Numerical Simulation of Aircraft Seat Compliance Test using LS-DYNA® Implicit Solver

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Abstract

With the possibility of using numerical simulation results in place of dynamic tests for aircraft seat compliance, use of LS-DYNA for this purpose is gaining traction and visibility. This test is done in two parts – In the first part which is quasi-static, the seat undergoes "roll" and "pitch" at the attachment mounts, which preloads the seat structure, and, in the second part an acceleration pulse of 16g's is applied to the seat system and dummies. If the seat integrity is maintained, the test is considered a pass and the seat gets certified.

The challenge is, the first part of the simulation is quasi-static and currently explicit solver is used, which means the solution has to be time-scaled. Since the seat components are discretized with fine mesh, mass-scaling is used to an extent the regulation allows. Time-scaling and mass-scaling is necessary to achieve a decent turn-around. This paper explores the possibility of using LS-DYNA's Implicit solver to reduce the computation time for the quasi-static part of the simulation – by improving the solver and developing FE dummies that are implicit-ready.

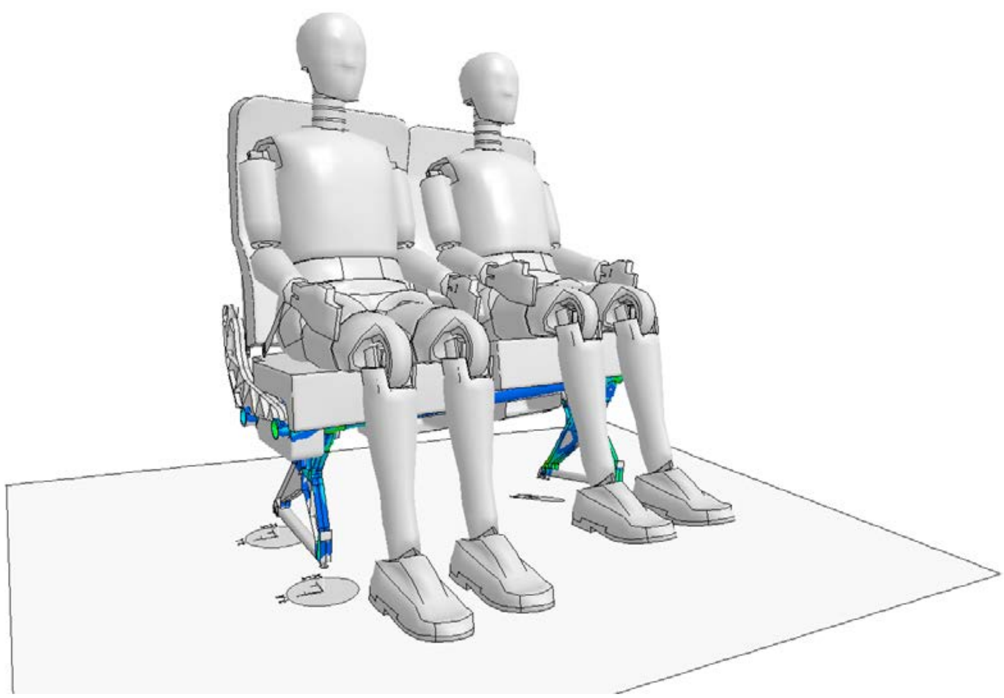

Fig 1. Dummies on pre-loaded aircraft seat

Introduction

FAA requires two loading conditions (14g Down and 16g Forward) for dynamic seat certification, this is per 14 CFR 25.562 of "Emergency landing dynamic conditions"[1]. The first test combines vertical and longitudinal loads to simulate ground impact, where the seat is accelerated at 14g's with the airplane's longitudinal axis canted at 30 degrees. This test is to measure the occupant's injury numbers so a seat design can be improved to reduce the spinal injuries. The second test is predominantly a longitudinal component, where the seat structure is deformed to simulate a deformed floor which is then subjected to an acceleration field of 16g's. This test is to measure the restraint system and seat structure integrity. This paper will only focus on the second, 16g Forward, test.

FAA's AC 20-146 [2] provides guidance on using CAE tools and simulations for seat certification. This document also provides guidance for validating seat models and conditions under which computer modeling can be used in support of certification.

