Simulation of a Helicopter Cockpit Air Bag System with MSC/DYTRAN

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ABSTRACT

In the development of inflatable restraints for automobiles, engineers have become increasingly reliant on analytical methods to support design efforts. Current efforts to develop inflatable restraints for helicopter cockpits are also relying on analytical methods to gain efficiency in the design process. Applying inflatable restraint technologies to a helicopter cockpit is often a retrofit system integration, since typical airframe service lives are on the order of 30 years and new aircraft models remain rare. Thus, since the placement of air bag components is usually not optimum, the trajectory of the deploying air bag must be precisely controlled. This is accomplished with innovative folding schemes and prescribed bag-structure and bag-occupant contacts that will guide the air bag to its desired position. In the majority of helicopter applications, adequate air bag load-bearing surfaces do not exist. This drives the air bag shapes to be fairly complex, compared to an automotive air bag. To meet the challenges of this modeling effort, the MSC/DYTRAN code was selected and modeling techniques have been developed to realistically simulate single- and multiple-bag helicopter air bag systems.

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1. INTRODUCTION

Designing a cockpit air bag system (CABS) for helicopter applications involves several unique and challenging design issues. First, potential crash scenarios cover a wide range of conditions, creating a need for multiple air bags per occupant. The need for multiple air bags is exacerbated by the proximity of lethal strike hazards that the occupant may impact during a crash event. Second, several helicopter models include energy-absorbing crewseats that displace downward relative to the airframe (up to 17 in.) to prevent excessive loading of the occupant's spine in crashes with significant vertical impact velocities. Third, most helicopter applications for CABS involve complex geometric challenges because of the layout of the controls, structure, and for military applications, targeting systems and armor. Finally, the majority of potential applications are retrofit, often requiring placement of CABS components in non-optimum positions. It is, therefore, essential to control the air bag's deployment trajectory by using specific air bag fold patterns and tailoring the air bag's interactions with the bag cover, occupant, and aircraft components.

MSC/DYTRAN, a program developed to simulate highly nonlinear transient dynamic events, was chosen as the analytical tool for the simulating and design support analyses of the CABS program. MSC/DYTRAN's robust contact algorithm allowed the modeling of the air bag fold contacts, as well as the air bag's contact with the surrounding cockpit structure. In addition, MSC/DYTRAN's ability to model an occupant's motion via a public-domain crash victim simulator program was also useful for investigating the effectiveness of CABS in an occupant/air bag/cockpit combination.

2. PROBLEM DEFINITION

The primary goal for the CABS analytical efforts described in this paper was to develop a model which can simulate the function of a folded air bag in a helicopter cockpit environment. Accurate representation of the internal bag fold contacts as well as the air bag's contact with the crewmember and surrounding cockpit structure is required. Simulating the motion of the restrained pilot and stroking energy-absorbing seat in a crash situation must also be addressed. In addition, the modeling of the cockpit strike hazards must be of adequate fidelity for proper interaction with the occupant and deploying air bag. The analytical simulation must also be correlatable with test data.

3. ANALYSIS

3.1 METHODOLOGY

Since all of the helicopter safety devices are assumed to work as a system, the efforts included modeling, as a system, the occupant, the energy-absorbing crewseat, the five-point restraint, the cockpit structure, and the air bags. Each part of the model was developed individually in a manner that allowed the models to be combined into a single system model. First, an occupant model was developed to represent the seated, restrained crewmember. The occupant model represented the crewmember's body segments, their mass properties, and the stiffness properties of the joints. Second, the energy-absorbing crewseat was modeled. Third, the cockpit structure was modeled with surfaces that will contact the air bag(s) and potential strike hazards defined appropriately. Any surface in the cockpit which the occupant may contact (e.g., the instrument panel, cyclic control stick, canopy, etc.) was modeled with adequate fidelity to accurately represent the strike hazard. Fourth, a deploying air bag model was developed which can contact the occupant and surrounding cockpit structure. This air bag model must have sufficient contact definitions for the internal folds as well as adequate fidelity to properly simulate the unfolding of the bag. The inflation of the bag was defined by the user in the form of gas mass flow time histories and gas inflow temperatures. Finally, the three simulated components (occupant/seat model, air bag model, and cockpit structure model) were integrated into a single model for conducting simulations to examine the effectiveness of the CABS.

