Benchmark Public Risk Levels for Australian Space Launch Activities

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Benchmark public risk levels for Australian space launch activities

Neale Fulton and Geoff Robinson
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1. Background

The Australian Government intends to allow rocket launches and other space activities to be conducted from Australia, provided that the risks of such activities are acceptable and provided that Australia's obligations under UN Space Treaties can be satisfied.

The Space Activities Act[1], section 18 requires that, before granting a licence to launch space vehicles from Australia, the Minister must be satisfied that the risk of operation of the launch facility causing substantial harm to public health or public safety is "sufficiently low". The Department of Industry, Science and Resources is developing a regulatory regime for implementing the requirements of the Space Activities Act. The regime will include regulations aimed at limiting the level of public risk associated with space launch activities.

2. Terms of Reference

The Department of Industry, Science and Resources has asked CSIRO Mathematical and Information Sciences to develop a risk benchmark which can be used by the Space Licensing and Safety Office for evaluating the risk of casualties to the general public from space launch activities.

- The benchmark level of acceptable risk is to be based on the aviation industry, as suggested in Fulton and Robinson[2], or an alternative industry.
- The arguments used to derive a level of risk deemed to be acceptable are to be presented in a clear and accessible manner which is capable of withstanding public scrutiny.
- Comparisons are to be made with the benchmark risk levels accepted by other countries which operate launch sites.

3. Recommendations

Recommendation 1: Commercial rocket launches in Australia should be required to satisfy the condition that the estimated public collective risk is less that 0.06 casualties per A$ billion of value added. This will be about 0.0006 per launch, based on estimated added value of A$10 million per launch. The value added is to be calculated as the value of the goods and services produced by conducting a launch (principally the fee for conducting the launch) minus the cost of the goods and services used by the space launch industry in the production process (including cost of the payload).

Recommendation 2: The maximum risk of casualty to any individual member of the public not associated with launches should be 1.E-7 for a single launch and 1.E-6 per year.

Recommendation 3: Risks to the public from rocket launches should be calculated conservatively. An Australian licensing authority should have some discretion in interpreting what is meant by "conservatively".

Recommendation 4: Information describing the risks associated with rocket launches should be readily available to the Australian public. For each launch, this information should include a contour map indicating the individual casualty risk as a function of geographic location.

Recommendation 5: The Australian government should support the establishment of an international register of space industry accidents.

4. Terminology

Note about precision: As remarked on page 3-1 of IRIG Standard 321.00[10], evaluation of risks involves much uncertainty. There are generally many steps in the estimation of the risk of a hazard, with a one order of magnitude (that is a factor of ten) uncertainty likely in the results of such calculations. It would therefore be unreasonable to expect to derive and quote a benchmark to high precision.

Public risk: It is common to differentiate between the risk to people who work in an industry or otherwise gain some benefit from that industry and people who can be regarded as uninvolved members of the public. The public risk is the risk that uninvolved people will be injured or killed.

Public hazards from the aviation industry do not include hazards to passengers. They only include hazards such as being injured by aircraft crashing into houses or by pieces of aircraft falling off and hitting people. See Table 10 on page 23 for a list of recent accidents in Australia in which people not involved in the aviation industry were killed or injured as a result of aviation accidents.

Individual risk is the risk that an individual person will be killed or injured. The unit in which risk is measured is probability of injury or death or injury per time period or per event. When discussing hazards associated with the aviation or space industries, it is usually specified as a probability of death per year. It is likely to depend on the person’s location and may also need to be qualified in other ways.

For instance, consider a person who spends their working hours in a lightly-constructed shed 20 metres from the end of a runway at Sydney airport on the grass inside the perimeter fence and directly in line with the runway. The probability that the person would be injured by an aviation-related accident might be, say, 0.01 per year. This level of individual risk is considered too high, so people are not permitted to spend time unnecessarily in such a risky location.

The individual risk to members of the public from a rocket launch is expected to vary along the launch corridor. Possible causes of injury such as being struck by inert debris, being injured by exploding fuel or receiving a dangerous dosage of hazardous chemicals from the rocket generally become smaller at locations further from the intended flight path and further from the launch site.

Collective risk is the average number of deaths or injuries expected from some class of causes to some defined group of people. It is sometimes also referred to as **societal risk** or **casualty expectation**. It can be calculated by summing the individual risks multiplied by the numbers of people in various classes of exposure multiplied by the average exposure.

For instance, Table 1 gives a hypothetical example of how the total collective risk might be calculated when various numbers of people are exposed to various levels of individual risk. The first row of the table says that there are 20 people exposed to a 1.E-6 chance (which means 1 times 10 to the power -6, or one in a million) of being injured. The average number of casualties expected for people in this group is the product of these two numbers, and is shown in the third column.

For this artificial example which has been constructed to illustrate the calculation of collective risk, there are small numbers of people exposed to relatively large risks and large numbers of people exposed to relatively small risks. The total casualty expectation is obtained by adding the casualty expectations for the various classes of risk exposure. Here the total casualty expectation is 0.001. This is equivalent to a one in a thousand risk that a single person will be injured or a one in a million chance that a thousand people will be injured.

The last column of Table 1 shows the percentage of the total casualty expectation associated with the various classes of exposure. The largest contribution to the total casualty expectation comes from the 100,000 people who have a 3.E-9 individual risk.

Number exposed	*Chance of injury*	*Casualty Expectation*	*Percentage of total casualty expectation*
20	1.E-06	0.000020	2.0
20	3.E-07	0.000006	0.6
90	1.E-07	0.000009	0.9
1,000	3.E-08	0.000030	3.0
2,000	1.E-08	0.000020	2.0
5,000	3.E-08	0.000150	15.0
10,000	1.E-08	0.000100	10.0
100,000	3.E-09	0.000300	30.0
200,000	1.E-09	0.000200	20.0
1,000,000	1.E-10	0.000100	10.0
500,000	1.E-11	0.000005	0.5
10,000,000	1.E-12	0.000010	1.0
100,000,000	1.E-13	0.000010	1.0
4,000,000,000	1.E-14	0.000040	4.0
Total		0.001000	100.0

Table 1: Artificial example to illustrate calculation of collective risk or casualty expectation

5. A limit on collective risk from Australian space launch activities

5.1. Assessment of public risks associated with aviation

Table 10 on page 23 lists all Australian aircraft accidents involving ground crew or members of the public for the period from 1974 to 1999, except for accidents in which there were injuries to ground staff and no other injuries or fatalities which are listed in Table 11. These tables were compiled using information provided by the Bureau for Air Safety Investigation which is part of the Australian Transport Safety Bureau.

There have been seven deaths and seven non-fatal injuries to members of the public in the 26 years from 1974 to 1999 inclusive. The two accidents causing deaths were both ones in which aircraft crashed into houses. One accident in Essendon killed six members of the public and injured another member of the public as well as two crew and one passenger. Another accident in Goulburn killed one member of the public as well as killing one crew and two passengers. Six other accidents each injured one member of the public, so the total number of non-fatal injuries to members of the public was seven, the same as the total number killed.

Some people who live near Essendon Airport regard the 1978 and 1993 accidents as being grounds for closing Essendon Airport. Some others would argue that public safely needs to be improved in other ways. For the present purpose of considering what is a reasonable level of public risk for the space launch industry, it is interesting that there has been a substantial amount of public discussion but that no dramatic changes have been made to reduce the risk. This can be taken as indicating that the rate of public casualties is near to the limit of acceptable risk given the economic importance of the aviation industry.

Given this data, the rate of public fatalities from aviation in Australia has been 7/26 = 0.27 per year and the rate of casualties has been 14/26 = 0.54 per year. While any rate of casualties greater than zero is undesirable, this rate has been to some extent accepted by the Australian public.

There are two reasons for being conservative when using the observed rate of public casualties from aviation to derive a limit to the predicted rate of casualties from space activities.

1. The predicted risk to the public from space activities is based on models. These models may not be completely reliable. Some risk also arises from hazards not modelled. It seems desirable to constrain the **predicted** rate of casualties from space activities more tightly than the **observed** rate of casualties from aviation.
2. The proportions of casualties which are fatalities may be higher amongst public casualties from space activities than amongst public casualties from aviation.

Considering these two arguments, we believe that it is appropriate to use the observed rate of public fatalities from aviation as a limit to the predicted rate of public injuries from space activities. Hence we will base further calculations on the fatality rate of 0.27 per year.

5.2. Why the aviation industry is being used as basis for determining acceptable collective risk

For most industries, risk is incurred by people who also receive benefits. The risk of automobile accidents is borne by the same people who benefit from the convenience of this mode of transport. The risk of workplace accidents is borne by people who benefit by getting paid employment.

Aviation and rocket launches both cause some risk to members of the public who receive no direct benefit from those industries. As discussed in our previous report[2], we believe that it is reasonable to use the current collective risk of injuries to the public from aviation as a basis for setting a limit to the collective risk to the public from space launch activities. The nature of the public risks from the two industries is similar. The risk from aviation is implicitly accepted, although some reduction in the level of risk might be expected as technology improves. We believe that if the economic activity associated with aviation were to increase and the level of risk relative to economic activity remained constant, then the consequent increase in public risk would not be questioned.

It seems reasonable that the public's preference not to be exposed to risks of death or injury should be regarded as applying equally to rocket launches and to the aviation industry. One argument for treating them similarly is that the Australian Bureau of Statistics generally has a single industry category in its economic statistics which includes both air and space transport. Another argument is that the distinction between aviation and the space industry is likely to become harder to draw in the future if sub-orbital passenger transport facilities are developed.

Public Law 60[7] in the United States was based on the reasonableness of comparing the risk of rocket launches to the aviation industry. It requires that the risk to the general public from rockets be no greater than the risk from aircraft flying overhead in the vicinity of the launch facility. The risks being compared are not analogous. Public Law 60 compares the *maximum* individual risk from rocket launches to the *local* individual risk from aircraft, which will generally be much less than the *maximum* individual risk from aircraft.