Like any other simulation, there are challenges in developing a reliable numerical model that correlates well to physical test responses. Along with these challenges, there is also a challenge of being able to produce results and design iterations at a faster pace. As per the FAA's AC 20-146 document, LS-DYNA's explicit solver is recommended, with a cautionary note that using mass-scaling could and will alter numerical responses. Also, since the seat deformation or pre-load is achieved quasi-statically, using explicit solver will require you to solve the pre-loading part of the simulation at a slower rate, which means long run times.

Model Description

This seat model was provided by Aerospace Working Group (awg.lstc.com) [7] termed as "Burns Seat", which was developed by National Institute for Aviation Research (NIAR). The model contains 449,614 deformable elements and 1,144 rigid elements. All the material properties were assigned to the seat components by NIAR. We had to incorporate the seat mounting bolts and floor to pre-load the seat by applying the required "roll" and "pitch" motion. A tied contact was used to define the welded joints and a global single surface mortar contact [4] was used to capture the contact interaction between the seat components.

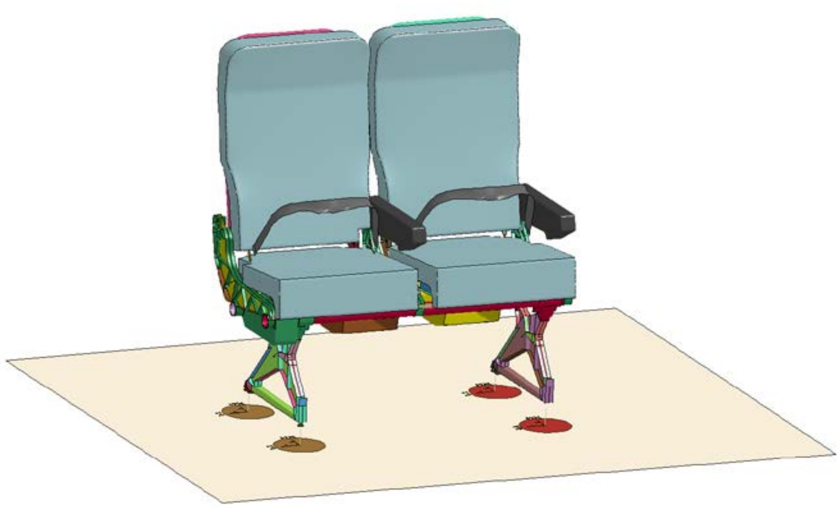

Fig 2. Burns Seat developed by NIAR [7]

The occupant models that were used were LSTC's H-III fast dummy. This dummy model was primarily developed to work with LS-DYNA explicit solver, significant effort was required to get this dummy to be able to use with implicit solver.

