WHY PLANE CRASH: GENERAL AVIATION ACCIDENT STATISTICS AND ADDITIONAL SAFETY ASPECTS

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Abstract. The paper summarises general aviation accidents, their impact on safety issues of flying, the new technology used for increasing safety flight and for mitigate the consequences of the accidents. The study of accidents and additional safety aspects are related to the activities in the part of European project called PPlane. The 7.FP EU project PPlane is being solved in joint cooperation with the others European research teams. The PPlane project is aimed to assessment and validation of pioneering concepts for personal plane and the whole personal air transport systems.
Used accident statistics are based on NTSB reports in a year 2010. These reports are extracted from NTSB aviation accident database. The data are valid for Northern America region and include general aviation aircraft, similar to considered PPlane vehicles. The aircraft with significantly different utilization were excluded – i.e. agricultural aircraft, experimental aircraft, homebuilt aircraft, and old timer aircraft. The main purpose of accident statistics was detection and comparison of safety effects on single-engine vs. multi-engine configuration. Additional safety aspects include using of the new technology especially impact of use of BRS (Ballistic Recovery System).

Keywords. Accident statistic, BRS, general aviation, PPlane, safety.

1 Introduction

In present time, the safety and reliability of flying is more discussed issue, especially when the small aircraft are taken into a consideration. For example in United States, a general aviation included 223,370 aircraft [5] in 2010. On the other side, a commercial aviation (air carrier under 14 CFR 121 and 14 CFR 135) included only 7,431 aircraft [5] in 2010. It means that the general aviation creates approximately 96% of total amount of aircraft in United States. In addition, the risk of accident is also higher under the general aviation conditions because the aircraft fly in lower part of the airspace where turbulences are occurring more frequently and pilots sometimes do not have enough experiences to resolve sudden more serious problems. Regarding these factors, a necessity of improving current aircraft systems for a small aircraft should be considered. The accident statistics are important input to determine which of the systems match the safety requirements and are reliable and which not and therefore should be improved.

The research of general aircraft accidents was done within the 7.FP European Project called Personal Plane: Assessment and Validation of Pioneering Concepts for Personal Air Transport Systems as a part of assessment of safety and reliability. The accident statistics were supposed to help to reveal the weak areas or components in the general aviation. The main accident statistic was based on the data collected in 2010 by National Transportation Safety Board. The NTSB is agency conducting independent investigations of all civil aviation accidents in the United States and major accidents in the other modes of transportation. The main goal of this statistic was detection and comparison of safety effects on single-engine versus multi-engine configuration. The details are discussed in chapter 2.

2 GA Accident Statistics

The accident statistics are very important input for decisions related to safety assessment of aircraft. The accident reasons indicate critical events and also critical systems contributing to accidents and also reveal which the aircraft systems need to be improved and which general aviation areas are insufficient. For example, the accident statistics may be also significant input to Functional Hazard Assessment (FHA), which was conducted within PPlane project for further evaluation of the aircraft systems.

Following statistical data were gathered on basis of the accident reports during the year 2010 from NTSB accidents database [3]. The accident data are valid for Northern America and include particularly the aircraft related to future PPlane vehicles. The PPlane aircraft should be equipped with single or multi-engine and should carry up to 8 passengers. Consequently, the accident statistic is divided into two main categories: single-engine and multi-engine configuration and only the aircraft up to 8 seats are included.

2.1 Comparison a Single-engine Aircraft with Multi-engine Aircraft

As mentioned earlier, the main goal of the accidents statistic was a comparison of single-engine configuration with multi-engine configuration and their impact on a safety issue. The results of the analysis are described in Table 1. The 809 accidents of single-engine aircraft and 75 accidents of multi-engine aircraft were registered in 2010.

In general, it can be expected that per flying hour a twin-engine aircraft compared to a single-engine aircraft is approx. two times more likely to develop problems in any of its engines. On the other hand, twin-engine aircraft has significantly lower probability of loss of both engines.