Two comparisons between rocket launch risks and the risk to the public from aviation are useful.

1. The maximum individual risk from rocket launches should not exceed the maximum individual risk from aviation. This is discussed further in Section 6.
2. The collective risk from rocket launches should not be more than commensurate with the collective risk from aviation. This comparison is the topic of the Section 1 of this report.

5.3. Scaling by economic activity

The acceptable collective public risk from a small airport ought to be less than the acceptable collective public risk from a large airport. The most natural way of comparing acceptable risks for operations of different scale seems to be to use economic added value as a scaling factor, since combining two different operations into a single economic entity should not change the acceptable total level of risk.

The risk of fatalities to the public caused by the aviation industry has been expressed above as 0.27 per year. It could also be expressed using a measure of the economic importance of the aviation industry as the denominator.

An Australian Bureau of Statistics report[3] (page 27) shows that in 1997-98, the air and space transport industry in Australia had total income of A$14,340 million. Assuming that the public fatality risk of 0.27 per year applies to 1997-98 and assuming that most of the income accrued to the air transport industry rather than the space transport industry, we could express the risk of fatalities as 0.019 per A$ billion of income to the aviation industry.

Another Australian Bureau of Statistics report[4] gives the Industry Gross Value Added for air and space transport in millions of A$. These figures are listed in Table 2. The value added can be thought of as being the difference between the income of those industries and that portion of their expenditure which would be regarded as income by other industries, including overseas industries.

1990-91	1991-92	1992-93	1993-94	1994-95	1995-96	1996-97	1997-98	1998-99
2,544	2,965	3,273	3,582	3,895	4,202	4,464	4,475	4,525

Table 2: Gross Value Added by air and space transport in Australia (A$ millions)
[Source: Australian Bureau of Statistics]

We could also express the public fatality expectation of 0.27 per year as 0.06 fatalities per A$ billion of Gross Value Added by the aviation industry. We suggest that the predicted rate of public casualties (including both fatal and non-fatal injuries) for the space industry should be kept below 0.06 casualties per A$ billion of Gross Value Added.

The permitted casualty expectation should not be interpreted as implying that the value of a human life is more than A$10 billion. We are here talking about the risk of injuries to uninvolved persons who receive no benefit from the activities that cause that risk.

Note also that the figure of "0.06 casualties per A$ billion of Gross Value Added" is based on recent (1998) estimates of the risk to the public from the aviation industry and value added by the aviation industry in current dollar terms. It would be prudent to revise the limit to acceptable collective public risk from Australian space launch activities every five years.

The value added for a single rocket launch will vary from one launch to another. Information in Table 3 from Table No. 1007 of a United States Statistical Abstract[5] gives some annual US Commercial Space Revenues in millions of US$, indicating that launching rockets is only a small part of the overall commercial rocket launch business.

Year	*1990*	*1991*	*1992*	*1993*	*1994*	*1995*
Total	3,385	4,370	4,860	5,295	6,640	7,768
Commercial Launches	145	280	350	420	480	510

Table 3: US Commercial space revenues (US$ millions)
[Source: United States Census Bureau]

It is more appropriate to use a measure like Gross Value Added than total industry income when scaling the public risk associated with the aviation industry to derive a number for the acceptable public risk from the space launch industry. Anomalies can arise with using industry income for both the space and aviation industries.

- Suppose that one rocket is launched by a company registered in Australia. The company pays A$500 million to companies outside Australia for the rocket, the communications satellites to be launched and insurance. It spends A$10 million within Australia and receives income of A$510 million. A second rocket is launched by a company registered outside Australia, with A$10 million being spent within Australia. It would not be reasonable to allow the first rocket launch to have a much greater public casualty expectation than the second.
- Some aviation industry income is used by Australian companies for the import of aircraft. Other income accrues to overseas companies operating in Australia.

It might be argued that some of the casualty expectation associated with rocket launches is due to hazards that non-Australian people might be injured, and that therefore we should consider all economic activity not merely the economic activity of benefit to Australia. This approach would give a higher number for the benchmark casualty expectation for a single launch. This number includes the casualty expectation associated with tasks apart from launching the rocket. We do not accept this argument, since it would encourage Australia to be willing to conduct the risky stages of multi-stage projects, thereby incurring risks without gaining benefits which justified the taking of those risks.

Suppose that the Gross Value Added for a single launch is A$10 million. Then multiplying this by 0.06 casualties per A$ billion of Gross Value Added gives an acceptable casualty expectation of 0.0006 for such a launch.

Note that our approach leads to the conclusion that a higher public casualty expectation may be acceptable for a launch for which there are more tangible benefits to Australia. Also, the total casualty expectation per year would rise as the number of launches increases. However, with improving technology (and inflation) we would expect that the benchmark level of public risk per A$ billion of Industry Gross Value Added would slowly decrease.

Recommendation 1: Commercial rocket launches in Australia should be required to satisfy the condition that the estimated public collective risk is less that 0.06 casualties per A$ billion of value added. This will be about 0.0006 per launch, based on estimated added value of A$10 million per launch. The value added is to be calculated as the value of the goods and services produced by conducting a launch (principally the fee for conducting the launch) minus the cost of the goods and services used by the space launch industry in the production process (including cost of the payload).

5.4. The risk of accidents involving multiple casualties

People are often concerned about the likely extent of possible accidents. It is natural to feel more concern about potential accidents involving multiple injuries than about potential accidents involving only a single injury.

Society's concern about casualties ought to depend primarily on the total number of casualties per unit time. News media and politicians may be more affected by a single incident which kills or injures 100 people than by 100 incidents with one casualty each, but the impact of the accidents on the victims and their communities, relatives and friends are equally grave in both scenarios.

Figure 1 illustrates a useful way of showing the proportion of casualties from incidents involving multiple casualties for historical data. The quantity shown on the vertical axis is the percentage of casualties which occur in accidents in which there are *n* or more casualties per accident, where *n* is shown on the horizontal axis.

The solid line shows how this percentage varies for an artificial example of aviation accidents described in Table 4 in which a total of 10,000 people were injured or killed. The accidents have been categorised according to the number of casualties, with accident severity approximately doubling between successive rows of the table. About 60% of casualties are from the 25 accidents involving 126 or more casualties per accident. There are no accidents involving more than 1000 casualties per accident. The pattern of casualties per accident is not surprising given that aviation passenger casualties are likely to occur a plane-load at a time.

The dotted line is for Australian aviation accidents involving injuries to members of the public or ground staff as listed in Table 10 and Table 11. There have been 47 accidents involving one casualty per accident, 12 accidents involving 2 casualties per accident (24 casualties), and one accident involving each of 3, 4, 7 and 8 casualties.

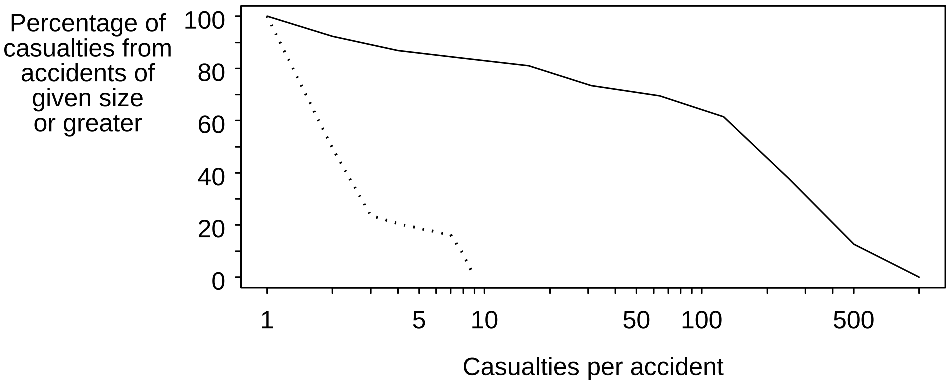

Figure 1: Graphs illustrating the percentage of casualties occurring in multiple-casualty accidents. The horizontal scale gives the number of casualties per accident. The vertical scale gives the percentage of casualties occurring in accidents with a given number of casualties per accident or more. The solid line is for the artificial example of aviation accidents described in Table 4. The dotted line is for Australian aviation accidents involving injuries to members of the public or ground staff described in Table 10 and Table 11.

Minimum	*Maximum casualties*	*Average*	*Number of Accidents*	*Number of casualties*	*Percentage of casualties*
1	1	1	768	768	7.7
2	3	2.2	250	550	5.5
4	7	4.8	60	288	2.9
8	15	9.8	30	294	2.9
16	30	19	40	760	7.6
31	63	39	10	390	3.9
64	125	80	10	800	8.0
126	250	158	15	2,370	23.7
251	500	315	8	2,520	25.2
501	1,000	630	2	1,260	12.6
	Total		1,193	10,000	100.0

Table 4: Artificial example illustrating accidents classified according to the number of casualties in single accidents. In this artificial illustration, most accidents have only one casualty but most casualties have occurred in a relatively small number of accidents. The last column shows us which categories of accident severity have made the largest contributions to the total number of casualties.

For historical data, graphs like Figure 1 necessarily show a large change (down to zero) in the percentage of casualties at the position on the horizontal scale corresponding to the worst accident which has actually occurred. In contrast, the prospective risk that accidents with various numbers of casualties might occur decreases steadily for accidents with larger and larger numbers of possible casualties.

The hazard from space launch activities that has been most thoroughly studied is that of people being hit by inert debris from a failed launch. (Note that ‘inert’ means that there is no propellant that might burn or explode, no chemical hazard and no radiation hazard.) For this hazard, the chance of large numbers of casualties from launch vehicles that fail is reduced by dumping propellant or by exploding vehicles at great altitude. However, if a person were to be hit by a large piece of inert debris then other people who were physically very close to that person would also be likely to be hit. Multiple injury accidents in which a small number of people are injured have a similar probability to accidents in which only a single person is injured. We expect the proportion of casualties from multiple-casualty accidents from rocket launches to be similar to the dotted line on Figure 1 rather than to the continuous line.

