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Executive Summary

The objective of this analysis was to assess the number of Serious Injuries and Fatalities that might be avoided from the use of '16g dynamic seats configured without enhancements to head injury criteria' and to compare this with the assessed benefit from 'fully compliant dynamic seats'.

The analysis was based on twenty-five impact related accidents, occurring during the period from 1984 to 1998, that may have involved seat related Fatal or Serious Injuries. An earlier Benefit Analysis carried out on "fully compliant dynamic seats" used the same accidents as a basis for predicting number of lives saved and reduction in Serious Injuries. Using the same accidents in this analysis enabled a direct comparison between the two analytical methods.

Each accident was analyzed in detail and a mathematical technique was used to model each accident scenario. The analysis was based on an evaluation of the injuries sustained by the passengers to determine the total achievable benefits.

The prediction of benefit for '16g dynamic seats configured without enhancements to head injury criteria' over the period 1984 to 1998 to U.S. registered aircraft, operating under 14 CFR Part 121 is:

Reduction in Fatalities = 28

Reduction in Serious Injuries = 22

The re-evaluation of the benefit, based on currently available data, for 'fully compliant dynamic seats' over the period 1984 to 1998 approximates to:

Reduction in Fatalities = 45

Reduction in Serious Injuries = 40

This reduction in Fatalities and Serious Injuries is to a similar level as that determined from the earlier analysis.

The proportion of benefit attributable to the enhanced Head Injury Criteria (as defined in TSO-C127a) is:

Fatalities = 39%

Serious Injuries = 46%

Account has been taken of the reduction in fire threat afforded to the impact survivors by the improved fireworthiness of cabin interiors compliant with the standards defined in 14 CFR Part 25 at amendment 72. The fire threat is often severe in accidents where '16g seats' are likely to reduce the number of impact Injuries and Fatalities. This is a significant factor in terms of the ultimate benefit attained even when the recent improvements in the fireworthiness of aircraft cabins is taken into account

Due to the extensive disruption to the floor during the impact sequence, a number of accidents analyzed would not have any potential for lives being saved with the introduction of '16g seats'.

The analytical methods employed provide as accurate an assessment, as is possible with the available data, using the mathematical tools currently in existence. However, there will still remain an element of uncertainty associated with assessments of this kind, and this should be borne in mind when making decisions concerning aircraft safety that are predicated on the results of this analysis.

A Benefit Analysis for Aircraft 16G Dynamic Seats Configured without Enhancements to Head Injury Criteria

1 Introduction

1.1 This report has been prepared on behalf of the U.S. Federal Aviation Administration (FAA). It contains the method and results of a benefit analysis on '16g dynamic seats configured without enhancements to head injury criteria'. The analysis relates to aircraft, type certificated with 30 or more passenger seats, operating to 14 CFR Part 121 or equivalent.

1.2 TSO-C127a prescribes the minimum performance standards for Transport Airplane Seats. Seats that are fully compliant with this Standard are identified in this report as 'fully compliant dynamic seats'. Seats that meet this Standard but are not compliant with the enhanced head injury criteria (HIC) are identified in this report as '16g dynamic seats configured without enhancements to head injury criteria'. The term '16g seats' is used generically to refer to both standard of seat.

1.3 An earlier analysis of past accidents determined the benefit to be derived from 'fully compliant dynamic seats' (Reference [1]). This analysis was carried out using the Cabin Safety Research Technical Group Accident Database (Reference [2]) as a means of selecting the appropriate accidents from which to assess benefit. Since the time of this earlier analysis, further data have become available enabling a more detailed assessment of the benefit likely to accrue. The same accidents were analyzed in this assessment as used in the earlier analysis, thus enabling a direct comparison between the two analytical methods.

1.4 The assessments have been carried out such that they reflect the benefit likely to accrue to aircraft compliant with the latest standard of cabin fireworthiness as prescribed in 14 CFR Part 25 at amendment 72.

1.5 The methodology utilized is aimed at providing an indication as to the order of benefit likely to be achieved. Certain assumptions have been made in the analysis of data. The more significant of these are described in paragraph 5·1.

1.6 Any analysis of this kind must involve a degree of subjective judgment and relies on the accuracy of the data available. The analytical methods employed are intended to provide as accurate an assessment as is possible with the available data, using the mathematical tools currently in existence. However there will still remain an element of uncertainty associated with assessments of this kind, and this should be borne in mind when making decisions concerning aircraft safety that are predicated on the results of this analysis.

1.7 Section 9 of this report contains the definition of terms used in this analysis.

2 Objectives

The objective of this analysis was to assess the number of Serious Injuries and Fatalities that might be avoided from the use of '16g dynamic seats configured without enhancements to head injury criteria' and to compare this with the assessed benefit from 'fully compliant dynamic seats'.

3 Accidents Analyzed

3.1 The earlier assessment (Reference [1]) of benefit from 'fully compliant dynamic seats' was based on an analysis of accidents occurring over the period 1984 to 1998. The accidents analyzed to determine benefit are shown in Table 1.

Table 1 List of Accidents Analyzed in the Earlier Benefit Analysis for 'Fully Compliant Dynamic Seats'

Date	Location	Aircraft
20-Dec-95	Buga, Nr. Cali, Colombia	B757-223
02-Jul-94	Charlotte Airport, Charlotte, North Carolina	DC9-31
26-Apr-94	Nagoya/Komaki Airport, Nagoya, Japan	A300B4-622R
21-Mar-94	Vigo Airport, Spain	DC9-32
14-Sep-93	Warsaw, Poland	A320-211
06-Apr-93	Nr. Shemya, Alaska, U.S.A.	MD11
21-Dec-92	Faro, Portugal	DC10-30CF
22-Mar-92	La Guardia, New York, U.S.A.	F28-4000 a
20-Jan-92	Nr Strasbourg, (France)	A320-100
01-Feb-91	Los Angeles, California, U.S.A.	B737-300
03-Dec-90	Romulus, Detroit, U.S.A.	DC9-14
14-Feb-90	Bangalore, India	A320-231
25-Jan-90	Cove Neck, Long Island, New York, U.S.A.	B707-321B
20-Sep-89	La Guardia, New York, U.S.A.	B737-400
19-Jul-89	Sioux City, U.S.A.	DC10-10
10-Mar-89	Dryden, Ontario, Canada	F28 Mk1000
08-Jan-89	Kegworth, East Midlands Airport, U.K.	B737-400
31-Aug-88	Hong Kong	TRIDENT 2E
31-Aug-88	Dallas Fort Worth, U.S.A.	B727-232
26-Jun-88	Habsheim	A320-100
15-Apr-88	Seattle-Tacoma Intl. Airport, Seattle, U.S.A.	DHC8-102
15-Nov-87	Denver Colorado U.S.A.	DC9-14
16-Aug-87	Detroit	DC9-82
02-Aug-85	Dallas Fort Worth, U.S.A.	L1011-385-1
21-Jan-85	Reno Nevada, U.S.A.	L188C