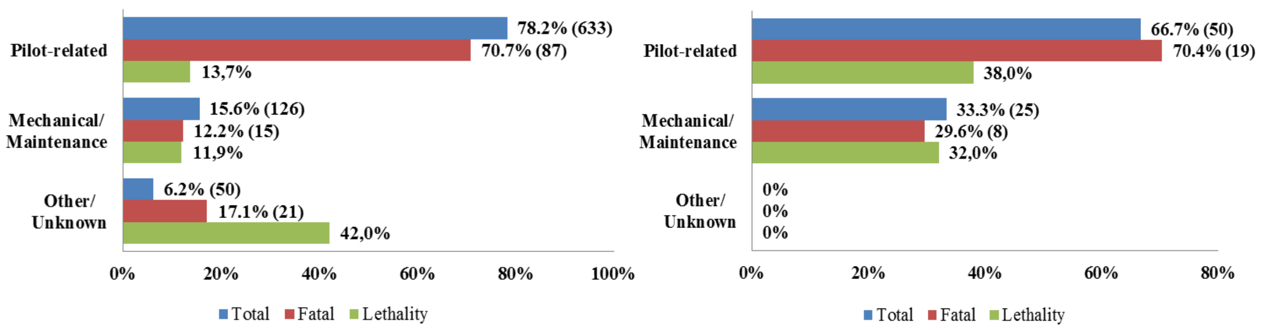
Single-engine Aircraft			**Multi-engine Aircraft**		
Aircraft	809		Aircraft	75	
Aeronca	13		Aero Commander	4	
American Champion	16		Beechcraft	22	
Beechcraft	57		Cessna	25	
Cessna	333		Piper	22	
Cirrus	24		Smith Aerostar	2	
Luscombe	14				
Maule	16				
Mooney	16				
Piper	198				
Light Sport Aircraft	23				
Other Manufacturers	99				
Total of Accident	**809**	**100%**	**Total of Accident**	**75**	**100%**
Non-fatal Accident	**686**	**84.8%**	**Non-fatal Accident**	**48**	**64%**
Fatal Accident	**123**	**15.2%**	**Fatal Accident**	**27**	**36%**

Table 1: Accidents single-engine vs. multi-engine aircraft [3].

There are several reasons for higher percentage of multi-engine fatal accidents [6]:

- **Proficiency** – incompletely trained or rusty pilots can fly multi engine aircraft, but not really safely. In normal operation, they would be at least twice safer flying a single engine aircraft. This is due to the higher probability of any of the engines failing in a multi-engine configuration and the pilots are not being prepared to handle those cases.
- **Mountains** – multi-engine aircraft have a significant safety advantage over single-engine in mountain over flights. This is a true only if take-off and flight are ensured at safe altitudes above peak levels is possible after the engine failure.
- **Oceans** – long over water flights are safer in multi-engine aircraft, but only with proper pre-flight planning. The pilot needs to make computations which prove that, in case of engine failure, enough range is available to reach the destination or the alternate airport.
- **Weather** – multi-engine aircraft is operated in worst environmental conditions (i.e. in rainy conditions, instrument meteorological conditions etc.) and pilots do not have adequate level to manage unsafe conditions.

As shown in Figure 1, the main cause of the accidents in General Aviation (GA) is the pilot's incorrect actions or inactivity. The accidents related to pilot create most than 70% of total accidents for both single-engine and multi-engine configuration. The second major category is accidents caused by mechanical or maintenance reasons. These contribute with 16% by single-engine and 33% by multi-engine aircraft. The last category includes other and unknown accidents such as midair collision. It is obvious that these situations are very dangerous which the high lethality percentage confirms.



a) Single-engine aircraft **b) Multi-engine aircraft**

Figure 1: Accident causes in GA in 2010 [3].