The risk that space activities will cause an accident involving, say, 100 or more casualties could be estimated as the probability that a rocket or a large piece of debris might land in the small number of regions where people are densely congregated. This might be a total of, say, ten hectares out of the geographical area near to a proposed flight path and have a probability of the order of 1.E-11.

It should be noted that estimation of the expected number of casualties is not sensitive to assumptions about the small-scale geographical distribution of people on the ground. In contrast, estimation of the distribution of the likely number of casualties per incident is very sensitive to such assumptions. For instance, if the distribution of people on the ground were changed so that people were always in pairs then the probability of zero casualties would increase and the probability of 2 casualties would increase but the probability of 1 casualty would decrease. However, the overall expected number of casualties would not change. This illustrates the point that uncertainty about the distribution of the number of casualties per accident does not imply that estimation of the casualty expectation is unreliable

5.5. Collective risk limits in context

Figure 2 shows a number of collective risks and collective risk limits which put the proposed Australian collective risk limit of 0.06 times launch added value in A$ billion (approximately 0.0006 per launch) into context. The various risks and risk limits will be discussed further in this section of the report.

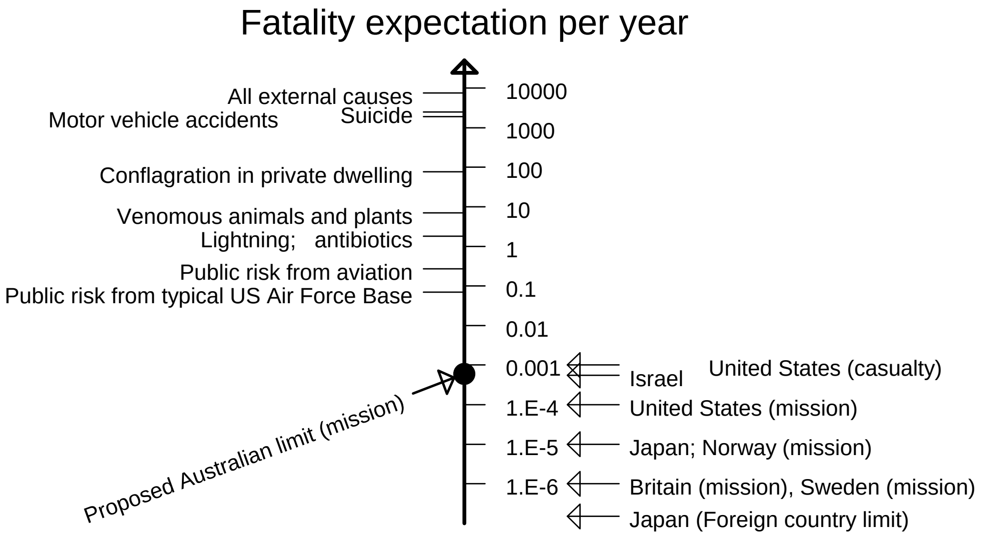

Figure 2: Some collective risks and collective risk limits. Unless otherwise indicated, the risks are expressed in fatalities per year for Australia. The collective risks shown on the left hand side of the number line are based on fatality data. The numbers on the right hand side of the number line are collective risk limits which are based on models.

Numbers of Australian deaths due to external causes are presented in Table 15 in Appendix C. These are classified by ICD codes 800-999, by sex and by year. This table was provided by Sam Savige, of Australian Bureau of Statistics Client Service. The risk shown on the top left of Figure 2 is that for all external causes, which includes accidents, assaults and suicide. Other risks shown on the left of Figure 2 include some external causes shown in Table 5, below. These death rates are tens or hundreds of thousands of times bigger than the casualty expectation which is likely to be permitted from rocket launches.

Code	*Description*	*Deaths*
890	Conflagration in private dwelling	387
905	Venomous animals and plants as the cause of poisoning and toxic reactions	35
907	Lightning	9
908	Cataclysmic storms; and floods resulting from storms	27
909	Cataclysmic earth surface movements and eruptions	20

Table 5: Number of deaths in Australia over 1994-98 due to some external causes [Source: Australian Bureau of Statistics]]

The public collective risk of fatality from aviation in Australia is 0.27 per year, as shown in Section 5.1 on page 5.

In Appendix B we have endeavoured to compare the Australian rate of public fatalities from aviation with the United States's rate of public fatalities from aviation. Regrettably, we could not find data that tell us specifically about that aspect of United States's experience. The data on aircraft accidents which we present in Appendix B has the following major problems.

- Fatalities to uninvolved members of the public are not separated from fatalities to ground staff or from fatalities to passengers and crew who were aboard other aircraft.
- Data on aircraft accidents is collected according to country of registry of aircraft, not according to country of accident. The U.S. data includes many fatalities of ground staff and members of the public who were in other countries. It seems likely that the number of fatalities within the U.S. associated with aircraft registered outside the U.S. (which may not be included in the U.S. data) is smaller.

After considering some specific accidents in which large numbers of people “not on board” were killed, it is estimated at the end of Appendix B that the United States aviation industry’s rate of fatalities to ground staff and members of the public has averaged about 14.5 fatalities per year over 18 years. The Australian figure corresponding is 1.3 fatalities per year, which is 9% of the United States’s rate. Australia’s population is about 7% of that of the United States and the income of Australia’s aviation industry is about 8.5% of that of the United States, so the rate of fatalities to ground staff and members of the public appears to be similar in the two countries.

The next value of risk shown on the left hand side of Figure 2 is 0.07 for the collective risk to the public from a typical US Air Force base. The United States IRIG Standard 321-00[10] in section 3.2.1.4.4 quotes the estimates given in Table 6 of the risks to the general public due to military aircraft crashes from five Air Force Bases. These estimates were “based on accident data for the years 1977-1981, and on models addressing aircraft crash frequency by runway angular sector and representative aircraft crash area”. This estimate of risk has been placed on the left hand side of Figure 2 because it is partly based on data. Some modelling work has been done, but the numbers in Table 6 are presumably coherent with what has been observed.

On the right hand side of Figure 2 are the levels of collective risk from rocket launches which are considered to be acceptable in other countries. These are also given in Table 7. Note that the nominal United States limit on collective public risk is 3.E-5, but there is latitude to permit individual launches with estimated public casualty expectations up to 3.E-4 and an intermediate value, 1.E-4, has been used in Figure 2. Note also that Japan also imposes a maximum collective fatality expectation of 1.5E-7 for each foreign country that might be affected by a launch from Japan.

Air Force Base	*Annual Collective Risk*
March AFB	0.004
Mather AFB	0.02
McClellan AFB	0.1
Nellis AFB	0.2
Sheppard AFB	0.01
Average	0.07

Table 6: Estimated casualty expectations for the public due to crashes of military aircraft from five “representative” United States Air Force Bases with relatively large nearby populations.

In Figure 2, the numbers on the left hand side are more based on data than those on the right hand side. The spread amongst the risk limits specified by the various countries could be interpreted as evidence that the real level of risk is not accurately known. We are comfortable with suggesting that Australia allow estimates of collective public risk from space activities to exceed the nominal limits used in other countries, provided that the estimation procedures used are conservative as discussed in Section 7.

Country	*Individual risk per mission*	*Individual risk per year*	*Collective risk per mission*	*Collective risk per year*
Britain			1.E-6 [S]	
Guyana			1.E-7 [F]	
Israel	1.E-5	1.E-4 [F]		5.5E-4 [F]
Japan				1.E-5 [F]
Norway	1.E-9 [C]		1.E-5 [C]	
Sweden			1.E-6 [C]	
United States	1.E-7 [C]	1.E-6 [C]	3.E-5 [C]	1.E-3 [C]

Table 7: Maximum levels of public risk from rocket launches cited in various countries. Risks are variously quoted for fatal outcomes [F], casualties [C] or serious injury or death [S]. [Sources: ACTA report[6], ACTA[7] and U.S. IRIG Standard 321.00[10].]

6. Individual risk from space launch activities

Figure 3 displays several individual risks and national limits to individual risk for rocket launches or nuclear facilities. They will be discussed further in this section of the report. Note that our recommendation at the end of this section is that Australia limit individual public risk from rocket launches to 1.E-7 per launch and to 1.E-6 per year.

Average individual risks can be calculated from data as the number of casualties or fatalities per year divided by the population at risk. For instance, the average Australian mortality rate from all causes is approximately 0.0068 per year. (The reciprocal of this is about 148 years, which is much larger than the average life expectancy because Australia has more young people than would a stable population.) The Australian rate of accidents, obtained from Appendix C after omitting codes 950-969 for suicides and assaults, is approximately 2.6E-4. This is shown on Figure 3. We note that a similar probability of 2.2E-4 for the USA was quoted by Wilson[8].

Ingles[9] argued that the community as a whole notices risks at a level of about 1.E-5. He noted that the total risk due to rare natural hazards such as snake bite, spider bite and shark attack was approximately 2.E-5 and that the individual risk due to natural disasters such as earthquake and wind storm is about 2.E-6 in prone areas. Appendix C shows that about 60 people per year die as a result of aviation accidents (codes 840-844), about 2 people per year die due to antibiotics (codes 856 and 930), about 7 people per year die as a result of venomous animals and plants (code 905), about 2 people per year die due to lightning (code 907), and about 9 people per year die as a result of storms, floods, earth movements and eruptions (codes 908 and 909). These risks are not uniformly distributed across the population because people spend their time in different ways and in different places, but the data on accident rates do tend to support the idea that individual risks of 1.E-5 are noticed.

