The 9th Triennial International Fire & Cabin Safety Research Conference
Federal Aviation Administration - FAA
October 28-31, 2019 – Atlantic City, New Jersey, USA

Research Paper – Crash Dynamics

The effectiveness of the dynamic analyses for the crew seat of KC-390 aircraft qualification for emergency landing conditions.

ABSTRACT

The objective of this work is to evaluate the effectiveness of dynamic analyses in the development and qualification of the crew seat of EMBRAER KC-390 aircraft on PART 25 certification basis, analyzing the emergency landing conditions defined by requirement 14 CFR § 25.562 and comparing the results with the ones obtained by dynamic tests carried out in January 2017, in the laboratory of the National Institute of Aviation Research – NIAR / Wichita. In September 2015, LHColus Technology was contracted by EMBRAER to develop and qualify a double crew seat for KC-390 aircraft, denominated BUNK BED SYSTEM.

During the design of the crew seat, in the development phase, several dynamic analyses were carried out with different seat configurations, studying the emergency landing conditions 14g + 30° PITCH UP, 16g ±10 YAW and 16g ±10 degree YAW with deformed floor. The analyses of +10 degrees and -10 degrees of YAW under 16g conditions were also performed to define the most critical cases to be executed on the dynamic tests.

The overall result of these analyses was very positive, once it was observed a very good correlation with the dynamic test performed and contributing to expedite the product development and qualification. The double crew seat was approved in the dynamic tests, complying with all the requirements defined by the 14 CFR §25.562, including HIC conditions, without any failures.

Key words: KC390 Aircraft; Crew Seat; Emergency Landing; Dynamic tests; Dynamic Analysis, HIC conditions.

Authors:
LOUREIRO, P. L. G.
COLUS, L. H.

Corresponding authors: E-mail:
pedro.loureiro@lhcolus.com.br
luiscolus@lhcolus.com.br

INTRODUCTION

In September 2015, LHColus Technology was contracted by EMBRAER to develop and qualify a double crew seat for KC-390 aircraft, denominated BUNK BED SYSTEM.

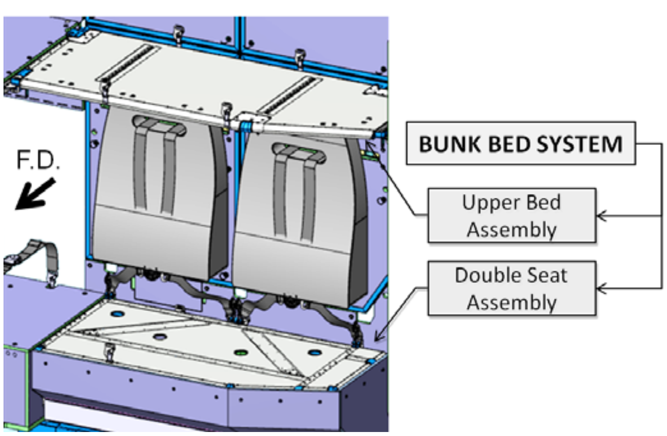


Figure 1 - Bunk Bed System

The customer requested a seat for two occupants, each weighing 250 pounds, this exceeds requirement 14 CFR 25.562, which requires a weighing of 170 pounds for each occupant and total target weight of double seat ≤ 37 lb.

Several seat configurations have been evaluated through dynamic analyses during the development phase, with the primary objective of succeeding in the dynamic tests defined by requirement 14 CFR 25.562 without exceeding the target weight. Some of the leg configurations analyzed are shown in the Figure 2.

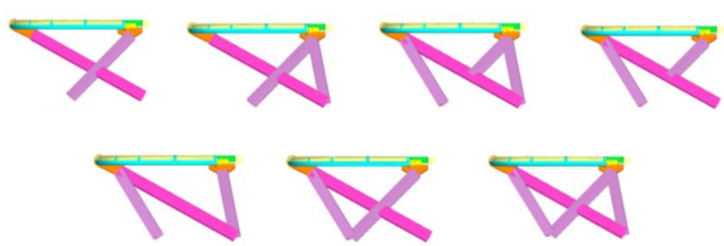


Figure 2 - Configurations evaluated during the development phase.

MATERIAL AND METHODS

The units considered for this finite element model are:

Length: inches (in)
Time: milliseconds (ms)
Force: pound-force (lbf)

The analyses were performed with a HYBRID III 95th Percentile Dummy provided by LSTC.
The seatbelt was modeled using 2D/1D seatbelt segments connected by rigid elements as shown in Figure 3.

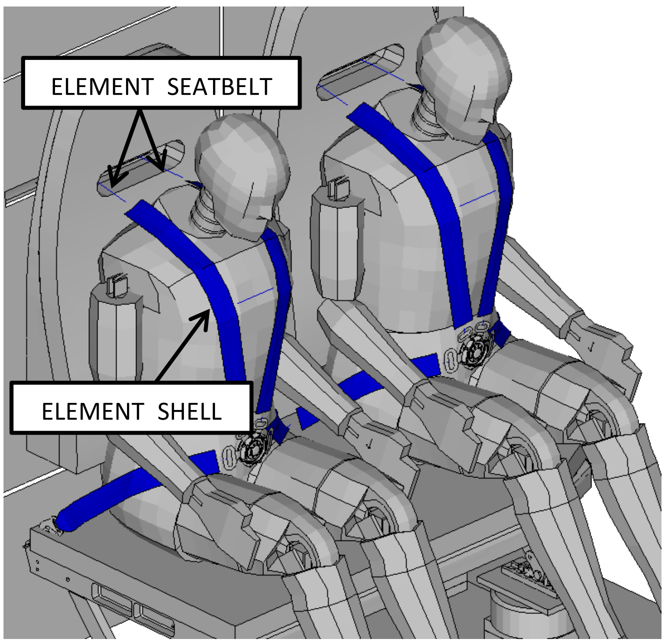
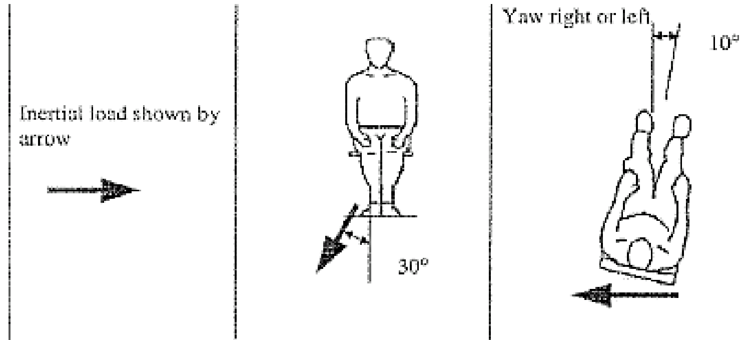