A major causes of investigated accidents (pilot, mechanical, other) are further divided into more categories, for example by flight phase or aircraft system where the accident occurs. The Table 2 provides the results in more details. The most of pilot-related accidents happens during take-off and landing flight phase. Nevertheless, these accidents mostly do not have fatal consequences. On the other hand, the high percentage indicates the need of higher or even full automation supporting take-off and landing phase. Such technology should be motivated by a similar development in the UAVs field and it is also considered for an automation of PPlane vehicles.

The other source of high percentage of pilot-related accidents is the accidents during a reduced weather conditions (e.g. thunderstorm, icing, turbulence). There are not many weather accidents, but at least a half of them results in fatal injury for both single-engine and multi-engine configuration.

The manoeuvring is the most dangerous flight phase ever. There are not many accidents in this stage, but if they are, they mostly have catastrophic consequences. The single-engine configuration accounted for 30 fatal of the 50 total accidents, which means more than 50% is catastrophic and all accidents are fatal for the multi-engine configuration during the manoeuvring.

The second main category is the accidents caused by mechanical or maintenance reasons. The highest number of fatal accidents is categorized as a power plant, which is also one of the most significant categories in non-fatal occurrences within both engine configurations. These accidents are followed by the accidents related to flight controls or airframe. The failure of these components induces the highest number of lethality, namely 28.6% for single-engine aircraft.

The other and unknown accidents generate the third main category. The most of total and fatal accidents are described as unknown reason. At this type of accidents, the reason, which caused the accident, has not been found or there were more events that led to a fatality. It is expected that the most dangerous cause is mid-air collision with almost 70% of lethality, because there are not many chances or possibilities how to avoid the collision when this situation occurs.

	Single-engine aircraft					**Multi-engine aircraft**				
Types of Pilot-related Accidents										
Major cause of accident	Total		Fatal		Lethality	Total		Fatal		Lethality
Fuel Management	67	10.6%	5	5.7%	7.5%	7	14.0%	2	10.5%	28.6%
Weather	37	5.8%	16	18.4%	43.2%	2	4.0%	2	10.5%	100%
Takeoff and Climb	105	16.6%	11	12.6%	10.5%	10	20.0%	4	21.1%	40.0%
Maneuvering	58	9.2%	30	34.5%	51.7%	7	14.0%	7	36.8%	100%
Descent and Approach	35	5.5%	12	13.8%	34.3%	8	16.0%	3	15.8%	37.5%
Landing	271	42.8%	4	4.6%	1.5%	13	26.0%	0	0%	0%
Other	60	9.5%	9	10.3%	15.0%	3	6.0%	1	5.3%	33.3%
Types of Mechanical/Maintenance Accidents										
Major cause of accident	Total		Fatal		Lethality	Total		Fatal		Lethality
Power Plant	62	49.2%	10	66.7%	16.1%	13	52.0%	5	62.5%	38.5%
Fuel System	15	11.9%	1	6.7%	6.7%	3	12.0%	1	12.5%	33.3%
Instruments	0	0%	0	0%	0%	1	4.0%	1	12.5%	100%
Gear and Brakes	28	22.2%	0	0%	0%	5	20.0%	0	0%	0%
Electrical	7	5.6%	0	0%	0%	1	4.0%	0	0%	0%
Airframe/Flight Controls	14	11.1%	4	26.7%	28.6%	2	8.0%	1	12.5%	50.0%
Types of Other/Unknown Accidents										
Major cause of accident	Total		Fatal		Lethality	Total		Fatal		Lethality
Birdstrike	6	12.0%	0	0%	0%	0	0%	0	0%	0%
Unknown Reason	35	70.0%	15	71.4%	42.9%	0	0%	0	0%	0%
Midair Collision	9	18.0%	6	28.6%	66.7%	0	0%	0	0%	0%

Table 2: Accidents single-engine vs. multi-engine aircraft in more details [3].

The results related to probability of accidents are described in the Table 3. The probability is accounted on the basis of estimated number of active aircraft and estimated total flown hours in 2010 for both single-engine and multi-engine aircraft.