3.2 Table 2 shows the Total Number of Fatalities and Serious Injuries to passengers and the benefit assessment for each accident determined from this earlier benefit analysis.

Table 2 List of Accidents Identified as having Potential for Benefit from 'Fully Compliant Dynamic Seats' showing the Number of Fatalities and Serious Injuries

Date	Location	Aircraft	Total No. of Fatalities	Total No. of Serious Injuries	Benefit	
					Lives Saved	Injuries Saved
20-Dec-95	Buga, Cali	B757	159	4	0	0
02-Jul-94	Charlotte	DC9-31	37	16	3	0
26-Apr-94	Nagoya	A300B4	264	7	0	0
21-Mar-94	Vigo	DC9-32	0	2	0	0
14-Sep-93	Warsaw	A320	2	47	0	4
06-Apr-93	Shemya	MD11	2	60	0	25
21-Dec-92	Faro	DC10	56	U/K	3	6
22-Mar-92	La Guardia	F28-4000	27	9	4	5
20-Jan-92	Strasbourg	A320	87	5	7	-5
01-Feb-91	Los Angeles	B737	22	13	0	0
03-Dec-90	Romulus	DC9-14	8	10	0	0
14-Feb-90	Bangalore	A320	92	22	9	-5
25-Jan-90	Cove Neck	B707	73	81	23	21
20-Sep-89	La Guardia	B737	2	3	0	0
19-Jul-89	Sioux City	DC10-10	111	47	3	1
10-Mar-89	Dryden	F28	24	18	0	5
08-Jan-89	Kegworth	B737	47	74	5	0
31-Aug-88	Hong Kong	TRIDENT	7	4	0	0
31-Aug-88	Dallas	B727-232	14	26	0	0
26-Jun-88	Habsheim	A320-100	3	30	0	0
15-Apr-88	Seattle	DHC8	0	4	0	2
15-Nov-87	Denver.	DC9-14	28	28	4	5
16-Aug-87	Detroit	DC9-82	154	1	0	0
02-Aug-85	Dallas	L1011	134	15	0	2
21-Jan-85	Reno	L188C	70	1	1	0

NOTE: (U/K = unknown)

3.3 These accidents have been reassessed using the methodology described in Section 4 to re-evaluate the benefit from 'fully compliant dynamic seats' and to assess the benefit from '16g dynamic seats configured without enhancements to head injury criteria'.

4 Method

4.1 General Overview

4.1.1 Each accident, shown in Table 2, that exhibited a reduction in the number of Fatalities or Injuries based on the earlier assessment for 'fully compliant dynamic seats' was reassessed in accord with the methodology described in the following Sections.

4.1.2 Additional data have become available, since this earlier analysis was carried out, pertaining to individual occupants. In many instances, the full extent of the nature and severity of injuries sustained was available together with their age and sex. Survivor statements often provided additional information relating to localized areas of the cabin, including whether the seats were detached and the level of disruption of the floor.

4.1.3 The methodology adopted for this analysis was to consider the injuries for all of the passengers where data were available. This assessment was carried out for both 'fully compliant dynamic seats' and '16g dynamic seats configured without enhancements to head injury criteria'. This enabled a comparison to be made between the assessed benefit likely to accrue from the two seat standards.

4.2 Accident Scenarios

4.2.1 The severity of hazard in an accident can vary markedly throughout the aircraft. Experience has shown that considering occupant injuries on a "whole" aircraft basis can be misleading when assessing the effects of survivability factors. It is therefore desirable to divide the aircraft into "Scenarios".

4.2.2 A Scenario is defined as:

"That volume of the aircraft in which the occupants are subjected to a similar level of threat."

4.2.3 A similar level of threat need not necessarily result in the same level of injury to occupants. The extent of injury sustained can vary with numerous factors including age, sex, adoption of the brace position etc. Furthermore, the threat to occupants can vary over relatively small distances. For example, a passenger may receive Fatal Injuries because of being impacted by flying debris, and a person in an adjacent seat may survive uninjured. However, dividing accidents into scenarios provides a more meaningful basis on which to analyze accidents than considering the whole aircraft due to the marked variation in potential for survival with occupant location.

4.2.4 The flight deck and flight attendant areas are generally considered as separate scenarios. The flight crewmembers usually have full harness restraints, and sliding cockpit windows in the area provide a nearby method of egress. The flight attendant areas are normally considered as a separate scenario from the passenger cabin, again due to the significant differences in seating, restraint systems and exit availability.

4.2.5 For these reasons, where sufficient data were available, the assessments of injury reduction were carried out for each accident scenario.

4.3 Injury Reduction Assessment

4.3.1 For many of the accidents analyzed sufficient data were available to consider each passenger separately and to assess the probability of their injuries being ameliorated by the use of '16g seats'. An assessment was made of the probability that:

4.3.2 For the Fatally injured, that their injuries would:

a) Remain Fatal

b) Be reduced to Serious

c) Be reduced to Minor/None

4.3.3 For the Seriously injured, that their injuries would:

a) Remain Serious

b) Be reduced to Minor/None

4.3.4 The factors taken into account in deriving these probabilities included the following:

a) The nature and extent of their injuries. Often the data was such that a determination could be made as to whether or not the occupant sustained:

   i) Injuries that might have been ameliorated by the enhanced head injury criteria specified in TSO-C127a.

   ii) Other impact related injuries that might have resulted from cabin disruption, such that '16g seats' would not have changed the nature and extent of their injuries.

   iii) Injuries resulting from any existing fire threat.

b) Statements made by Survivors as to the nature of the disruption in various areas of the cabin. This might include whether seats were detached, floors failed or local structure crushed

c) The age of the passenger can be an important factor in their survivability. An age related issue, particularly relevant to this analysis, is that children would be less likely to benefit 'from fully compliant dynamic seats', simply because of their stature.