3.2 OCCUPANT MODEL

In order to simulate the occupant motion and interaction with MSC/DYTRAN elements, the crash victim simulator program called Articulated Total Body (ATB) Model is included in the MSC/DYTRAN code. ATB is a public-domain program developed by the U.S. Air Force Armstrong Medical Research Laboratory for predicting gross occupant motion for a variety of dynamic events, including aircraft ejection with windblast exposure. ATB has been in existence since 1975, and has frequently been used to simulate an occupant's motion in crash conditions. The occupant's body segments are represented as rigid sections with mass properties and joint stiffnesses taken from a statistical database of human measurements. The input file for ATB is separate from the MSC/DYTRAN input deck and follows the format defined in Reference 2.

For the efforts described in this paper, a 95th-percentile human male model was developed with the ATB program (see Figure 1). The occupant is oriented in a seated position with rectangular planes defining the seat pan, seat back, and floor. The contact of body segments with each other and with the rectangular planes is defined in the ATB program. In addition, the stroking energy-absorbing seat was modeled using two ATB contact segments which simulated the function of the seat's energy absorbers. Several check runs were made to ensure the stability of the ATB pilot model input data.

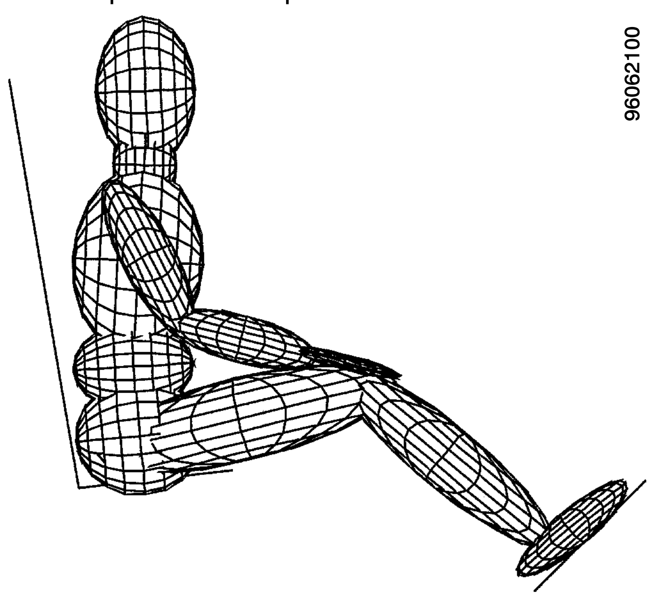

Figure 1.
Articulated Total Body occupant model.

A three-step process was used to incorporate the ATB occupant model into the MSC/DYTRAN simulation. First, RELEX cards were used to define each rigid ellipsoid in ATB that may have contact with an MSC/DYTRAN element. For example,

RELEX,UT,ATB

defines a rigid ellipsoid in MSC/DYTRAN for the upper torso as specified in the ATB program.

Second, shell elements were created to represent the contact surfaces of the ATB ellipsoids. While these shell elements usually are formed in an ellipsoidal shape with the same size as the ATB ellipsoids, they can be of any shape desired for contact purposes. For example, the head segment in ATB is represented as an ellipsoid, but the contact surface for the head in an MSC/DYTRAN simulation can have more realistic features (see Figure 2). For the simulations described in this paper, ellipsoidal shapes were used for defining the occupant body contact surfaces.