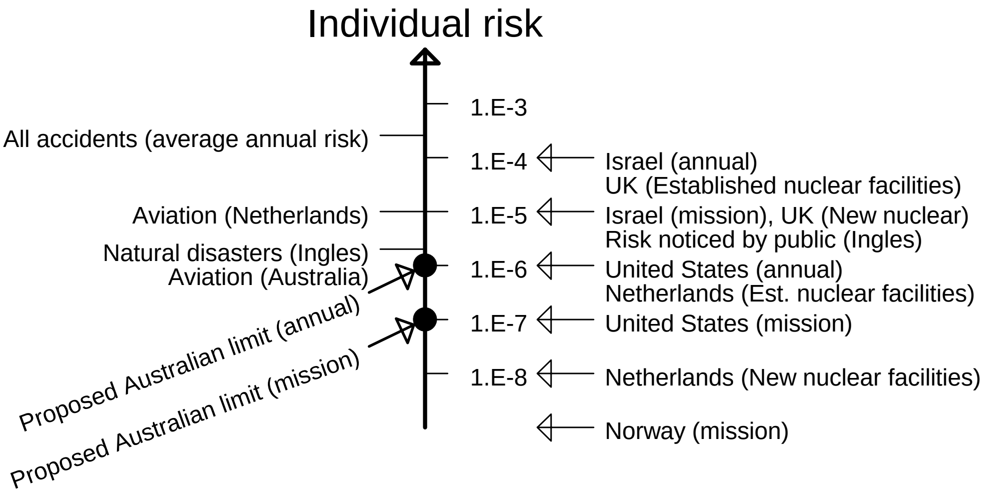

Figure 3: Individual risks and individual risk limits. The risks are maximum risks of fatality to Australians unless otherwise indicated. Estimated risks based on fatality data are shown on the left hand side of the number line. The average risks of accidents is reliably estimated, but maximum risks cannot generally be estimated accurately because the distribution of individual risk across the population cannot be reliably estimated. The risk limits on the right of the number line are generally based on models.

One argument for specifying a limit to individual risk caused by aerospace industries is that the individual risk to members of the public from rocket launches should be substantially less than the level of 1.E-5 per year which would be perceived as significant. This suggests an annual individual risk limit of 1.E-6, being one order of magnitude below the onset level of public awareness.

An estimate of the maximum individual risk from aviation in Australia is shown on Figure 3 as 2.E-6. This has been derived by assuming that 0.4 of the public casualty expectation (0.54 per year) is uniformly distributed over the 200,000 people who are most at risk of being public casualties of aviation accidents because they live or work near airports.

According to ACTA[6] pages 27-29, following an accident in October 1992 in which an El-Al Boeing 747 crashed into an apartment building near Schipol Airport, a Dutch government study found that individual risks were as high as 1.E-5 and that efforts should be made to reduce risk where the individual risk exceeded 1.E-6. Because the estimate of maximum individual risk was derived following a major accident it has been put on the left hand side of Figure 3.

Other countries' limits to individual risk to members of the public from rocket launches were given in Table 7 on page 12. For a single launch, these limits are 1.E-5 for Israel, 1.E-7 for United States and 1.E-9 for Norway.

The other individual risk limits shown on Figure 3 are for the public risk from nuclear facilities in UK and the Netherlands. These limits are 1.E-4 and 1.E-6 for established facilities and 1.E-5 and 1.E-8 for new facilities, for the UK and Netherlands, respectively, as given in ACTA[6] pages 25 and 28. As with the collective risk limits displayed on Figure 2, the spread of limits provides evidence that the real level of individual risk is not precisely known.

The United States' benchmarks for individual risk are, as stated in IRIG[10] and FAA[11], Chapter 3, paragraph 3.5, Table 3-1 and listed in Table 7, 1.E-7 for a single mission and 1.E-6 for an annual total individual risk. These are the same as the individual risk limits proposed for Australia. We believe that it is preferable to have the same risk limits as other countries unless there are good reasons for having different limits, so that launch sites bidding for commercial rocket launch business do not use tolerance of risk as an argument in the bidding processes.

The public travelling by air or sea may also be at risk from the failure of a commercial space launch. International guidelines to acceptable risk for aviation are available from of the Review of the General Concept of Separation Panel (RGCSP) of the International Civil Aviation Organisation (ICAO)[12]. However, recommending such risk limits is considered to be outside the scope of this study.

Recommendation 2: The maximum risk of casualty to any individual member of the public not associated with launches should be 1.E-7 for a single launch and 1.E-6 per year.

7. Considering uncertainty in the estimated risks

For launches to be permitted, the estimates of public risk must be acceptably low. This might be handled by simply estimating the risk and comparing the number to a numerical risk limit. This approach is not completely satisfactory because the estimated risk is not the same as the real risk in two important ways.

- Some possible modes of failure may have been poorly modelled or not modelled at all. The real risk includes all modes of failure whereas the estimated risk can only ever include the risks that have been modelled in some way.
- For modes of failure that are well modelled, there are generally many parameters or assumptions in the models. It is important to check that the chosen values for parameters and the assumptions made do not result in risks being under-estimated.

While it is important for the estimates of public risk to be acceptably low, we believe that it is even more important to reduce the possible gap between estimated risk and real risk. Three strategies for doing this are as follows. They require that people supervising space activities make conservative decisions.

1. Use the best available models or use conservative models which are expected to overestimate the risks. The models for estimation of the public risk due to inert debris seems to us to be fairly well developed. We are less confident about estimation of the public risks due to explosion and chemicals. We would have no confidence in any estimate of the risk due to sabotage which is virtually impossible to estimate, but is not zero.
2. Use conservative assumptions in the calculation of estimates of risks. For instance, untested systems should be assumed likely to fail at such times are as most likely to cause casualties. Less conservative assumptions might be used once more information and experience becomes available.
3. Ensure that procedures implicit in risk calculations are actually followed. If a launch vehicle strays from its intended path then rules for destroying it or dumping propellant which were used in the calculation of risk must be followed. Similarly, if risk calculations assumed that wind speeds and atmospheric turbulence were within certain bounds then launches should not be permitted if such bounds might be exceeded.

Recommendation 3: Risks to the public from rocket launches should be calculated conservatively. An Australian licensing authority should have some discretion in interpreting what is meant by “conservatively”.

8. Can public risk be kept within these limits?

The individual risk per launch can be contained by controlling the extent of the area around the launch site into which unprotected people will not be permitted at the times of launches. The annual total individual risk can be controlled by making decisions about allowing people to live permanently near to a launch site and allowing a large number of launches to be conducted from that launch site. These risks are also affected by the reliability of the rockets being used, but we expect that the principal actions which will be taken to ensure that individual risk limits are not exceeded will be to ensure that people are not close to launch sites.

In contrast, the limit on allowable public casualty expectation might affect the decisions made by a launch operator in a number of ways, including choice of launch vehicle, choice of launch site, choice of launch path and restriction on predicted weather at the time of the launch.

The limit on casualty expectation of 0.06 times the launch added value in A$billion (approximately 0.0006 per launch) should be achievable. For instance, the casualty expectation due to impacts from inert debris is approximately the probability of failure of the launch, say 20%, times the effective lethal area of the debris from a rocket, say 1000 square metres, times the average population density over the likely region of impact, say 0.1 per square kilometre which is 0.0000001 per square metre. This product is 0.00002.

Various sources provide figures on the reliability of rocket launches such as the following.

- The Vostok has had 3 failures in 1108 launches (99.73%).
- The Delta rocket family is cited as having a total of 15 failures in 278 launches over 40 years (95% successful launches) and the Delta II as having a 98% success rate.
- According to one source, the ITAR-TASS agency, the USSR between 1957 and February 1995 has incurred 142 failed launches in 2,656 rocket sets (95%).
- The Atlas has had 10 failures in 100 launches (90%).
- The Ariane 1 rocket 2 has had failures in 8 launches (75%).
- The Zenit-2 rocket has had 8 failures in 31 launches (74%).

Provided that errant rockets can be exploded or propellant vented, possible injuries should be able to be contained to a tightly-defined geographic area in which the population density is low. For Australia excluding Sydney, Melbourne, Brisbane, Adelaide, Perth, Hobart and Darwin the average population density is 0.88 persons per square kilometre, so it should be possible to ensure that the average population density of the likely region of impact is less than this.

Note that the reliability of Flight Termination Systems is discussed in Range Policies and Procedures[13], Chapter 1, paragraph 1.4.1.2. Special consideration of communications availability should be given in this calculation to take account of any anomalous electromagnetic propagation characteristics during launch[14].

8.1. USA experience

So far as we can ascertain, no members of the public have been injured by rocket launches in the United States, at least since 1947. London[15] explained that high priority has been given to range safety since an incident on 29 May 1947. Four seconds into the flight of a V-2 US army General electric missile from White Sands in New Mexico, there were control problems and the missile was allowed to expend propellant. It impacted the ground near Juarez in Mexico. There were no fatalities, but the accident was considered to be an ‘International Incident’.

There have been several fatalities of astronauts and many fatalities of ground staff, but fatalities of ground staff have apparently not occurred during launches. We have been unable to get information about fatalities of ground staff, except for Cape Canaveral. We did not expect to be able to get information about fatalities of ground staff at military bases.

Lethbridge[16] wrote about fatalities at Cape Canaveral: ‘On July 9, 1958 the Cape experienced its first operational fatality. On that day, Fred D. Adams fell from an Atlas missile service tower and died as a result of injuries sustained. .... Specific records on fatalities are not available for review, but it is estimated that less than 20 people have died as a result of operational activities at the Cape. This number does not include those who may have died in automobile accidents on government property, but anyone would agree that given the volatile nature of rocket and missile launches, the number of operational fatalities has been remarkably low.'

