance activities, maintenance personnel, and aircraft type. This description will provide an overview of the linkages between GA maintenance and accidents, as well as point the way for more in-depth investigations.

METHOD

GA Accident Data

Final reports for all accident investigations involving GA aircraft between 1988 and 1997 were obtained from the U.S. National Transportation Safety Board (NTSB). For purposes of this analysis, each of the accidents that were coded as involving a maintenance error were reviewed. Each accident report contains detailed information about the aircraft, crew, passengers, maintenance history, weather conditions and accident location. The NTSB defines GA aircraft as "all civil flying except revenue air carrier (including all part 121 and all part 135) operations" (S. Smith, personal communication, May 16, 2000). Of the 20,884 reported GA accidents that occurred during this ten year period, 1,503 (7.21%) were reported to involve at least one maintenance-related error as a primary cause or factor in the accident.

NTSB accident investigation report data were provided in the form of tab-delimited data files and narrative text files. Data files were imported into SPSS 9.0 for analysis. Each accident report was treated as a single case. Several string variables required transformation to numeric values. The resulting SPSS file contained 603 variables, seven of which are the focus of this study.

Data Classification

NTSB maintenance activity classification included: routine maintenance, service of aircraft equipment, inspection, compliance with airworthiness directive (AD), annual inspection, adjustment, alignment, installation, lubrication, modification, replacement,

major repair, major alteration, service bulletin/letter, design change, overhaul, major overhaul and rebuild/remanufacture. Maintenance personnel classification included: company maintenance personnel, FAA principal maintenance inspector, kit manufacturer, manufacturer, other maintenance personnel, owner/pilot mechanic, and supplier distributor of parts (other than manufacturer). Aircraft classification included: airplane, helicopter, glider, balloon, blimp/dirigible, ultralight, and gyroplane.

Analyses

Analyses of the report data included frequency counts for type of maintenance activity and maintenance personnel listed as a primary cause or factor in the accident. Additional analyses included comparing type of maintenance, maintenance personnel and aircraft type by number of fatalities, non-fatal injuries and uninjured persons involved in the accident.

RESULTS

Figure 1 depicts graphically the 10-year trend for all GA and for maintenance-related GA fatalities. The percentage of fatalities for maintenance-related GA accidents were quite variable across the 10-year time frame, with peaks observed in 1989, 1992, and 1994 when 43%, 54%, and 42% (respectively) of all maintenance-related accidents resulted in fatalities. Despite the decline from 1994 through 1997, fatalities still occurred in over one-fourth of the accidents. The year with the lowest percentage of maintenance-related fatalities was 1990 (22%). Comparison of fatal injuries across ten years of GA maintenance-related accidents are found in Table 1.

Type of Maintenance Activity

Table 2 presents the frequency and percentage of each type of maintenance issue occurring in the accident reports as a primary cause or factor in the accident. Of the 1,503 NTSB maintenance-related GA accident reports analyzed, 300 (20.0%) cited installation as a primary cause or factor in the accident. Other frequently occurring primary maintenance causes or factors included routine maintenance (n=221, 14.7%), maintenance inspection (n=207, 13.8%), and annual inspection (n=125, 8.3%). Maintenance activities that account for less than 4% of the total are combined into the category, *Other Maintenance Activity*.

Installation problems were not only the most frequently cited maintenance issue; they also resulted in the most severe consequences. Accident reports citing installation problems accounted for 100 fatalities (19.8%), and 210 injuries (22.7%). Installation issues combined with routine maintenance and routine inspection accounted for over 50% of the fatal injuries in this sample. Information regarding why the installations were necessary would be of interest in a human factors study of GA maintenance, however, that information is not available in most of the reports. Table 3 provides the total number and percentage of fatalities, non-fatal injuries and uninjured for each maintenance activity.

Maintenance Personnel

When possible, NTSB aviation accident reports describe the personnel that performed the maintenance activity associated with the investigation. Unfortunately, many of the accident reports did not include information about the maintenance personnel's certification or experience with aircraft. Of the 1,503 NTSB GA accident reports analyzed, 1,426 had information about the maintenance personnel. Table 4 presents the frequencies for personnel performing the maintenance that was cited as a primary cause or factor in the maintenance accident. *Other maintenance personnel* was the category most frequently cited as a primary cause or factor in this sample (n=670, 44.6% of all GA maintenance accident reports). The definition of *other maintenance personnel* is rather ambiguous, but the authors believe it usually refers to those maintenance personnel who are not salaried employees of the aircraft operator. *Other maintenance personnel* accounted for 210 (42.9%) fatalities and 391(45.4%) of GA maintenance-related injuries. *Company maintenance personnel* appeared in 233 (15.5%) accident reports, and accounted for 61 (12.5%) fatalities and 150 (17.4%) of injuries. Table 5 presents the number of fatalities, injuries and uninjured by maintenance personnel.

