RISK ASSESSMENT OF ACCIDENT ASSOCIATED WITH AIRCRAFT TRANSPORTATION

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ABSTRACT

The new 1996 IAEA regulation for the transportation of radioactive material states a 90 m/s drop test on unyielding surface for packages transported by air. This figure originates from a statistical analysis on civil aircraft accident during the period 1975 to 1985. A review on the 1983-1989 period demonstrates comparable velocity with a less stringent definition of accident. The statistical analyses are combined with the hardness of the fly-over ground and the impact angle to generate probabilities curves giving the occurrence of a mechanical stress overtaking the drop test velocity.

The following steps were carried out:

- Statistical analysis of the accident database from the ICAO (International Civil Aviation Organisation) to appreciate the accident characteristics with special attention to the impact velocitiy and angle

- Modelling of the impact speed in each phase of flight (Take off, Climbing, Cruise, Approach and Landing), in order to evaluate the probability of occurrence of a given crash impact for different flight configurations

- Qualitative analysis of recorder failures available in France

As the statistical analysis is based on the available impact speed, a bias can be introduced if major crashes are neglected. In this respect, the qualitative analysis should give some elements to characterize the relationship between the non-availability of the information recorded on the black box and the severity of the accident.

PRINCIPLES AND PURPOSES

The principle of a specific package (Type C) devoted to the transport of radioactive material by air was introduced in the last IAEA 1996 regulation. It states that the package should be design in such a way to withstand a 90 m/s drop test on unyelding surface. This figure is based on a probabilistic analysis of aircraft impacts on the period 1975 to 1985. In order to check its veracity according to regular evolution of aircraft design and air transport regulation, an update of the study was performed on the period 1983 to 1989. Current further analysis is in process for the more recent period (up to 1995).

In order to assess the risk associated with aircraft transportation of radioactive material, the following steps were carried out:

- Statistical analysis of the accident database from the ICAO (International Civil Aviation Organisation) to appreciate the accident characteristics with special attention to the impact velocitiy and angle

- Modelling of the impact speed in each phase of flight (Take off, Climbing, Cruise, Approach and Landing) in order to evaluate the probability of occurrence of a given crash impact for different flight configurations and allow the specification of the safety criteria required for a hazardous material package

- Qualitative analysis of recorder failures available in France

The analyses of aircraft accidents was realised for Institut de Protection et de Sûreté Nucléaire (IPSN) and the Environmental Ministry of France, they are mainly based on the treatment of an accident file extracted from an ICAO file called the "ADREP" file. It deals with 364 accidents having occurred in the world from 1983 to 1989, involving civil aircraft of unladen weight greater than 5.7 tons and leading to at least one of the following consequences: one or more deaths or serious injuries or aircraft structural damage.

PROBABILITIES OF ACCIDENT

The probability of accident whatever the accident scenario observed has been extrapolated on the basis of available figures on severe accident (i.e. destruction of the aircraft and one or more fatalities). A value of $2.5\ 10^{-6}$ accident/flight for West European countries and United States was estimated. As the average journey represents about 1000 km, the probability per km can be asessed. Nevertheless, as some flight operations are quite independent of the distance travelled, a breakdown of the flight in phases was performed. This approach allows to estimate accident probabilities for different lengths. Except for the cruise phase, risks associated with ground manoeuvre, take off, climbing, approach or landing are similar whatever the length of flight. The phase distribution and the probability of accident related to western Europe are presented in Table 1, these statistics exclude ground accidents (10 % of the total). Two representative flights have been selected, a 1000 km flight related to an flight inside Europe and a 6000 km one, related to a trip from Europe to Japanese (2 steps of 5800 km and 7400 km).