4.3.5 An example of the way in which an estimate of the resultant number of Fatalities and Serious Injuries may be derived from the assessed probabilities is shown in Table 3.

Table 3 Example of the Method for Assessing the Resultant Number of Fatalities and Serious Injuries in a Scenario

					FULL 16G SEAT			16G SEAT LESS HIC		
SEAT/IDENT	AGE	INJURY/ AIS	HEAD	SEAT DETACHED	IMPACT M/N	IMPACT SERIOUS	IMPACT FATAL	IMPACT M/N	IMPACT SERIOUS	IMPACT FATAL
					2.65	4.5	0.85	2	5.1	0.9
6A	39	S4	NO	YES	0.5	0.5	0	0.5	0.5	0
7A	57	S4	NO	NO	0	1	0	0	1	0
7C	54	S5	NO	NO	0	1	0	0	1	0
8E	30	S4	NO	YES	0.3	0.7	0	0.3	0.7	0
12F	25	S2	NO	YES	0.7	0.3	0	0.7	0.3	0
13A	?	F6	YES	YES	0.05	0.1	0.85	0	0.1	0.9
13C	?	S2	NO	YES	0.5	0.5	0	0.5	0.5	0
13D	?	F4	YES	YES	0.6	0.4	0	0	1	0

For each seat location (**Seat/Ident**) the following information was recorded:

- **Age:** of the passenger
- **Injury/AIS:** The extent of the injuries S= Serious, F=Fatal and AIS = Abbreviated Injury Scale indicating the severity of the injuries (see Section 9, Definitions).
- **Head:** YES = the passenger sustained head injuries; NO = the passenger did not sustain head injuries.
- **Seat Detached:** YES = the seat became detached; NO the seat did not become detached.

Having made the assessment of the probabilities, pertinent to each passenger, based on these data, the probabilities in each impact injury category were summed to arrive at the total number of passengers in the scenario, following the introduction of '16g seats', sustaining:

a) Minor/No Impact Injuries (**Impact M/N**)

i) 2·65 in the example for 'fully compliant dynamic seats' (**Full 16G Seat**), and

ii) 2·0 in the example for '16g dynamic seats configured without enhancements to head injury criteria' (**16G Seat Less HIC**).

b) Serious Impact Injuries (**Impact Serious**)

i) 4·5 in the example for 'fully compliant dynamic seats' (**Full 16G Seat**), and

ii) 5·1 in the example for '16g dynamic seats configured without enhancements to head injury criteria' (**16G Seat Less HIC**).

c) Fatal Impact Injuries (**Impact Fatal**)

i) 0·85 in the example for 'fully compliant dynamic seats' (**Full 16G Seat**), and

ii) 0·9 in the example for '16g dynamic seats configured without enhancements to head injury criteria' (**16G Seat Less HIC**).

4.4 **Survivability Chains**

4.4.1 The assessment described in paragraph 4.3 results in a prediction of the number of Fatally Injured, Seriously Injured and surviving passengers (Minor/No Injuries) resulting from the impact in each accident scenario. A determination is required of the probability of those Seriously Injured or surviving the impact with Minor or No Injuries, succumbing to any fire threat that might also exist. Such an assessment may be made by the use of a mathematical model, known as a Survivability Chain (see Figure 1). This model enables an assessment to be made of the overall effect on survivability, from improvements made to impact related survivability factors such as '16g seats'.

4.4.2 The following is an example of the model and the effects of improvement in Injuries and Fatalities resulting from changes to survivability factors for a hypothetical accident scenario.

