AGATE

(ADVANCED GENERAL AVIATION TRANSPORTATION EXPERIMENT PROGRAM)

FULL-SCALE TEST AND DEMONSTRATION

REPORT NO: C-GEN-3451 - 1 (REV N/C)

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REFERENCES

1. Jones, L.E., and Carden, H.D., "Overview of Structural Behavior and Occupant Responses from a Crash Test of a Composite Airplane," SAE Technical Paper 951168.

2. McGuire, R., Nissley, W., and Wilson, A., "Drop Test-Cessna Golden Eagle 421B," DOT/FAA/CT-TN91/32, 1992.

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EXECUTIVE SUMMARY

This report presents the results of Cessna's crash experiments conducted onboard the Beech Starship aircraft fuselage. The test parameters were configured to attain the impact requirements of FAR 23.562(b)(1) and (b)(2). The aircraft was dropped from a vertical height of 50 feet and followed a flight path of 27 degrees, resulting in an vertical impact velocity of 29 fps and horizontal impact velocity of 89 fps. The structural response of the airframe, seats and ATD's were measured throughout the test and are presented in this report. The data collected and analysis serves as a baseline study for improved crashworthiness standards for general aviation commuter airplanes.

1.0 INTRODUCTION

The Starship full-scale drop test was conducted as part of AGATE Workpackage W.B.S. 3.4.5.1 at the NASA Langley Drop test Facility, Hampton Virginia in May 1998. The objective of the test was to document and investigate the performance of current (or 'as-is') sub-floor structures, seat and restraint systems. This will provide a baseline for an additional test with modified energy absorbing mechanism to enhance occupant protection.

The Starship drop test airframe was supplied by Raytheon Aircraft, which was configured to served as a platform for a collective number of experiments conducted by Cessna Aircraft, Simula Technologies, Impact Dynamics Inc., Aircraft Modular Products and Raytheon. This report presents specifically the test results and analysis pertaining to Cessna's experiment onboard the Starship airframe, and results of experiments conducted by other workpackage members are not included.

Two Cessna's experiments were conducted. One experiment was to investigate the structural performance of an energy absorbing seat structure that is subjected to a real-world crash pulse. A second experiment investigates the effectiveness of airbag systems to provide occupant protection.

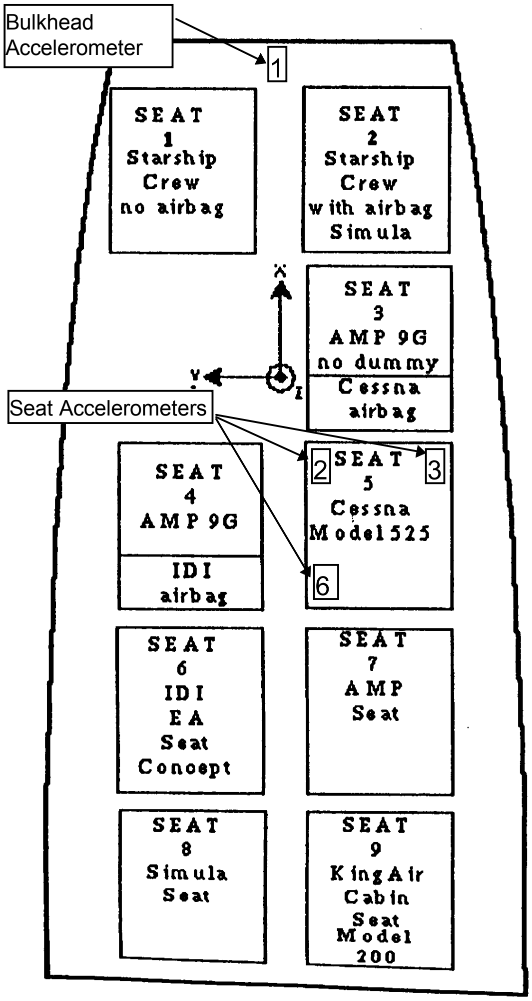
2.0 TEST ARTICLE

The Starship airframe is an all-composite structure. The fuselage, frames and sub-floor structure is fabricated from carbon fiber composite. For this test, ballast weights were used to simulate engine masses, and the fuel cells were filled with water to simulate fuel contents. Final weight of the test article is 14,200 lbs.

The cabin compartment was configured to accommodate 9 occupants as shown schematically in Figure 2.1.

Figure 2.1

Schematic of Floor Plan with Hardware



Cessna's experiments are located at Seat 3 and 5. Seat No.3 was supplied by AMP and is a 9-G non-dynamic seat. A Simula Seat Bag Airbag System was installed at the seat back frame of Seat No.3 and was positioned in the path of anticipated head strike envelope.

The Seat Bag Airbag System consist of two modules: the air bag module and the crash sensor. The air bag module is approximately 2 inches deep by 6 inches wide by 7 inches tall, and weights about 4 lbs. It is mounted to the back of the seat by means of adapters that are attached to the seat frame. Upholstery on the seat back was modified to incorporate a tear seam through which the airbag would deploy. The airbag itself is relatively small, approximately 38 liters in size, as oppose to a typical 60 liter airbag that are currently used in automotive applications. Airbag inflation is provided by a conventional sodium azide gas generator. The gas generator is initiated by an electrical signal coming from the crash sensor. The sensor weighs about 3 lbs. It is wired to the aircraft electrical system and contains a capacitor discharge unit that is able to discharge the airbag in the event of loss of aircraft power. If an acceleration threshold is reached, the sensor sends an electrical signal to the gas generator to initiate airbag deployment. The airbag deploys in approximately 20 ms, and remains inflated for several seconds to provide secondary impact protection to the occupant. Seat No. 3 was left unoccupied to create a worst-case head strike scenario.

