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Seat Dynamic Performance Standards for a Range of Sizes

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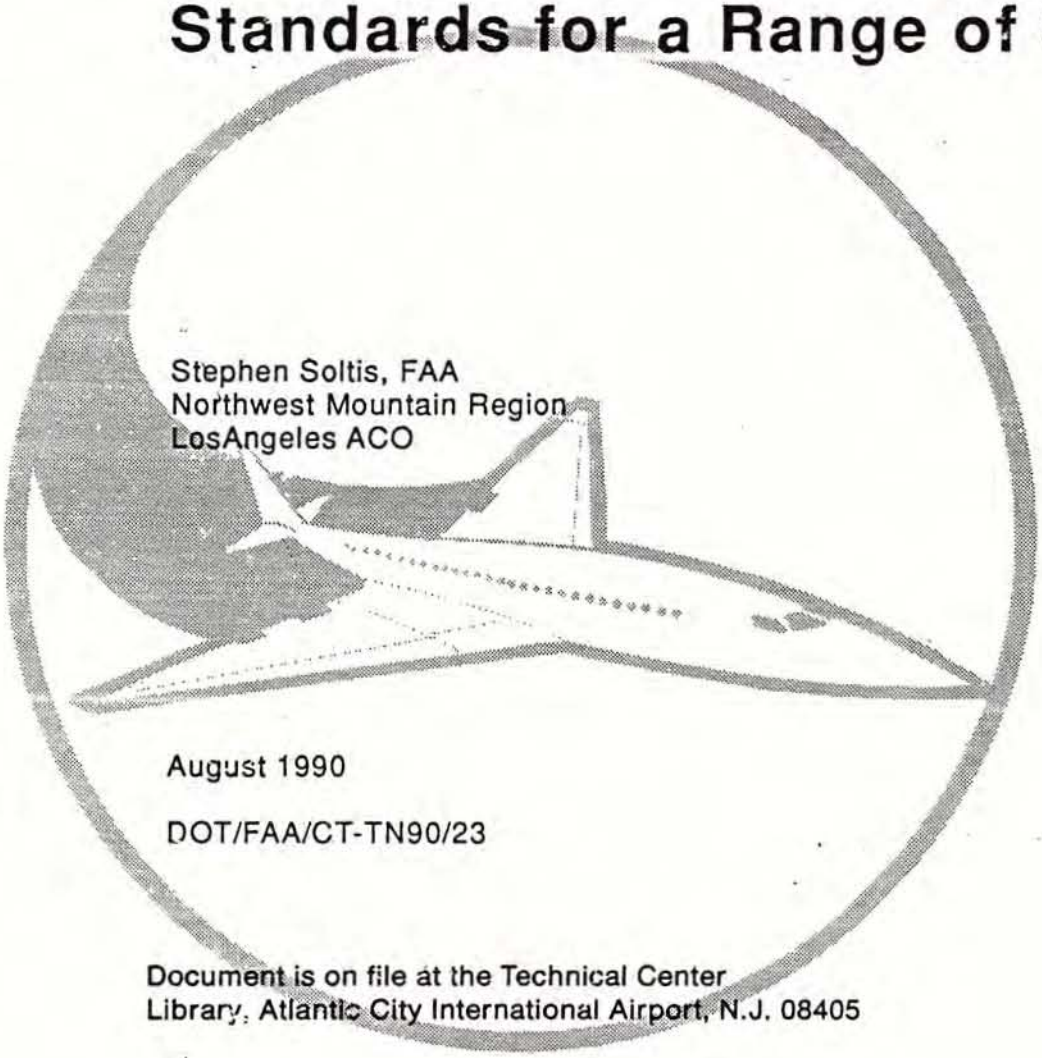

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16. Abstract

This paper presents a summary of the rationale that was used to determine the crash impact characteristics for a range of aircraft sizes and places emphasis on developing seat dynamic performance standards that might be used for commuter category size aircraft. The existing crash dynamics data base which includes twin engine general aviation aircraft, rotorcraft, narrow body and wide body transport aircraft were used in this study. The crash impact characteristic of typical airframe structure will be related to the geometric size of the airframe.

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Abstract

This paper presents a summary of the rationale that was used to determine the crash impact characteristics for a range of aircraft sizes and places emphasis on developing seat dynamic performance standards that might be used for commuter category size aircraft. The existing crash dynamics data base which includes twin engine general aviation aircraft, rotorcraft, narrow body and wide body transport aircraft were used in this study. The crash impact characteristic of typical airframe structure will be related to the geometric size of the airframe.

Airframe Size Comparisons

A survey of the airframe sizes of various aircraft types was initiated. The survey data used herein includes small twin engine general aviation aircraft, commuter usage aircraft, and three small transport category aircraft. Tables 1 through 3 and Figures 1 and 2 present a summary of that data.

Table 1 - Summary of Airframe Sizes for Typical Small General Aviation Aircraft

AIRCRAFT	GROSS WGT LBS	NO. OF SEATS	INTERNAL CABIN HEIGHT - INCHES	UNDERFLOOR DEPTH - INCHES
PILATUS BN2T	7045	2+8	49.2	5.4
CESSNA 425	8675	1+7	51.6	7.5
PIPER PA-31T2	9540	1+6/7	52.8	7.6
PIPER PA-42-720	11285	1+8/10	52.8	7.6
CESSNA 441	9925	1+9	51.6	10.7
BEECH C90A	10160	1+7/9	57.6	12.0
BEECH F90	11030	1+7/9	57.6	12.0
BEECH 200	12590	1+8/10	57.6	12.0

Of particular interest is the distance between the aircraft floor and the lower mold line of the aircraft. That distance, which is the available structural depth or vertical impact stopping distance, establishes a physical limit that will be used to define the crash impact characteristics of a range of aircraft sizes.