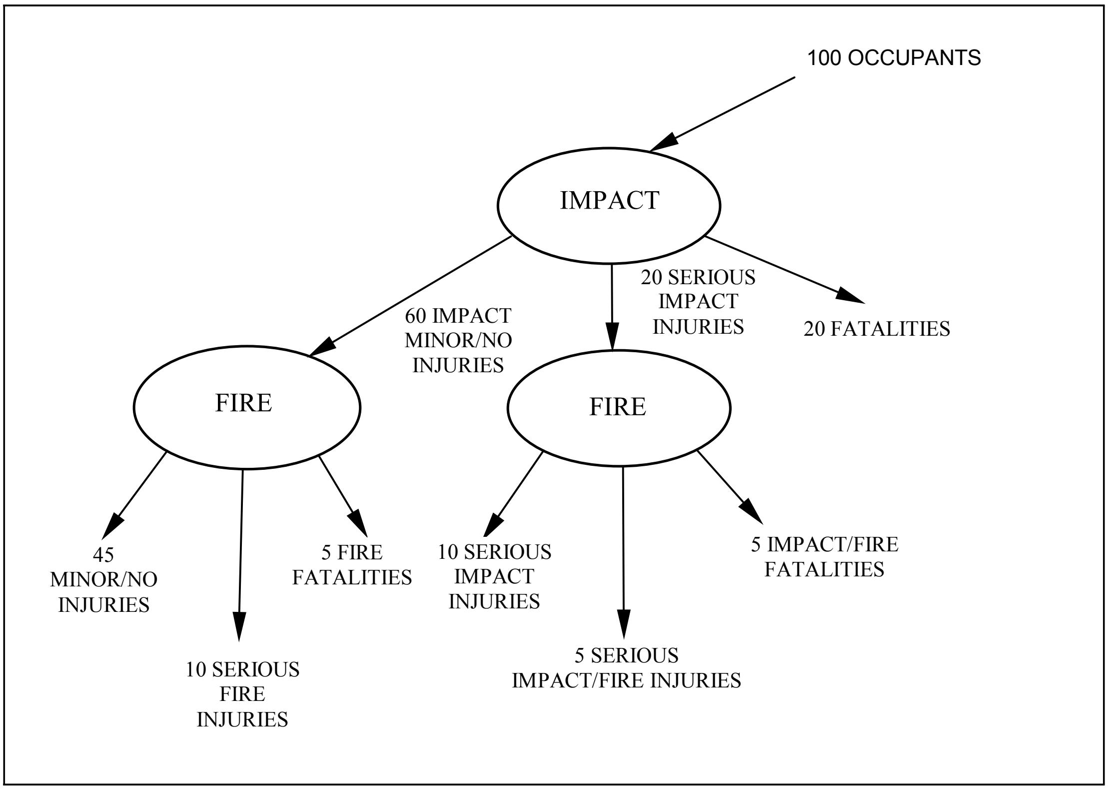

Figure 1 Example of a Survivability Chain for an Accident Scenario

4.4.3 In this example, of the 100 occupants in the scenario there are:

- 45 uninjured survivors (Minor/No Injuries).
- 25 Serious Injuries, 10 because of the impact, 10 because of the fire, and 5 seriously injured because of the impact and fire.
- 30 Fatalities, 20 because of the impact, and 10 because of the fire (5 of whom sustained Serious injuries from the impact).

4.4.4 If improvements are made to an impact-related survivability factor, such that there are only 12 Fatalities and 16 Seriously Injured of the 100 occupants, the survivability chain then becomes:

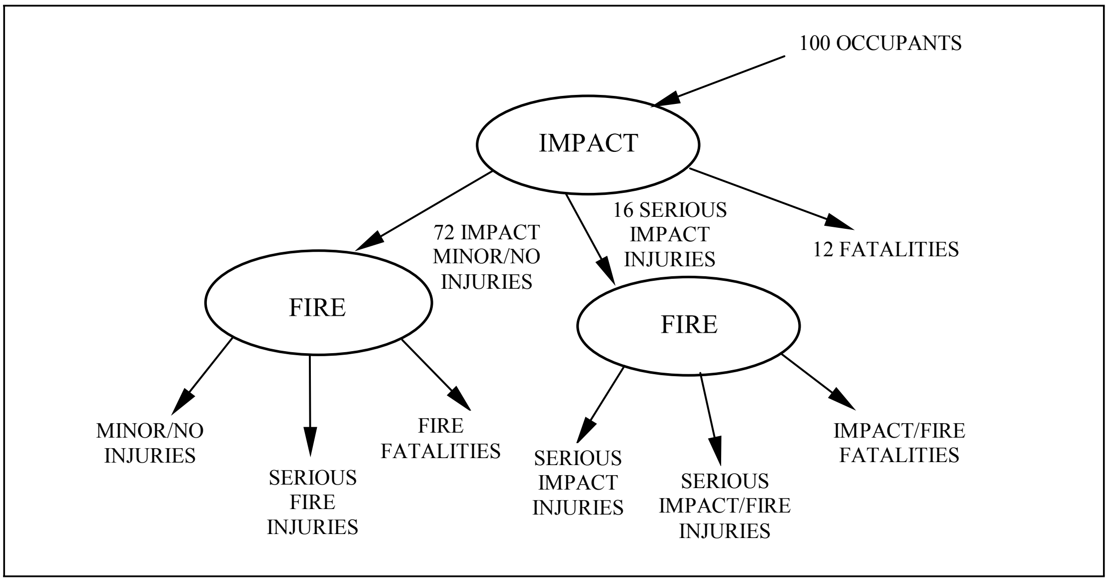

Figure 2 Example of Survivability Chain showing Possible Improvements in Impact-related Survivability Factor

4.4.5 It is known from the accident that 5/60^{ths} of those that survive the impact uninjured and 5/20^{ths} of those that sustain injuries from the impact subsequently succumb to death because of the fire. Furthermore, 10/60^{ths} of those that survive the impact seriously injured are seriously injured from fire and 5/20^{ths} of those that sustain injuries from the impact also sustain injuries because of the fire. It is assumed that these ratios are constant for this particular scenario.

4.4.6 On this basis an assessment of the numbers of Fatalities and Injuries may be made as follows:

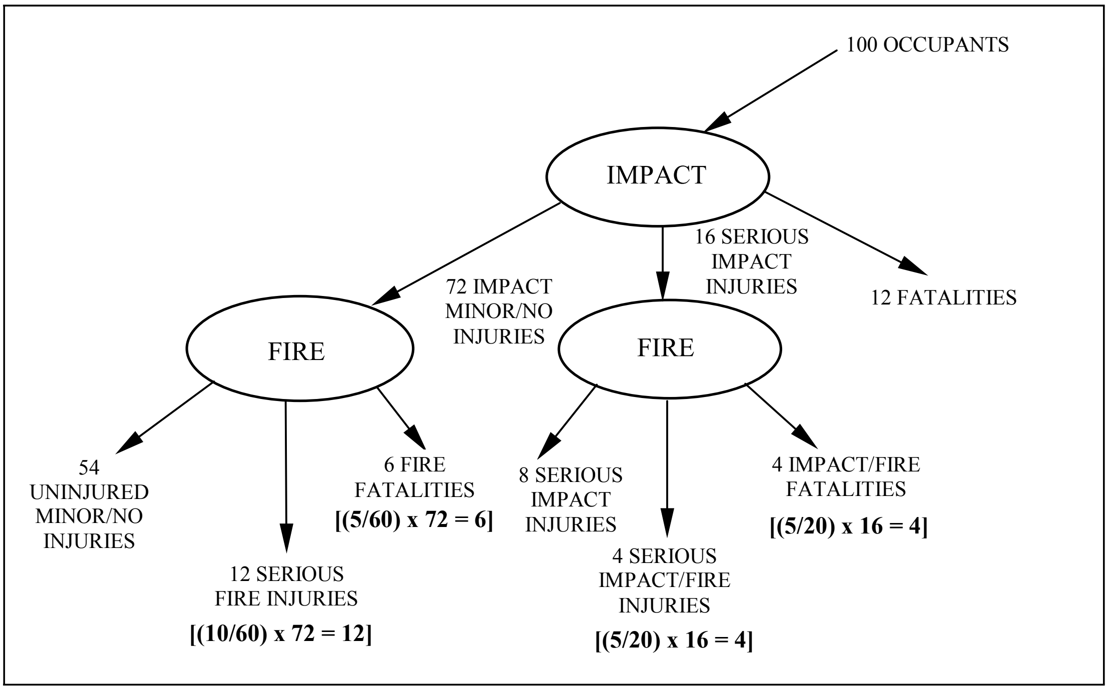

Figure 3 Example of Survivability Chain showing the Overall Improvements in Survivability