Seat No.5 is a Part 23 dynamically certified seat. A Hybrid II 50th percentile ATD was placed in the seat and is restrained using a 3-point nylon harness system. The ATD is used to evaluate HIC, lumbar loads and to investigate the overall dynamic response when it comes into contact with the airbag. The relative position of Seat No.5 with respect to Seat No.3 is shown in Figure 2.2. The inboard feet for both seats are attached to the seat tracks which are directly mounted to the floor beams. Due to the difference in spacing between the seat legs and floor beams, the outboard feet could not be installed directly to the outboard floor beams. Instead, a cross-beam was installed across the inboard and outboard floor beams, and the outboard seat legs were attached to the cross-beam. Figure 2.3 shows the installation and relative position of Seat No.3 and Seat No.5 in the fuselage.

Figure 2.2

Schematic of Seat Position

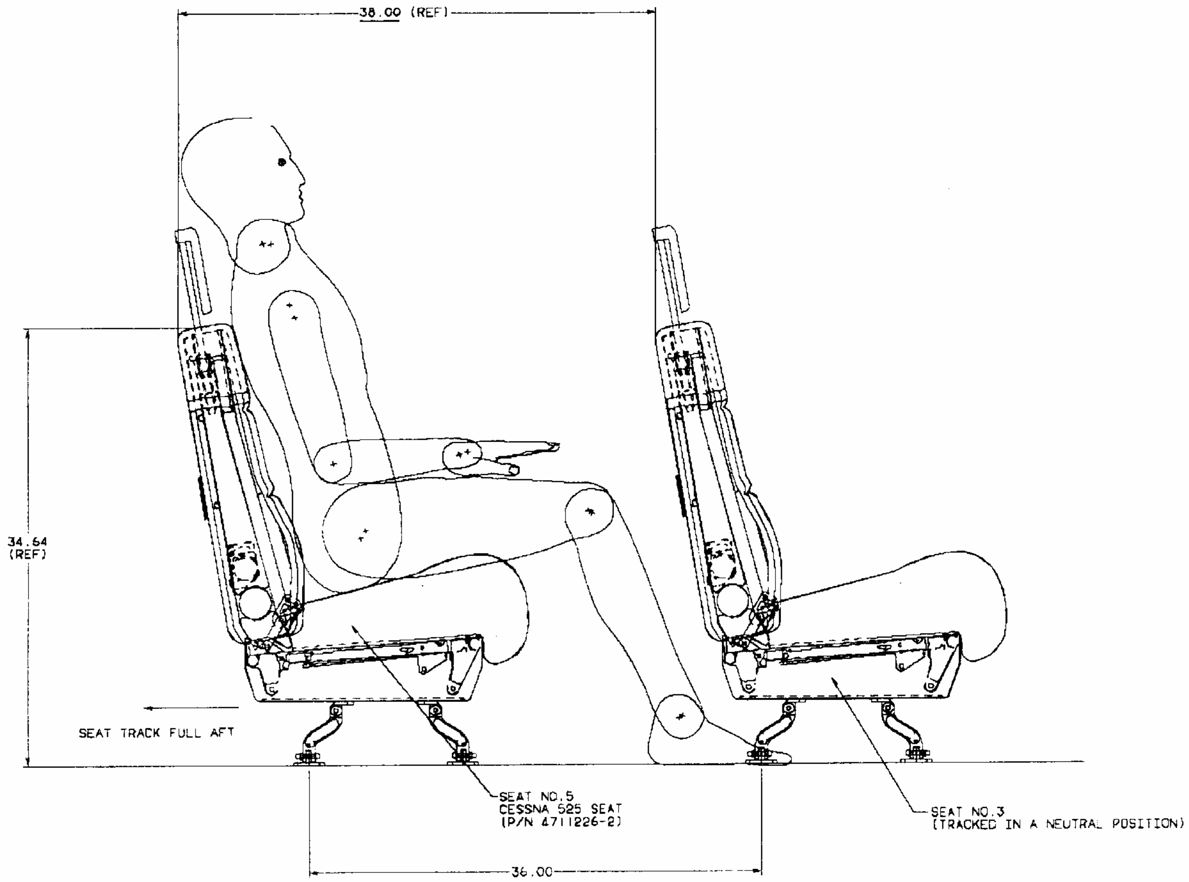

38.00 (REF)
34.64 (REF)
SEAT TRACK FULL AFT
SEAT NO.5
CESSNA 525 SEAT
(P/N 4711226-2)
SEAT NO.3
(TRACKED IN A NEUTRAL POSITION)
36.00