Type of Aircraft

Table 6 provides the frequency and percentage of aircraft types cited in accident reports. The type of aircraft most frequently involved in accidents in this sample were fixed-wing aircraft (n=1,289, 85.9%). This is consistent with the fact that fixed-wing airplanes constituted 86% of GA aircraft in 1996 (DOT, 1999). Helicopters were involved in 184 (12.3%) accidents, although since at least 1991, all rotorcraft combined have accounted for only 3% of all GA aircraft (DOT, 1999). Less than 2% of GA

maintenance related accidents involved other types of GA aircraft.

Airplane accidents accounted for 446 (89.4%) fatalities and 786 (85.1%) injuries. Helicopters accounted for 46 (9.2%) fatalities and 114 injuries (12.3%). Table 7 presents the total number and percentage of fatalities, injured and uninjured by type of aircraft.

Type of Aircraft by Type of Maintenance

Installation was the number-one maintenance problem for all aircraft combined and for fixed-wing alone (19%). For helicopters, installation and inspection were nearly equal in citation as the primary maintenance problem (16% and 17% respectively).

DISCUSSION

Since 1988, there has been no significant decrease in either the percentage of GA accidents involving fatalities or the rate of fatalities in maintenance-related accidents. The current study has provided a descriptive look at ten years of maintenance causes and factors as coded by the NTSB. This paper is the beginning of a large-scale effort to investigate the human factor issues involved in GA maintenance. Such an investigation will provide greater understanding and effective suggestions that, if implemented, would increase the safety of GA operations. This study has already shown that one procedure alone is linked to 19% of the maintenance-related accidents: the installation process. Indeed, if human errors associated with improper installation were eliminated completely, the number of GA maintenance-related fatalities could decrease by 19%. Based on this finding the authors have begun a more detailed archival research of all NTSB narrative reports involving GA installation problems. A focus of this review will be to determine the relationship of improper maintenance to type of error and aircraft system. Errors include use of the wrong part, reversals, incorrect attachments and connections, omission of parts or omitted inspections. Systems include flight controls, powerplant, landing gear, flight/navigation instruments, electrical and fuselage. The second part of the study of the installation process will include a thorough review of all cases from 1997 utilizing a human factors maintenance-error taxonomy.

The results of this study also confirm that some types of GA aircraft are more prone to accidents associated with maintenance-related problems. While rotorcraft account for 3% of all GA aircraft, they appear to involve a disproportionate percentage of maintenance-related GA accidents (12%), fatalities (9%) and injuries (12%). Future research needs to focus on the role of installation and inspection procedures in rotorcraft.

As the examples above illustrate, the NTSB database of GA maintenance-related accidents allows for in-depth analyses of the quantifiable aspects of accident investigation. As more results emerge, researchers will have a roadmap for future assessments of maintenance environments, testing of the various human error theoretical models, and suggestions for preventative safety measures.

References

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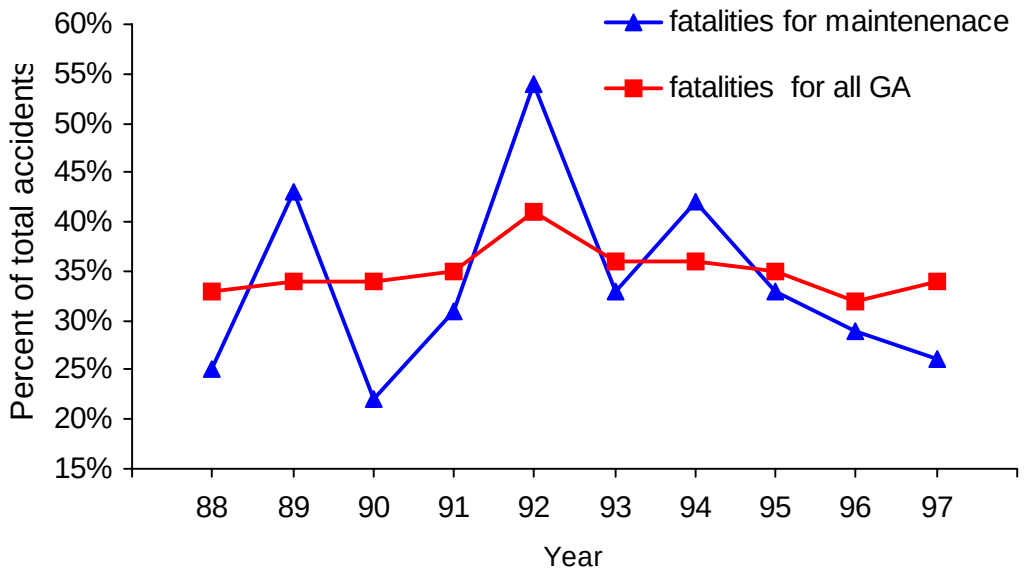

Figure 1. Fatalities: All GA vs Maintenance-Related Fatalities

Table 1

Maintenance-Related Accidents[a] and Fatalities to All GA, 1988-1997

	All GA			Maintenance-related		
Year	# Accidents	# Fatalities	% Fatalities	# Accidents	# Fatalities	% Fatalities
1988	2,385	792	33%	180	45	25%
1989	2,233	765	34%	169	72	43%
1990	2,215	762	34%	151	33	22%
1991	2,175	772	35%	159	49	31%
1992	2,073	855	41%	152	82	54%
1993	2,039	732	36%	123	41	33%
1994	1,994	718	36%	124	52	42%
1995	2,053	727	35%	140	46	33%
1996	1,908	615	32%	164	48	29%
1997	1,853	637	34%	141	36	26%