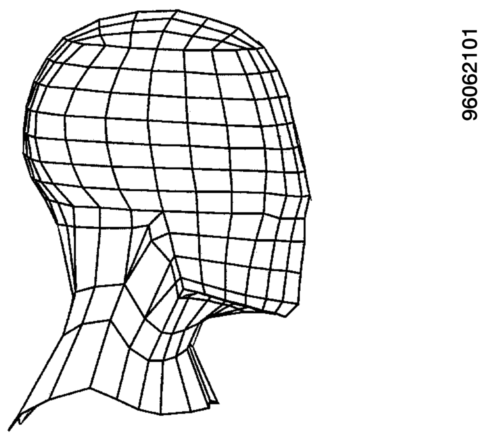

Figure 2.
Realistic head contact surface in MSC/DYTRAN.

Third, the shell elements representing the body segment contact surfaces were attached to the appropriate ATB segment by using the RCONREL card. This was done by specifying that all shell elements with a certain rigid material ID shall be connected to a specific ATB rigid ellipsoid. For example, the following cards specify that all elements with the rigid material ID of 7001 will be attached to the external rigid ellipsoid defined on a RELEX card with the label "UT":

```
SETC,100,UT
SET,200,7001
RCONREL,1,100,RIGID,200
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After completing these steps, a CONTACT card was used to specify contact between the shell elements attached to the ATB segments and other MSC/DYTRAN elements in the simulation. Parameters such as contact friction and force factors also were adjusted on the CONTACT card.

3.3 AIR BAG MODEL

The forward air bag in this simulation was designed to protect the pilot from striking the instrument panel, glare shield, and cyclic control stick in a crash situation. Because of the air bag's unique shape (see Figure 3), modeling the folded bag is a complex task.

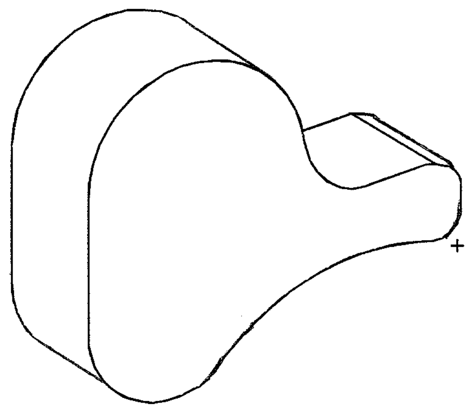

Figure 3.
Forward air bag design.

A technique was developed by Simula and the MacNeal-Schwendler Corporation (MSC) which allows the folding of uniquely shaped air bag models. This technique is based on the premise that the surface along the perimeter of the bag is the driving force in the bag's deployment. Therefore, the sides of the bag can be excluded from the internal fold contact definition. This simplifies the folding of the bag, since the primary concern is the perimeter surface of the bag, which can be modeled as a series of flat surfaces. Using this premise, the bag can be folded in three steps:

(1) Using MSC/PATRAN, the air bag is modeled in its unfolded state using triangular membrane elements (see Figure 4). Flat surfaces are used to represent the perimeter of the bag with the edges of the surfaces located on the bag fold lines. Then, a bulkdata file for this model is written to a file called bag_model.bdf.

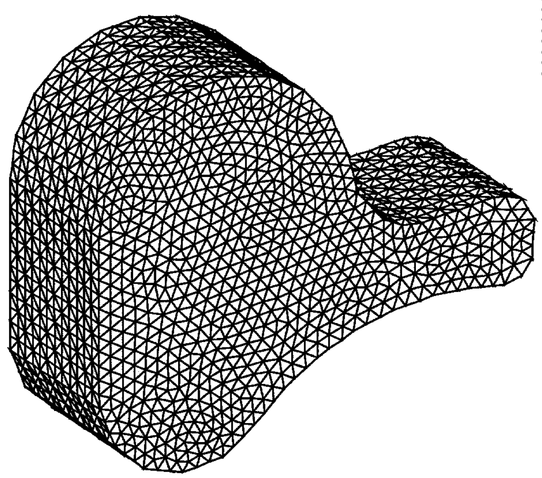

Figure 4.
Unfolded air bag model.

(2) Using MSC/PATRAN, the sides of the air bag model were removed and the perimeter sections of the bag (see Figure 5a) were folded consecutively until the entire bag was folded (see Figure 5b). An in-plane folding method was used, making a folding operation equivalent to rotating grid points over 180 degrees around a fold line. Note that the majority of the bag folds lie in the same plane, which represent a zero-thickness condition. Then, a bulkdata deck containing the GRID cards for the folded bag perimeter was written to a file called folded_grids.bdf.

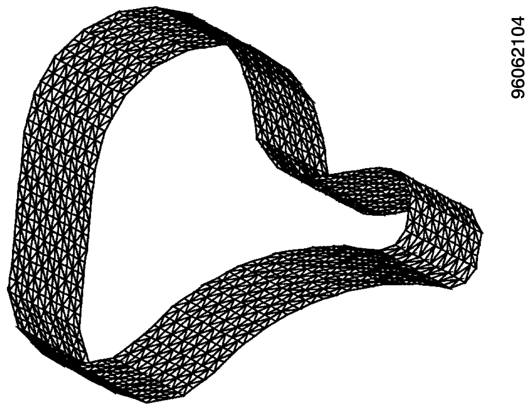

Figure 5a.
Perimeter of the air bag.

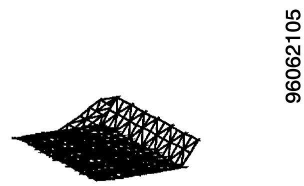

Figure 5b.
Folded air bag perimeter.

(3) Using MSC/DYTRAN in conjunction with a FORTRAN-user routine called simula_fold.f (see Figure 6), a simulation was conducted so that the grids on the perimeter of the unfolded air bag model were moved slowly to the location of the grids defined in folded_grids.bdf. During the transforming process, the sides of the bag were allowed to crumple up (due to the stress build-up in the membrane elements) as the perimeter grids were moving to the folded position (see Figure 7). The geometry for the final folded air bag model was written out at the end of the MSC/DYTRAN folding run to a file called folded_bag.dat.

Figure 6.
Air bag folding flowchart.

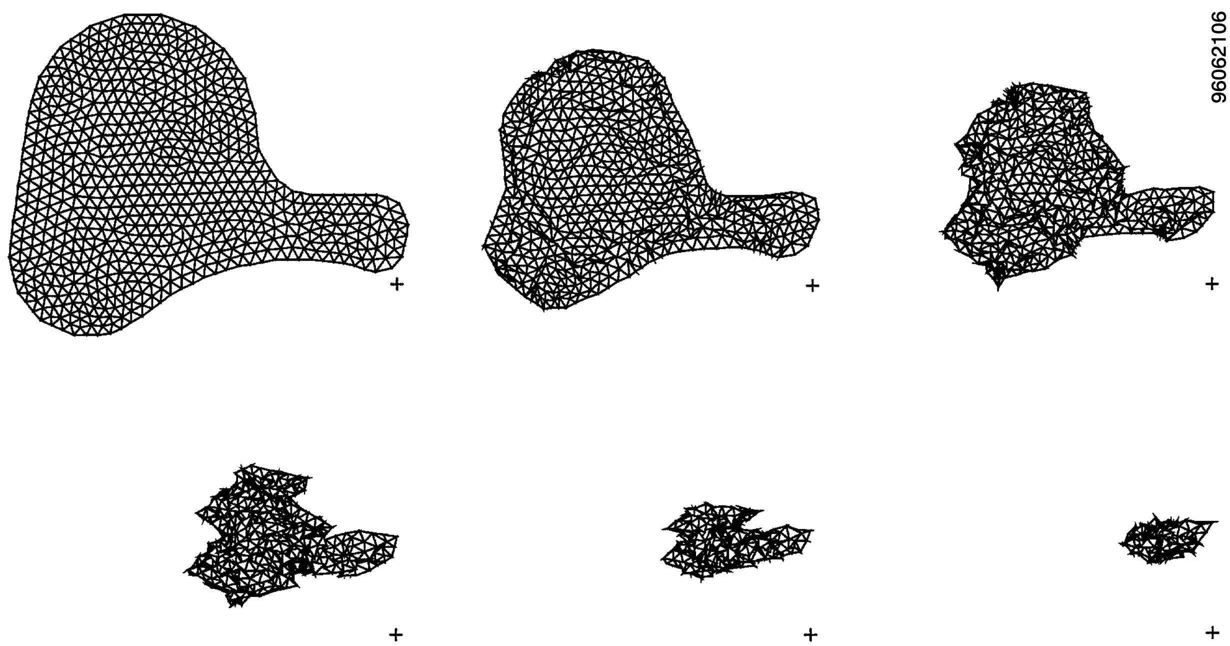

Figure 7.
Air bag folding sequence.