Figure 2.3

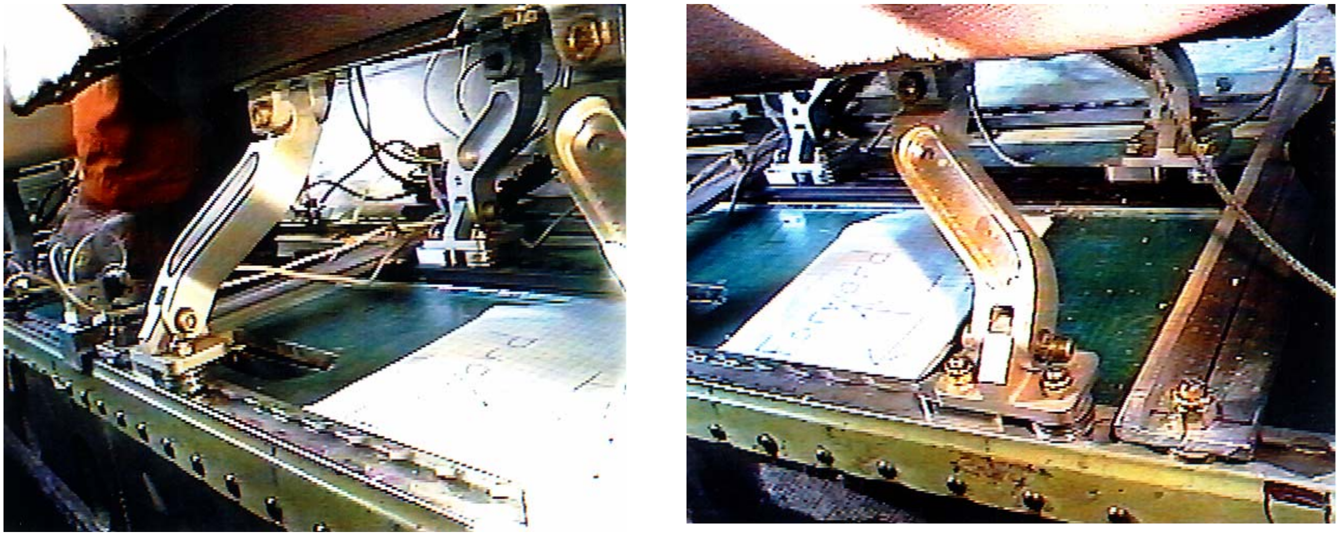
Cessna Seat in Fuselage

3.0 Instrumentation

The interior paneling of the fuselage was removed to facilitate instrumentation and sensor installation. A total of 10 tri-axial accelerometers were installed along the length of the fuselage (Ref. Fig. 2.1). Accelerometer No. 2,3 and 6 are used to record the response of the floor structure at Seat No.5 as shown in Figure 3.1(a) and (b). The reference orientation of all accelerometers mounted to the fuselage are defined in accordance with standard aircraft coordinate system i.e. X is longitudinal, Y is lateral and Z is vertical.

Figure 3.1

Accelerometer Placement



(a) Forward Seat Feet

(b) Aft Seat Feet

The Hybrid II 50th percentile ATD in Seat No.5 was instrumented with tri-axial accelerometers in the head, chest and pelvis region as well as a tension/compression transducer in the lumbar. The orientation of the instrumentation in the ATD are positioned in the dummy's body axis system. A pressure transducer was also mounted to the airbag system to monitor the airbag pressure.

Three high speed camera were installed in the fuselage used to record the crash event. A fish-eye wide angle lens camera was installed at the top front cockpit section in between the pilot and copilot. A second camera was installed between Seat No.6 and 7. The third camera was installed at the aft bulkhead section. The cameras recorded at a rate of 400 pictures per second.

4.0 TEST PARAMETERS

A two-phase impact scenario was planned for the test:

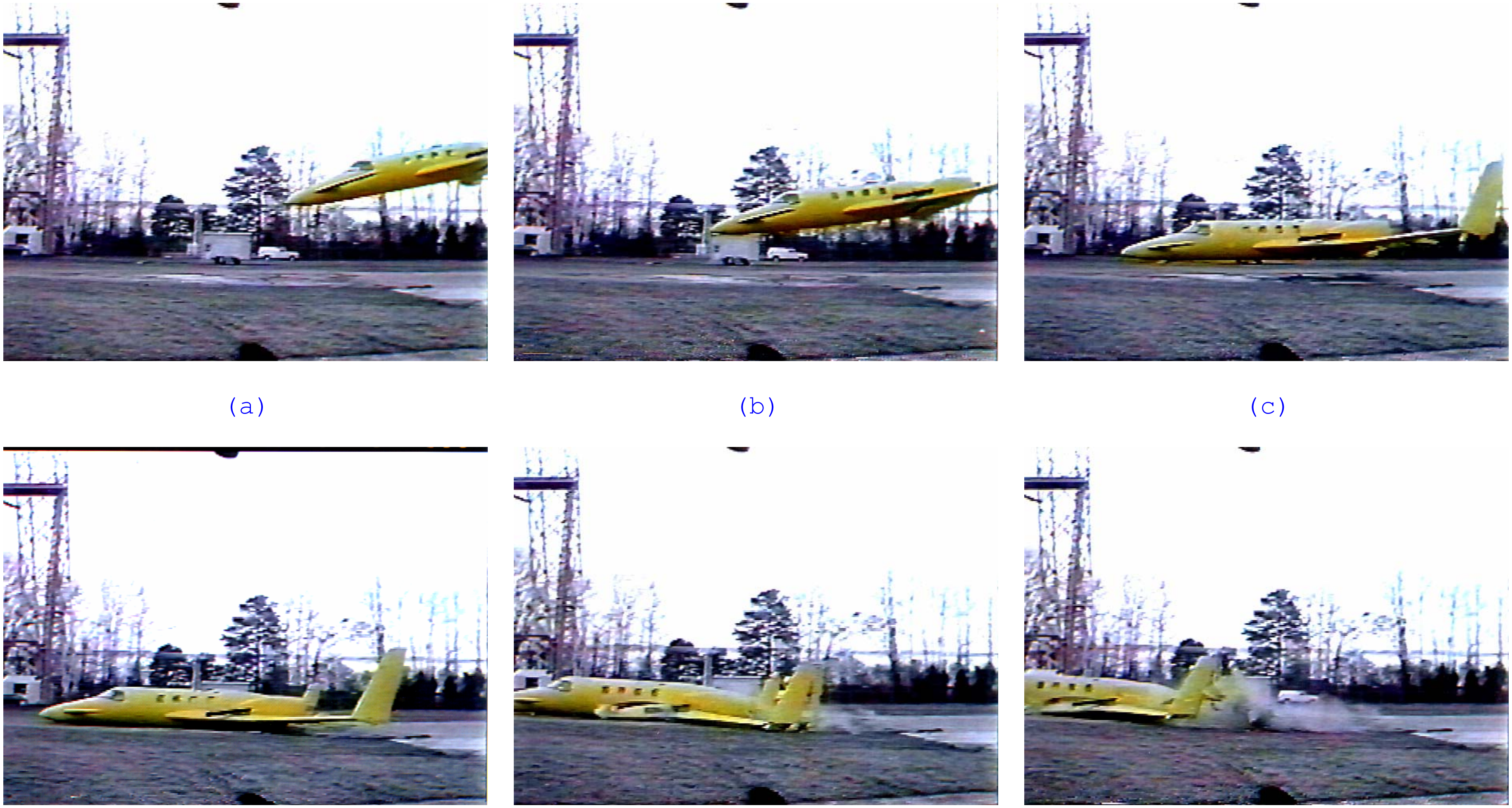
1. An initial ground impact that will result in a vertical velocity change of 31 fps as defined in FAR Part 23(b)(1).