[a] Maintenance accidents refer to cases reported in the NTSB database, whether or not they were accidents or incidents, in which there was a maintenance-related factor or cause in the first occurrence.
GA figures available at http://www.ntsb.gov/aviation/Stats.htm

Table 2

Frequencies for Maintenance Activity

Maintenance Activity	Frequency	Percent
Installation	300	20.0
Maintenance	221	14.7
Inspection	207	13.8
Annual Inspection	125	8.3
Service of Aircraft	92	6.1
Adjustment	84	5.6
Modification	63	4.2
Overhaul	60	4.0
Other Maintenance Activity	321	21.4
Other[a]	30	2.3
Total	1,503	100.0

[a] Other refers to codes used in the NTSB accident reports that are not labeled as 'maintenance'. Some examples include landing gear, tailwheel lock, flight manuals and radar assistance to VFR aircraft.

Table 3

Type of Maintenance Activity by Number of Fatalities, Injuries and Uninjured

	Fatality		Injured		Uninjured	
Maintenance Activity	Sum	Percent	Sum	Percent	Sum	Percent
Installation	100	19.8	210	22.7	268	17.6
Maintenance	84	16.7	155	16.8	215	14.1
Inspection	78	15.5	120	13.0	249	16.4
Annual Inspection	39	7.7	80	8.7	124	8.2
Adjustment	28	5.6	41	4.4	84	5.5
Overhaul, Major	28	5.6	32	3.5	45	3.0
Modification	26	5.2	19	2.1	73	4.8
Replacement	22	4.4	31	3.4	37	2.4
Service of Aircraft	18	3.6	61	6.6	90	5.9
Overhaul	15	3.0	35	3.8	58	3.8
Other Maintenance Activity	46	9.2	131	14.1	255	16.7
Other	20	4.0	9	0.9	22	1.5
Total	504	100.0	924	100.0	1,520	100.0

[a] Other refers to codes used in the NTSB accident reports that are not labeled as 'maintenance'. Some examples include landing gear, tailwheel lock, flight manuals and radar assistance to VFR aircraft.

Table 4

Frequencies for Maintenance Personnel

Maintenance Personnel	Frequency	Percent
Other Maintenance Personnel	670	44.6
Company Maintenance Personnel	233	15.5
Pilot in Command	220	14.6
Unknown	64	4.3
Company/Operator Management	63	4.2
Manufacturer	55	3.9
Owner/Pilot Mechanic	32	2.1
Owner/Builder	27	1.8
Other[a]	62	4.3
Missing Values	77	5.1
Total	1,503	100.0

[a]Other refers to codes used in the NTSB accident reports that indicated personnel whom may not be 'maintenance' personnel. Some examples include flight engineer, FBO personnel, airport personnel, ground personnel.

Table 5

Maintenance Personnel by Number of Fatalities, Injuries and Uninjured

Maintenance Personnel	Fatalities		Injuries		Uninjured	
	Sum	Percent	Sum	Percent	Sum	Percent
Other Maintenance Personnel	210	42.9	391	45.4	723	50.3
Company Maintenance Personnel	61	12.5	150	17.4	265	18.5
Pilot in Command	92	18.8	113	13.1	160	11.1
Unknown	23	4.7	38	4.4	72	5.0
Company/Operator Management	38	7.8	64	7.4	73	5.1
Manufacturer	20	4.1	33	3.8	45	3.1
Owner/Pilot Mechanic	14	2.9	30	3.5	19	1.3
Owner/Builder	7	1.4	16	1.9	24	1.7
Other[a]	24	4.8	27	3.1	55	3.6
Total	489	99.9	862	100.0	1,436	100.0

[a]Other refers to codes used in the NTSB accident reports that indicated personnel whom may not be 'maintenance' personnel. Some examples include flight engineer, FBO personnel, airport personnel, ground personnel.

Table 6

Frequencies for Type of Aircraft

Type of Aircraft	Frequency	Percent
Airplane	1,289	85.9
Helicoptor	184	12.3
Glider	9	0.6
Balloon	7	0.5
Gyroplane	7	0.5
Blimp/dirigible	3	0.2
Ultralight	2	0.1
Total	1,501	100.0

Table 7

Type of Aircraft by Number of Fatalities, Injuries and Uninjured

Type of Aircraft	Fatalities		Injuries		Uninjured	
	Sum	Percent	Sum	Percent	Sum	Percent
Airplane	446	89.4	786	85.1	1,320	86.8
Helicoptor	46	9.2	114	12.3	173	11.4
Gyroplane	4	0.8	4	0.4	3	0.2
Balloon	2	0.4	5	0.5	6	0.4
Glider	1	0.2	12	1.3	2	0.1
Blimp/dirigable	-	-	2	0.2	11	0.7
Ultralight	-	-	1	0.1	5	0.3
Total	499	100.0	924	100.0	1,520	100.0