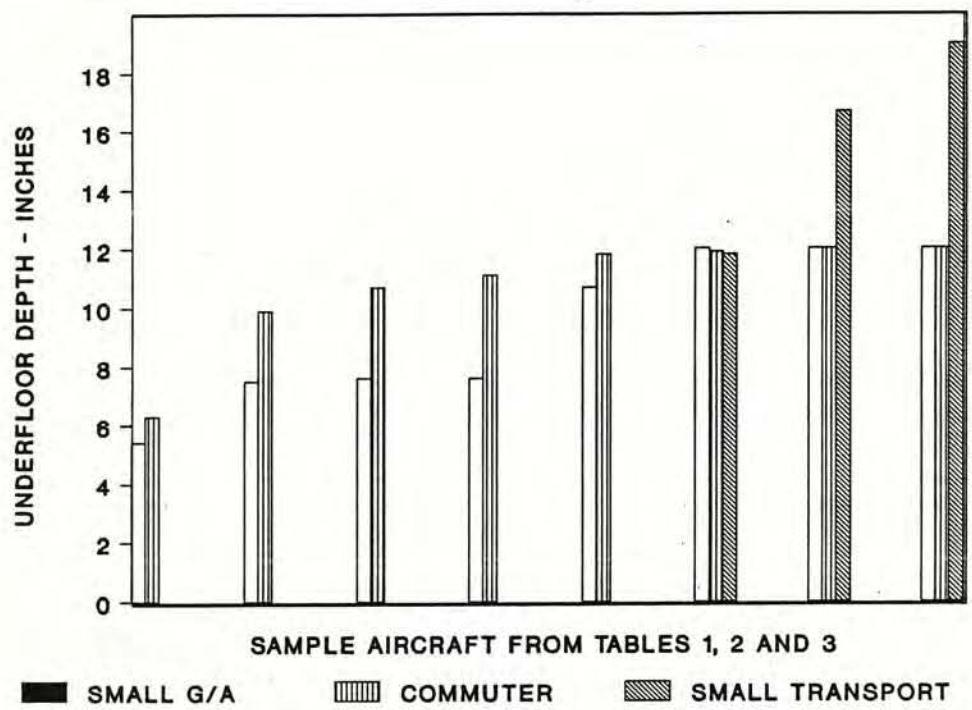

Figure 1 - Size Comparison
Small G/A / Commuter / Small Transport Aircraft

Of note in Figure 1 is that the range of underfloor structural depths for the general aviation aircraft and the commuter usage aircraft overlap each other. The commuter usage aircraft actually don't differ significantly with respect to underfloor structural depth from the twin engine general aviation aircraft. The major difference between those aircraft classes appears to be with respect to cabin length as illustrated in Figure 2.

Vertical Impact Conditions

This section presents a brief discussion of some of the rationale used by the General Aviation Safety Panel (GASP I) in their deliberations which led to their recommendations regarding seat dynamic performance standards. The GASP I recommendations will be used in part to formulate seat performance standards that would be applicable for commuter and other category aircraft. This discussion addresses the predominately vertical impact condition. The longitudinal impact condition will be addressed in a later section of this paper.

GASP I selected a nominal impact pulse duration of 100 ms to be representative of most general aviation aircraft accidents. Figure 3 (reference 1) indicates that a 100 ms pulse duration is representative of impacts which occur at aircraft pitch angles that would equal or exceed +/- 15 degrees. Figure 4 (reference 2) also illustrates the range of impact pulse durations that could be expected for general aviation aircraft for various impact conditions.

Studies conducted by B&M Technological Services, Inc., (reference 3) which are related to general aviation aircraft, suggest that for 63.3 cumulative percent of their data sample, aircraft pitch angles at impact range from 1 to 15 degrees. Their data also suggests that for 16.7 cumulative percent that aircraft pitch angles at impact equal "0" degrees or in effect a flat impact.

Table 2 - Summary of Airframe Sizes for Typical Commuter Aircraft

AIRCRAFT	GROSS WGT LBS	NO. OF SEATS	INTERNAL CABIN HEIGHT - INCHES	UNDERFLOOR DEPTH - INCHES
DORNIER 228-200	13734	2+19	61.0	6.3
BEECH 1900	16710	2+19	57.5	9.9
CESSNA 406	9435	1+13	51.6	10.7
FAIRCHILD SA227-AC	14600	2+19	57.6	11.1
EMBRAER EMB-110	13073	2+19	63.6	11.8
BRITISH AEROSPACE JETSTREAM 3100	15322	2+18	70.8	11.9
BEECH C99	11380	2+15	57.6	12.0
BEECH 300	14100	1+8/10	57.6	12.0

Seat performance standards were established for other category aircraft using rationale appropriate for each respective aircraft category. For example, rotorcraft, which typically impact at relatively low impact pitch angles ("0" degrees for 32.1 cumulative percent and 1 to 10 degrees for 71.2 cumulative percent (reference 4), use a 62 ms impact pulse which is representative of impact at low pitch angles. Transport category aircraft also typically impact at relatively low pitch angles. The 160 ms pulse duration selected to represent transport category aircraft was based on impact pulse durations measured during a series of transport aircraft fuselage and fuselage section vertical impact tests.

This review of pulse durations and impact angles is not meant to suggest that the 100 ms pulse duration used for the general aviation aircraft seat performance standards is deficient. It only indicates that a 100 ms pulse duration does not necessarily represent a worst case condition. The 100 ms general aviation aircraft pulse duration represents a pragmatic decision to recommend a nominal pulse duration which would require a practical seat dynamic performance criteria and seat energy absorption requirements (i.e., seat stroke) that would be consistent with the level of safety expected for small general aviation aircraft. Figure 5 (reference 2) illustrates how seat stroke requirements vary with pulse duration.

Table 3 - Summary of Airframe Sizes for Typical Small Transport Aircraft

AIRCRAFT	GROSS WGT LBS	NO. OF SEATS	INTERNAL CABIN HEIGHT - INCHES	UNDERFLOOR DEPTH - INCHES
CASA 212-300	17086	3+26	70.8	11.8
EMBRAER EMB-120	25529	3+30	69.6	16.7
SAAB SF 340A	27300	3+35	72.0	19.0

Commuter category aircraft should possess a level of safety which approaches that of transport category aircraft. Commuter category aircraft accidents are expected to typically occur at low impact pitch angles. A study being conducted by B&M Technological Services, Inc., currently verifies that contention.