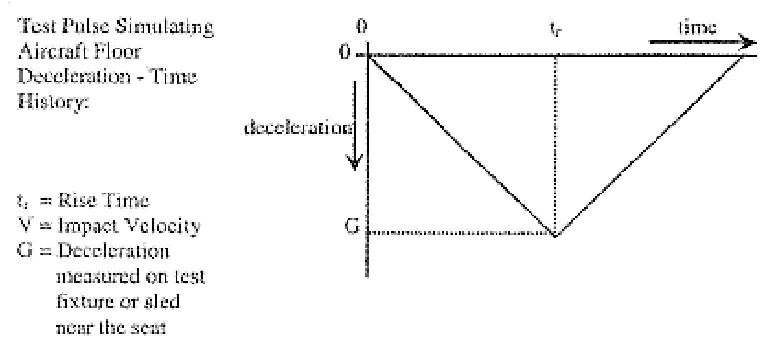
Figure 3 – Seatbelt Elements Analyses

The element type used for 1D seatbelt segments was ELEMENT_SEATBELT with Material type MAT_SEATBELT and for 2D seatbelt modeling ELEMENT_SHELL with material type MAT_FABRIC.
The force versus engineering strain curves for load and unload were used as input for material model seatbelt provided by supplier.
The metal parts were modeled using 2D or 3D elements with MAT_PIECEWISE_LINEAR_PLASTICITY, MAT_ELASTIC, MAT_NULL or MAT_RIGID material. 3D elements were covered with 2D elements using MAT_NULL materials in order to improve contact behavior.
The dynamic impact load conditions prescribed in Table 1 are applied to the seat and support structure. The failure criteria for dynamic load are the loss of primary load path or detachment of the seat. Seat damage is acceptable, provided a continuous load path remains between the occupant and the seat attachments. Acceptable damages to the load-carrying elements include bending deformation, tension deformation, compression crippling, shear buckling and the shearing or separation of fasteners.

Table 1 – Dynamic Impact Load Conditions, 14 CFR 25.562



Configuration 1	1-Man/2-Man	1-Man/2-Man
Configuration 2	3-Man	3-Man
Min V m/s (ft/s)	10.67 (35)	13.41 (44)
Max t_r (sec)	.08	.09
Peak G	14	16
Deform floor:		
Degrees roll	0	0
Degrees pitch	0	0



We analyzed a total of 7 different cases from OCTUBER 8th, 2015 to NOVEMBER 12th, 2016 to determine the most severe cases to perform in dynamic tests.

CASE	1	2	3	4
CONDITION	16g +10°YAW	16g -10°YAW	16g +10°YAW	16g -10°YAW
DEFORMED FLOOR	- 10° PITCH and +10° ROLL		- 10° PITCH and -10° ROLL	

CASE	5	6	7
CONDITION	16g +10°YAW	16g -10°YAW	14g +30°PITCH
	HIC		-

Figure 4 Cases Evaluated in Dynamic Analysis

RESULTS

The results of the analyses determined that the most critical configuration in the 16g structural condition (deformed floor) was case 1. This case has a +10 YAW rotation and a floor deformation of -10 pitch +10 Roll, as shown in Figure 5. The most critical region is the beam that supports the front leg, which shows 9.7% plastic strain. Based on the dynamic analyses, only the most critical cases (16g FWD and 14g DOWN) were performed at the National Institute for Aviation Research (NIAR) laboratory in Wichita, on January 5th and 6th, 2016.

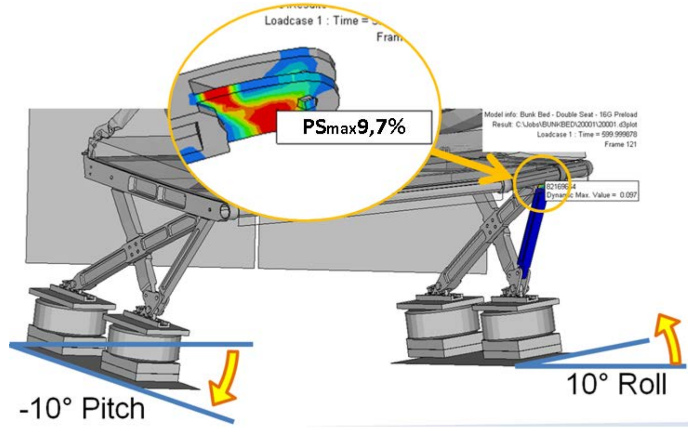


Figure 5 – Critical Case Evaluated in Dynamic Analyses

16g FORWARD - DYNAMIC TEST RESULTS

The acceleration and speed employed on the sled in the 16g FWD test are shown in Figure 6.