Table 1. Accident rate in the different flight phases

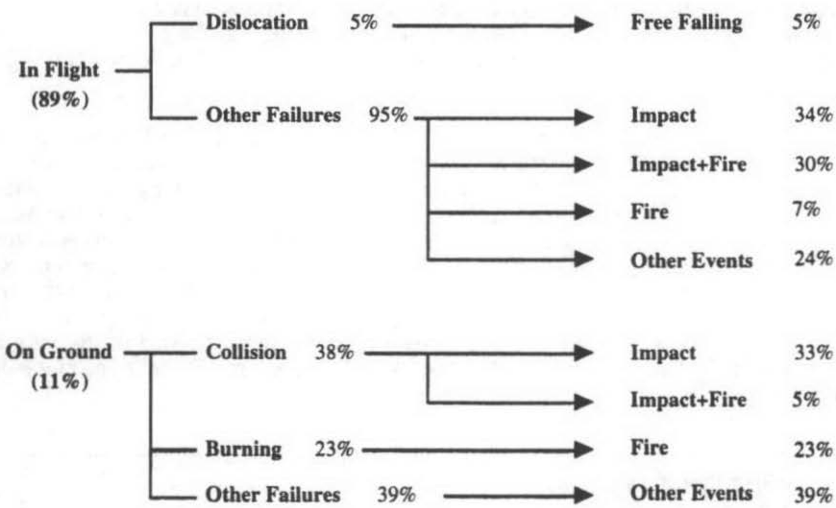
Flight phase	Accident rate	1000 km reference flight	6000 km reference flight
Take off	$3.4.10^{-7}$ per flight	13.5 %	9.0 %
Climbing	$2.7.10^{-7}$ per flight	10.8 %	7.2 %
Cruise	$2.5.10^{-10}$ per km	9.8 %	39.9 %
Approach	$9.6.10^{-7}$ per flight	38.5 %	25.5 %
Landing	$6.9.10^{-7}$ per flight	27.4 %	18.4 %
Accident rate per flight		$2.5\ 10^{-6}$	$3.8\ 10^{-6}$

Concerning the 1000 km flight, more than 50 % of the accidents occur during the final manoeuvre (approach or landing), and mostly within the approach phase (38.5 % of the accidents). Owing to the dependence of the cruise phase on length of travel, the accident distribution and the length are linked. Thus, unlike on continental flight, on a standard Europe-Japan flight (2 times 6000 km assumed), most of the accidents occur within the cruise phase (40 %).

EVENT TREE OF AN AIRCRAFT ACCIDENT

Beyond the accident rate analysis, the conditional probabilities of some given scenarios have to be assessed (Figure 1). In this respect, five different kinds of accidents have been distinguished: impact, fire, impact and fire, explosion and the other events.

Figure 1. Event tree of an aircraft accident



The distribution of these accidental events within the given flight phases has to be established so as to appraise the extent of the strain scenarios (impact, fire) at each step of the flight. According to Table 2, impact (alone or associated with fire) represents the most significant part of the accidental events (64 %, except ground manoeuvre accidents), this strain occurring mainly within the approach phase (80 % of the approach accidents).

Table 2. Accident distribution related to phases and scenarios (number of events)

	T*	C	E	A	L	*R*	Total
Impact	13	11	11	55	20	*13*	**123**
Fire	5	3	4	6	6	*9*	**33**
Other events	16	8	6	10	38	*13*	**91**
Explosion	0	2	3	8	3	*2*	**18**
Impact + Fire	10	11	8	46	22	*2*	**99**
Total	**44**	**35**	**32**	**125**	**89**	***39***	**364**

* T : "Take off"; C : "Climbing; E : "Cruise"; A : "Approach"; L : "Landing"; R : "Ground manoeuver"

STRAINS ASSESSMENT

In order to assess the risk associated with aircraft transportation, the statistical distributions of the main strains likely to harm the package must be estimated. Afterward, these strains have to be described, using a representative parameter in agreement with the available physical data. For this reason, impact is represented by the crash velocity, while fire is linked to its duration. But contrary to impact, the effect of fire duration is inferred from tests and observations.

Accident analysis reveals that the thermal resistance of the package is broadly dependent on the duration of the fire. In this respect, according to former studies, 20 % of fires exceed a 30 minutes duration. Fires of a 1 hour duration are observed from 10 to 15 % of any fire, while 2 hour fires occur from 2 to 5 %.

Concerning impact accident, the flight phase distribution of accident rate has been primarily extracted from the ICAO file. Therefore, the recorded absolute impact velocities have been normalised to the stall or cruise speed to account for the considerable range of performance characteristics between different aircraft types. It was thus possible to derive an impact velocity distribution for each flight phase and to adjust it to a given rated speed distribution assuming that only the normal component of the velocity acts upon the severity of the crash. An equivalent impact speed on an unyielding surface can then be calculated in each phase, considering the hardness of the fly-over ground, expressed by its ratio of hard ground. Figure 2 shows the probability per flight of having an equivalent normalised speed of impact greater than a given speed, for two standard flight of 1000 km and 6000 km and different kinds of fly over ground.