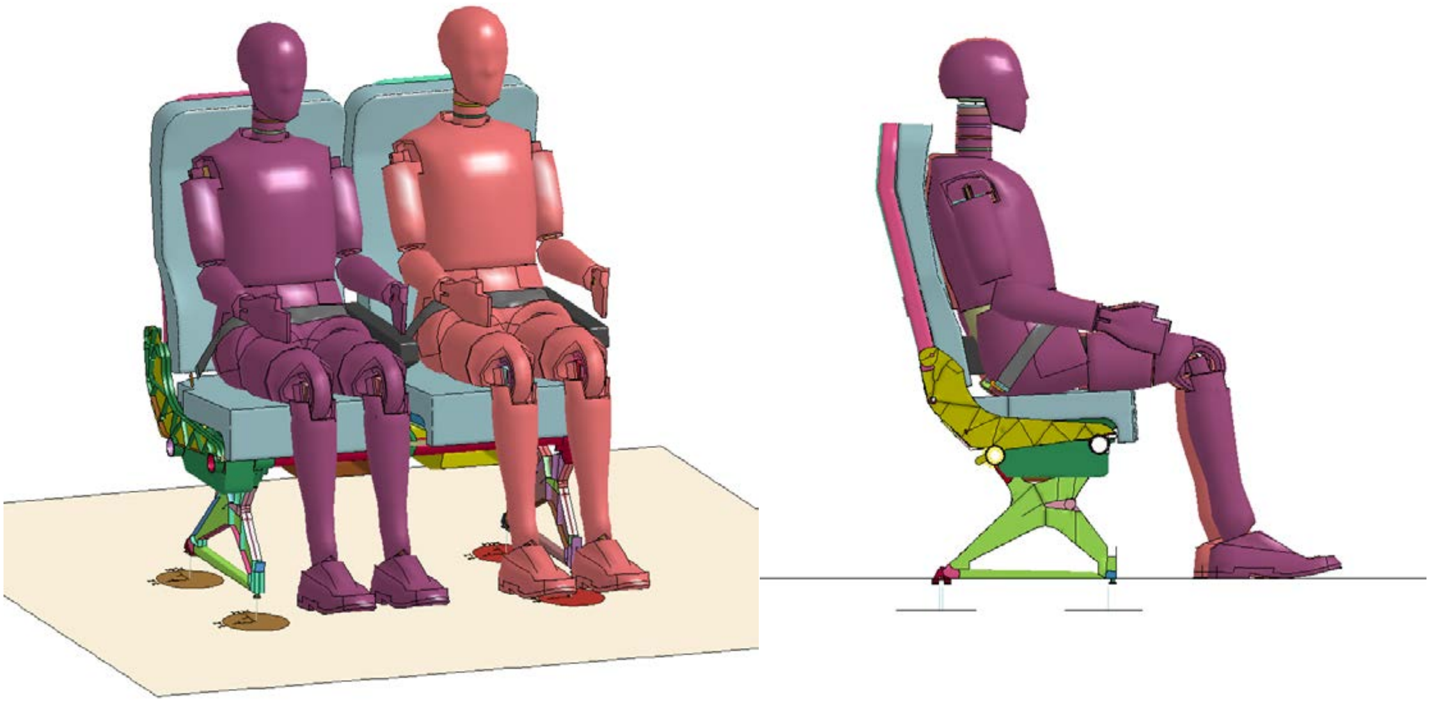

Fig 3. Dummies positioned on Burns aircraft seat

One of the feature that was developed, was to automatically add joint stiffness to all the unconstrained "Joints" in the model. This would help remove the zero energy body modes and therefore significantly improving convergence experience. This feature is in *CONTROL_RIGID, fields 2-5 on the second card.

Model Set-up

Dummy Model

The main purpose of the dummy model in this analysis is represent occupant's mass and load transfer to the seat accurately. The feedback from occupant injury measurement channels are not so important with only criteria that we capture the dummy kinematics fairly realistically.

So for this purpose we chose the simplest dummy model that is available, HIII 50th Rigid FE dummy. This model was initially developed to provide as a quick way to include a dummy that is inexpensive for occupant simulations using LS-DYNA's explicit solver. For this to work in implicit several modifications were to be made to the dummy model itself as well as add some new features in the code. The effort to get this dummy model implicit-ready was considerable and we hope to make the same improvements to other LSTC dummy models that might be used with implicit solver.

Another version of "dummy" was used for testing. For this version, we took the outer shell of the dummy torso, upper legs and head to create a fully rigidized dummy, which had the same mass-center and inertial properties of the above described Rigid-FE dummy.

Seat Model

The Burns Seat model was first run using the Eigen-solver to ensure the model did not have any rigid body modes. The model was then made sure to have all the settings as laid out in ftp://ftp.lstc.com/outgoing/support/FAQ/implicit_guidelines and also in Appendix P of LS-DYNA's keyword manual [6].

In brief, these settings are

(1) Shell element formulation 16
(2) Solid element formulation -2
(3) Mortar Contacts
(4) Implicit accuracy flag was invoked
(5) Implicit Dynamics with numerical damping
(6) Added joint stiffness automatically via *CONTROL_RIGID to remove rigid body modes

The pre-loading part of the simulation was done in three steps –

(1) Dummy seating using gravity field
(2) Left seat mounts subjected to "roll" motion
(3) Right seat mounts subjected to "pitch" motion

Since the "roll" and "pitch" motion applied to the seats in a physical environment is very subjective, we chose arbitrary time to apply this motion in the simulation. For instance, the roll motion was applied over 50seconds and the pitch motion was applied over 75seconds. The test protocol dictates a roll motion of 10 degrees to the left seat mount and a pitch motion of 10 degrees is applied to the right seat mount, in the model this motion was applied using *BOUNDARY_PRESCRIBED_MOTION_RIGID.