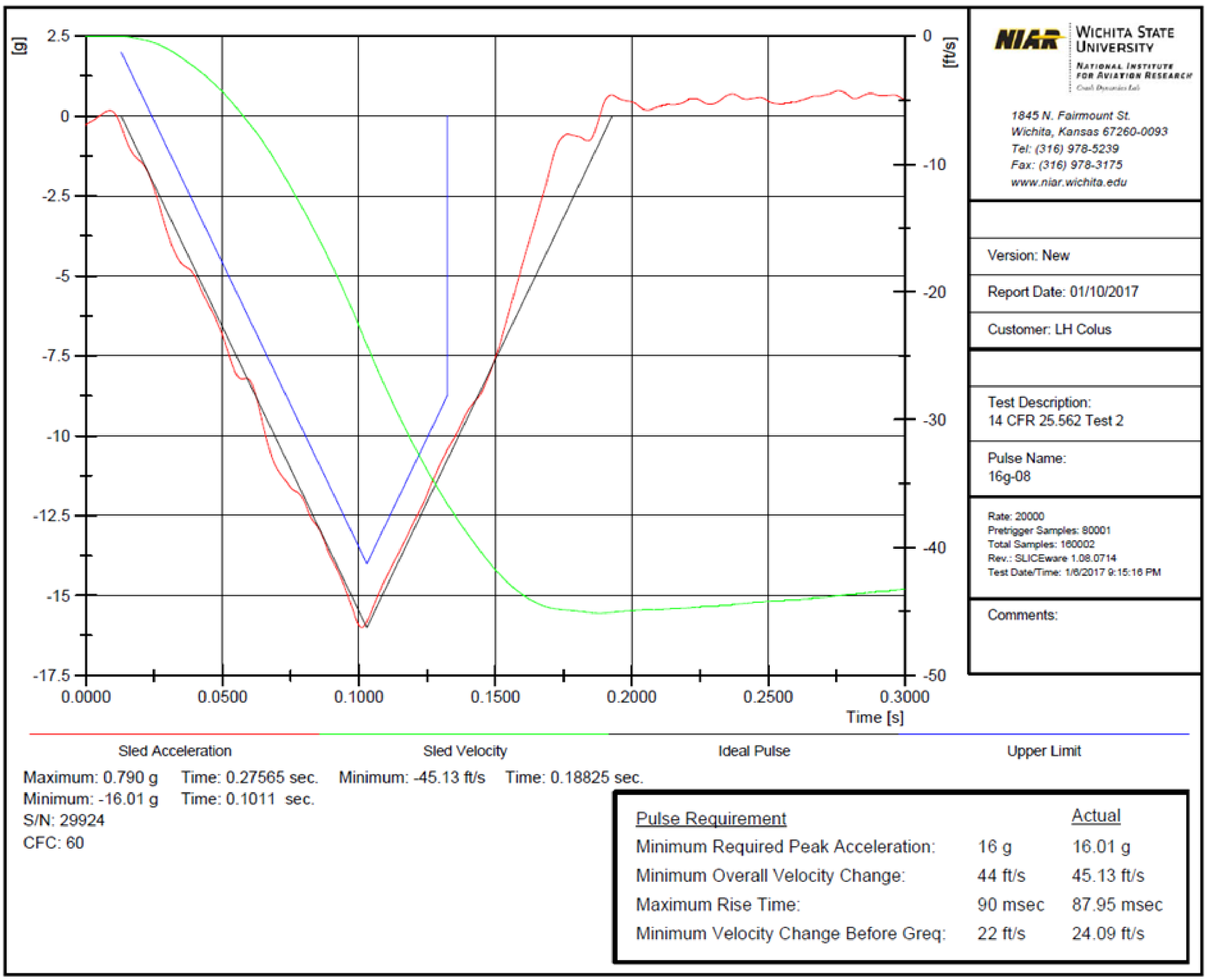


Figure 6 Acceleration and speed employed on the sled in the 16g FWD test

The dynamic model showed a kinematic behavior very similar to the 16g FWD test. The Figure 7 shows a comparison between analyses and test at the point where the seat showed the greatest deformation, at the exact moment the dummy collides with the seat. The Figure 7a and Figure 7b show the results obtained in the test and by analyses respectively, while figure 7c shows an overlap of test vs. analyses images in the seat structural region only. It can be seen from Figure 7c that the structural "X" beams deformed visually identically.

A total of 13 points were measured before and after testing in order to record the plastic strain of the structure (Figure 8).

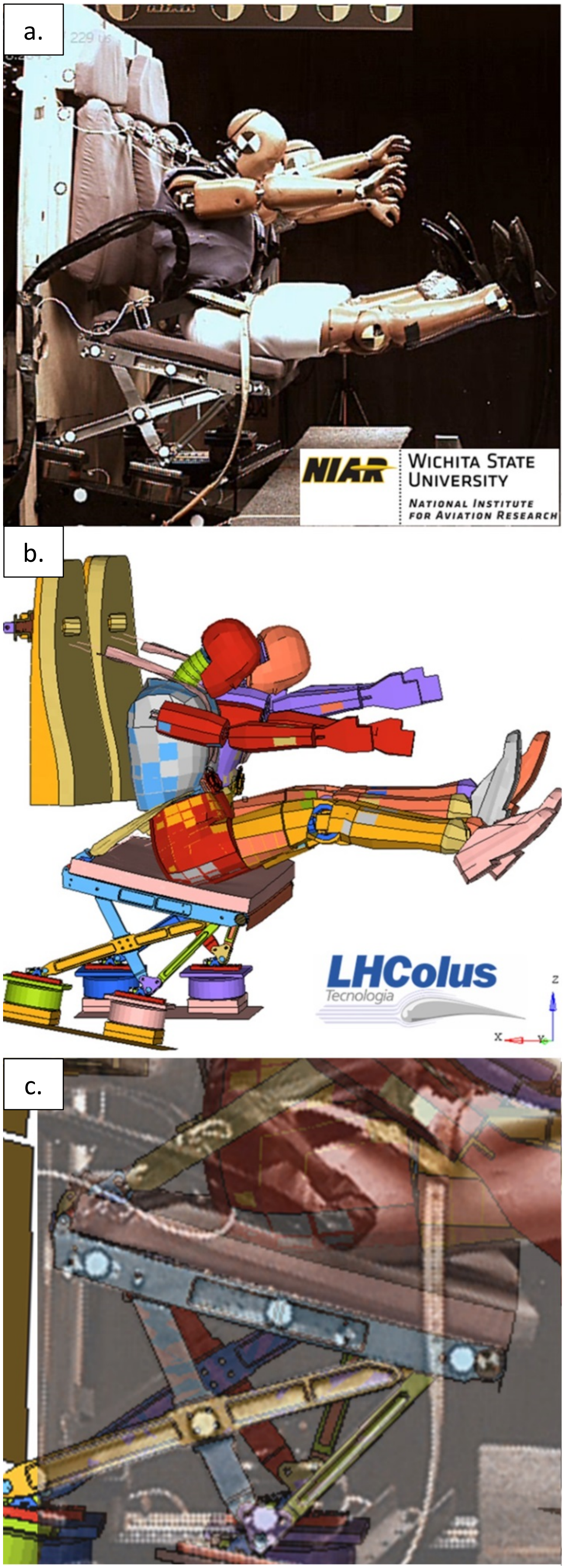


Figure 7 Comparison between analyses and test 16 FWD

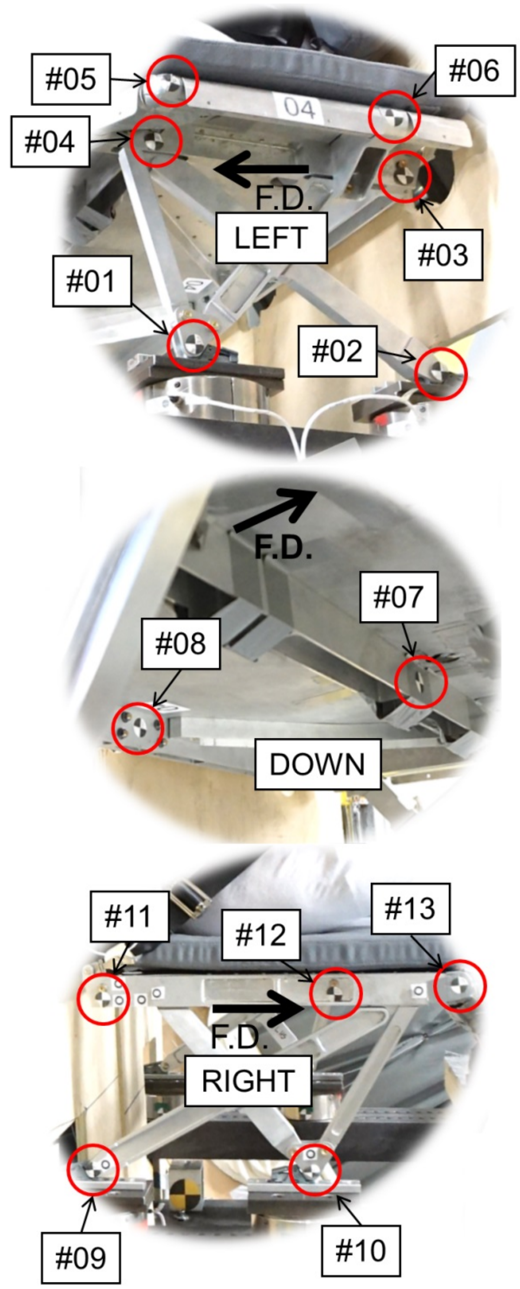


Figure 8 Measurement points of plastic deformation

Subsequently, the same points were evaluated in the dynamic model and summarized in a Table 2, with the delta displacements (final minus initial displacement). The highest delta displacement value found in the case of 16g FWD was 0.7 in at point 8.

The result in the most critical region as previously shown in Figure 5, which was expected for 9.7% of plastic strain, is shown in Figure 9, presenting a visual correlation between test and analyses result, with an overlapping image of the two results. The Figure 9a shows the result of the analyses with a front view of the item, Figure 9b shows the result of the test with a front view of the item, and Figure 9c shows an overlapping image of the results 7a + 7b. The same is shown in Figures 9d, 9e and 9f, only in the rear view.