The internal bag fold contacts then were defined using the SURFACE, SUBSURF and CONTACT cards. Because some of the elements representing the bag fold surfaces lie in the same plane, CONTINI cards were required to specify initial contact conditions.

The inflation of the air bag may be defined using either the uniform pressure method, which inflates all parts of the bag simultaneously using uniform pressure, or by the Euler method, which models the physics of the gas flow into and throughout the bag. For this simulation, the uniform pressure method was chosen for the initial case study because it was simpler to set up and results in a faster execution time than the Euler method.

Several check runs were made to ensure the proper unfolding of the air bag model. A cross-section of the air bag inflating is presented in Figure 8 to illustrate the effectiveness of the internal fold contacts

Figure 8.
Inflating air bag.

3.4 COCKPIT STRUCTURE MODEL

The helicopter cockpit contains many structural surfaces which the air bag and/or occupant can contact. For this reason, major surfaces in the cockpit were modeled in MSC/DYTRAN to be used as rigid contact surfaces. This was done by importing the geometric information of the cockpit via an IGES file into MSC/PATRAN and meshing the cockpit surfaces using shell elements. In addition, certain areas of the cockpit were modeled with relatively high fidelity to ensure proper contact behavior with the deploying air bag. Then the elements representing the cockpit components were defined as rigid by use of the MATRIG card.

3.5 OCCUPANT/AIR BAG/COCKPIT SIMULATION

To create a complete simulation model, the individual models of the occupant, air bag and cockpit structure were combined (see Figure 9). The occupant model was positioned in the pilot seat, while the folded air bag model was positioned under the glareshield with appropriate constraints to simulate the bag's mounting fixture. The five-point belt system used to restrain the occupant was simulated using MSC/DYTRAN CROD elements. The new PBELT card was used to define the belt material's properties.