One incident worth mentioning specifically is that on 17 January 1997 there was a launch failure of a Delta 7925 at Space Launch Complex 17A, Cape Canaveral. According to an electronic mail message from Jonathan McDowell who maintains a Space Home Page at http://hea-www.harvard.edu/~jcm/space/space.html, many cars in a car park were thoroughly roasted. It would be interesting to know whether such an outcome was considered in the models which were being used for estimating public risk before the incident.

8.2. China's experience

It may not be easy to keep the risk to members of the public to within the limits. It appears that China's record is outside the risk limits.

- According to Phillip Clark[17], at Xi Chang in China on 14 February 1996 the maiden flight of the CZ-3B with payload Intelsat 708 crashed close to the launch pad after an inertial guidance system failed. The Chinese reported at least two deaths and 80 injuries, although later reports suggested a higher casualty total.
- According to Dave Dooling[18], China lost a U.S.-built communications satellite, Apstar-2, in a launch accident in January that killed six people on the ground as debris fell from the sky. Mark Wade[20] reported the date as 25 January 1995, and said that shortcomings in the guidance system led to the vehicle not anticipating the true effects of horizontal wind-shear once the mountains surrounding the launch site were cleared. This caused the nose fairing to collapse and the spacecraft to be destroyed.

9. Public scrutiny of the levels of risk

Since members of the public are being exposed to risk, they have a right to be informed about that risk. It also seems reasonable that they be able to scrutinise the efforts which are made to minimise the risk.

In order to estimate the risk of public casualties from a launch, we expect that it will be necessary to compile estimates of the risk of launch failure as a function of time after liftoff, like that given in Table 8 which is for an Atlas rocket and which was taken from Chapter 3 of Streamlining Space Launch Range Safety[19].

At any time during a rocket launch, the instantaneous impact point (IIP) can be calculated. This is the point on the Earth's surface at which the rocket would land if the propulsion system failed at that moment, ignoring air resistance. One purpose of computing the IIP is to check whether it is near to a boundary beyond which significant pieces of debris should not be permitted to penetrate.

The rate of change of the IIP during a launch is generally very much larger than the ground speed of the rocket. For instance, at about a minute after liftoff, a rocket might be travelling almost vertically with a vertical component of velocity of a kilometre per second. If the propulsion system failed then it would take a few minutes before the rocket hit the ground, assuming that it wasn't broken up by turbulent interactions with the atmosphere and was not deliberately destroyed. The horizontal component of velocity will be taking the rocket further from the horizontal location of the launch during all of this few minutes, so the rocket would be likely to land tens of kilometres away from launch point, even if the horizontal component of the rocket's velocity was only 100 metres per second. While the vertical and horizontal components of velocity are both increasing due to the thrust of the propulsion system, the IIP might be changing by several kilometres per second.

The risk of inert debris landing in various geographical areas could be calculated using the probability distribution of the possible time of launch failure, the way the IIP varies during the phases of the launch, the likely precision of the launch path and the likely effects of winds. The individual risk that a person at a particular location would be injured by debris could be computed assuming an effective debris area of, say, 1000 square metres. This information could be presented as a map with contours showing probabilities of being injured. The maximum individual risk to the public of, say, 1.E-7 might be associated with a small region including the launch zone. The risk 200 kilometres from the launch site might be 1.E-9 directly under the intended launch path, dropping to 1.E-10 at a cross-track distance of 10 kilometres from the intended launch path and dropping to 1.E-11 at a cross-track distance of 20 kilometres from the intended launch path.

Phase	*Start Time (seconds)*	*End Time (seconds)*	*Probability of Failure (ppm per second)*	*Probability for phase (ppm)*
Liftoff	0.0	5.0	884.0	4420.0
GLSRB burn	5.0	59.0	85.5	4617.0
ALSRB ignition	59.0	64.0	106.0	530.0
ALSRB burn	64.0	103.4	106.0	4176.4
GLSRB jettison	103.4	104.4	94.3	94.3
ALSRB burn continue	104.4	117.3	94.3	1216.5
ALSRB jettison	117.3	118.3	74.1	74.1
Booster flight	118.3	164.8	74.0	3441.0
Booster engine cutoff	164.8	165.8	3980.0	3980.0
Booster engine cutoff to booster package jettison	165.8	168.9	51.4	159.3
Booster package jettison	168.9	169.9	1820.0	1820.0
Sustainer flight	169.9	190.9	51.4	1079.4
Payload fairing jettison	190.9	191.9	50.7	50.7
Sustainer flight (continued)	191.9	282.9	50.7	4613.7
Sustainer engine cutoff	282.9	283.9	1.2	1.2
Atlas/Centaur separation	283.9	284.9	1610.0	1610.0
Coast	284.9	301.5	0.5	7.5
Main engine start (upper stage)	301.5	306.5	1530.0	7650.0
First Centaur burn	306.5	670.0	25.7	9342.0
TOTAL				48883.1

Table 8: Risk of launch failure as a function of time after liftoff for the Atlas IIAS. [Source: Chapter 3 of reference 19]

These numbers are indicative values based on relatively little information. We suggest that a contour map like Figure 4 indicating the estimated individual risk as a function of geographic location should be available to the Australian public as one of the conditions according to which launches are licensed. Such diagrams would also be of interest to operators of ships, aircraft and offshore oil platforms, and to owners of infrastructure assets such as electricity lines and gas pipelines.

On Figure 4, the launch site is located where the down-range and cross-range distances are both zero. A town directly under the proposed flight path and a city 20 kilometres from the proposed flight path are indicated on the map. Note that, in this example, altering the flight path by a few kilometres would affect the individual risk for people in the city by a larger multiplicative factor than it would affect the risk of the people in the town.

The risk for locations directly down-range from the launch site has a local maximum about 120 kilometres from the launch site. Such local maxima would be likely to occur because the risk of launch failure is not uniform during the launch and because there are phases of the launch during which there is no rocket propulsion, so the IIP does not change. The public would be interested in knowing whether such a local maximum was near a centre of population. One simple way of ensuring that an appropriate balance is made between the technological difficulties of launching rockets and the public interest that risk be reduced is to ask that information about the risk be readily accessible to the public.

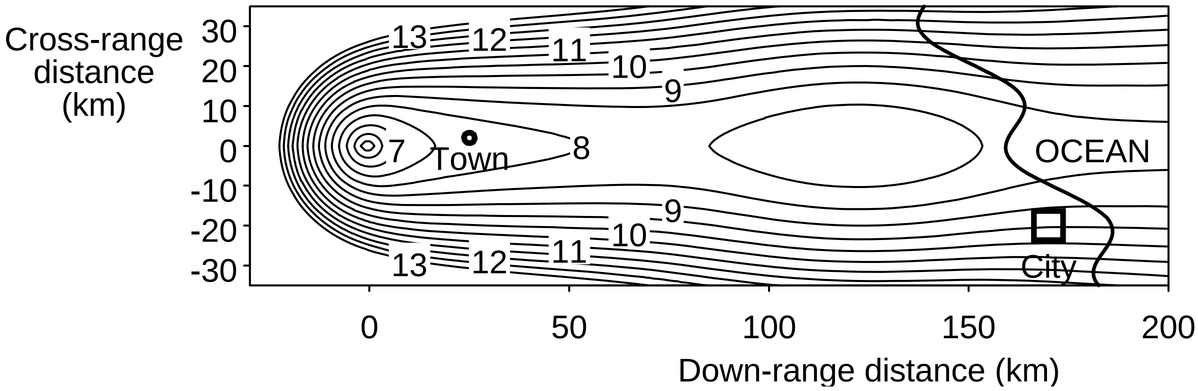

Figure 4: Illustrative example of contour map of individual risk for a launch. The contours are isopleths on which the public casualty risk is constant. The label "n" on a contour means that the risk is 10^{-n}.

We recommend that the Australia government support the establishment of an international register of space industry accidents. The nearest to this that we could find was provided by Wade[20], but it does not include information about injuries or fatalities. McDowell[21] has compiled a list of launches and failed launches, not including pad explosions during pre-launch preparations. Table 9 shows how the number of failed launches has varied from year to year according to McDowell's list. However, it should be noted that there are substantially fewer failed launches on McDowell's list than on Wade's.

Provision of information to the public provides a feeling of security where this is justified. It also tends to expose the taking of unreasonable risks.

Recommendation 4: Information describing the risks associated with rocket launches should be readily available to the Australian public. For each launch, this information should include a contour map indicating the individual casualty risk as a function of geographic location.

Recommendation 5: The Australian government should support the establishment of an international register of space industry accidents.