Table 2 Deformation Data 16g FWD

16g 25.562 - DEFORMATION DATA				
POINT	DELTA ANALYSIS (in)	DELTA TEST (in)	DIFFERENCE	
	RESULTANT	RESULTANT	(in)	(%)
1	0,12	0,07	0,05	72%
2	0,04	0,02	0,02	117%
3	1,14	0,53	0,61	116%
4	1,10	0,53	0,57	108%
5	1,09	0,54	0,56	104%
6	1,10	0,53	0,57	108%
7	1,17	0,56	0,62	110%
8	1,21	0,51	0,70	137%
9	0,10	0,07	0,03	43%
10	0,06	0,02	0,03	149%
11	1,17	0,57	0,61	107%
12	1,04	0,55	0,49	89%
13	1,08	0,58	0,49	85%

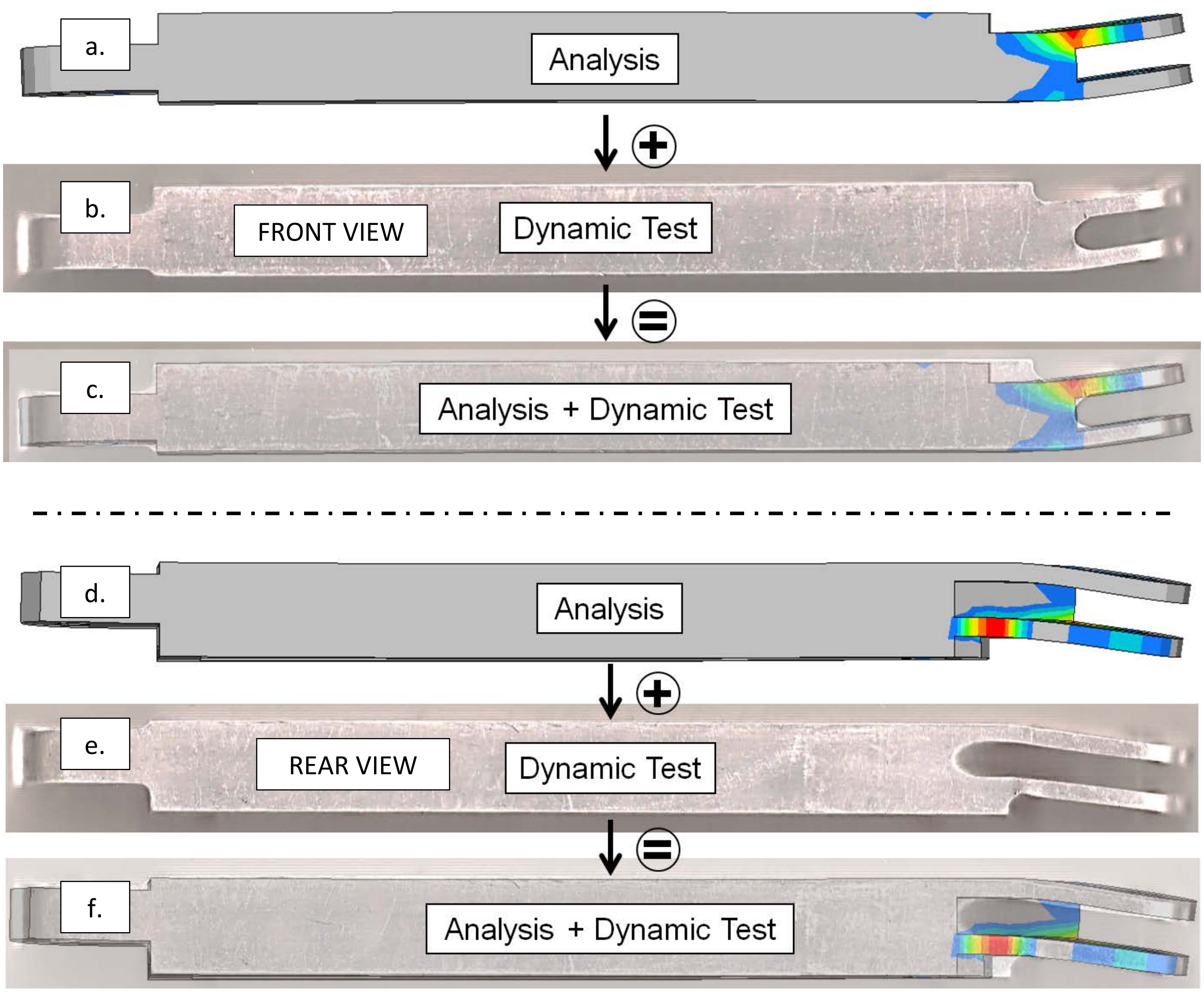


Figure 9 Maximum Plastic Strain Results

The Head Injury Criterion (HIC) is a measure of the likelihood of head injury arising from an impact.

The Figure 10 shows the HIC results in the test, and Figure 11 and Figure 12 shows the HIC results by analyses. The Table 3 provides a summary of HIC results, where all results are well below the maximum value of 1000 allowed by requirement 25.562.