The probability of accident by number of active aircraft is slightly different for single-engine and multi-engine configuration. The single-engine aircraft have higher probability to meet with an accident ($5.63 \cdot 10^{-3}$ to $4.85 \cdot 10^{-3}$) but then their fatality is lower ($8.56 \cdot 10^{-4}$ to $1.75 \cdot 10^{-3}$). The number of accidents per 100,000 flight hours for single and multi-engine is in the same proportion. For single-engine aircraft, 6.12 total accidents and less than one fatal accident are rated at each 100,000 flight hours. The lower amount of total accidents is rated for multi-engine aircraft, but the number of fatal accidents per 100,000 flight hours is higher, namely 1.25. It means that the multi-engine aircraft crash much less within the number of flown hours, but the following accidents are more dangerous.

Estimated number of active aircraft in 2010			
Single engine		Multi engine	
143,733		**15,469**	
Estimated total hours flown in 2010			
Single engine		Multi engine	
13,247,001		**2,160,457**	
Accidents in 2010			
Single engine		Multi engine	
All	Fatal	All	Fatal
809	**123**	**75**	**27**
Accidents per 100,000 flight hours			
Single engine		Multi engine	
All	Fatal	All	Fatal
6.12	**0.93**	**3.47**	**1.25**
Probability of accident by flight hours			
Single engine		Multi engine	
All	Fatal	All	Fatal
6.12E-05	**9.29E-06**	**3.47E-05**	**1.25E-05**
Probability of accident by number of active aircraft			
Single engine		Multi engine	
All	Fatal	All	Fatal
5.63E-03	**8.56E-04**	**4.85E-03**	**1.75E-03**

Table 3: Probability of accidents of single-engine vs. multi-engine aircraft [1], [3].

3 Additional Safety Aspects

Additional safety aspects analysis includes using of the new technology especially impact of use of BRS (Ballistic Recovery System). Also the impact of higher level of aircraft onboard automation on the safety issue is assessed.

3.1 Higher Reliance on Avionic Systems

The analysis also indicated relatively low percentage of accidents caused by instruments and electrical systems. As the Table 2 shows, in case of electrical systems, there is no fatal accident after failure of the electric systems and number of total accidents is very low, namely 7 accidents from 126 mechanical accidents for single-engine configuration. In case of instruments, there is only 1 fatal accident, which means 3.7% of fatal and 1.3% of all multi-engine aircraft accidents.

In comparison with pilot related accidents, significantly lower percentage of the mechanical accidents is evident. It is obvious that the higher level of onboard automation positively influences a safety and reduces a probability of accident. The aircraft equipped with an extensive avionics, generally known as “glass cockpit” aircraft, have greatly expanded into the general aviation fleet in recent years. This type of aircraft is also commonly known as Technologically Advanced Aircraft (TAA). TAA are equipped with a new-generation avionics that take full advantage of computing power and modern navigational aids to improve pilot situational awareness, system redundancy and dependence on equipment, and to improve in-cockpit information about traffic, weather, airspace and terrain. All mentioned avionics help to reduce the accident rate of aircraft.