4.4.7 Hence, the improvement to the impact related survivability factor results in:

- 54 uninjured survivors. (Minor/No Injuries)
- 24 Serious Injuries, 8 because of the impact, 12 because of the fire, and 4 seriously injured because of the impact and fire.
- 22 Fatalities, 12 because of the impact, and 10 because of the fire (4 of whom sustained Serious Injuries from the impact).

4.4.8 It should be noted that the survivability factor improvement resulted in a reduction in impact Fatalities of 8 and impact Injuries of 4. However, the overall situation is as follows:

	Survivors	**Serious Injuries**	**Fatalities**
Prior to survivability factor improvement:	45	25	30
Post survivability factor improvement:	54	24	22

4.5 Analysis of Accidents with Limited Passenger Injury Data

4.5.1 There were limited data available to assess the benefit, based on the injuries sustained, for two of the accidents - those occurring at Bangalore and Strasbourg. It was assessed, from the earlier benefit analysis (Reference [1]) that these accidents would yield significant benefit. Therefore, it was assumed that the proportionate reduction in impact Fatalities and Injuries would be similar to that experienced on other accidents from which there was significant benefit. By reference to Table 2 it may be seen that the total derived benefit exceeded more than one Fatality in nine accidents. Two of these were Bangalore and Strasbourg. The remaining seven accidents may be classified as yielding significant benefit. Six of these accidents, Kegworth being excluded, were used to derive an assessment of the proportionate reduction in impact Fatalities and Injuries. Kegworth was not considered since the accident aircraft was fitted with seats that were likely to meet the 16g criteria in all respects other than with regard to head injury protection.

4.5.2 Therefore, the average reduction in impact Fatalities and Injuries was derived for the accidents occurring at Sioux City, La Guardia, Cove Neck, Denver, Faro and Charlotte in the following manner:

4.5.2.1 The total number of impact Fatalities derived from this assessment, following the introduction of '16g seats', T_{f1}, was simply divided by the actual total number of impact Fatalities, T_{f0}, experienced in these accidents. :

$$F = \frac{T_{f1}}{T_{f0}}$$

4.5.2.2 A similar factor, I, was derived to assess the reduction of impact Injuries likely to occur following the introduction of '16g seats':

$$I = \frac{T_{i1}}{T_{i0}}$$

Where:

T_{i1} = the total number of impact Injuries assessed for all of the accidents yielding significant benefit following the introduction of '16g seats'.

T_{i0} = the total number of impact Injuries actually experienced in all of the accidents yielding significant benefit following the introduction '16g seats'.

4.5.2.3 The values of F and I may be derived for both 'fully compliant dynamic seats' and '16g dynamic seats configured without enhancements to head injury criteria'. They could then be applied to the actual impact Fatalities and impact Serious Injuries experienced in the accidents at Bangalore and Strasbourg to assess the number of impact Fatalities and impact Serious Injuries likely to occur following the introduction of '16g seats'. In order to make a determination of the proportion of those surviving the impact (Serious Injuries or Minor/No Injuries) succumbing to any fire threat that might also exist, the methodology described in paragraph 4.4 was used. In this way, the number of lives saved and injuries saved could be made for the accidents at Bangalore and Strasbourg.

5 Analysis and Results

5.1 Assumptions

The assumptions made in this analysis include the following:

a) If seat standards were not specifically stated in the accident report, they are normally considered *not* to be '16g seats'.

b) No disbenefit from the introduction of '16g seats' has been considered. For example, '16g seats' might reduce the evacuation capability of occupants due to seat backs not breaking over.

c) The accidents determined to yield zero benefit from the earlier analysis (Reference [1]) would not show any reduction in the number of Fatalities or Injuries if re-evaluated using the methodology described in this report.

5.2 Results

5.2.1 Assessed Benefit From Accidents with Limited Injury Data

Since there were limited injury data available for the accidents occurring at Bangalore and Strasbourg the methodology described in paragraph 4.5 was utilized. This involved making a determination of the average reduction in impact Fatalities and Injuries based on the average reduction in impact Fatalities and Injuries determined for the accidents yielding significant benefit. Tables 4 and 5 show the Injury data pertinent to these accidents.

Table 4 Injury Data for Accidents Analyzes Yielding Significant Benefit - Fully Compliant Dynamic Seats

	ACTUAL ACCIDENT			FULL 16G			IMPROVEMENT	
TOTALS>	**157**	**187**	**224**	**123**	**159**	**286**	**0.79**	**0.85**
ACCIDENT LOCATION	**IMPACT FATAL**	**IMPACT SERIOUS INJURY**	**IMPACT M/N**	**IMPACT FATAL**	**IMPACT SERIOUS INJURY**	**IMPACT M/N**	**IMPACT FATAL**	**IMPACT SERIOUS INJURY**
SIOUX CITY	55	23	113	51	23	117	0.9	1.0
LA GUARDIA	9	17	21	5	13	29	0.6	0.8
COVE NECK	65	80	4	48	67	34	0.7	0.8
DENVER	18	22	6	14	21	11	0.8	1.0
FARO	6	41	80	2	31	94	0.4	0.8
CHARLOTTE	4	4	0	3	4	1	0.7	1.1

Rgwc 1707/Master Record/Imprvmnt.Impact inj Full 16g

Table 5 Injury Data for Accidents Analyzed Yielding Significant Benefit - 16g Seats Configured without Enhancements to Head Injury Criteria