The following analysis will use a "0" degree pitch angle at impact as the normalized basis of comparison for all aircraft categories. A general aviation "0" degree pitch angle impact pulse will be derived for that purpose alone.

Assume that the triangular pulse shape and impact velocity change found in Federal Aviation Regulations (FAR) Part 23, Amendment 23-36, are maintained where:

$$\Delta V = 31 \text{ Ft/Sec (combined vertical/longitudinal condition)}$$

The vertical component of the above velocity change equals:

$$\Delta V_{vertical} = 31 \ (\cos 30^\circ) = 26.8 \text{ Ft/Sec}$$

As seen from Figure 3, a pulse direction of 60 ms is representative of a 0° pitch angle at impact. For a triangular pulse shape:

$$G_{peak} = \frac{2 \ \Delta V}{\Delta t}$$

$$G_{peak\ vert} = \frac{(2)(26.8)}{(0.060)(32.2)} = 27.7 \text{ G's}$$

The required underfloor stroking or stopping distance equals:

$$S_{vert} = \frac{\Delta V^2}{a} = \frac{(26.8)^2(12)}{(27.7)(32.2)}$$

$$S_{vert} = 9.6 \text{ inches}$$

That distance is in excess of the underfloor depth found in most general aviation aircraft as shown in Table 1. The above data point, identified as one of the Item D data points on Figure 7, falls at the lower end of the test data envelope suggested by references 1 and 5. Assuming a 40 ms pulse duration yields the following acceleration and displacement levels.

$$G_{peak\ vert} = 41.6 \text{ G's} \qquad S_{vert} = 6.4 \text{ inches}$$

These values, also identified as one of the Item D data points, are more consistent with the general aviation aircraft structural underfloor depth and the aforementioned test data envelope.

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Current commuter usage aircraft as shown in Table 2, have underfloor depths of 12 inches or less. Pulse durations of 40-60 ms are considered representative of "0" degree pitch angle impacts for those aircraft. Table 4 summarizes the acceleration levels and airframe stroking requirements that are believed representative for "0" degree pitch angle impacts for general aviation and commuter category aircraft.

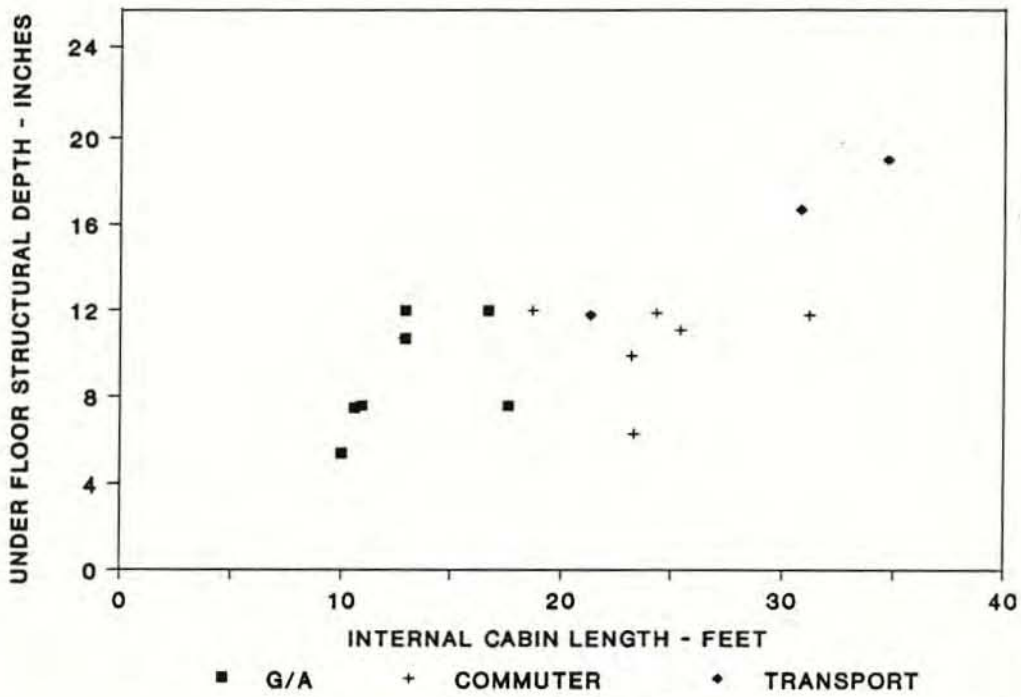

Figure 2 - Aircraft Size Comparison

As can be seen from Table 2, the range of underfloor structural depths of current computer usage aircraft are insufficient to reduce the acceleration levels for "0" degree pitch angle impact to an acceleration level which would be equal to or less than that currently adopted for general aviation aircraft.