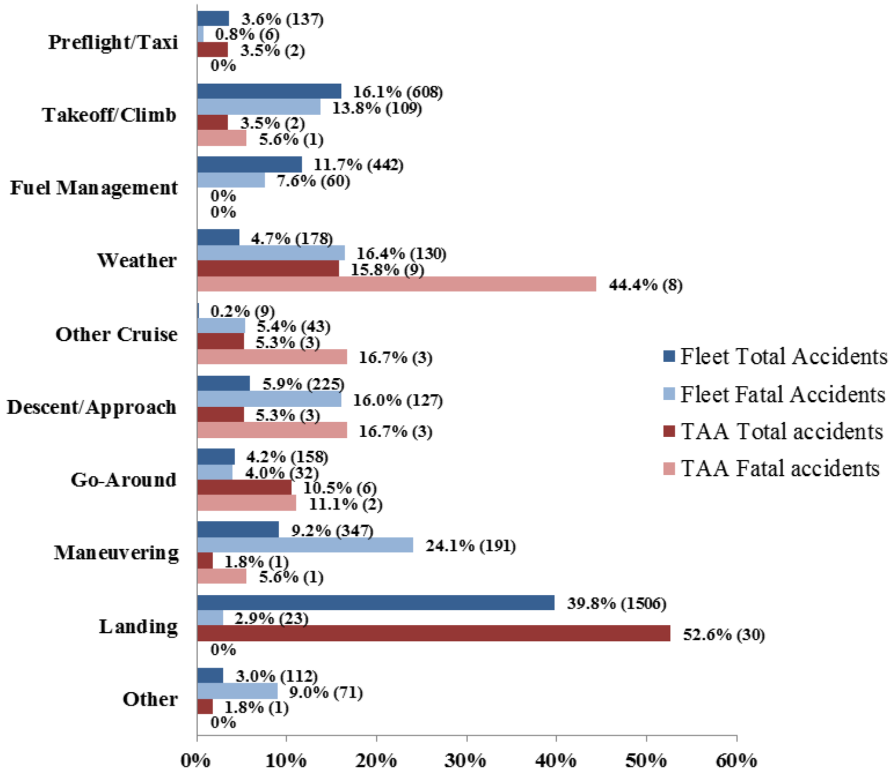


Figure 2: Types of pilot-related accidents, TAA vs. Fleet [7].

Figure 2 shows a comparison of TAA accidents with all GA accidents. Between 2003 and 2006, TAA aircraft accounted for 57 of the 3,783 total GA accidents. Only 18 of the 792 fatal accidents happened in such aircraft. The distribution of these accidents provides several interesting comparisons. For both total and fatal accidents, TAA had fewer or no accidents related to takeoff/climb and fuel management. This is very significant moment in long-time causes of GA accidents. Manoeuvring accidents, a leading cause of fatalities in GA overall, were reduced in TAA. These positives are the result of using the MFD displaying useful information, such as moving maps, obstructions, critical speed and more. The accidents caused by landing still take up high percentage even in TAA. The worst statistic is in weather related accidents. It may be caused by lack of graphic presentation of non-radar weather data. This may have negative impact on the pilot's ability to get a clear mental picture of overall weather conditions, and relate it to the route being flown. A ref. [7] provides more information.

3.2 Effect of BRS Utilization on Aircraft Safety

Another critical aspect studied was the effect of Ballistic Recovery System (BRS or emergency parachute) on survival rate during accidents. This statistic was done on the basis of NTSB reports in a year 2010 and based on records collected by Cirrus aircraft as well. During the whole study, several important facts were revealed and noted. For example, rate of initiation of BRS is $6.40 \cdot 10^{-6}$ per flight hour for the aircraft equipped with this system (valid for CAPS).

There have been 32 known BRS activations from January, 2002 to January, 2012. Of those activations, 28 deployments are considered "saves" that involved 53 survivors with one fatality. Four other activations were not successful deployments with five fatalities and two serious injuries. The four unsuccessful deployments involved one activation at very high speed (exceeding 555 kilometres per hour indicated, over twice the deployment speed), one activation at too low an altitude to fully inflate the canopy (15 to 60 meters above ground), another activation where the rocket took an unusual trajectory resulting in a failure to extract the parachute, and a mid-air collision where the parachute was activated by impact forces. The rocket trajectory anomaly was investigated and an airworthiness directive was published requiring a modification of the BRS rocket assembly [2]. These fatal accidents, where the parachute has deployed by forces due to impact with the ground, are not considered in this history. This means that probability of successful deployment and saving lives in dangerous situations is 89.8% [2], [3]. All analysed data are summarized in Table 4 below. The Figure 3 summarizes the CAPS deployment distributed by the severity of injury and the reasons of unsuccessful deployment results in fatal injury, as mentioned above.