TOTALS	ACTUAL ACCIDENT			16G NO HIC			IMPROVEMENT	
	157	187	224	135	167	267	0.86	0.89
ACCIDENT LOCATION	IMPACT FATAL	IMPACT SERIOUS INJURY	IMPACT M/N	IMPACT FATAL	IMPACT SERIOUS INJURY	IMPACT M/N	IMPACT FATAL	IMPACT SERIOUS INJURY
SIOUX CITY	55	23	113	53	23	115	1.0	1.0
LA GUARDIA	9	17	21	6	15	26	0.7	0.9
COVE NECK	65	80	4	52	69	28	0.8	0.9
DENVER	18	22	6	15	25	6	0.8	1.1
FARO	6	41	80	5	31	91	0.8	0.8
CHARLOTTE	4	4	0	4	4	1	0.9	0.9

Rgwc 1707/Master Record/Imprvmnt.Impact inj 16g noHIC

NOTE: M/N = Minor/No Injury

5.2.1.1 The values in the final two columns of Tables 4 and 5 have been rounded to one decimal place.

5.2.1.2 The values in the columns headed 'IMPACT FATAL', 'IMPACT SERIOUS INJURY' and 'IMPACT M/N' have been rounded to the nearest whole number.

5.2.1.3 For certain accidents the introduction of '16g seats' results in an increase in the number of Serious Injuries. This is due to the number of Fatally injured, having their injuries reduced to Serious, being greater than the number of Serious Injuries having their injuries reduced to Minor /None.

5.2.1.4 The column headings in Tables 4 and 5 are:

- **Actual Accident:** These three columns show the actual number of impact Fatalities, impact Serious Injuries and passengers with Minor or No Injuries in the actual accident. The TOTALS figure relates to the total number of passengers sustaining the injuries indicated in all six accidents.
- **Full 16G:** These three columns in Table 4 show the assessed number of impact Fatalities, impact Serious Injuries and passengers with Minor or No Injuries that would result had the aircraft been configured with 'fully compliant dynamic seats'. The TOTALS figure relates to the total number of passengers sustaining the injuries indicated in all six accidents.
- **16G No HIC:** These three columns in Table 5 show the assessed number of impact Fatalities, impact Serious Injuries and passengers with Minor or No Injuries that would result had the aircraft been configured with '16g dynamic seats configured without enhancements to head injury criteria'. The TOTALS figure relates to the total number of passengers sustaining the injuries indicated in all six accidents.
- **Improvement:** These two columns, in Tables 4 and 5, show the ratio of the resultant impact Fatalities to the actual impact Fatalities and the ratio of the resultant impact Serious Injuries to the actual impact Serious Injuries after configuring the aircraft with the improved seat standard in all six accidents. The TOTALS figure relates to the ratio of the total resultant impact Fatalities to the total actual impact Fatalities and the ratio of the total resultant impact Serious Injuries to the total actual impact Serious Injuries after configuring the aircraft with the improved seat standard.

5.2.1.5 The derived values of F and I may then be determined from the data in the tables using the formulae in paragraph 4.5 as follows:

a) For 'fully compliant 16g seats':

$$F = \frac{T_{f1}}{T_{f0}} = \frac{123}{157} = 0{\cdot}79$$

$$I = \frac{T_{i1}}{T_{i0}} = \frac{159}{187} = 0{\cdot}85$$

b) For '16g dynamic seats configured without enhancements to head injury criteria':

$$F = \frac{T_{f1}}{T_{f0}} = \frac{135}{157} = 0{\cdot}86$$

$$I = \frac{T_{i1}}{T_{i0}} = \frac{167}{187} = 0{\cdot}89$$

5.2.1.6 These factors were applied to the number of impact Fatalities and Serious Injuries occurring in the accident Scenarios, which had the potential to yield benefit from '16g seats', for both the Bangalore and Strasbourg accidents. The survivability chains derived for each of the pertinent Scenarios were used (see paragraph 4.4) to determine the resultant number of Fatalities, Serious Injuries and Minor/No Injuries following any existing fire threat. The final assessed number of lives and Serious Injuries saved for these accidents is included in Table 6.

5.2.1.7 Table 6 shows that the benefit for these accidents is:

a) For 'fully compliant dynamic seats':

Lives Saved = **56**

Serious Injuries Saved = **49**

b) For '16g dynamic seats configured without enhancements to head injury criteria':

Lives Saved = **34**

Serious Injuries Saved = **27**

NOTE: All values are rounded to the nearest whole number.

5.2.2 Assessed Benefit from all Accidents Studied

Table 6 shows the prediction of the number of lives and Serious Injuries saved. The column headings are:

Date: Date of Occurrence of the accident analyzed

Location: Location of the accident

Aircraft: Aircraft involved in the accident

Operation:	Whether the aircraft was operating under 14 CFR Part 121 or for non-US operators, or its equivalent, annotated as {Part 121}
Total No. of Fatalities:	The total number of passenger Fatalities in the accident analyzed
Total No. of Serious Injuries:	The total number of passenger Serious Injuries in the accident analyzed
A - Benefit Full 16g Seats:	The benefit for 'fully compliant dynamic seats' derived from the earlier assessment as described in Reference [1].
B - Revised Benefit Full 16g Seats:	The assessed benefit derived from this analysis for 'fully compliant dynamic seats'
C - Benefit 16g Seats No HIC:	The assessed benefit derived from this analysis for '16g dynamic seats configured without enhancements to head injury criteria'.