Year	*Number*	*Year*	*Number*	*Year*	*Number*	*Year*	*Number*	*Year*	*Number*
		1961	15	1971	14	1981	3	1991	3
		1962	9	1972	7	1982	8	1992	2
		1963	15	1973	7	1983	2	1993	4
		1964	13	1974	7	1984	0	1994	4
		1965	12	1975	7	1985	4	1995	5
		1966	13	1976	3	1986	7	1996	4
1957	1	1967	12	1977	6	1987	4	1997	3
1958	20	1968	9	1978	4	1988	5	1998	5
1959	9	1969	15	1979	4	1989	1	1999	5
1960	19	1970	10	1980	3	1990	5	2000	1

Table 9: Number of failed launches (worldwide) [Source: McDowell's master launch log]

Appendix A: Australian aircraft accidents involving ground staff or members of the public

			Fatalities					*Injuries*					
Date	*Place*	*State*	*Cr*	*Px*	*Gd*	*Pu*	*All*	*Cr*	*Px*	*Gd*	*Pu*	*All*	*Comments*
14-Jan-74	Melbourne	VIC			1		1			1		1	
11-Oct-74	Townsville	QLD					0		1	3		4	
27-Oct-74	Bathurst	NSW					0	1		1		2	
13-Jun-75	Sydney	NSW			1		1					0	
24-Oct-75	Sydney	NSW			1		1					0	
5-Jan-77	Alice Springs	NT	1		4		5			4		4	murder/suicide
7-Oct-77	Bullo RvR Stn	NT			1		1					0	
10-Jul-78	Essendon	VIC				6	6	2	1		1	4	crashed into houses
21-Jan-79	King Junction	QLD			1		1			1		1	
3-May-81	Bassendean	WA	1				1				1	1	crashed into backyard
17-Jun-81	Gladstone	QLD					0		1	2		3	
5-Jan-82	Archerfield	QLD	1		4		5					0	crash after takeoff
19-Sep-82	Corowa	NSW			1		1					0	
3-Jul-82	Luddenham	NSW	1	1			2				1	1	debris injuring public
15-May-84	Goulburn	NSW	1	2		1	4					0	crashed into houses
24-Jul-84	Wilton	NSW			1		1					0	
9-May-88	Edgeroi	NSW			1		1					0	
1-Dec-92	Warren	NSW			1		1					0	
10-Jan-93	Torquay	VIC					0				1	1	person swimming at beach
18-Mar-93	Wire Lagoon	NSW			1		1					0	
3-Dec-93	Essendon	VIC					0	1	9		1	11	crashed into houses
21-May-95	Toowoomba	QLD	1				1			2		2	
13-Aug-96	Brisbane	QLD					0		1			1	
1-Aug-97	Comboyne	NSW					0	1	1	2		4	
11-Apr-98	Mangalore	VIC					0	1		1		2	
28-Mar-99	Pittsworth	QLD					0				1	1	car on road struck
20-Aug-99	Ungarra	SA					0				1	1	child hit in backyard
TOTAL			6	3	18	7	34	6	14	17	7	44	

Table 10: Aircraft accidents in Australia in which members of the public were injured or killed or ground staff were killed. Note that Table 11 lists accidents in which the only casualties to public or ground staff were injuries to ground staff. Codes used for headings are Cr - Crew; Px - Passengers; Gd - Ground staff; Pu - Public not involved with aviation. [Source: Australian Transport Safety Bureau]

Date	*Place*	*State*	*Injuries*
16-May-69	Mt. Bedford	WA	2
31-Oct-69	DN	NT	1
25-Nov-69	Bonshaw	NSW	1
12-Apr-71	Bankstown	NSW	1
17-Apr-71	Aeropelican	NSW	1
25-Sep-71	Sydney	NSW	2
22-Oct-71	Darwin	NT	1
22-May-73	Barraba	NSW	1
6-Aug-73	Trangie	NSW	1
21-Oct-75	Sydney	NSW	1
17-Jul-76	Pakenham	Vic	1
23-Jul-77	Halls Creek	WA	1
14-Aug-78	Sydney	NSW	1
15-Sep-79	Dubbo	NSW	1
12-Jul-80	Lochiel	SA	1
11-Jun-81	Hobart	TAS	1
24-Jul-83	Sydney	NSW	1
8-Nov-84	Arubial Lagoon	QLD	2
27-Mar-85	Freemantle	WA	1
16-Apr-85	Boonah	QLD	1
16-Nov-85	Jondaryn	QLD	1
23-Nov-85	Pulparee	SA	2
20-Feb-88	Gawler	SA	2
25-Jun-88	Carrick	NSW	1
3-Dec-88	Benalla	VIC	1
18-Dec-89	Leongatha	VIC	1
19-Dec-89	Williamsford	TAS	2
4-Mar-90	Melbourne	VIC	1
27-Jul-92	Brooklyn	NSW	1
24-Nov-93	Barrow Island	WA	1
28-Nov-93	Port Melbourne	VIC	2
16-Apr-94	Beverley	WA	1
28-Jul-94	Bankstown	NSW	1
20-May-95	Canberra	ACT	1
27-Nov-95	Hay	NSW	1
23-Dec-96	Cairns	QLD	1
5-Jul-99	Walcha	NSW	1
TOTAL			44

Table 11: Aviation accidents in Australia in which there were injuries to ground staff but no other injuries or any fatalities to public or ground staff. [Source: Australian Transport Safety Bureau]

Appendix B: United States data on aircraft accidents

	Fatalities of people aboard					*Fatalities of people not aboard*					*Millions of flight hours*				
Year	*121S*	*121N*	*135S*	*135N*	*GA*	*121S*	*121N*	*135S*	*135N*	*GA*	*121S*	*121N*	*135S*	*135N*	*GA*
1982	222	1	14	72	1,170	12	0	0	0	17	6.70	0.34	1.30	3.01	29.64
1983	14	0	10	57	1,062	1	0	1	5	7	6.91	0.38	1.51	2.38	28.67
1984	4	0	46	52	1,021	0	0	2	0	21	7.74	0.43	1.75	2.84	29.10
1985	196	329	36	75	945	1	0	1	1	11	8.27	0.44	1.74	2.57	28.32
1986	4	3	4	61	881	1	0	0	4	88	9.50	0.48	1.72	2.69	27.07
1987	229	1	57	63	823	2	0	2	2	15	10.12	0.53	1.95	2.66	26.97
1988	274	0	21	55	792	11	0	0	4	8	10.52	0.62	2.09	2.63	27.45
1989	130	146	31	81	765	1	1	0	2	3	10.60	0.68	2.24	3.02	27.92
1990	12	0	5	49	762	27	0	2	2	5	11.52	0.63	2.34	2.25	28.51
1991	49	0	77	74	772	13	0	22	4	14	11.14	0.64	2.29	2.24	27.68
1992	31	0	21	65	855	2	0	0	3	2	11.73	0.63	2.34	1.97	24.78
1993	0	0	23	42	732	1	0	1	0	4	11.98	0.72	2.64	1.66	22.80
1994	237	0	25	62	718	2	0	0	1	7	12.29	0.83	2.78	1.85	22.24
1995	160	2	9	52	727	6	0	0	0	7	12.78	0.73	2.63	1.71	24.91
1996	342	8	12	63	615	0	30	2	0	17	12.97	0.77	2.76	2.03	24.88
1997	2	4	46	39	637	1	1	0	0	6	15.06	0.78	0.98	2.25	25.46
1998	0	0	0	44	617	1	0	0	4	6	15.94	0.90	0.35	2.54	26.80
1999	11	0	12	38	622	1	0	0	0	6	16.50	0.93	0.27	2.81	27.08
Total	1917	494	449	1044	14516	83	32	33	32	244	202.3	11.5	33.7	43.1	480.3

Table 12: Data on accidents involving US registered aircraft.
[Source: United States National Transportation Safety Board]

This data was compiled by the United States of America National Transportation Safety Board based on records of incidents which involved U.S. registered aircraft. The data are broken down firstly according to whether the aircraft were conducting operations under Title 14 Code of Federal Regulations (CFR) Parts 121 and 135. Briefly stated, Part 121 applies to air carriers, such as major airlines and cargo haulers, that fly large transport aircraft. Part 135 applies to commercial air carriers commonly referred to as commuter airlines and to air taxis. Other aircraft are described as General Aviation (GA). Data are also classified according to whether the aircraft were part of a scheduled service.

From 10-March-1997, aircraft with 10 or more seats conducting scheduled passenger operations were required to comply with 14 CFR 121. This caused a decrease in the amount of scheduled flights hours under 135 and an increase in both scheduled flights under 121 and unscheduled flights under 135.

As a guide to the interpretation of the numbers of fatalities of people "not aboard", we would highlight the following specific accidents, details of which were found from the United States National Transportation Safety Board[22].

- On 31-August-1986 at Cerritos in California, an accident killed 64 people aboard a Mexican-registered DC-8, 3 people aboard a US-registered small plane (Piper PA-28, N4891F), and 15 members of the public. Note that 64 of the fatalities "not aboard" according to the table for 1986 General Aviation were people who were aboard the Mexican flight. (NTSB Identification: DCA86AA041A)
- On 21-December-1988 at Lockerbie, Scotland, an accident thought to be sabotage killed 259 people aboard a Boeing 747-121 and 11 on the ground.

- On 5-May-1990 at Guatemala City, Guatemala, a Douglas DC-6B crashed into a residential neighbourhood just after takeoff, killing 3 crewmembers and 24 people on the ground. The flight was a scheduled 14 CFR 121 operation of Aerial Transit (D.B.A. TRANSLADOS) and the fatalities are counted in the table above. (NTSB Identification: DCA90RA025)
- On 1-February-1991 at Los Angeles in California, an accident killed 22 people aboard scheduled 14 CFR 121 operation of a USAIR BOEING 737-300 and 12 people aboard scheduled 14 CFR 135 operation of a SkyWest commuter aircraft. The table includes 12 fatalities "not aboard" in the column for scheduled 14 CFR 121 flights and 22 fatalities "not aboard" in the column for scheduled 14 CFR 135 flights. This was clarified in a footnote to the source table. (NTSB Identification: DCA91MA018A)
- On 29-February-1996 at Arequipa, Peru, an accident killed 123 people who were aboard a Boeing 737-222. Note that this is regarded as General Aviation in the table. (NTSB Identification: DCA96RA034)
- On 2-October-1996 at Lima, Peru, an accident killed 70 people who were aboard a Boeing 757-23A. This is also regarded as General Aviation in the table. (NTSB Identification: DCA97RA001)
- On 22-October-1996 a Boeing 707-323C, operating as a non-scheduled 14 CFR Part 121 flight, crashed after takeoff from the Eloy Alfaro Airport, Manta, Ecuador, killing three crew, one passenger and about 30 people on the ground. (NTSB Identification: MIA97RA011)
- On 23-November-1996 at Comorso Islands, an accident during a hijacking attempt killed 125 people. Again, this accident is counted as General Aviation in the table. (NTSB Identification: DCA97WA011)

In order to compare the sizes of the aviation industries in United States and in Australia, Table 13 presents data from Table No. 1070 of [5] on the total operating revenue in millions of US$ for the US Scheduled Airline Industry. Australian Bureau of Statistics data reported in section 5.3 on page 6 shows that in 1997-98, the air and space transport industry in Australia had total income of A$14,340 million. Using an exchange rate of A$1=US$0.65, the Australian aviation industry has about 8.5% of the revenue of the United States' aviation industry.