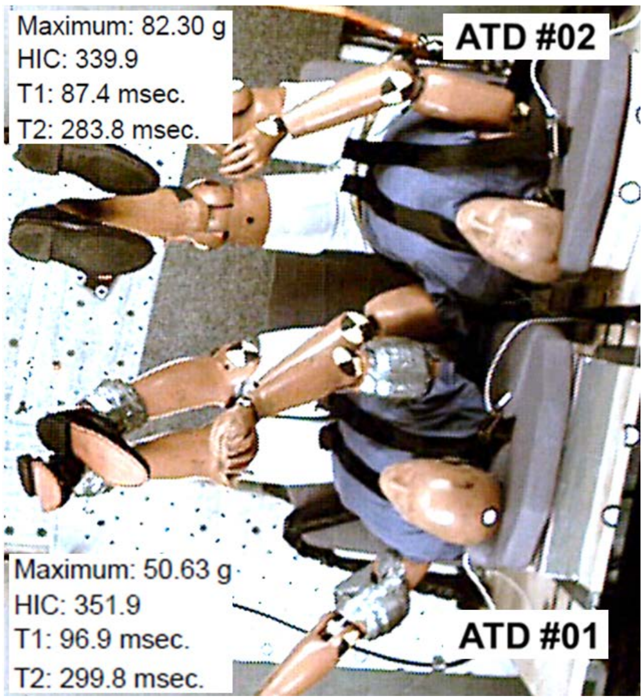


Figure 10 HIC Test Result

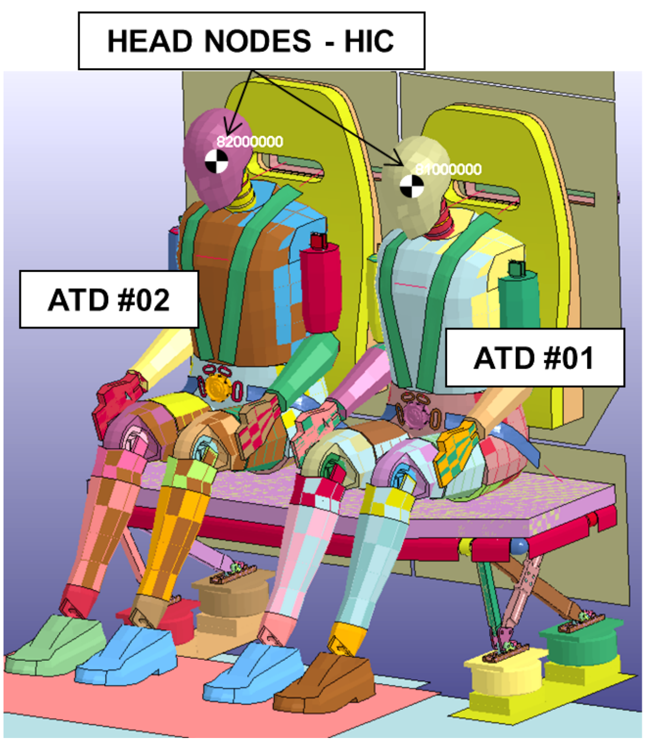


Figure 11 HIC Analysis Result

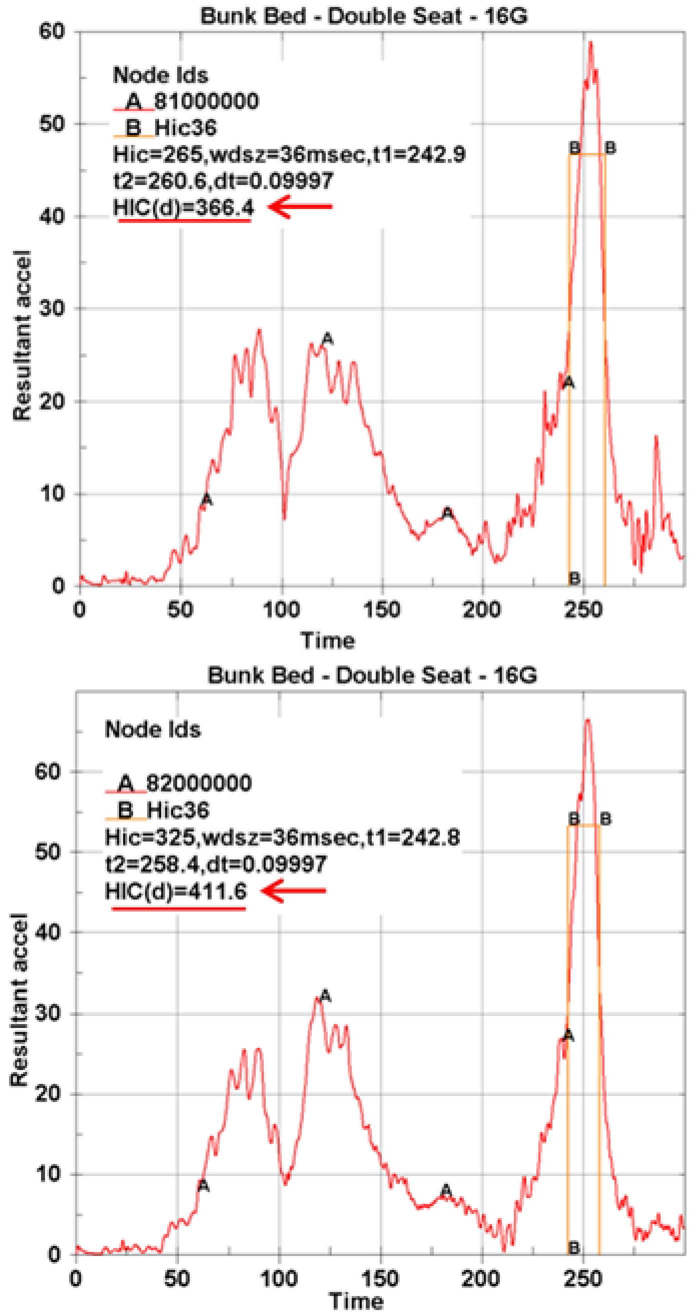


Figure 12 HIC Analysis Result

Table 3 Resume HIC Results

HIC - Head Injury Criterion			
DUMMY	ANALYSIS	TEST	DIFFERENCE
ATD #01	366	352	4%
ATD #02	412	340	21%

The loads obtained on the seat belts were divided into torso and lap loads, right and left loads, as shown in Figure 13.

The results obtained by testing and dynamic analyses are presented in Figure 14, containing the load vs. time graph. The maximum loads and some statistics, such as the percentage of load that followed the TORSO and LAP path, are shown in Table 4.