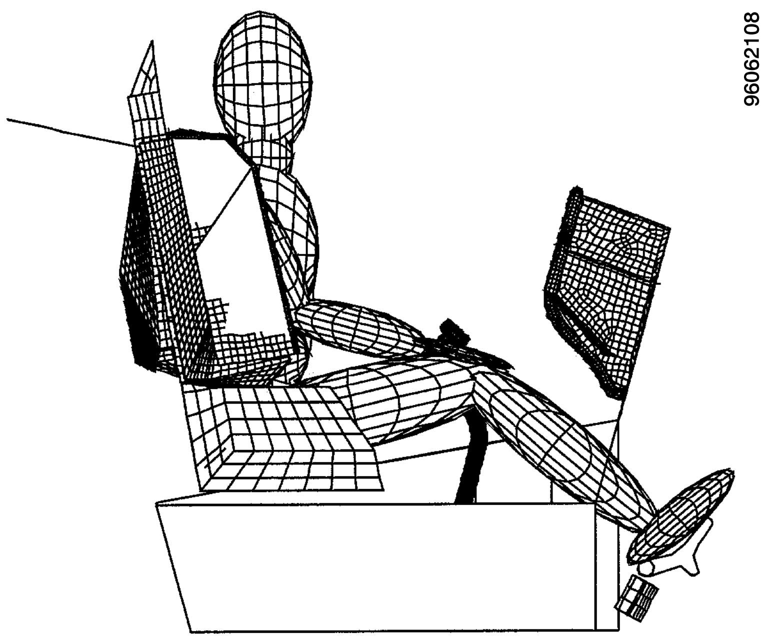

Figure 9
Complete simulation model.

The contact definitions for the various components in the simulation were defined both in ATB and MSC/DYTRAN. The rigid contact definitions, such as the occupant body segments contacting each other, were defined within ATB because of the efficiency and greater flexibility in specifying the force-deflection characteristics. Table 1 summarizes the contact definitions used in ATB and MSC/DYTRAN.

Table 1. Contact definitions		
Specified Contact	**Program Handling the Contact**	
	ATB	**MSC/DYTRAN**
Occupant body segment contacts	X	
Occupant segment-plane surface contact	X	
Air bag fold contacts		X
Air bag contact with occupant		X
Air bag contact with cockpit structure		X
Restraint belts contact with occupant		X

The dynamic condition for this simulation was a drop test with a 30-deg nose-down pitch, 50-ft/sec velocity change with a 30-G peak deceleration. The typical crash pulse profile for this condition is a symmetric triangular pulse (see Figure 10). To simulate this crash pulse, the ATBACC card was used to apply an acceleration field to the ATB segments.

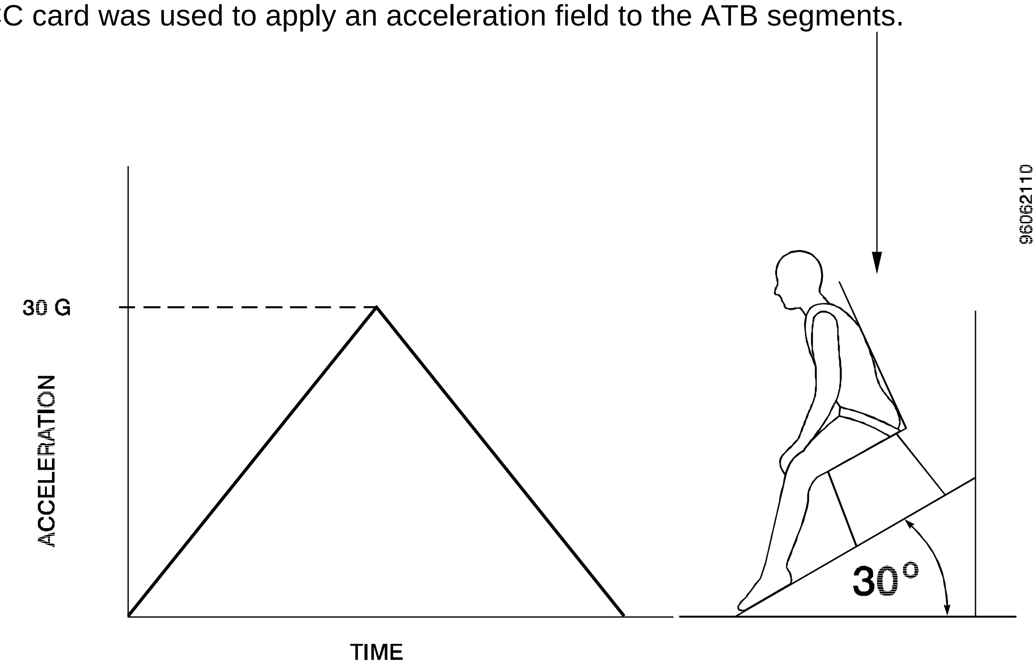

Figure 10.
Crash pulse profile.

4. DISCUSSIONS

4.1 SIMULATION RESULTS

In general, the MSC/DYTRAN simulation described in this paper appears to have worked quite well for simulating the occupant/air bag/cockpit interaction. Figure 11 illustrates the simulation results. The unfolding of the air bag is judged to be realistic, as is the contact between the air bag and the surrounding cockpit structure. Although there were some initial concerns over using the uniform pressure method to accurately simulate the inflation of the air bag, the resultant unfolding of the air bag is believed to be adequate for initial studies.