Table 6 Summary of Assessed Reduction in Number of Fatalities and Serious Injuries

Date	Location	Aircraft	Operation	Total No. of Fatalities	Total No. of Serious Injuries	A Benefit Full 16 g Seats		B Revised Benefit Full 16 g Seats		C Benefit16 g Seats NO HIC	
						Lives Saved	Injuries Saved	Lives Saved	Injuries Saved	Lives Saved	Injuries Saved
TOTALS >						62	66	56	49	34	27
25-Jan-90	Cove Neck	B707	{Part 121}	73	81	23	21	17	14	13	11
14-Feb-90	Bangalore	A320	{Part 121}	92	22	9	-5	3	-1	3	-1
20-Jan-92	Strasbourg	A320	{Part 121}	87	5	7	-5	12	1	8	0
08-Jan-89	Kegworth	B737	{Part 121}	47	74	5	0	5	11	0	0
22-Mar-92	La Guardia	F28-4000	Part 121	27	9	4	5	4	2	3	1
15-Nov-87	Denver.	DC9-14	Part 121	28	28	4	5	4	1	3	-3
21-Dec-92	Faro	DC10	{Part 121}	56	U/K	3	6	4	10	1	10
19-Jul-89	Sioux City	DC10-10	Part 121	111	47	3	1	4	0	2	0
02-Jul-94	Charlotte	DC9-31	Part 121	37	16	3	0	1	0	1	0
21-Jan-85	Reno	L188C	Part 121	70	1	1	0	2	0	0	0
06-Apr-93	Shemya	MD11	{Part 121}	2	60	0	25	0	6	0	7
10-Mar-89	Dryden	F28	{Part 121}	24	18	0	5	0	3	0	1
14-Sep-93	Warsaw	A320	{Part 121}	1	50	0	4	0	4	0	0
15-Apr-88	Seattle	DHC8	Part 121	0	4	0	2	0	0	0	0
02-Aug-85	Dallas	L1011	Part 121	134	15	0	2	0	1	0	1

P/Rgwc1707/Master Record/Summary of Benefit

NOTES: 1 Assessed benefit rounded to the nearest whole number of passengers. (The total number of injuries saved in column B is 49 although it would appear to be 52 by adding the rounded numbers for each of the accidents

2 A negative value for Serious Injuries reflects situations where the number of Fatal Injuries that are reduced to Serious Injuries is higher than the number of Serious Injuries reduced to Minor or No Injuries. The net outcome is an increase in Serious Injuries.

3 U/K = Unknown

4 Part 121 = Accident to aircraft operating under 14 CFR Part 121

5 {Part 121} = Accident to aircraft operating under equivalent rules to 14 CFR Part 121

5.2.3 Benefit Assessment for the World Fleet

5.2.3.1 The assessed number of lives saved and injuries saved shown in Table 6 are those predicted for the accidents to the world fleet of aircraft, operating to 14 CFR Part 121 or equivalent, analyzed over the period 1984 to 1998 inclusive. To make a determination of the benefit likely to accrue for US aircraft operating under 14 CFR Part 121 over this period, these values must be factored to take into account the following:

a) Other accidents where seat related injuries occurred but because there are little or no data available, they cannot be analyzed.

b) The proportion of the world fleet of impact related accidents that occur to the US fleet of 14 CFR Part 121 aircraft.

5.2.3.2 Two methods for deriving these factors were considered in the earlier analysis (Reference [1]). The method considered to give the more accurate prediction, since it was based on a larger sample size, yielded the following factors appropriate to a) and b) above:

5·37 and 0·152 respectively

5.2.3.3 Applying these factors to the total benefit shown in Table 6 yields the predicted number of lives and injuries to be saved for the accidents applicable to the US fleet of 14 CFR Part 121 aircraft over the period 1984 to 1998 inclusive:

a) The revised benefit for 'fully compliant dynamic seats' becomes:

Lives Saved = 56 x 5·37 x 0·152 = **45**

Serious Injuries Saved = 49 x 5·37 x 0·152 = **40**

b) The revised benefit for '16g dynamic seats configured without enhancements to head injury criteria' becomes:

Lives Saved = 34 x 5·37 x 0·152= **28**

Serious Injuries Saved = 27 x 5·37 x 0·152= **22**

NOTE: All total values are rounded to the nearest whole number.

5.2.4 Proportion of Benefit From Enhanced Head Injury Criteria

It may be seen from Table 6 that based on the analysis described in this report the proportion of benefit from 'fully compliant dynamic seats' attributable to the enhanced Head Injury Criteria defined in TSO-C127a is:

Fatalities: $= \dfrac{56 - 34}{56} =$ **39%**

Serious Injuries: $= \dfrac{49 - 27}{49} =$ **46%**

6 Discussion

6.1 Accuracy of Predictions

6.1.1 The analytical methods employed are intended to provide as accurate an assessment as is possible with the available data, using the mathematical tools currently in existence. However there will still remain an element of uncertainty associated with assessments of this kind, and this should be borne in mind when making decisions concerning aircraft safety that are predicated on the results of this analysis. Any analysis of this kind must involve a degree of subjective judgment and relies on the accuracy of the data available. The methodology utilized is aimed at providing an indication as to the order of benefit likely to be achieved. Certain assumptions have been made in the analysis of data and the more significant are described in paragraph 5·1.

6.1.2 This analysis considered only the accidents studied in the earlier analysis (Reference [1]). This earlier analysis utilized an early standard of the CSRTG Accident Database (Reference [2]), which at the time had few accidents with 100% Fatalities. It is unlikely that there are many lives to be saved from the introduction of '16g seats' in accidents of this severity. However, it is feasible that the benefit assessment might increase slightly if accidents of this type were studied.

6.1.3 The accidents yielding zero benefit in the earlier analysis were not re-evaluated as part of this analysis (Reference [1]). It is considered unlikely that a reassessment of these accidents would yield any significant benefit.

6.2 Factors Influencing the Determination of Benefit

6.2.1 Impact intensity is a significant factor in the accrued benefit from '16g seats' likely to be achieved in an accident. It is evident that there will not be any benefit from the introduction of '16g seats' when the impact intensity is beyond the level of resilience of the seat design. Furthermore, at impact intensities below those sustainable by '9g seats', there would be little benefit beyond that afforded by enhanced Head Injury Criteria. This limits the number of ground impact related accidents that would benefit from the introduction of '16g seats'.

6.2.2 It might be expected that the higher the impact intensity the greater the probability of an intense fire. Since the accidents that would benefit from the introduction of '16g seats' are at higher levels of impact intensity, it is hence more likely that there will also be an intense fire. This secondary threat to survival is extremely significant in the determination of lives to be saved. If passenger impact injuries are prevented with '16g seats', and there is an intense fire threat, then the occupants are likely to perish even if they survive the impact uninjured. If the fire threat could be reduced, then the enhanced impact protection afforded by '16g seats' may provide the occupants with the capability of evacuating the fire-threatened area.