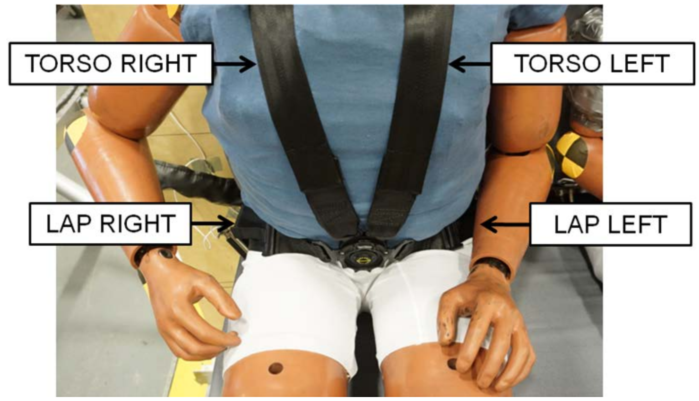


Figure 13 Nomenclature Seat Belt

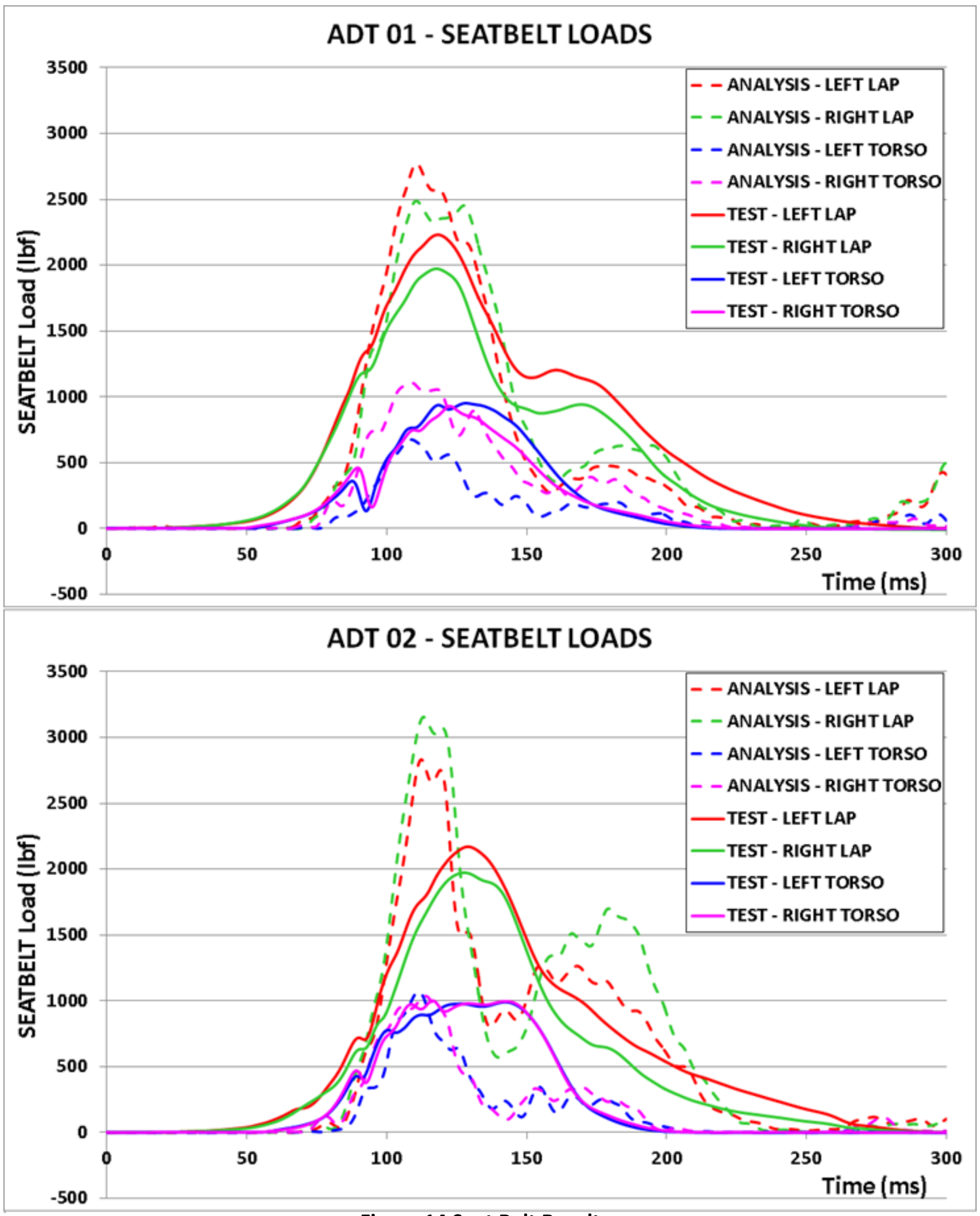


Figure 14 Seat Belt Results

Table 4 Resume Seat Belt Results

MAXIMUM SEATBELT LOADS - ATD 01			
POSITION	SEATBELT LOAD (lbf)		DIFFERENCE (%)
	ANALYSIS	TEST	
LEFT LAP	2773	2231	24%
RIGHT LAP	2487	1973	26%
LEFT TORSO	675	951	-29%
RIGHT TORSO	1105	928	19%
STATISTICS	LOAD (lbf)		DIFFERENCE (%)
	ANALYSIS	TEST	
TOTAL LOAD	7040	6083	16%
TORSO LOAD	1779	1880	-5%
LAP LOAD	5260	4203	25%
TORSO LOAD PERCENTAGE	25%	31%	-
LAP LOAD PERCENTAGE	75%	69%	

MAXIMUM SEATBELT LOADS - ATD 02			
POSITION	SEATBELT LOAD (lbf)		DIFFERENCE (%)
	ANALYSIS	TEST	
LEFT LAP	2832	2170	30%
RIGHT LAP	3155	1973	60%
LEFT TORSO	1070	990	8%
RIGHT TORSO	1037	1001	4%
STATISTICS	LOAD (lbf)		DIFFERENCE (%)
	ANALYSIS	TEST	
TOTAL LOAD	8094	6133	32%
TORSO LOAD	2107	1990	6%
LAP LOAD	5987	4143	45%
TORSO LOAD PERCENTAGE	26%	32%	-
LAP LOAD PERCENTAGE	74%	68%	

14g DOWN - DYNAMIC TEST RESULTS

For the 14g down case, the lumbar load parameters and deformations in the seat structure were evaluated. The Figure 15 shows the initial setup of the test setup and the dynamic model. The acceleration and velocity employed on the test sled are shown in Figure 16.

Similar to the 16g FWD case, for the 14g DOWN condition the dynamic model showed a kinematic behavior very similar to the test, as shown in Figure 17. The figure 17a shows the exact moment when the dummy collides with the seat, while Figure 17b shows the maximum displacement of the dummies.