1990	1991	1992	1993	1994	1995	1996	1997
76,142	75,158	78,140	84,559	88,313	94,578	101,938	109,535

Table 13: Operating revenue for US scheduled airline industry (US$ millions) [Source: United States Census Bureau]

There are 424 fatalities of people "not aboard" listed in Table 12. Considering the specific accidents itemised above, at least 64+12+22 = 98 of those people were actually aboard an aircraft; and at least 11+24+30 = 65 were people on the ground who were residents of countries other than United States. Therefore the total number of fatalities to ground crew and members of the public in the United States for the 18-year period is not greater than 424-98-65 = 261. (It should be remembered that fatalities of members of the public or ground crew in United States involving aircraft registered in other countries are not included in Table 12.) This is an average of 14.5 fatalities per year.

Table 10 shows 34 fatalities of ground crew or members of the public in Australia caused by aviation over 26 years. This is 1.3 fatalities per year which is 9% of the United States rate of fatalities. The revenue of the Australian aviation industry is near enough to 9% of the revenue of the US aviation industry for the accidents rates to be regarded as similar.

Appendix C: Principal external causes of death in Australia

Table 15 which starts on the next page tells us how many Australians died from a variety of causes during the period from 1994 to 1998. It classifies principal causes of death according to the 9th Revision of the World Health Organisation's International Classification of Diseases (ICD-9). Only deaths for which the principal cause of death had a code between 800 and 999 are included. This means that the death was due to "External causes". Note that we have added the horizontal lines in Table 15. They are not an official categorisation of ICD codes.

The total numbers of deaths from all causes during the years 1994 to 1998 are available in reports of the Australian Bureau of Statistics[23] and are summarised in Table 14. Deaths from external causes represent about 6% of all deaths.

Year	*1994*	*1995*	*1996*	*1997*	*1998*
Females	67,464	66,251	68,206	67,752	67,073
Males	59,228	58,882	60,513	61,598	60,129
Total	126,692	125,133	128,719	129,350	127,202

Table 14: Number of deaths in Australia from all causes. [Source: Australian Bureau of Statistics]

For considering the risks associated with the space industry, the main message to be derived from looking at Table 15 is that there are hundreds of other hazards which have risks greater than the risks of rocket launches. For some of these hazards, such as road traffic accidents, the risk is many orders of magnitude greater than the risk associated with rocket launches.

One weakness of this data is that some deaths may have been classified in inoffensive ways. For instance, classifying a death using a code in the range 870-879 tends to suggest that medical or surgical procedures contributed to the death, so it is likely that other codes will have been used where the choice of code for the principal cause of death was not clear-cut. Similarly, code 980 might be used for a death by poisoning when classification of the death as suicide (code 950) or assault (code 962) or accidental poisoning by tranquillizers (853) or other psychotropic agents (854) would be more accurate.

Some codes seem less specific than is desirable. For instance, code 843 is described as "Fall in; on or from aircraft", yet a fall *from* an aircraft is quite a different incident from a fall *in* an aircraft. This code has only been used for one death in the table, so the amalgamation of possible causes into a single code is not unreasonable. Code 858 is described as "Accidental poisoning by other drugs and has been used to describe a large number of deaths. It might be interesting to separate heroin from other drugs and to know how many accidental poisonings were associated with recreational drug use.

It is hard to see what differentiates some codes. For instance, codes 856 and 930 both describe deaths from antibiotics, while 857 and 931 both describe deaths from anti-infectives.

Note that the Australian Bureau of Statistics does not release data giving cell frequencies less than 3 where this might enable information to be deduced about individuals. The data might be easier to interpret if further breakdowns were provided. For instance, it seems likely that the people who died falling from ladders and scaffolding (code 881) were generally younger than those who died from "fractures; cause unspecified" (code 887).

Code	*Description*	*Total*	*Female*	*Male*	*1994*	*1995*	*1996*	*1997*	*1998*
800	Railway accident involving collision with rolling stock	2	0	2	0	0	2	0	0
801	Railway accident involving collision with other object	4	0	4	0	1	0	1	2
804	Fall in; on or from railway train	20	3	17	4	5	1	4	6
805	Hit by rolling stock	169	29	140	33	39	29	33	35
806	Other specified railway accident	5	0	5	1	2	1	1	0
807	Railway accident of unspecified nature	3	0	3	1	1	1	0	0
810	Motor vehicle traffic accident involving collision with train	79	25	54	18	12	16	21	12
811	Motor vehicle traffic accident involving re-entrant collision with another motor vehicle	9	0	9	2	1	2	3	1
812	Other motor vehicle traffic accident involving collision with another motor vehicle	3519	1232	2287	738	767	711	659	644
813	Motor vehicle traffic accident involving collision with other vehicle	243	39	204	59	47	53	48	36
814	Motor vehicle traffic accident involving collision with pedestrian	1754	559	1195	365	409	342	324	314
815	Other motor vehicle traffic accident involving collision on the highway	2361	598	1763	477	502	478	472	432
816	Motor vehicle traffic accident due to loss of control; without collision on the highway	1133	273	860	242	238	242	192	219
817	Noncollision motor vehicle traffic accident while boarding or alighting	5	2	3	1	0	0	3	1
818	Other noncollision motor vehicle traffic accident	108	20	88	18	22	27	19	22
819	Motor vehicle traffic accident of unspecified nature	253	85	168	40	31	72	60	50
820	Nontraffic accident involving motor-driven snow vehicle	1	0	1	0	0	1	0	0
821	Nontraffic accident involving other off-road motor vehicle	70	7	63	20	14	9	9	18
822	Other motor vehicle nontraffic accident involving collision with moving object	114	43	71	19	22	24	28	21
823	Other motor vehicle nontraffic accident involving collision with stationary object	46	6	40	13	8	9	6	10
824	Other motor vehicle nontraffic accident while boarding and alighting	3	1	2	0	0	2	1	0
825	Other motor vehicle nontraffic accident of other and unspecified nature	85	20	65	14	24	20	15	12
826	Pedal cycle accident	44	8	36	4	10	13	8	9
827	Animal-drawn vehicle accident	2	1	1	0	0	1	1	0
828	Accident involving animal being ridden	58	25	33	15	18	8	6	11
829	Other road vehicle accidents	5	1	4	0	1	2	1	1
830	Accident to watercraft causing submersion	132	8	124	33	40	21	22	16
831	Accident to watercraft causing other injury	13	1	12	4	2	3	3	1
832	Other accidental submersion or drowning in water transport accident	94	2	92	20	16	26	20	12

Code	*Description*	*Total*	*Female*	*Male*	*1994*	*1995*	*1996*	*1997*	*1998*
834	Other fall from one level to another in water transport	1	0	1	0	0	0	0	1
836	Machinery accident in water transport	3	0	3	1	0	1	1	0
837	Explosion; fire or burning in watercraft	6	1	5	0	0	1	0	5
838	Other and unspecified water transport accident	19	2	17	4	2	7	2	4
840	Accident to powered aircraft at takeoff or landing	50	6	44	14	9	10	9	8
841	Accident to powered aircraft; other and unspecified	208	29	179	28	46	59	29	46
842	Accident to unpowered aircraft	23	1	22	5	5	0	6	7
843	Fall in; on or from aircraft	1	0	1	0	0	1	0	0
844	Other specified air transport accidents	16	4	12	3	5	1	5	2
846	Accidents involving powered vehicles used solely within the buildings and premises of an industrial or commercial establishment	4	0	4	1	1	1	1	0
848	Accidents involving other vehicles not elsewhere classifiable	2	1	1	0	1	0	1	0
850	Accidental poisoning by analgesics; antipyretics; antirheumatics	853	166	687	138	183	186	105	241
851	Accidental poisoning by barbiturates	7	3	4	1	3	3	0	0
852	Accidental poisoning by other sedatives and hypnotics	11	9	2	7	0	2	2	0
853	Accidental poisoning by tranquillizers	114	49	65	25	26	29	23	11
854	Accidental poisoning by other psychotropic agents	179	101	78	54	35	34	26	30
855	Accidental poisoning by other drugs acting on central and autonomic nervous systems	35	12	23	10	9	2	3	11
856	Accidental poisoning by antibiotics	3	1	2	0	0	1	0	2
857	Accidental poisoning by anti-infectives	2	0	2	1	0	0	0	1
858	Accidental poisoning by other drugs	563	200	363	48	42	40	156	277
860	Accidental poisoning by alcohol; not elsewhere classified	27	6	21	5	1	8	9	4
861	Accidental poisoning by cleansing and polishing agents; disinfectants; paints and varnishes	18	7	11	5	5	5	2	1
862	Accidental poisoning by petroleum products; other solvents and their vapours; not elsewhere classified	18	1	17	4	7	6	1	0
863	Accidental poisoning by agricultural and horticultural chemical and pharmaceutical preparations other than plant foods & fertilizers	12	3	9	2	1	4	1	4
864	Accidental poisoning by corrosives and caustics; not elsewhere classified	4	2	2	1	0	1	1	1
865	Accidental poisoning from foodstuffs and poisonous plants	11	3	8	1	3	3	4	0
866	Accidental poisoning by other and unspecified solid and liquid substances	20	6	14	3	3	0	8	6
867	Accidental poisoning by gas distributed by pipeline	2	1	1	0	0	1	0	1