2. A secondary impact into an embankment during slide-out that will result in a vertical velocity change of 42 fps and 10 degree yaw as defined in FAR Part 23(b)(2).

The slide-out embankment impact condition is used to determine the occupants response in a more realistic crash scenario, to evaluate the practicality of implementing airbag systems in the cabin environment, and to assess the effectiveness of an airbag in providing occupant protection.

5.0 RESULTS AND DISCUSSION

The test article was dropped with the landing gear retracted onto concrete surface. During the drop, the aircraft followed a flight path of -18 degrees with a +18 pitch angle relative to the flight path. At impact, the flight attitude were 0 degrees of pitch, 0 degrees of yaw and 5 degrees of roll. After primary impact, the aircraft rebounded and rose approximately 2 feet off the surface, and traveled for another 55 feet before impacting the ground again and sliding towards the embankment. As the aircraft impacted the dirt embankment, its canard dug into the dirt causing the nose section to lift up. The aircraft began to climb up the embankment until it came to rest at a 30 degree pitch angle with the mid-fuselage section resting on the top side of the embankment. Photographic coverage of the crash sequence is shown in Figure 5.1(a)-(f) and Figure 5.2(a)-(i).



(a) (b) (c)

(d) (e) (f)

Figure 5.1 (a)-(f): Crash Sequence - Side View

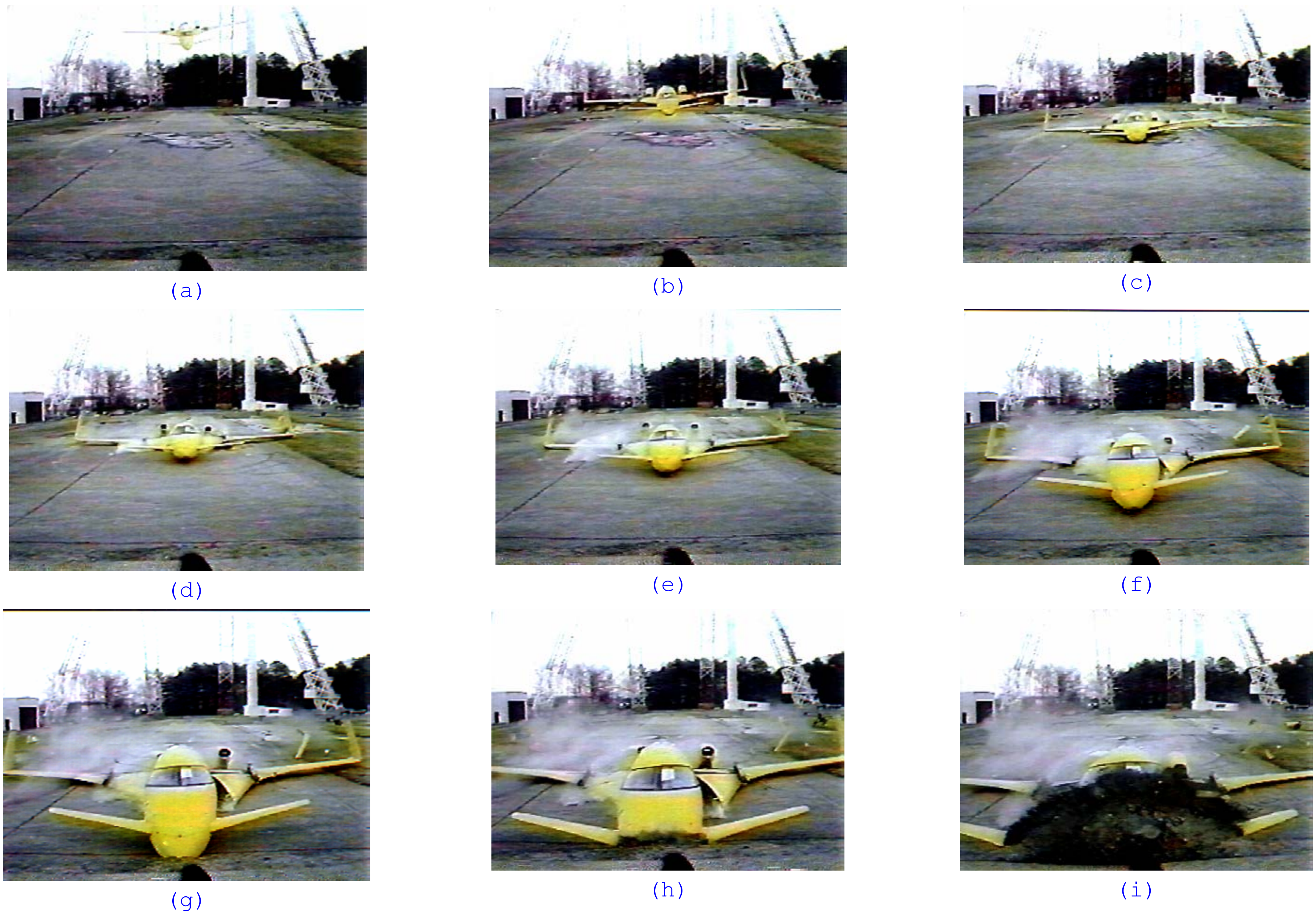

(a) (b) (c)
(d) (e) (f)
(g) (h) (i)

Figure 5.2 (a)-(i): Crash Sequence - Forward View

The impact velocities measured from film analysis were:

- Initial impact - 29 fps vertical, 89 fps horizontal
- Secondary impact - 73 fps horizontal

Of the 125 data channels onboard the aircraft, 68 channels of data were successfully retrieved from the test. Data loss for the other 57 channels were attributed sudden power surge during the drop sequence, resulting in failure to trigger the data acquisition system. In addition, only the primary impact acceleration data were recorded. The acceleration data during the slide-out and secondary impact were excessively noisy, and are therefore discarded. Table 5.1 presents a summary of Cessna's data channels that were on-board the test article.