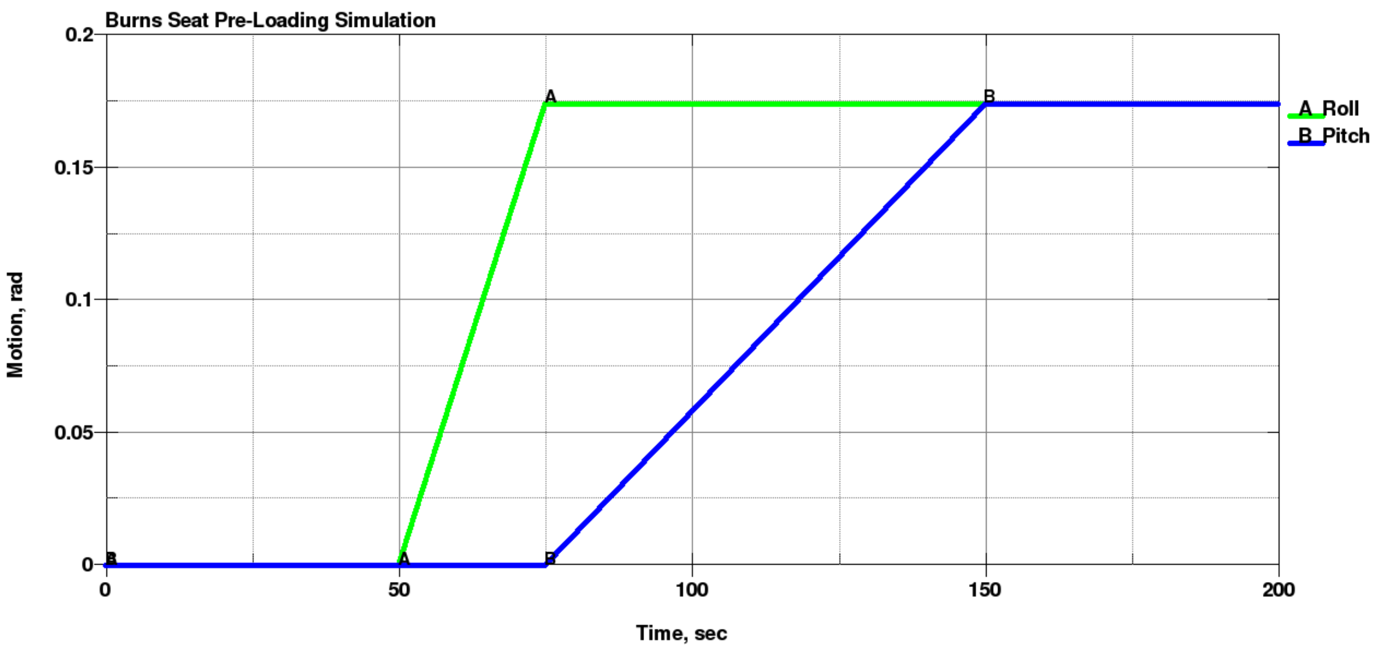

Fig 4. Roll and Pitch motion as applied to seat mounts

We first ran the pre-loading part of the simulation just with the seat to assess the integrity of the model and to get a feel for convergence. This simulation ran in less than an hour on 24cores.

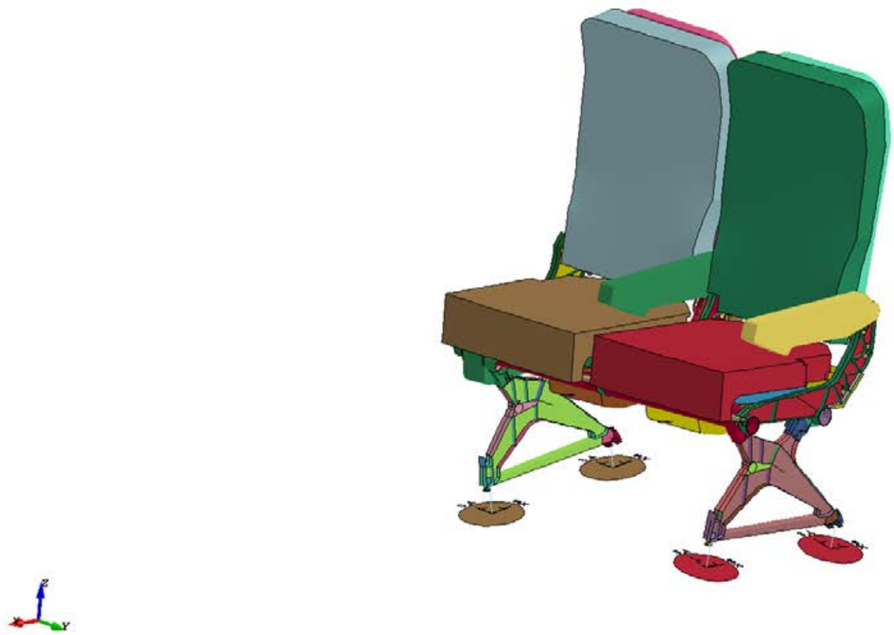

Fig 5. Seat Only subjected to pre-loading as integrity test

We then ran the simulation using a rigidized dummy shell. The reason to try this approach was to see if this would suffice to preload the seat. The dummy is present here just to facilitate the loading to the seat because of its mass. If the results from this compared well with the simulation that used full dummy model, then a proposal will be made to run the pre-load using a rigidized dummy shell. This simulation took ~3hrs to finish on 24cores.