Code	*Description*	*Total*	*Female*	*Male*	*1994*	*1995*	*1996*	*1997*	*1998*
868	Accidental poisoning by other utility gas and other carbon monoxide	87	19	68	15	13	24	18	17
869	Accidental poisoning by other gases and vapours	5	0	5	0	0	0	1	4
870	Accidental cut; puncture; perforation or haemorrhage during medical care	91	51	40	13	13	28	20	17
873	Failure in dosage	2	0	2	2	0	0	0	0
874	Mechanical failure of instrument or apparatus during procedure	4	2	2	1	2	1	0	0
875	Contaminated or infected blood; other fluid; drug or biological substance	36	9	27	13	6	13	3	1
876	Other and unspecified misadventures during medical care	10	5	5	1	0	2	5	2
878	Surgical operation and other surgical procedures as the cause of abnormal reaction of patient; or of later complication; without mention of misadventure at the time of operation	132	53	79	16	14	24	28	50
879	Other procedures; without mention of misadventure at the time of procedure; as the cause of abnormal reaction of patient; or of later complication	29	16	13	2	6	1	5	15
880	Fall on or from stairs or steps	184	79	105	42	40	37	22	43
881	Fall on or from ladders or scaffolding	90	7	83	16	15	26	19	14
882	Fall from or out of building or other structure	203	25	178	37	41	50	43	32
883	Fall into hole or other opening in surface	18	0	18	4	3	2	4	5
884	Other fall from one level to another	310	81	229	69	69	66	52	54
885	Fall on same level from slipping; tripping or stumbling	319	110	209	52	75	83	55	54
886	Fall on same level from collision; pushing or shoving; by or with other person	13	1	12	2	4	3	3	1
887	Fracture; cause unspecified	3219	2085	1134	601	558	643	692	725
888	Other and unspecified fall	1051	564	487	180	190	192	235	254
890	Conflagration in private dwelling	387	144	243	96	92	79	52	68
891	Conflagration in other and unspecified building or structure	27	10	17	4	5	7	9	2
892	Conflagration not in building or structure	25	5	20	3	0	8	6	8
893	Accident caused by ignition of clothing	66	30	36	17	12	14	10	13
894	Ignition of highly inflammable material	22	4	18	4	6	4	2	6
895	Accident caused by controlled fire in private dwelling	13	5	8	3	5	2	1	2
896	Accident caused by controlled fire in other and unspecified building or structure	1	0	1	1	0	0	0	0
897	Accident caused by controlled fire not in building or structure	7	3	4	0	0	1	4	2
898	Accident caused by other specified fire and flames	11	5	6	1	0	2	3	5
899	Accident caused by unspecified fire	50	12	38	4	2	15	12	17
900	Excessive heat	33	20	13	9	7	3	11	3

Code	*Description*	*Total*	*Female*	*Male*	*1994*	*1995*	*1996*	*1997*	*1998*
901	Excessive cold	87	39	48	21	25	16	12	13
902	High and low air pressure and changes in air pressure	13	4	9	2	3	5	3	0
903	Travel and motion	2	2	0	0	0	0	0	2
904	Hunger; thirst; exposure; neglect	14	4	10	3	3	5	2	1
905	Venomous animals and plants as the cause of poisoning and toxic reactions	35	8	27	9	8	4	9	5
906	Other injury caused by animals	39	12	27	12	7	8	6	6
907	Lightning	9	3	6	3	2	1	2	1
908	Cataclysmic storms; and floods resulting from storms	27	5	22	1	5	13	1	7
909	Cataclysmic earth surface movements and eruptions	20	8	12	0	0	0	20	0
910	Accidental drowning and submersion	1277	286	991	250	259	247	276	245
911	Inhalation and ingestion of food causing obstruction of respiratory tract or suffocation	311	116	195	70	55	62	66	58
912	Inhalation and ingestion of other object causing obstruction of respiratory tract or suffocation	84	35	49	11	11	7	27	28
913	Accidental mechanical suffocation	310	79	231	38	43	79	49	101
914	Foreign body accidentally entering eye and adnexa	1	0	1	0	0	1	0	0
915	Foreign body accidentally entering other orifice	5	3	2	2	1	1	1	0
916	Struck accidentally by falling object	237	14	223	49	45	36	51	56
917	Striking against or struck accidentally by objects or persons	57	7	50	9	12	9	14	13
918	Caught accidentally in or between objects	35	2	33	8	6	1	13	7
919	Accidents caused by machinery	298	14	284	77	53	57	63	48
920	Accidents caused by cutting and piercing instruments or objects	61	16	45	10	9	15	14	13
921	Accident caused by explosion of pressure vessel	14	0	14	3	3	1	2	5
922	Accident caused by firearm missile	105	9	96	20	15	30	19	21
923	Accident caused by explosive material	35	2	33	4	18	7	6	0
924	Accident caused by hot substance or object; caustic or corrosive material and steam	55	26	29	12	11	10	11	11
925	Accident caused by electric current	228	16	212	48	48	44	49	39
927	Overexertion and strenuous movements	2	1	1	0	2	0	0	0
928	Other and unspecified environmental and accidental causes	267	74	193	20	31	78	65	73
929	Late effects of accidental injury	451	138	313	85	93	91	93	89
930	Antibiotics	6	4	2	1	0	2	2	1
931	Other anti-infectives	3	2	1	3	0	0	0	0
932	Hormones and synthetic substitutes	5	3	2	1	0	1	0	3
933	Primarily systemic agents	3	2	1	1	0	0	1	1
934	Agents primarily affecting blood constituents	12	7	5	3	2	2	1	4

Code	*Description*	*Total*	*Female*	*Male*	*1994*	*1995*	*1996*	*1997*	*1998*
935	Analgesics; antipyretics and antirheumatics	11	7	4	1	4	3	2	1
937	Sedatives and hypnotics	1	0	1	0	0	1	0	0
938	Other central nervous system depressants	2	2	0	1	0	0	0	1
939	Psychotropic agents	7	1	6	1	1	2	0	3
942	Agents primarily affecting the cardiovascular system	3	2	1	1	1	1	0	0
944	Water; mineral and uric acid metalbolism drugs	2	1	1	0	0	2	0	0
946	Agents primarily affecting skin and mucous membrane; ophthalmological; otorhinolaryngological and dental drugs	6	5	1	1	3	1	1	0
947	Other and unspecified drugs and medicaments	9	6	3	1	3	2	1	2
949	Other vaccines and biological substances	3	0	3	0	1	2	0	0
950	Suicide and selfinflicted poisoning by solid or liquid substances	1819	811	1008	375	383	378	347	336
951	Suicide and selfinflicted poisoning by gases in domestic use	22	4	18	5	7	4	4	2
952	Suicide and selfinflicted poisoning by other gases and vapours	2674	418	2256	447	514	526	629	558
953	Suicide and selfinflicted injury by hanging; strangulation and suffocation	4334	698	3636	639	699	792	987	1217
954	Suicide and selfinflicted injury by submersion (drowning)	300	109	191	59	71	47	73	50
955	Suicide and selfinflicted injury by firearms and explosives	1759	96	1663	420	389	384	331	235
956	Suicide and selfinflicted injury by cutting and piercing instruments	221	43	178	45	38	37	53	48
957	Suicide and selfinflicted injuries by jumping from high place	537	135	402	117	108	99	116	97
958	Suicide and selfinflicted injury by other and unspecified means	749	179	570	149	156	123	181	140
959	Late effects of selfinflicted injury	10	2	8	2	3	3	2	0
960	Fight; brawl; rape	159	26	133	29	27	31	33	39
962	Assault by poisoning	34	13	21	6	0	6	10	12
963	Assault by hanging and strangulation	121	78	43	21	31	17	27	25
964	Assault by submersion (drowning)	18	3	15	2	5	1	7	3
965	Assault by firearms and explosives	386	126	260	79	67	104	79	57
966	Assault by cutting and piercing instrument	531	168	363	121	110	100	100	100
967	Child battering and other maltreatment	32	9	23	6	9	7	4	6
968	Assault by other and unspecified means	340	147	193	68	84	55	68	65
969	Late effects of injury purposely inflicted by other person	6	1	5	0	0	5	1	0
970	Injury due to legal intervention by firearms	27	3	24	7	6	0	7	7
975	Injury due to legal intervention by other specified means	1	0	1	1	0	0	0	0
980	Poisoning by solid or liquid substances; undetermined whether accidentally or purposely inflicted	411	126	285	59	88	90	90	84

Code	*Description*	*Total*	*Female*	*Male*	*1994*	*1995*	*1996*	*1997*	*1998*
981	Poisoning by gases in domestic use; undetermined whether accidentally or purposely inflicted	1	0	1	1	0	0	0	0
982	Poisoning by other gases; undetermined whether accidentally or purposely inflicted	10	2	8	0	3	2	2	3
983	Hanging; strangulation or suffocation; undetermined whether accidentally or purposely inflicted	14	2	12	5	1	1	0	7
984	Submersion (drowning); undetermined whether accidentally or purposely inflicted	50	20	30	8	8	15	11	8
985	Injury by firearms and explosives; undetermined whether accidentally or purposely inflicted	24	3	21	6	3	5	2	8
986	Injury by cutting and piercing instruments; undetermined whether accidentally or purposely inflicted	3	2	1	1	0	1	1	0
987	Falling from high place; undetermined whether accidentally or purposely inflicted	30	11	19	5	9	7	3	6
988	Injury by other and unspecified means; undetermined whether accidentally or purposely inflicted	69	10	59	10	14	15	17	13
989	Late effects of injury; undetermined whether accidentally or purposely inflicted	4	1	3	0	1	3	0	0
999	Late effects of injury due to war operations	3	0	3	3	0	0	0	0
	Total deaths due to external causes	37842	11158	26684	7188	7414	7557	7737	7946

Table 15: Number of deaths in Australia from external causes, broken down by gender and by year for each category of primary external cause. [Source: Australian Bureau of Statistics]

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