Total number of activations of BRS	**32**
Total number of survivors	**53**
Average number of survivors per aircraft	**1.66**
Total flight hours accumulated by Cirrus aircraft until January, 2011	**5,000,000**
Total number of Cirrus aircraft delivered by the end of 2011	**5,071**
Rate of BRS initiations (per flight hour)	**6.40E-6**
Rate of BRS initiations (per aircraft)	**6.31E-3**
Probability of successful deployment	**0.898 (89.8%)**

Table 4: Summary on activations of BRS [2].

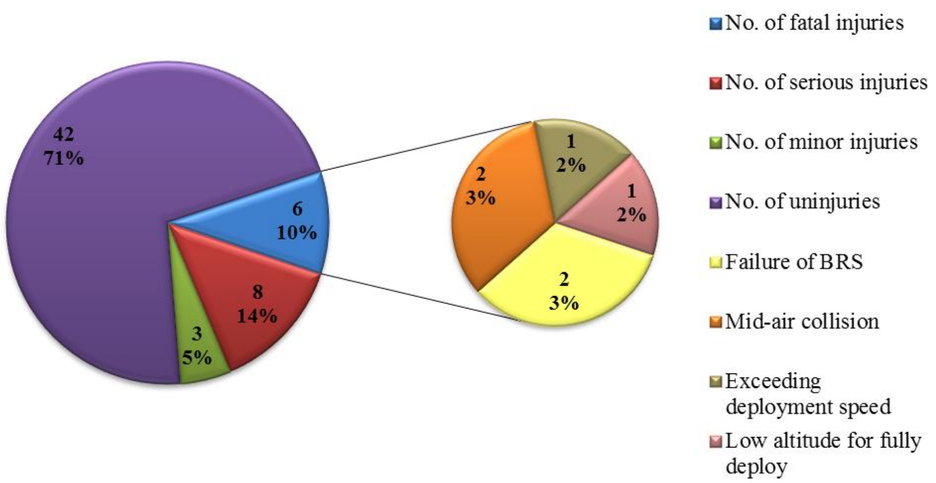


Figure 3: CAPS deployment summaries – distribution by injury severity [2].

In 2010, twenty-four Cirrus aircraft accidents occurred, seven of them fatal. The BRS was activated eight of seventeen non-fatal accidents. All of these accidents were a typical for activating the BRS. These are situations, when the pilot believes there is grave danger (i.e. loss of control, landing in inhospitable terrain, pilot incapacitation). If we assume that the BRS would not been used in these eight accidents, the number of fatal accidents would be increased to fifteen. This assumption implies that the use of BRS increases **survivability rate by approximately 33%**, see below in Table 5.

Assumption					
Without using of BRS			With using of BRS		
Total number of accidents	24	100%	Total number of accidents	24	100%
Non-fatal accidents	9	37.5%	Non-fatal accidents	17	70.8%
Fatal accidents	15	62.5%	Fatal accidents	7	29.2%
BRS reduces fatal accidents by	**33.3%**				

Table 5: Assumption based on NTSB statistics [3].

4 Comparison of Fatalities for Different Transportation Means

In 2010, 1.23 fatal accidents per 100,000 flight hours (1.23·10-5 per flight hour) occurred for all GA aircraft and for large air carriers operating under 14 CFR 121, the accident rate was 0,006 fatal accidents per 100 000 flight hours (6·10-8 per flight hour). The data are valid for Northern America region [4]. Worldwide data, provided by ICAO, showed that the fatal accident rate was 0.62 per 1,000,000 departures in 2010 [8]. To reach the same fatal accident rate for PPlane sized aircraft may not be realistic due to cost escalation for development and certification. Nevertheless, as shown in Figure 4, in comparison with other transportation means, the aviation remains the most safety transportation ever.