Table 5.1

Test Data Channels

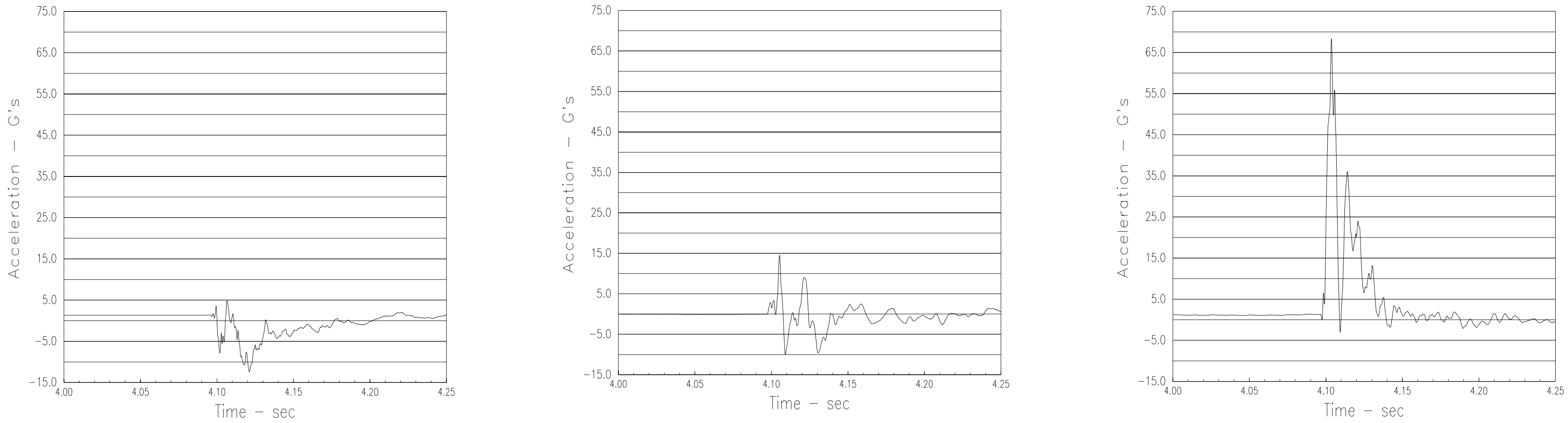
Installation Type	Sensor Type	Description	Channel Number	Data Collected
ATD Installation	Accelerometer	Head -X	C1	No
ATD Installation	Accelerometer	Head -Y	C2	No
ATD Installation	Accelerometer	Head -Z	C3	No
ATD Installation	Accelerometer	Pelvis -X	C4	No
ATD Installation	Accelerometer	Pelvis -Y	C5	No
ATD Installation	Accelerometer	Pelvis -Z	C6	No
ATD Installation	Accelerometer	Chest -X	4	Yes
ATD Installation	Accelerometer	Chest -Y	5	Yes
ATD Installation	Accelerometer	Chests -Z	6	Yes
ATD Lumbar	Load Cell	Dummy Lumbar Load Cell	F2	No

ATD Belt	Load Cell	Lap Belt Load Cell	B3	
ATD Belt	Load Cell	Shoulder Harness 7Load Cell	B4	
Airbag	Pressure Transducer	Sensor to monitor airbag deployment	P2	
Aircraft Floor	Accelerometer	Station 1 -X	27	Yes
Aircraft Floor	Accelerometer	Station 1 -Y	28	Yes
Aircraft Floor	Accelerometer	Station 1 -Z	29	Yes
Aircraft Floor	Accelerometer	Station 2 -X	30	Yes
Aircraft Floor	Accelerometer	Station 2 -Y	31	Yes
Aircraft Floor	Accelerometer	Station 2 -Z	33	Yes
Aircraft Floor	Accelerometer	Station 3 -X	34	Yes
Aircraft Floor	Accelerometer	Station 3 -Y	35	Yes
Aircraft Floor	Accelerometer	Station 3 -Z	36	Yes
Aircraft Floor	Accelerometer	Station 6 -X	43	Yes
Aircraft Floor	Accelerometer	Station 6 -Y	44	Yes
Aircraft Floor	Accelerometer	Station 6 -Z	45	Yes

Data from the fuselage accelerometers were filtered at channel class 60 and the ATD chest acceleration data were filtered at channel class 1000 using an in-house low pass first order Butterworth filter program.