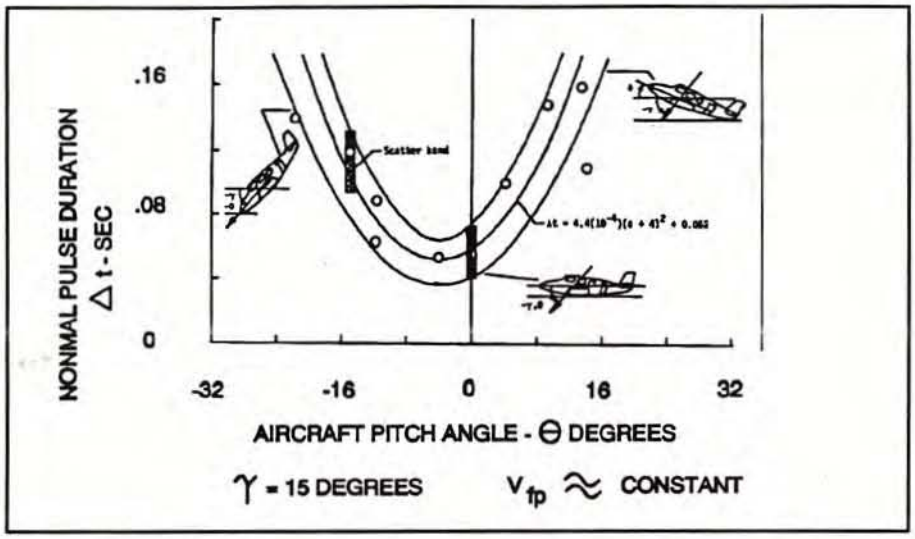

Figure 3 - Impact Pulse Duration
As A Function Of Impact Attitude

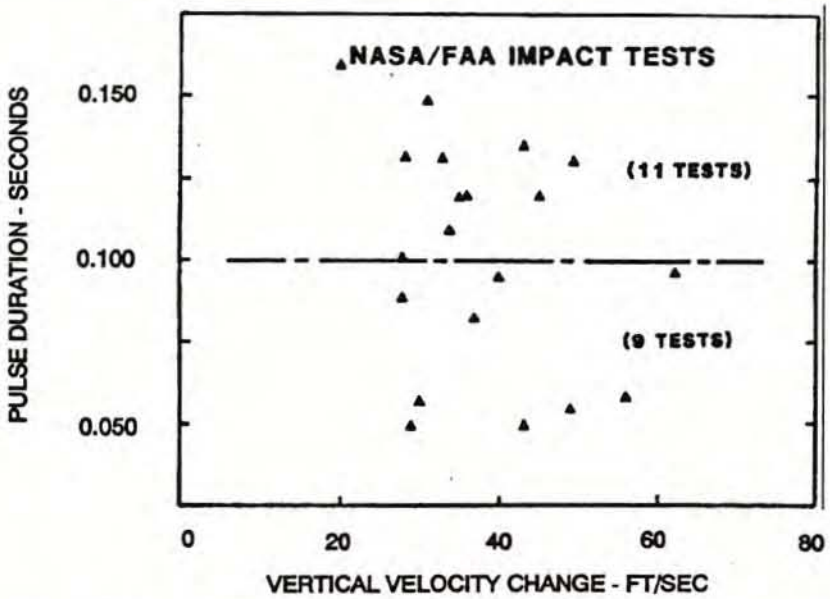

Figure 4 - Summary Of Measured Pulse Durations
For G/A Aircraft Full Scale Impact Tests

Table 4 - Airframe Stroking Requirements for "0" Degree Pitch Angle Impacts

$\triangle V$ VERT = 26.8 FT/SEC

PULSE DURATION MS	ACCELERATION G's (PEAK)	STROKE * INCHES
40	41.6	6.4
60	27.7	9.6

* SHOULD NOT EXCEED APPROXIMATELY 45% OF THE AVAILABLE UNDERFLOOR STRUCTURAL DEPTH

Relationship Between Airframe Impact Acceleration and Displacement for Vertical Impacts Derived from Full Scale Impact Test Data

The empirical analysis used herein assumes a triangular impact pulse shape. That assumption is typical of most measured airframe impact responses (Reference 1), is consistent with usual industry practice, and is consistent with the pulse shapes found in the newly adopted regulatory amendments regarding seat dynamic performance standards. The pulse shape can vary from the typical triangular shape when underfloor structure is purposefully designed to be energy absorbing (stroke at a desired load level) or when the available airframe vertical stroking depth (underfloor structural depth) is exceeded. The airframe stroking depths used in this analysis will be selected so that the airframe structure doesn't bottom out during the impact.

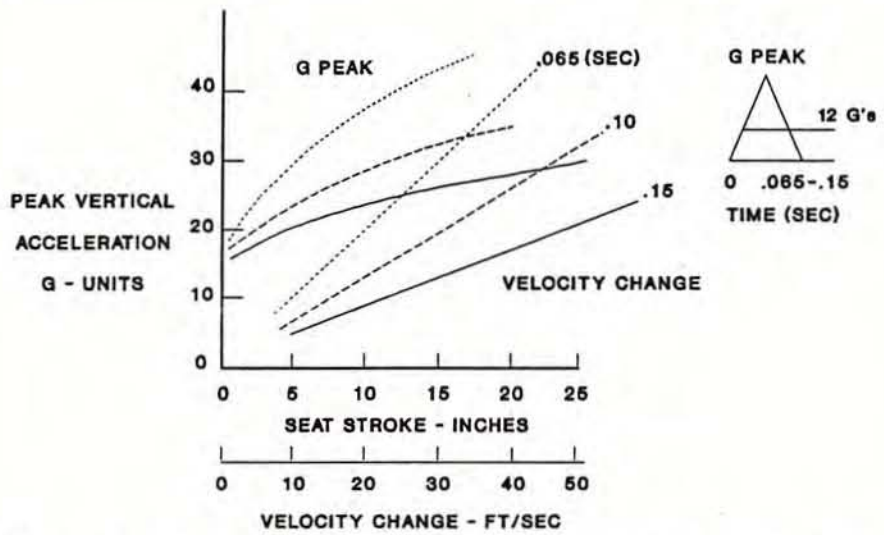

Figure 5 - Peak Vertical Acceleration vs Velocity Change and Seat Stroke for Various Pulse Durations