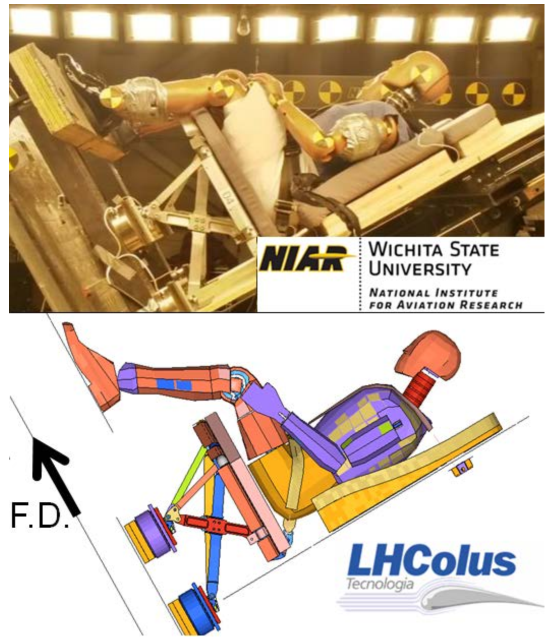


Figure 15 Test Setup 14g DOWN

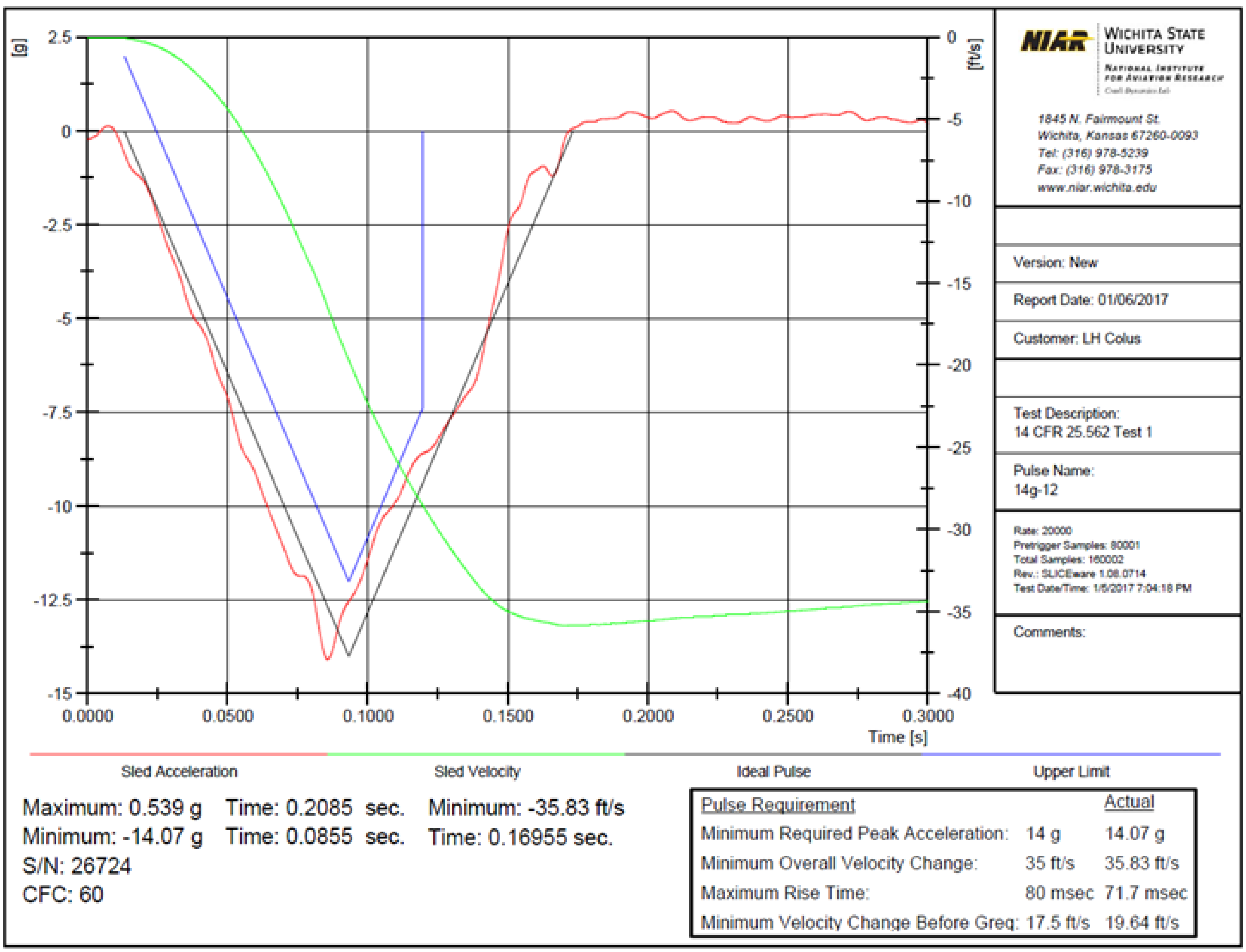


Figure 16 Acceleration and speed employed on the sled in the 14g DOWN test

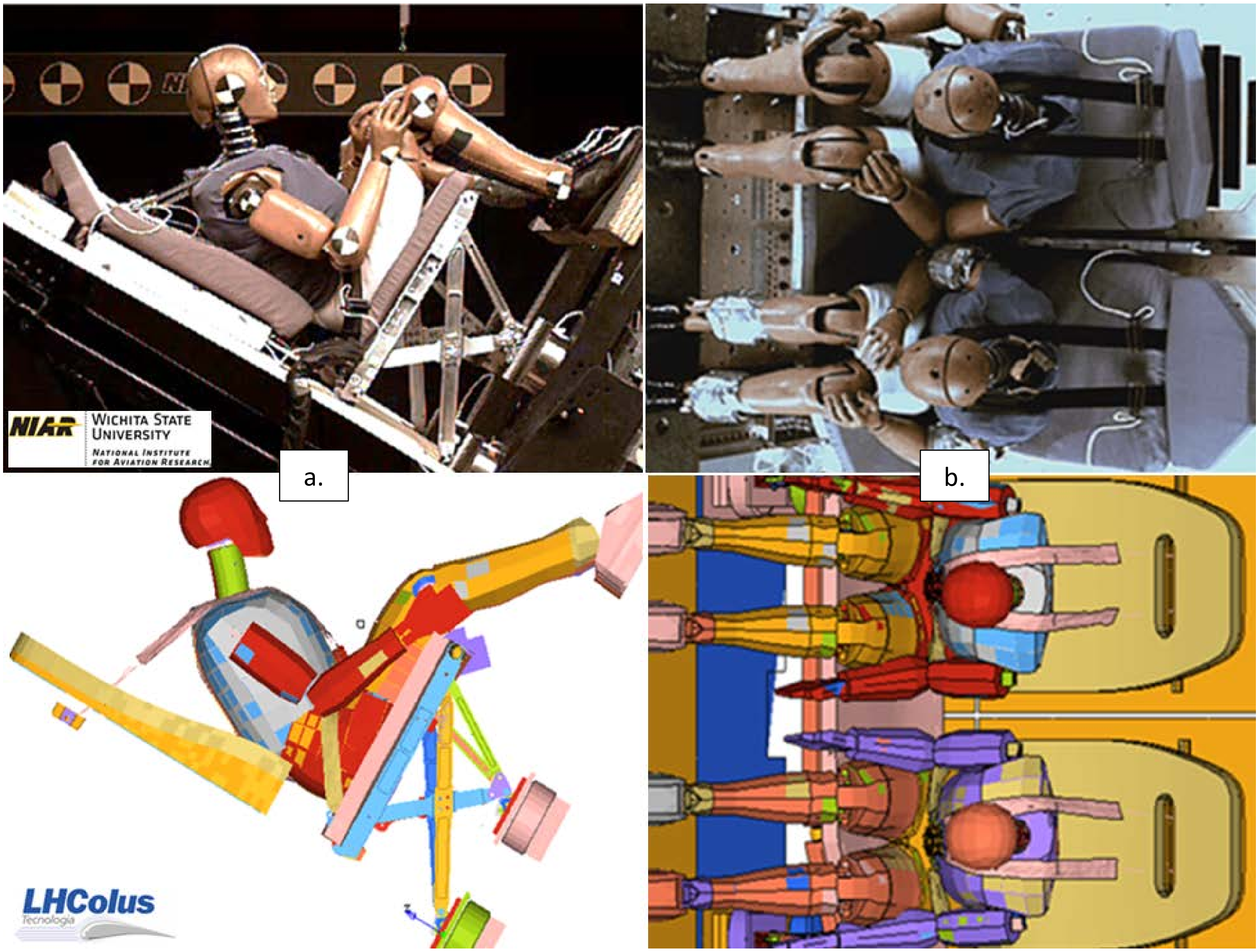


Figure 17 Kinematic behavior 14g DOWN

The same 13 points described in figure 8 were measured before and after the test to record the plastic strain of the structure. The Table 6 presents delta displacement values in the test and dynamic model. The highest delta displacement value found in the case of 14g DOWN was 1.7 in at point 13.

The results of lumbar loads obtained by analyses and test are summarized in Table 5 and a graph of LOAD vs. TIME of lumbar load is shown in Figure 18.

Table 5 Resume Lumbar Loads

Lumbar Load (lbf)			
DUMMY	ANALYSIS	TEST	DIFFERENCE TEST X ANALYSIS
ATD #01	-1457	-880	66%
ATD #02	-1469	-1153	27%

Table 6 Deformation Data 14g DOWN

14g 25.562- DEFORMATION DATA				
POINT	DELTA ANALYSIS	DELTA TEST (in)	DIFFERENCE	
	RESULTANT	RESULTANT	(in)	(%)
1	0,21	0,73	-0,53	-72%
2	0,39	0,86	-0,47	-55%
3	2,41	2,05	0,35	17%
4	1,27	1,95	-0,68	-35%
5	1,63	1,53	0,10	7%
6	1,71	0,78	0,93	118%
7	2,02	2,92	-0,90	-31%
8	0,86	1,66	-0,80	-48%
9	0,06	0,74	-0,68	-92%
10	0,15	0,54	-0,39	-73%
11	3,01	1,93	1,08	56%
12	0,63	2,26	-1,63	-72%
13	1,30	2,97	-1,67	-56%