5.1 Crash Pulse Analysis

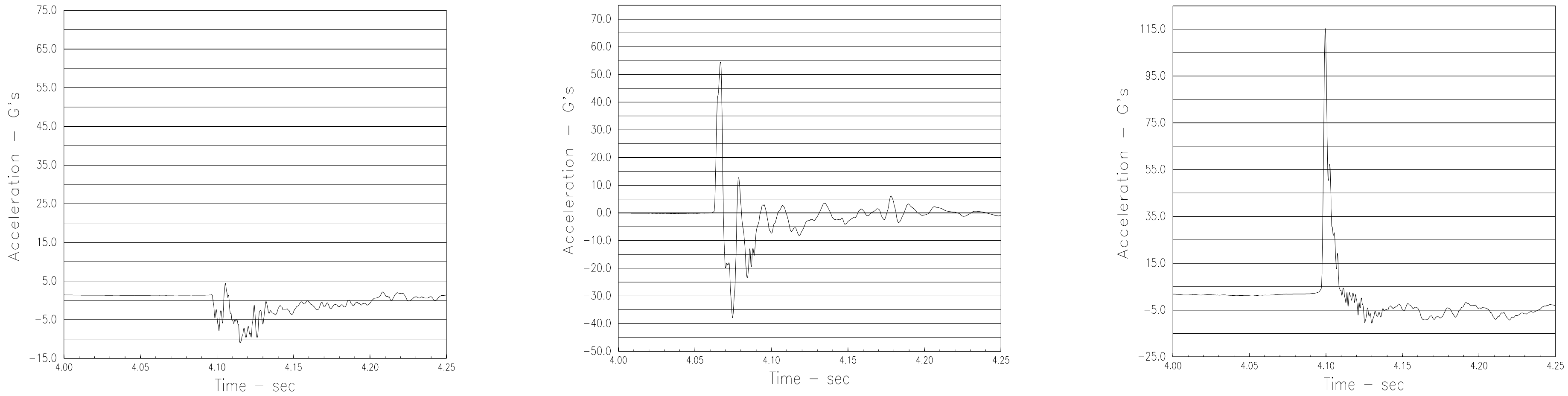
Time history plots of all floor accelerometer channels representing the primary impact are shown in Figure 5.3(a) and (b). A comparison of the acceleration data showed that the aircraft impacted the ground tail-end first, as indicated by the 6-3-2-1 accelerometer time sequence. The maximum X, Y and Z acceleration are -15g’s, 70 g’s



Station 1x

Station 1y

Station 1z

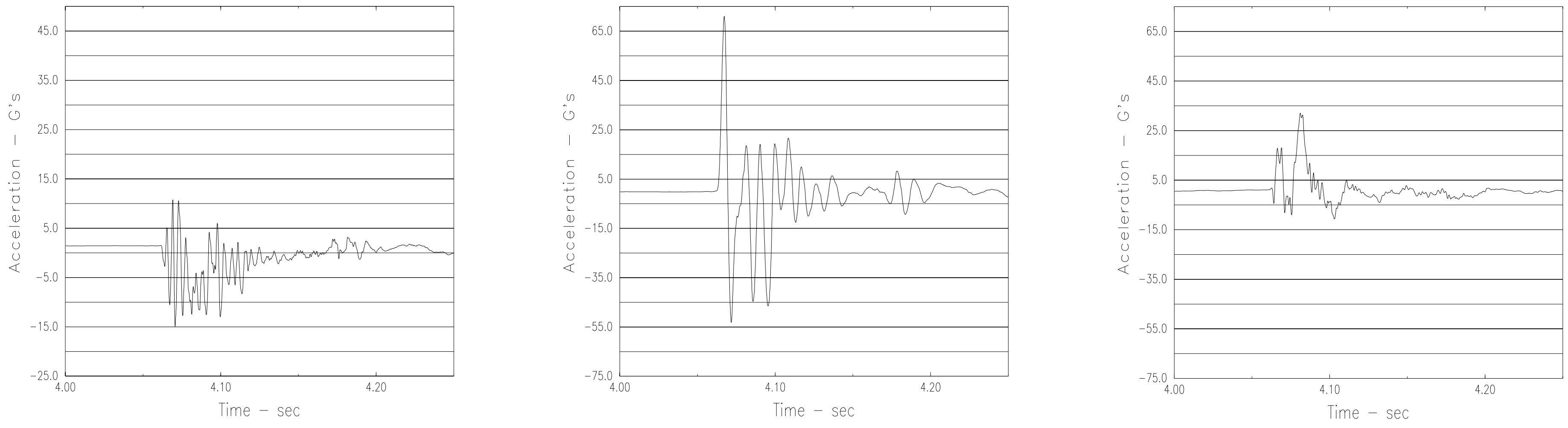


Station 2x

Station 2y

Station 2z

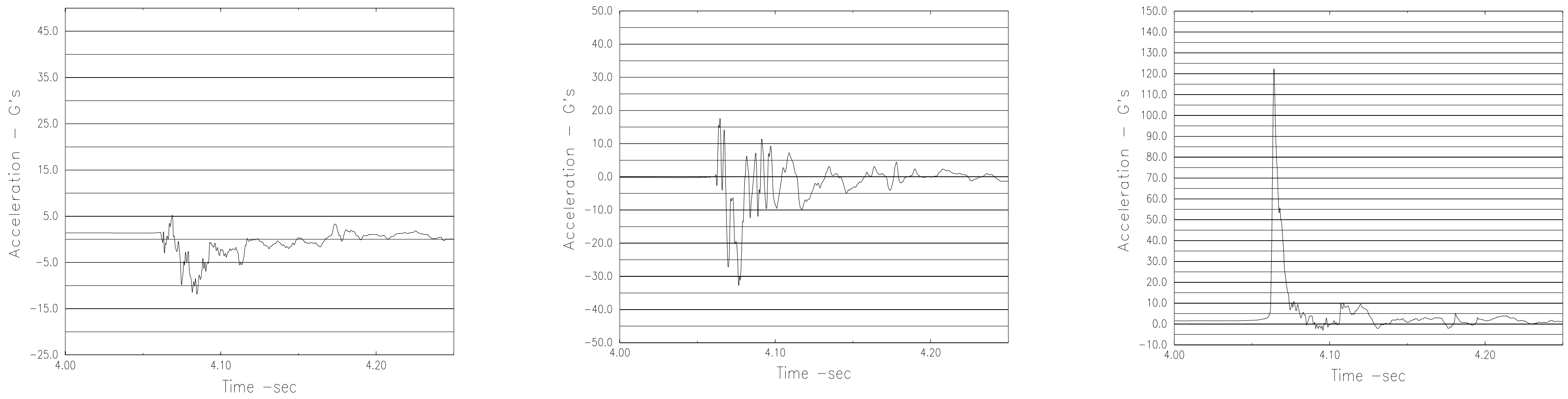
Figure 5.3(a) - Floor Acceleration



Station 3x

Station 3y

Station 3z



Station 6x

Station 6y

Station 6z

Figure 5.3(b) - Floor Acceleration

and 125 g's respectively. The average of the maximum accelerations for the X,Y and Z components are 12.6g's, 38.9g's and 84.5g's. The duration of each crash pulse did not exceed 50 ms.