6.2.3 As fire standards for transport category aircraft are improved, the potential for increasing the live saving capability of '16g seats', due to the occupants reduced exposure to the secondary fire hazard, will also improve.

6.2.4 Due to the extensive disruption to the floor during the impact sequence, a number of accidents analyzed would not have any potential for lives being saved with the introduction of '16g seats'.

6.3 Methodology used for the Determination of Benefit from the Accidents Occurring at Bangalore and Strasbourg

It was not possible to carry out an assessment of benefit based on an understanding of the injuries sustained in the accidents occurring at Bangalore or Strasbourg due to the unavailability of the appropriate data. The assessed total number of lives saved from these accidents based on the earlier analysis was 16 with an increase in the number of Serious Injuries of 10. This current analysis suggested that the total life saving from 'fully compliant 16g seats' would be 15 with 0 increase in the number of Serious Injuries (See Table 6). It may be seen that the derivation of the life saving improvement, from the methodology used for these accidents in this analysis, is similar to that determined from the earlier analysis, albeit with a difference in the reduction of Serious Injuries. On this basis, it is considered that the methodology used for these accidents is to a satisfactory level of accuracy.

6.4 Comparison of Derived Benefit with Earlier Analysis

6.4.1 In the earlier analysis, the Benefit for 'fully compliant dynamic seats' (derived from the method considered the most accurate when the analysis was carried out) applicable to the US fleet of CFR Part 121 aircraft over the period 1984 to 1998 inclusive, (see Reference [1]) was:

Reduction in Fatalities = 51
with a 95-percentile range from 33 to 68

Reduction in Serious Injuries = 54
with a 95-percentile range from 28 to 79

The equivalent Benefit derived from this analysis was:

Reduction in Fatalities = 45

Reduction in Serious Injuries = 40

6.4.2 It may be seen that the reduction in Fatalities and Serious Injuries is to a similar level and that the values derived from this analysis are within the 95-percentile range determined from the earlier analysis (Reference [1])

7 Conclusions

7.1 An analysis, based on the accidents studied in an earlier benefit assessment for 'fully compliant dynamic seats' over the period 1984 to 1998, has been carried out to assess the potential benefit that might result from the introduction of '16g dynamic seats configured without enhancements to head injury criteria'. This benefit has been derived in terms of reduction in Fatal and Serious Injuries for aircraft type certificated with 30 or more passenger seats and operating to 14 CFR Part 121. Account has been taken of the reduction in fire threat afforded to the impact survivors by the improved fireworthiness of cabin interiors compliant with the standards defined in 14 CFR Part 25 at amendment 72. The prediction of benefit for '16g dynamic seats configured without enhancements to head injury criteria' approximates to:

Reduction in Fatalities = 28

Reduction in Serious Injuries = 22

7.2 A re-evaluation, based on the accidents studied in an earlier analysis for 'fully compliant dynamic seats' over the period 1984 to 1998, has been carried out to assess the potential benefit that might result from the introduction of '16g seats'. This benefit has been derived in terms of reduction in Fatal and Serious Injuries for aircraft type certificated with 30 or more passenger seats and operating to 14 CFR Part 121. Account has been taken of the reduction in fire threat afforded to the impact survivors by the improved fireworthiness of cabin interiors compliant with the standards defined in 14 CFR Part 25 at amendment 72. The predicted benefit approximates to:

Reduction in Fatalities = 45

Reduction in Serious Injuries = 40

7.3 The proportion of benefit attributable to the enhanced Head Injury Criteria as defined in TSO-C127a is:

Fatalities = 39%

Serious Injuries = 46%

7.4 The fire threat, which is often severe in accidents where ’16g seats’ are likely to reduce the number of impact Fatalities, is a significant factor in terms of the ultimate benefit attained. If significant improvements to occupant protection from fire could be made this would result in an increase in the assessed benefit from ’16g seats’.

7.5 Due to the extensive disruption to the floor during the impact sequence, a number of accidents analyzed would not have any potential for lives being saved with the introduction of ’16g seats’.

8 References

[1] ‘Benefit Analysis for Aircraft 16g Dynamic Seats’
Report No. DOT/FAA/AR-00/13 (US Department of Transportation Federal Aviation Administration)

[2] ‘The Cabin Safety Research Technical Group (CSRTG) Accident Database’ (see www.fire.tc.faa.gov)

[3] ‘The Abbreviated Injury Scale’ 1990 Revision
(Association for the Advancement of Automotive Medicine)

9 Definitions

Abbreviated Injury Scale (AIS) (Source: Reference [3])

“The Abbreviated Injury Scale (AIS) is a consensus derived anatomically based system that classifies individual injuries by body region on a 6-point ordinal severity scale ranging from AIS 1 (minor) to AIS 6 (currently untreatable)."

Accident Scenario

“That volume of the aircraft in which the occupants are subjected to a similar level of threat.”

Fatal Injury (Source: NTSB, ICAO)

“An injury resulting in death within thirty days of the date of the accident.”

Serious Injury (Source: NTSB, ICAO Annex 13, Eighth Edition, July 1994)

“An injury, which is sustained by a person in an accident and which:

a) Requires hospitalization for more than 48 hours, commencing within seven days from the date the injury was received; or

b) Results in a fracture of any bone (except simple fractures of fingers, toes, or nose); or

c) Involves lacerations which cause severe hemorrhage, nerve, muscle or tendon damage; or

d) Involves injury to any internal organ; or

e) Involves second or third degree burns, or any burns affecting more than 5 per cent of the body surface; or

f) Involves verified exposure to infectious substances or injurious radiation."

Fully Compliant Dynamic Seats

The term is used in this report to refer to seats that are fully compliant with the minimum performance standards prescribed in TSO-C127a.

16g Dynamic Seats Configured Without Enhancements to Head Injury Criteria

The term is used in this report to refer to seats that are compliant with the minimum performance standards prescribed in TSO-C127a other than the enhanced head injury criteria (HIC).

16g Seats

The term is used generically, in this report, to refer to both fully compliant dynamic seats and 16g dynamic seats configured without enhancements to head injury criteria.