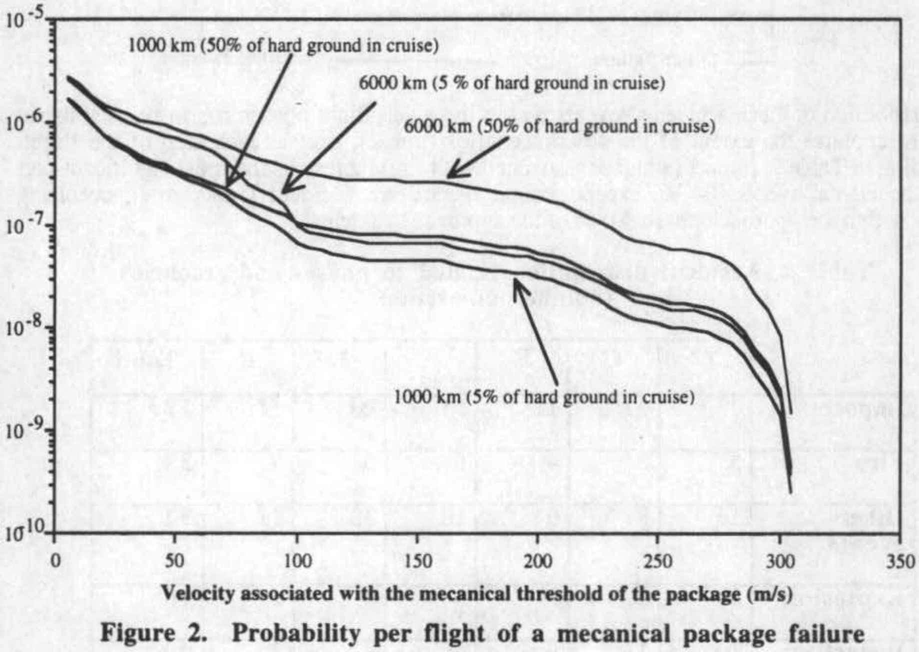


Figure 2. Probability per flight of a mecanical package failure

The physical characteristics of the package set a related opening threshold, expressed as a velocity (m/s). Beyond this normal speed value (acting upon an unyielding surface), the package is considered to have released a significant quantity of material. By referring to Figure 1, the associated probability of opening per flight can be deduced for different kinds of trips. With regard to the IAEA transport regulation related to Type C packages, an opening threshold of 90 m/s leads to a probability of 1.1 10^{-7} opening per flight (for a trip of 1000 km and 10 % of hard ground in the cruise phase). Reciprocally, a given acceptable probability (probability of failure) allows the evaluation of the associated threshold of mechanical strength of a package, and thus helps in its design.

QUALITATIVE ANALYSIS OF RECORDER FAILURES AVAILABLE IN FRANCE

As the statistical analysis is based on the available impact speed, a bias can be introduced if major crashes are neglected. In this respect, the qualitative analysis should give some elements to characterize the relationship between the non-availability of the information recorded on the black box and the severity of the accident.

For this purpose, five investigation reports available at the BEA (French authority in charge of the aircraft accidents) were analysed. They concern accidents of civil aircraft with unladen weight greater than 5.7 tons. On a total of 10 recorders, information were completly extracted from 4 of them and 6 were partially or totally damaged. The bad recuperation of data was induced by misfunctionings independent of the accident stresses in four cases. The two remaining recorder disfunctionings were related to the accident and consequent of the thermal stresses (especially long duration fire). Thus, the failure appears to stem mainly from maintenance errors and thermal stresses seem to be the more harmful to the recorders. To conclude, accident occurrences with high mechanical stresses (high velocity and angle) should not be greatly underestimated by lack of available recorder data.

CONCLUSION

The main purpose of this study was to establish a statistical description of the accidental environment associated with aircraft transportation. The treatment of an accident file has allowed the analysis of the components of accidents and the different scenarios harmful to a package.

In regard to impact, it was thus possible to assess the opening probability of a package, for any given flight (national or international) and for different hardnesses of fly-over ground. The corresponding chart has been calculated by flight phase, entire flight and by covered kilometres. Finally, the results have been validated by referring to a previous study.

It becomes apparent, therefore, that in spite of the impact severity, the general safety of aircraft transportation insures a relatively low rate of opening of a radioactive material package, especially if Type C packages are used.

REFERENCES

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