The combined vertical/horizontal acceleration component of the FAR Part 23.562(b)(1) crash pulse is 19.0 g's. The crash pulse duration is 100 ms (rise time of 50 ms) and the minimum velocity change is 31 fps. For the Starship test, the average magnitude of the vertical acceleration is 84.5 g, which is considerably higher than the FAR requirements. However, the duration of the crash pulse 15 ms. By evaluating the most severe seat rail vertical crash pulse (Station6-Z), the velocity change by integration is 22.5 fps, which is lower than the FAR requirements.

Similarly, the horizontal acceleration component for the FAR Part 23.562(b)(2) crash pulse is 25.6 g's (26 G's X cosine 10 degrees yaw), rise time of 50 ms and a minimum velocity change of 41.4 fps(42 fps X cosine 10 degrees yaw). For the Starship test, the maximum horizontal deceleration is approximately 12.6 g's measured at Station 3, and has a rise time of 33 ms. The calculated velocity change is 7.9 fps. Again, the parameters are below the FAR test requirements.

An interesting observation in the crash pulse is the magnitude of the vertical acceleration at Station 3. The accelerometer was located at the forward outboard rail of Seat No. 5, and was placed on a cross-beam (Ref. Figure 3.1(a)). During primary impact, the beam deflected approximately 3.6 inches downwards, as calculated by integrating the vertical acceleration. The maximum acceleration recorded was 32 G's. Therefore, the deflection of the beam at Station 3 resulted in a significantly lower G level in comparison to Station 2 (115 G's) and 6 (124 G's), where the seat attachment is fairly rigid.

In addition, the magnitude of acceleration at the point of impact and other locations along the fuselage varies significantly. For example, the Z-acceleration at Station 1, which is further away from the focal point of impact, is 45% lower than Station 2 and 6.

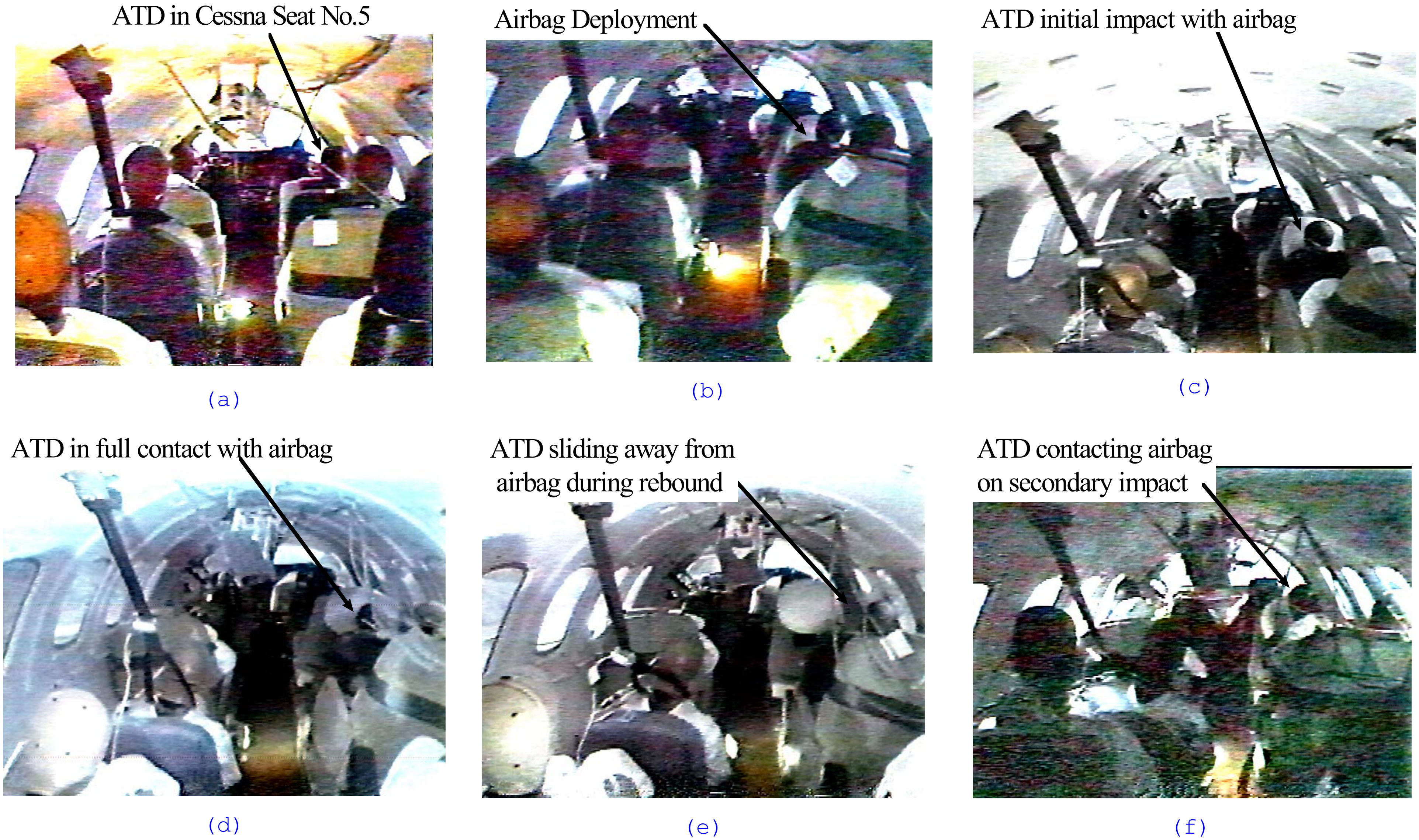
The characteristics of the crash pulse for the Starship crash test is comparable to the crash pulse obtained from the Lear-Fan crash-test (Ref.1)and Cessna 421B drop test(Ref. 2). The accelerations are higher than the FAR Part 23.562 requirements, but crash pulse duration and velocity change is significantly shorter.