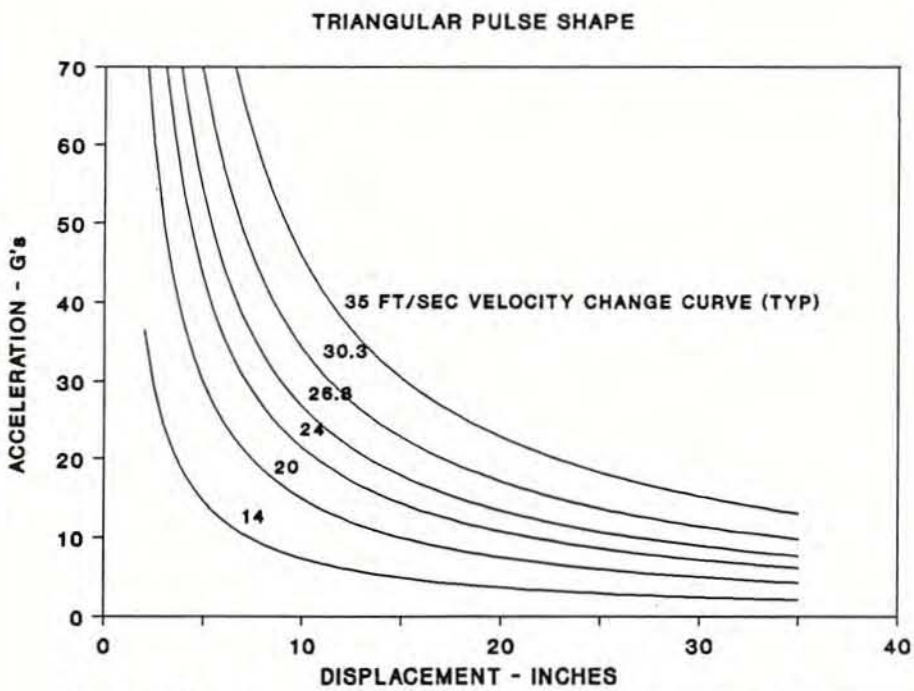

Figure 6 - Acceleration vs Displacement Curves

A series of constant velocity, acceleration versus displacement curves were generated for a triangular pulse shape as depicted in Figure 6. Dependent upon the aircraft size (underfloor structural depth) and the aircraft understructure loading (weight/surface area), the impact response of an airframe should fall somewhere along its respective impact velocity curve providing that the energy at impact doesn't exceed the airframe energy absorption capability which is a function of the underfloor structural characteristics. It is assumed in this analysis, that the airframe energy absorption capability has not been exceeded and that the airframe vertical impact response characteristics are primarily a function of the underfloor structural depth.

Table 5 - Data Item Summary Table
Data Sourced Depicted on Figure 7

DATA ITEM	VERTICAL IMPACT VELOCITY-FT/SEC	PEAK ACCELERATION TRIANGULAR PULSE-G's	STRUCTURAL DISPLACEMENT (CRUSHING)-INCHES
A	24	38 - 60	3 - 3.5
B	24	25 - 37.5	-
	28.5	40 - 55	-
	30.3	31.7 - 47.5	-
C	26	26	-
D	26.8	27.7	9.6
	26.8	41.6	6.4
E	26.8	16.6	16.3
F	12 - 14	7 - 14	6 - 7
G	25	20	12.75
H	20.16	8.3	18.16
I	30.3	12.1	-
J	34	11.6 - 19.8	30

NOTE: PEAK ACCELERATION AND STRUCTURAL DISPLACEMENT ARE PLOTTED WHERE GIVEN

The available crash dynamics vertical impact test data base was reviewed and the respective impact pulses were superimposed on Figure 6 as depicted on Figure 7. The low acceleration level data points represent low energy impact tests where little of the available underfloor structural depth was utilized. The upper acceleration level data points represent high energy impact tests where most or all of the available underfloor structural depth was

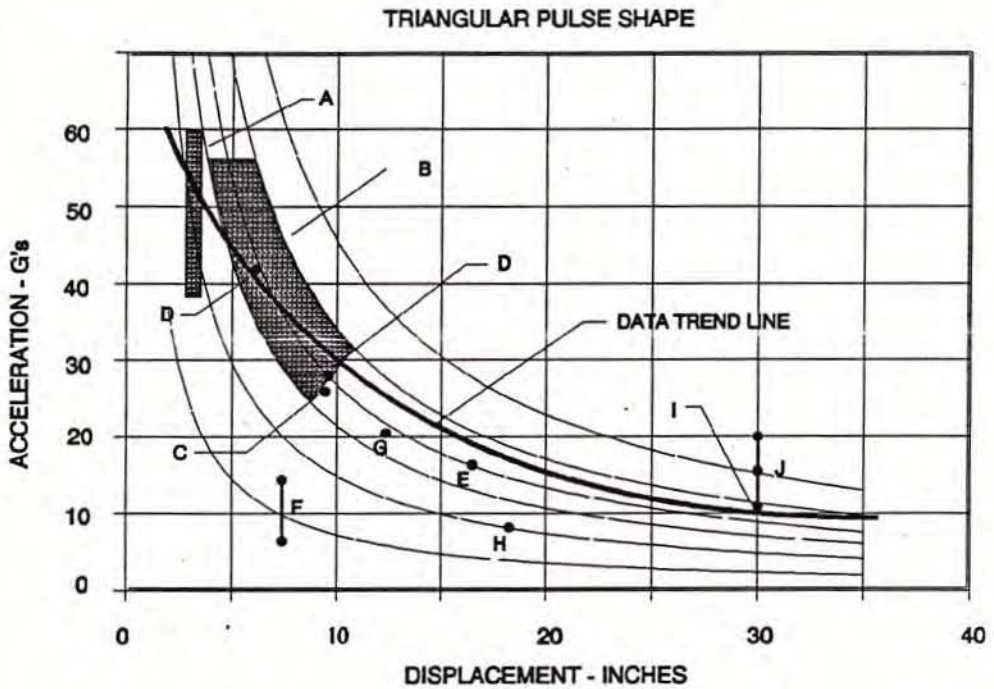

Figure 7 - Acceleration vs Displacement Trend Curve

tilized to arrest the impact. A summary discussion which describes the sources of the data points depicted in Figure 7 can be found in Appendix A.

Vertical Impacts - Aircraft Size Effects

A trend line which extends through the mid/lower range of the high energy impact tests data points was superimposed on Figure 7. This trend line somewhat follows the general shape of a constant velocity curve and it is believed that it represents the variance of airframe vertical acceleration levels with respect to airframe size for vertical impacts. The trend line in Figure 7 relates the airframe acceleration levels to airframe stroke or displacement (crushing) resulting from impact. The trend line will be redefined where the airframe acceleration levels will be related to airframe underfloor structural depth.