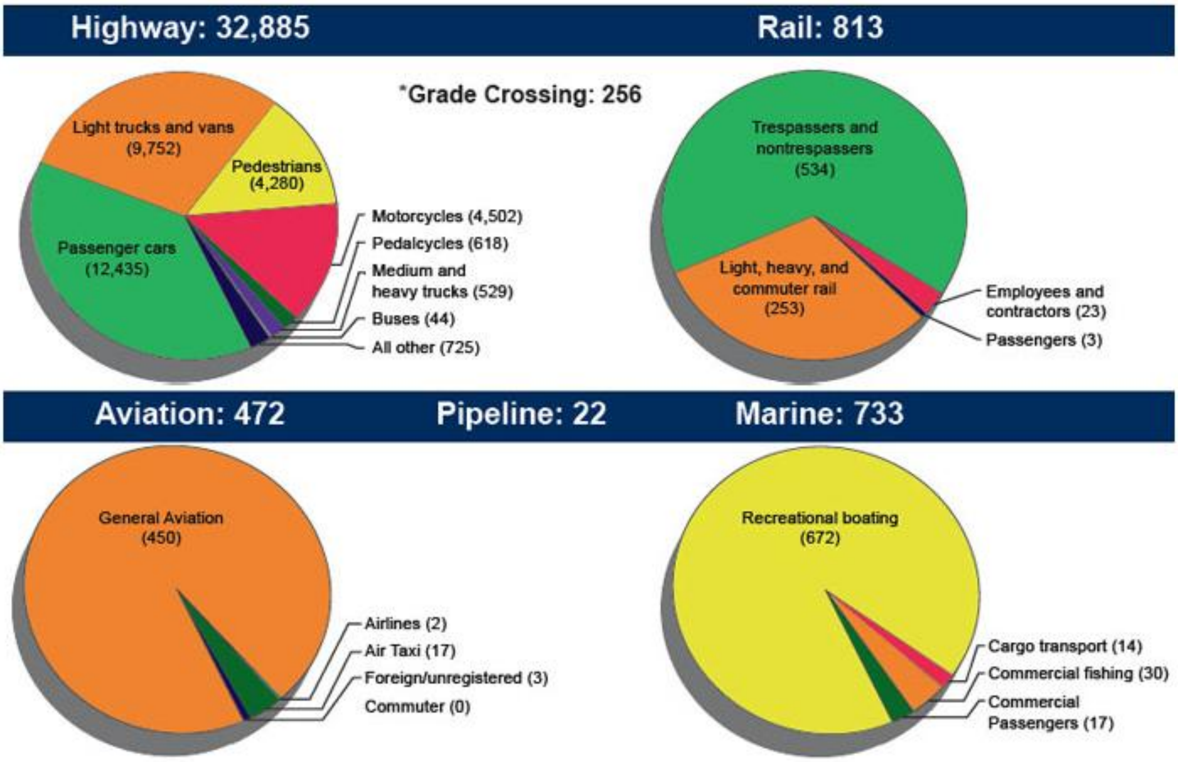


Figure 4: Transportation fatalities in 2010 [4].

5 Conclusion

The goal of the accident statistic was to reveal the potential differences related to safety issue between single-engine and multi-engine configuration. The results show that the single-engine aircraft tend towards more frequent accidents with minor consequences, while the accidents of multi-engine aircraft end mostly with serious or fatal consequence. The study of additional aspects showed that current new high technologies are available; therefore the PPlane vehicles could reach as accident rate as the airliners have. These accident statistics also show that the higher level of automation the GA aircraft have, the better possibility to reach such safety goals. Anyway, in comparison with other transportation means, the aviation is still the most safety way of transport ever.

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Acronyms

BRS	=	Ballistic Recovery System
CAPS	=	Cirrus Airframe Parachute System
CFR	=	Code of Federal Regulations
FHA	=	Functional Hazard Assessment
GA	=	General Aviation
ICAO	=	International Civil Aviation Organization
NTSB	=	National Transportation Safety Board
TAA	=	Technologically Advanced Aircraft

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