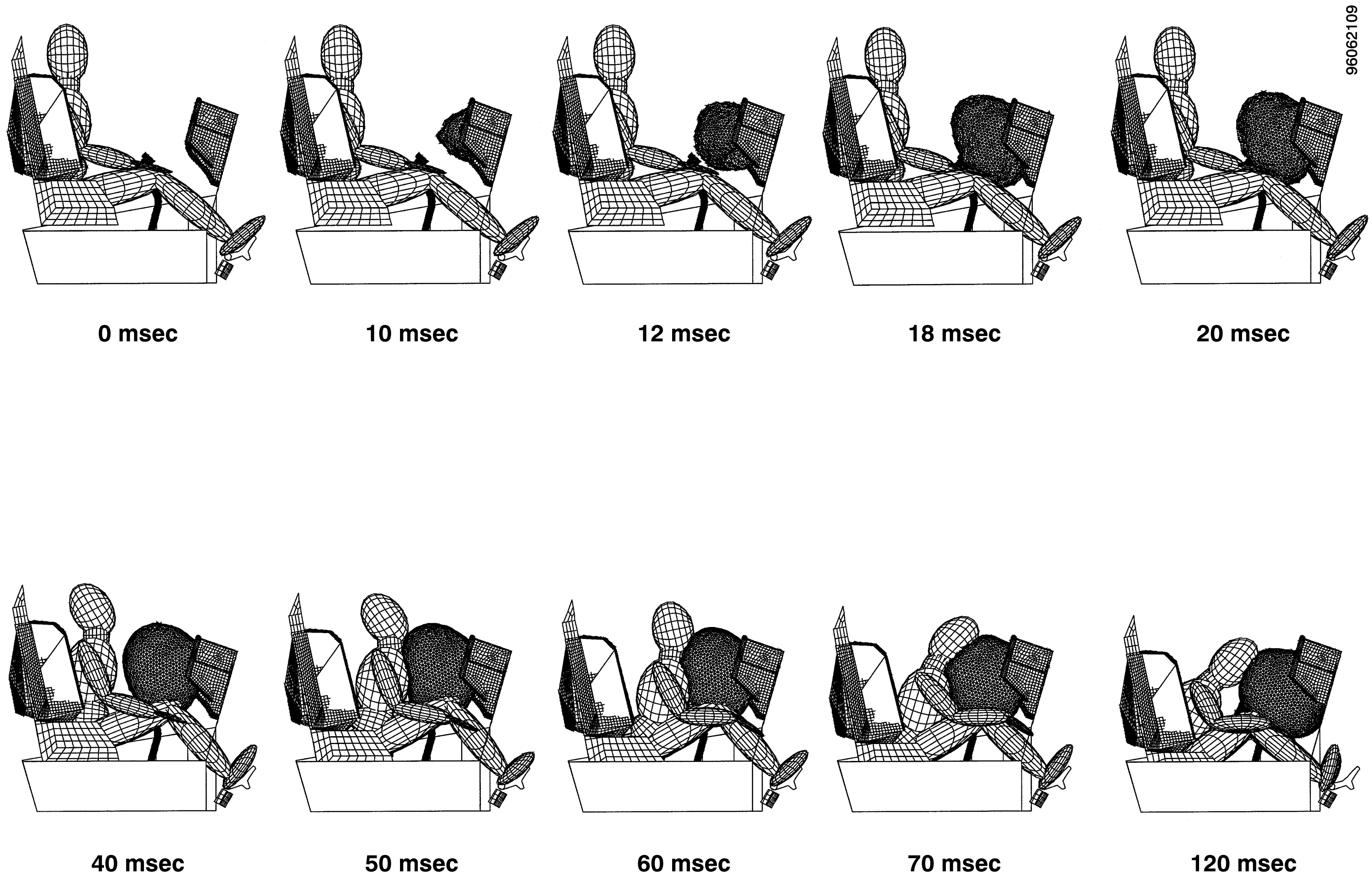

Figure 11.
Simulation results.

The simulation of the restrained occupant's motion also appeared realistic when compared to high-speed films of dummy motion in forward crash tests. Furthermore, the stroking of the energy-absorbing seat was consistent with the motion observed in crash tests under similar dynamic conditions.

At this time, Simula does not have experimental data with which to compare and correlate the described simulation results. However, a similar MSC/DYTRAN analysis was conducted for a different Simula air bag program which showed promising correlation between the experimental and analytical bag pressure time histories (Figure 12). Note that, although the bag in the experiment was inflated using a gas generator and the analytical model used uniform pressure, the resultant pressure time histories follow the same general trend. The 47 lb/in.^{2} pressure spike in the test data was due to the air bag's being constricted by the bag cover, which was not simulated in this analysis.

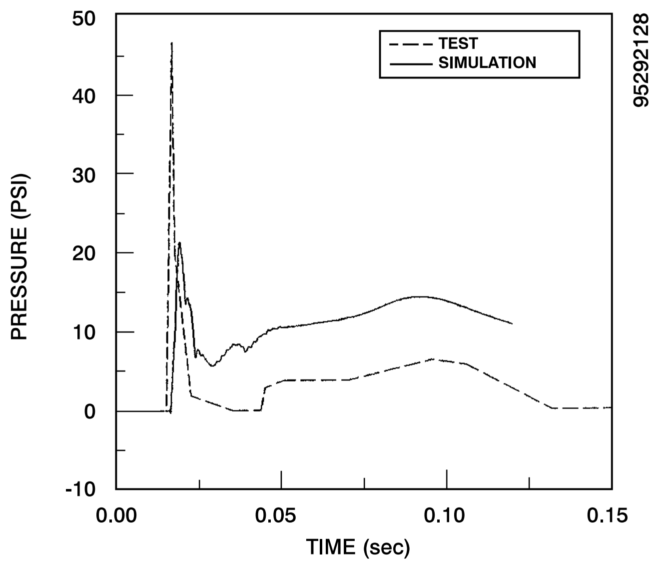

Figure 12.
Comparison between experimental and analytical air bag pressures.

4.2 MODELING DIFFICULTIES

Simulating the proper unfolding of the air bag folds required trial-and-error adjustment of the FACT parameter on the air bag CONTACT card. This is because a FACT value which is too high leads to instabilities (due to an over-stiff contact), while a FACT value which is too low leads to too much penetration of the contacting layers. Furthermore, additional contact definitions were needed to capture all of the contact between the different fold layers during the unfolding process.