A review of the respective test data base found in Table 5 led to the selection of the following airframe stroking limits. For small aircraft where the underfloor structural depth is 12 inches or

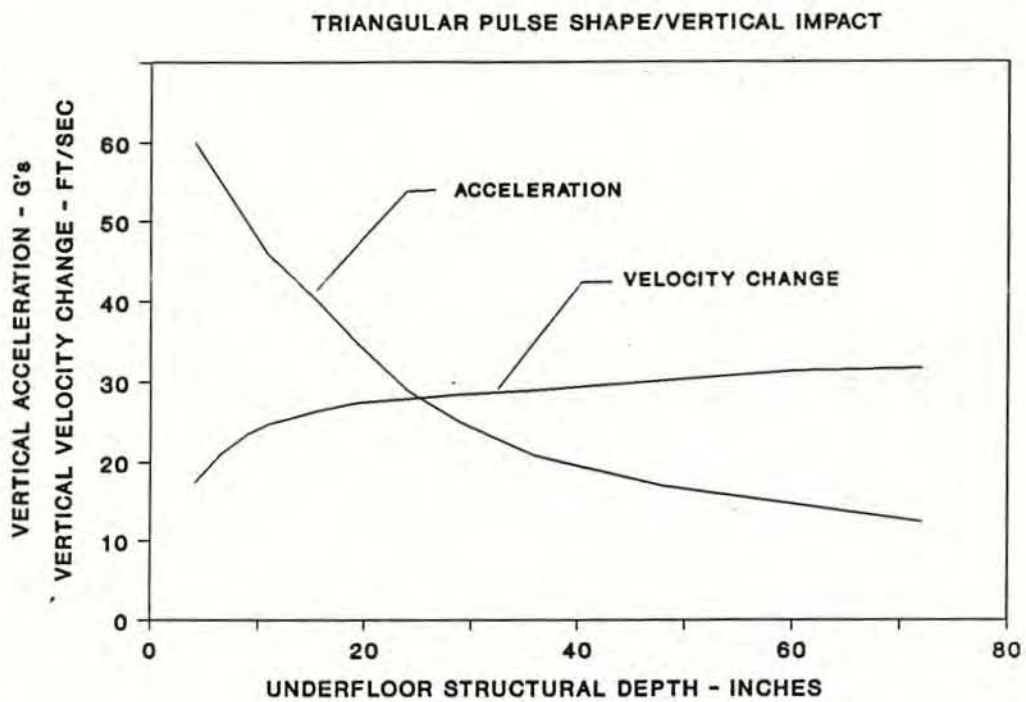

Figure 8 - Aircraft Size Effects

less, the allowable vertical displacement or stroking was limited to 45% of that depth. For aircraft structures where the underfloor structural depth exceeds 12 inches, the allowable vertical displacement was limited to approximately 42% of the airframe depth. These relationships were used in redefining the trend line in terms of underfloor structural depth as shown on Figure 8. Aircraft sizes that range from small general aviation aircraft to narrow body transport category aircraft are depicted on Figure 8. Figure 8 is extrapolated to include wide body aircraft as shown on Figure 9. Figure 9 depicts the full range of current aircraft types. A range of vertical impact pulses is suggested by the curve depicted in Figure 9 and those data are tabulated in Table 6.

The data range found in Table 6 suggests the combined vertical/longitudinal impact pulses that are shown in Table 7 for the range of current aircraft sizes. The aircraft size parameter to be used in selecting the appropriate impact pulse would be the underfloor structural depth. The impact pulses found in Table 7 have a triangular shape and are representative of typical aircraft construction. The impact response of airplanes with underfloor

structures that are designed specifically to increase the energy absorption characteristics of the underfloor structure and/or which alter the pulse shape or duration may be determined by conducting drop tests of those airplanes. Those tests could be used to define an alternate impact pulse which may differ from that found in Table 7.

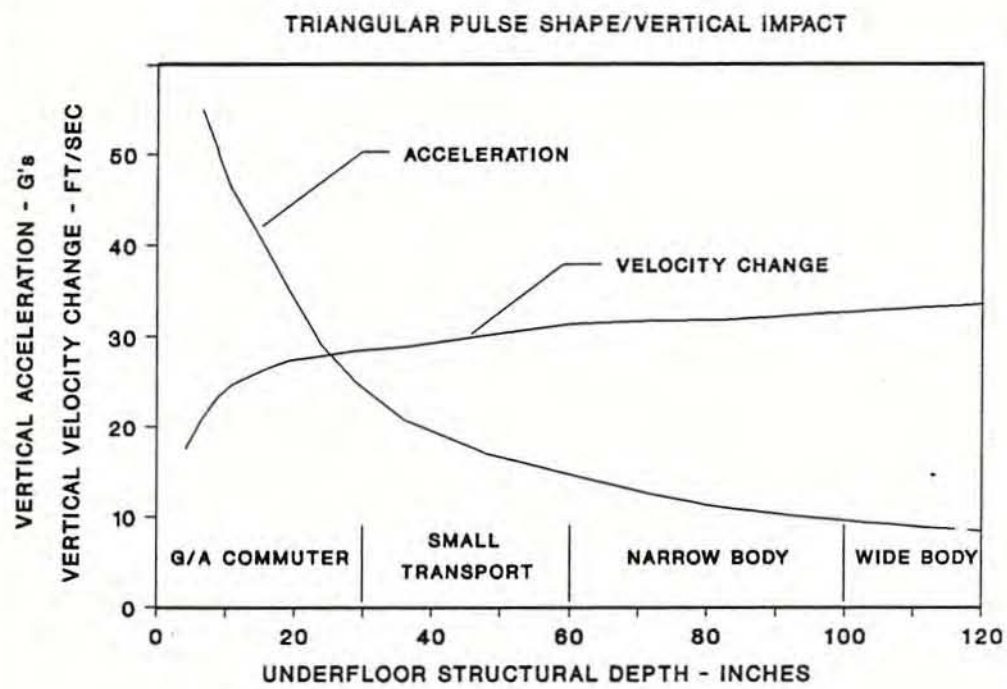

Figure 9 - Aircraft Size Effects

Commuter category aircraft which typically have less than 30 inches of underfloor structural depth should use the combined vertical/longitudinal impact pulse given in Table 7 for that size aircraft. The previous analysis which derived 40 to 60 ms duration impact pulses (which are representative of 0° pitch angle impact conditions) and the data shown in Figure 9 support that recommendation.