One major difference may be due to the stiffness of the fuselage construction. Airplanes that were crash tested to develop the FAR Part 23.562 requirements had a significant amount of fuselage deformation. The crushing effect increased the duration of the crash pulse. In addition, the FAR Part 23.562 crash pulse were primarily developed using high-wing aircrafts with gross-weights gross weights of less than 3500 lbs. The Starship, Cessna 421B and the Lear-Fan are low-wing aircrafts with gross weights of 14,200 lbs, 7500 lbs and 7200 lbs respectively.

5.2 Occupant and Seat Analysis

Post-test inspection showed that the primary structure in Cessna Seat No.5 did not exhibit any detrimental deformation. The seat pan were deformed and the tracking plate was partially sheared, as expected. The seat and the occupant remained intact throughout both primary and secondary impact. There were significant structural failure of the seat back frame at Seat No. 3 (non-dynamic 9 G seat). However, the 9 G seat did remain attached to the seat rail. By observation, there were no apparent permanent crushing of the composite seat floor beams or warpage of the floor structure.

Figure 5.4 shows the sequence of events in the fuselage, captured from an internal high speed camera. It shows the airbag deploying at impact and remained inflated throughout the crash event. The occupant impacted the center of the airbag during primary impact and rebounded outboard momentarily. As the aircraft impacted the embankment, the occupant struck the airbag again.



ATD in Cessna Seat No.5

(a)

Airbag Deployment

(b)

ATD initial impact with airbag

(c)

ATD in full contact with airbag

(d)

ATD sliding away from airbag during rebound

(e)

ATD contacting airbag on secondary impact

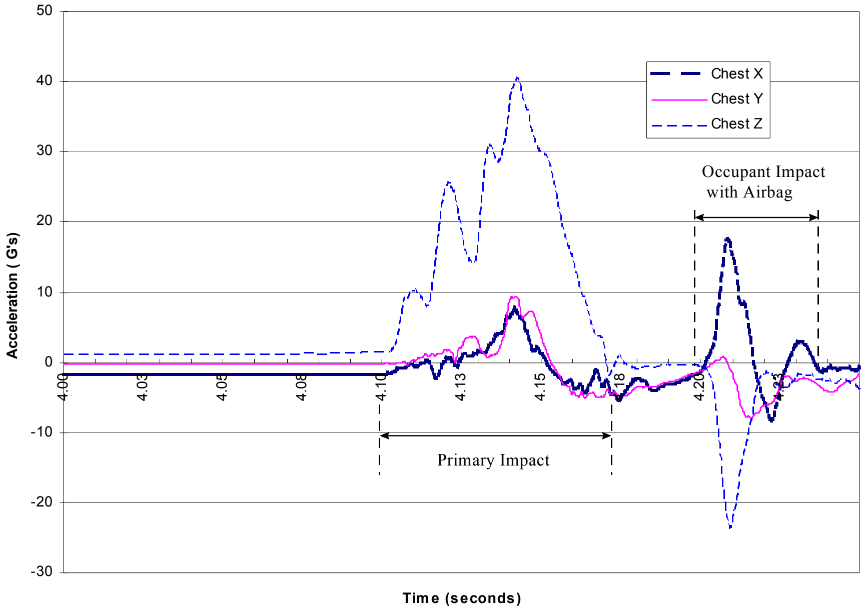
(f)

Figure 5.4 - Occupant Motion and Airbag Deployment Sequence

As seen from this test, the placement of the airbag using headpath trajectory obtained from dynamic seat testing is reasonably accurate. Although data for HIC was not recorded, the airbag may be beneficial for reducing head injuries, such as facial lacerations.

A plot of the occupant chest acceleration is shown in Figure 5.5. The maximum vertical chest acceleration is approximately 40 g's, while the lateral and forward acceleration's are relatively low.

Figure 5.5 - Chest Acceleration: Occupant No. 5



6.0 Conclusion

The data collected from the Starship drop test relative to Cessna's onboard experiments were analyzed. Significant cabin volume was maintained throughout the crash and there were minimal permanent deformation. The cabin sub-floor did not exhibit any permanent deformation.

Cessna's dynamic seat remained attached to the seat tracks throughout the crash and had minimal damage. However, significant structural failure was noted on the seat back of the non-dynamic seat. The deployment of Simula's Seat Bag Airbag System was relatively successful, and by observation, was useful in cushioning the occupant's head during both primary and secondary impact. However, the placement of the airbag must also take into account the scenario where the forward seat is occupied. This requires further investigation. There were no data to conclude the severity of injuries to the occupant.

There exist significant differences between the crash pulse generated by the Starship structure during impact and the crash parameters defined in FAR Part 23.562(b)(1) and (ii). The stiffer and higher gross weight construction of the fuselage produced crash pulses which have higher acceleration magnitudes, short rise time and low velocity change. In addition, the impact energy of the Starship crash pulse is lower in comparison to the FAR 23.562 requirements. The data obtained in this test (as well as crash test results documented in Ref. 1 and 2) questions the validity of applying FAR Part 23.562 standards for composite type fuselage structures, and its effectiveness in improving occupant survivability. Suitable crash parameters must be defined for AGATE type aircraft before the appropriate survivability countermeasures can be developed. This test will serve as a baseline study for future drop test.