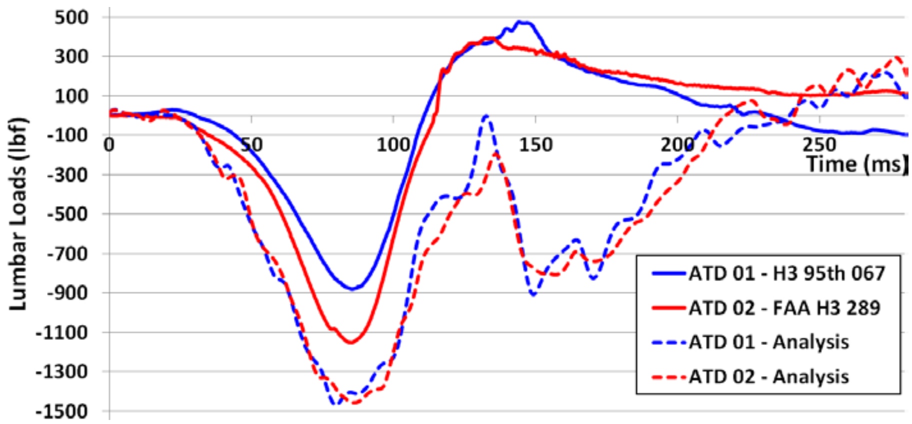


Figure 18 Lumbar Loads 14g DOWN

DISCUSSION

The discussion will be divided into 5 main topics covered in this paper. These are: Kinematics, Structural Deformations, Head Injury Criterion (HIC), Seat Load Loads and Lumbar Loads.

An extremely relevant point is that all the dynamic analyzes presented in this article were performed prior to performing the dynamic tests in the NIAR laboratory. No analysis was refined after testing to validate the dynamic model, because the intent of the modeling work was just to prevent a possible failure of the dynamic tests, but since no dynamic tests failed, no reworking of the models was necessary.

1. Kinematics:

The results of the displacements of the dummies were very representative with those obtained in the tests. This result was important to ensure that the torso seat belt remain on the occupant's shoulder during impact and the lap seat belt remains on the occupant's pelvis during impact, as required by requirement 14 CFR §25.562 (c)(3) and (c)(4).

2. Structural Deformations:

The results of plastic strain were widely used in the product development phase to design and calculate all structural components of the crew seat. Thus, it was possible to successfully meet the requirements of 14 CFR § 25.562 (c) (7) and (c) (8), where it requests that the seat remain fixed at all attachment points, although the structure may have yielded and that must not yield to the extent they would impede rapid evacuation of the airplane occupants. It was possible to map before the test the region with the most critical plastic strain, safely predicting the maximum plastic strain at 9.7% found in the structure shown in on Figure 9 and allowing local reinforcement of the part in anticipation of a possible failure.

A satisfactory correlation was also obtained between the delta displacement expected by the analyzes and those obtained in the tests, obtaining a maximum difference between the measurements of only 0.7 in for the structural condition of 16g FWD and 1.7 in for the condition 14g DOWN.

3. Head Injury Criterion (HIC):

A prior analysis of the HIC coupled with a good kinematic correlation allowed us to successfully pass the criteria established by requirement 14 CFR § 25.562 (c) (5). Where it determines that each occupant must be protected from serious head injury under 16g FWD conditions, ensuring that head impact does not exceed a Head Injury Criterion (HIC) of 1000 units. By analyzing the kinematics of seat belt clearance and seat deformation, it was possible to predict before performing the tests a low values for the HIC generated by the rebound effect on the head.

4. Seat Belt Loads:

Total torso seat belt loads shall not exceed 2,000 lbs as required by requirement 14 CFR § 25.562 (c) (1). However, the dynamic analysis result was slightly above the requirement limit, 2107 pounds. It was decided to proceed with the test, even with this result, because the torso seat belt attachment point was already set on the aircraft. The test result ended within the limit, with a sum of 1990 pounds of the most critical case.

5. Lumbar Loads:

The lumbar load parameter was used in the project development phase, balancing the seat's stiffness to absorb some of the energy that would be transferred to the occupant's lumbar region and still remain with structural integrity without major plastic deformations that make occupant evacuation difficult.

The 14 CFR § 25.562 (c) (2) requires that the maximum compressive load measured between the pelvis and the lumbar spine of the anthropomorphic manikin shall not exceed 1,500 pounds.

CONCLUSION

The overall result of these analyses was very positive, once it was observed a very good correlation with the dynamic test performed and contributing to expedite the product development and qualification. The double crew seat was approved in the dynamic tests, complying with all the requirements defined by the 14 CFR § 25.562, including HIC conditions, without any failures.

AUTHOR'S BIOGRAPHY

LOUREIRO, P. L. G.

Mr. Loureiro is graduated in Aerospace Engineering by the University of Vale do Paraíba - Brazil with one year at the Polytechnic University of Catalonia – Spain.

In 2015, received the Professional Training Award by the Brazilian Regional Engineering Council of the State of São Paulo (CREA-SP), received the Academic Merit of the University of Vale do Paraíba - Best student of the Aerospace Engineering Course and received the Institute of Engineering Award - Best Student of the Faculty of Engineering, Architecture and Urbanism of the University of Vale do Paraíba.

Currently working as an aeronautical engineer at LHColus Technology for more than four years with static/dynamic analysis and engineering tests for the development and qualification aeronautical products.

- Participations in the Embraer KC-390 Aircraft with the LHColus Technology team:

• Participated in development and qualification of Troop Seats and Litter (TSL); The Bunk Bed Seat (Crew Seat); The Buffer Stop Assembly (BSA), barrier system for cargo containment in the Cargo Handling System (CHS);

• Participated in Proof of Concept (PoC) of several electromechanical load release devices (Cargo Handling System - CHS);

• Coordinator of the Auxiliary Fuselage Fuel Tank (AFFT) TUBES ASSEMBLY Program, development and qualification.

- Other participations with the LHColus Technology team:

• Participated in modifications of aircrafts, obtaining Supplementary Type Certificates (STC) issued by the Brazilian Civil Aviation Regulatory Agency (ANAC).

COLUS, L. H. M.

Luís Henrique Médici Colus is a Brazilian Aeronautical Engineer, graduated by the USP (University of São Paulo), Brazil, in 1985. Its Master Degree in Aeronautical Engineering (Thesis in Aeroelasticity Phenomena) was obtained in ITA (Instituto Tecnológico Aeronáutico), Brazil, in 1993.

From 1987 to 1999, Luís Colus had an actuation as a member of the airframe group in the Brazilian Aircraft Certification Office (CTA). Since 2000 has a PCP (similar to FAA/DER) with CTA/Anac for Structures and interiors areas.

From 1999 to 2008, Luís Colus worked for Akaer Engenharia as the Engineer Coordinator including Structures, Damage Tolerance, SRM, and Certification activities.

Since 2008 to now, Luís Colus is the Company founder and executive director of L.H. COLUS TECNOLOGIA LTDA., an Engineering and design office, specialized in structural area, with wide experience in developing and conducting several approval processes in Brazilian certification authority (Anac).

Luís Colus is being ahead of LHColus Tecnologia, which is a company for structural design and engineering working simultaneously to create feasible solutions with lower costs, following weight restrictions, and maximizing performance of the final product.

LHColus Tecnologia was contracted by Embraer in 2012 for the workpackage “Troop Seats and Litters” (TSL), of Aircraft KC-390, in order to provide engineering services for the development and qualification of these items, including the manufacturing for series aircraft and aftermarket support. As a consequence of this initial program, other systems have been contracted later, such as the bunk bed (only development) and the cargo barrier – buffer stop (development and supplying for the series).