Wide body transport aircraft designers may have the option to use either the narrow body transport pulse or wide body transport pulse found in Table 7.

Table 6 - Vertical Impact - Triangular Pulse Shape

AIRCRAFT CATEGORY	UNDERFLOOR STRUCTURAL DEPTH - INCHES	ACCELERATION G's PEAK	VERTICAL VELOCITY CHANGE - FT/SEC
GENERAL AVIATION COMMUTER	< 30	25 - 60	17 - 28
SMALL TRANSPORT	30 - 60	15 - 21	28 - 31
NARROW BODY TRANSPORT	60 - 100	10 - 13	31 - 32
WIDE BODY TRANSPORT	> 100	8.5 - 10	32 - 33

Table 7 - Combined Vertical/Longitudinal Impact Pulse - Triangular Pulse Shape

AIRCRAFT CATEGORY	UNDERFLOOR STRUCTURAL DEPTH - INCHES	ACCELERATION G's PEAK	VERTICAL VELOCITY CHANGE - FT/SEC
GENERAL AVIATION COMMUTER	< 30	32	31
SMALL TRANSPORT	30 - 60	17	32
NARROW BODY TRANSPORT	60 - 100	14	35
WIDE BODY TRANSPORT	> 100	10	38

Longitudinal Impact Conditions

Other than the data found in reference 1, which pertains to general aviation aircraft, full scale longitudinal impact data are somewhat sparse. Additional full scale longitudinal impact tests for a range of aircraft sizes are believed necessary to provide a basis which might be used to relate the size of the aircraft to a longitudinal impact scenario and resultant impact pulse.

Notwithstanding the above, an estimate of the relationship between aircraft size and the expected longitudinal impact response for survivable impact scenarios for the range of aircraft sizes found between general aviation aircraft and transport category aircraft is presented herein.

Longitudinal impact pulses, shown here in Table 8, have been defined for both general aircraft and transport category aircraft in references 6 and 7.

Table 8 - Longitudinal Impact Pulse
Triangular Pulse Shape

AIRCRAFT CATEGORY	VELOCITY CHANGE FT/SEC	ACCELERATION G's PEAK	TIME DURATION MS
GENERAL AVIATION	42	26	100
TRANSPORT CATEGORY AIRCRAFT	44	16	180

The commuter category aircraft longitudinal impact pulse should fall somewhere between those values shown in Table 8. Two estimates will be made. One estimate will assume that the longitudinal impact pulse varies linearly between the two values shown in Table 8. A second estimate will assume that the longitudinal impact pulse varies along a 42 feet/second constant velocity curve drawn between the two values shown in Table 8. The transport category impact pulse will be adjusted to a 42 feet/second impact velocity for this estimate. Using the above assumptions and a maximum certified weight of 12,500 lbs. for general aviation aircraft and 200,000 lbs. for a narrow body transport category aircraft, the relationships shown in Figure 10

can be generated. Also depicted on Figure 10 is a data point which represents the 19,000 lb. maximum certified weight limitation for commuter category aircraft.

The methodology used to develop Figure 10 is certainly very empirical and, without supporting test data, that figure might be questioned. However, Figure 10 does serve one meaningful purpose. It is believed that irrespective of the methodology that one could use to fill the data range between the general aviation aircraft and transport category aircraft longitudinal impact pulses shown in Table 8, it would be expected, as shown here, that little or no difference would exist between the longitudinal impact pulse for general aviation and commuter category aircraft. In the example illustrated here, the difference shown in the acceleration magnitude of the impact pulse might be 0.5 G's or less or for all practical purposes equal.

The above empirical analysis and discussion suggests that the longitudinal impact pulse for general aviation and commuter category aircraft should be identical.

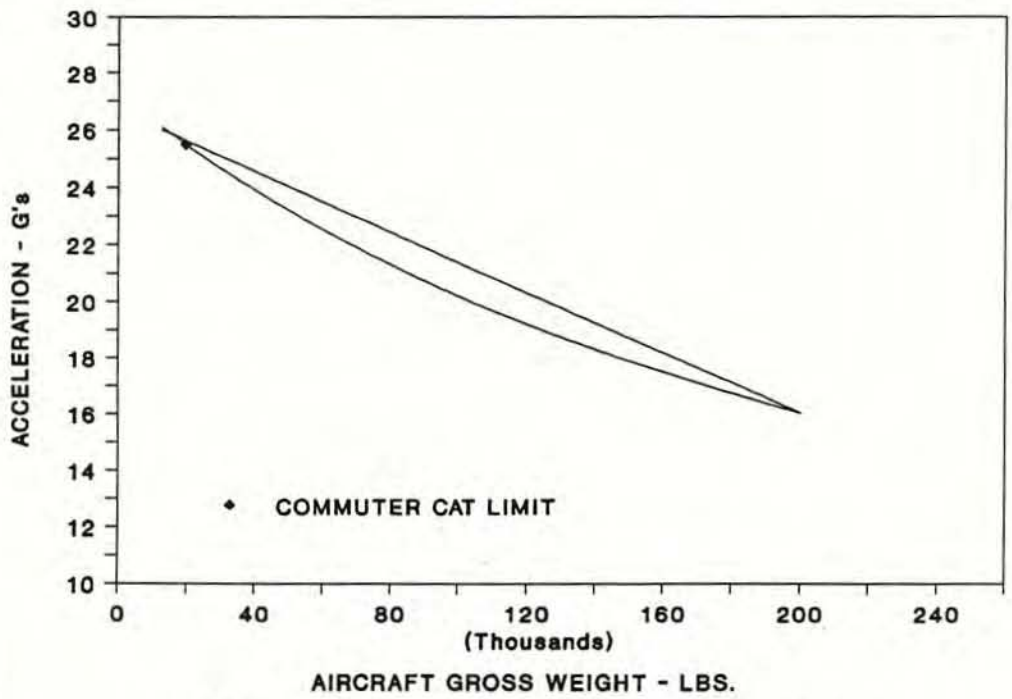

Figure 10 - Estimated Size Effects For Longitudinal Impacts

Summary/Conclusion

This paper defines seat dynamic performance standards for a range of aircraft sizes.