Another modeling concern is the inverse relationship between simulation timestep size and air bag mesh fidelity. To accurately simulate the inflation of the air bag, small triangular elements must be used to ensure proper unfolding of the bag. Because MSC/DYTRAN's timestep equation (1) is a function of the smallest element edge length, the smaller the element size the smaller the timestep. This is represented as

$$\Delta t = \frac{SL}{c} \tag{1}$$

where, S = timestep scale factor
L = smallest element dimension
c = speed of sound through the element material

Consequently, the run time for an MSC/DYTRAN simulation is based on the size of the smallest element in the run. Thus, a trade-off exists between having small elements to accurately simulate the air bag's unfolding and having reasonable execution times. The goal for this simulation was to have the smallest elements required for accurate air bag unfolding while maintaining a timestep greater than or equal to 1.0 μsec. The actual timestep for this simulation was 0.5 μsec, which resulted in a 6-hr run time (a 140-msec simulation) on a Silicon Graphics Power Challenge 75 MHz R8000.

5. CONCLUSIONS

The robustness of MSC/DYTRAN's contact algorithm allowed for accurate modeling of the air bag's fold contacts during deployment. Correlation studies to date, in which MSC/DYTRAN's results are compared with actual instrumented and filmed tests, indicate that MSC/DYTRAN can predict air bag behavior, air bag interactions with structure and occupant, and the resulting occupant response. It is now clear that MSC/DYTRAN has potential use as a design tool for air bag development and will, in the future, result in fewer required dynamic tests during the CABS development effort.

6. REFERENCES

(1) MSC/DYTRAN User's Manual, Version 2.3, The MacNeal-Schwendler Corporation, Los Angeles, CA, 1995.

(2) ARTICULATED TOTAL BODY MODEL ENHANCEMENTS - Volume 2: User's Guide, Louise A. Obergefell, Thomas R. Gardner, Ints Kaleps, John T. Fleck, January 1988.