The defined combined vertical/longitudinal seat dynamic performance standards are based on analyses of the results of full-scale aircraft impact test data. That data was used to establish a trend line that related the acceleration levels expected during a vertical impact to the geometric size of the airframe structure.

The longitudinal impact full-scale data base is sparse and a trend line to relate longitudinal impact accelerations to aircraft size could not be readily established. However, it was shown by using two assumed trend lines that large differences between aircraft sizes might be necessary to significantly change the longitudinal impact pulse for a given aircraft size.

Additional full-scale impact tests and/or other analytical approaches are needed to further define the relationship between longitudinal impact accelerations and aircraft size.

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Appendix A

Data Item A

Reference: Cronkhite, J.D. and Berry, V.L., "Crashworhty Airframe Design Concepts - Fabrication and Testing", NASA Contractor Report 3603, September 1982.

These test data are the result of a research program directed toward the investigation of crashworthy concepts applicable to metal airframe structures of general aviation aircraft.

Five airframe lower fuselage concepts were fabricated and tested both statically and dynamically to assess the energy absorption and impact characteristics of those structures.

Impact tests of those structures at a 24 feet/second vertical impact velocity produced somewhat trapezoidal impact pulse shapes. The resultant pulse shapes were normalized to equivalent triangular pulse shapes and the triangularized data ranged from 38-60 G's peak with 3 - 3.5 inches of structural crushing.

Data Item B

References: Carden, H.D., "Correlation and Assessment of Structural Airplane Crash Data with Flight Parameters at Impact", NASA Technical Paper 2083, November 1982.

These data represent a series of 21 controlled, full-scale impact tests conducted on single and twin engine general aviation aircraft. Several parametric relationships were developed to relate the impact scenario and the airframe response. These data show that the airframe response is typically triangular.

Using the parametric relationship found in reference 1 (Figure 4) for impact pulse durations of 40 - 60 ms (representative of a 0° pitch angle - flat impact) the following data range was established.

Pulse Duration	V Vertical	G's Peak
40 ms	24 feet/second	37.5
40 ms	30.3 feet/second	47.5
60 ms	24 feet/second	25
60 ms	30.3 feet/second	31.7

Reference: Carden, H.D., "Full-Scale Crash Test Evaluation of Two Load-Limiting Subfloors for General Aviation Airframes", NASA Technical Paper 2380, December 1984.

These data represent 3 controlled, full-scale (0° pitch angle - flat impact) tests conducted on twin engine general aviation aircraft one of which had an unmodified underfloor structure and two of which had modified underfloor structure. The resultant impact pulse shapes were triangular, however, the peak accelerations may have been somewhat lowered by the 20 Hz data filter used for the airframe acceleration data channels.

For a vertical impact velocity component of 28.5 feet/second, peak accelerations of 40 to 55 G's magnitude were recorded during the test of the unmodified airframe structure.

The two data ranges referenced above were combined and depicted on Figure 7.

Data Item C

Reference: "Occupant Restraint in Normal and Transport Category Rotorcraft," 14 CFR Parts 27 and 29, Amendments 27-25 and 29-29.

This data point represents the vertical component of the combined vertical/longitudinal seat dynamic test conditions found in the referenced regulatory amendments.

Data Item D

Reference: "Small Airplane Airworthiness Review Program, Amendment No. 1," 14 CFR Part 23, Amendment 23-36.

These data points represents the vertical component of the combined vertical/longitudinal seat dynamic test condition found in the referenced amendment "adjusted" to pulse durations of 40 and 60 ms which are representative of a 0° pitch angle - flat impact. The rationale for the pulse duration adjustment was discussed in a previous section of this paper.

Data Item E

Reference: "Small Airplane Airworthiness Review Program, Amendment No. 1," 14 CFR Part 23, Amendment 23-36.

These data points represent the vertical component of the combined vertical/longitudinal seat dynamic test condition as found in the referenced amendment.

Data Item F

Reference: Fasenella, E.L., et al, "Impact Data from a Transport Aircraft During a Controlled Impact Test," NASA Technical Paper 2589, September 1986.

These data represent an air-to-ground full scale impact test of a transport category aircraft with a 12 to 14 feet/second vertical fuselage impact velocity and a 2.5° nose down impact pitch angle.

Airframe accelerations were shown to range from 7 to 14 G's peak (triangular pulse shapes) with an average airframe vertical displacement (crushing) of 6 to 7 inches.

Data Item G

Reference: DC-10 Drop Test with Baggage Containers (preliminary data traces), FAA Technical Center, March 1985.

This data point represents the response measured on the center of the floor (channel #2/location #4) of a DC-10 fuselage section which was drop tested at a vertical impact velocity of 25 feet/second. The acceleration pulse appeared triangular with a peak response of 20 G's with approximately 12.75 inches of airframe crushing.

Data Item H

Reference: Pugliese, S.M., "707 Fuselage Drop Test Report," Arvin/Calspan Report No. 7252-1, March 1984.

This data point represents the vertical response at the mid-center floor beam on a 707 fuselage section which was drop tested at a vertical impact velocity of 20.16 feet/second. An average 4.17 G's and an idealized 8.3 G's peak triangular pulse were derived from the channel #1 compartment beam velocity data channel. The airframe crush was noted as 18.16 inches.

Data Item I

Reference: "Improved Seat Safety Standards," 14 CFR Part 25, Amendment 25-64.

This data point represents the vertical component of the combined vertical/longitudinal seat dynamic test condition as found in the referenced amendment for transport category aircraft.

Data Item J

Reference: Johnson, R. and Wilson, A., "Vertical Drop Test of a Transport Airframe Section," Technical Note DOT/FAA/CT-TN 86/34, October 1986.

These data points represent the range of measured responses on the floor of a transport airplane fuselage section which was drop tested with baggage in the lower lobe at a vertical impact velocity of 34 feet/second. Peak idealized triangular acceleration pulses typically ranged between 11.6 and 15.4 G's with one outstanding data point at 19.8 G's. The structural airframe crush was noted to be 30 inches.