Finally, we ran the simulation using full Rigid-FE dummy model. This simulation took the longest to complete, ~31hrs using 24cores.

Results and discussion

We compared the results of the seat deformation between tests that used fully rigidized dummy and full Rigid-FE dummy. Also, we compared the resultant contact forces between the dummy and the seat foam to make sure the reaction forces were similar. The results between these two tests were very comparable. Since most of the loading from dummy to seat was from gravity loading, it was important that the mass-center and inertial properties for the fully rigidized dummy matched with the full Rigid-FE dummy.

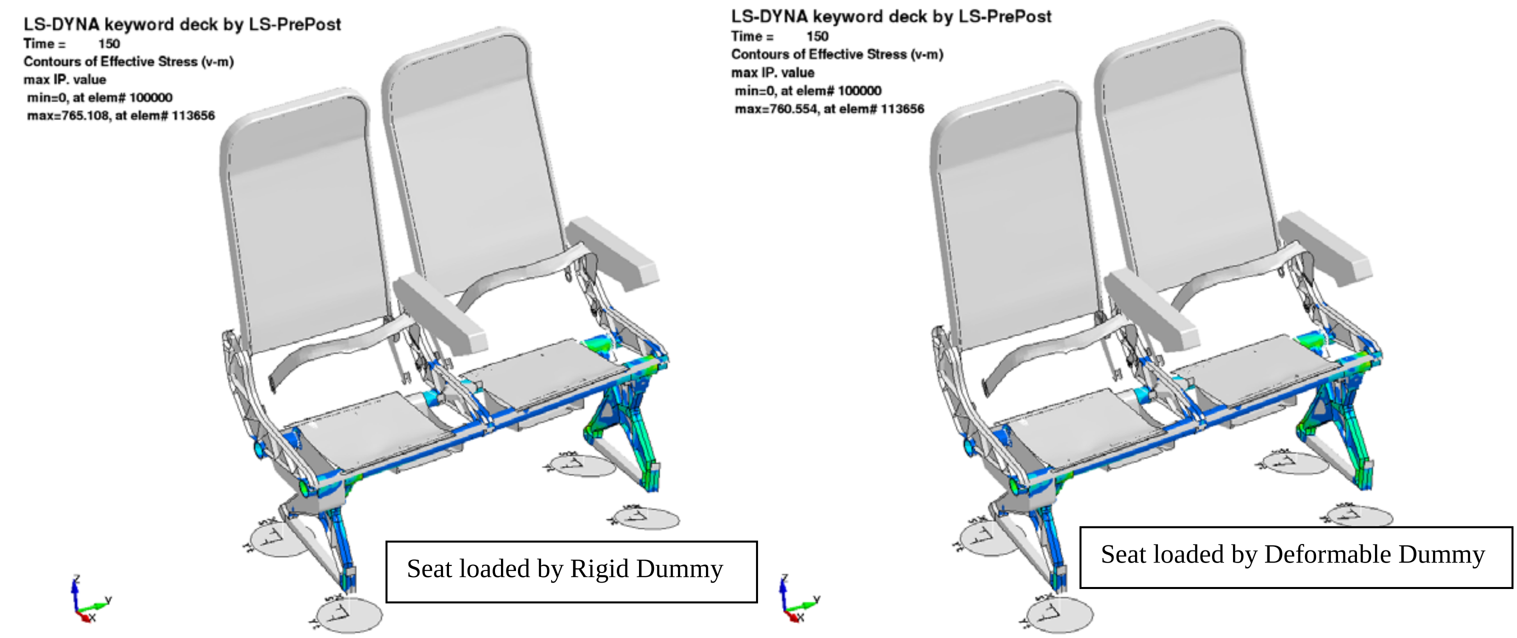

Fig 6. Von-mises stress fringe comparison

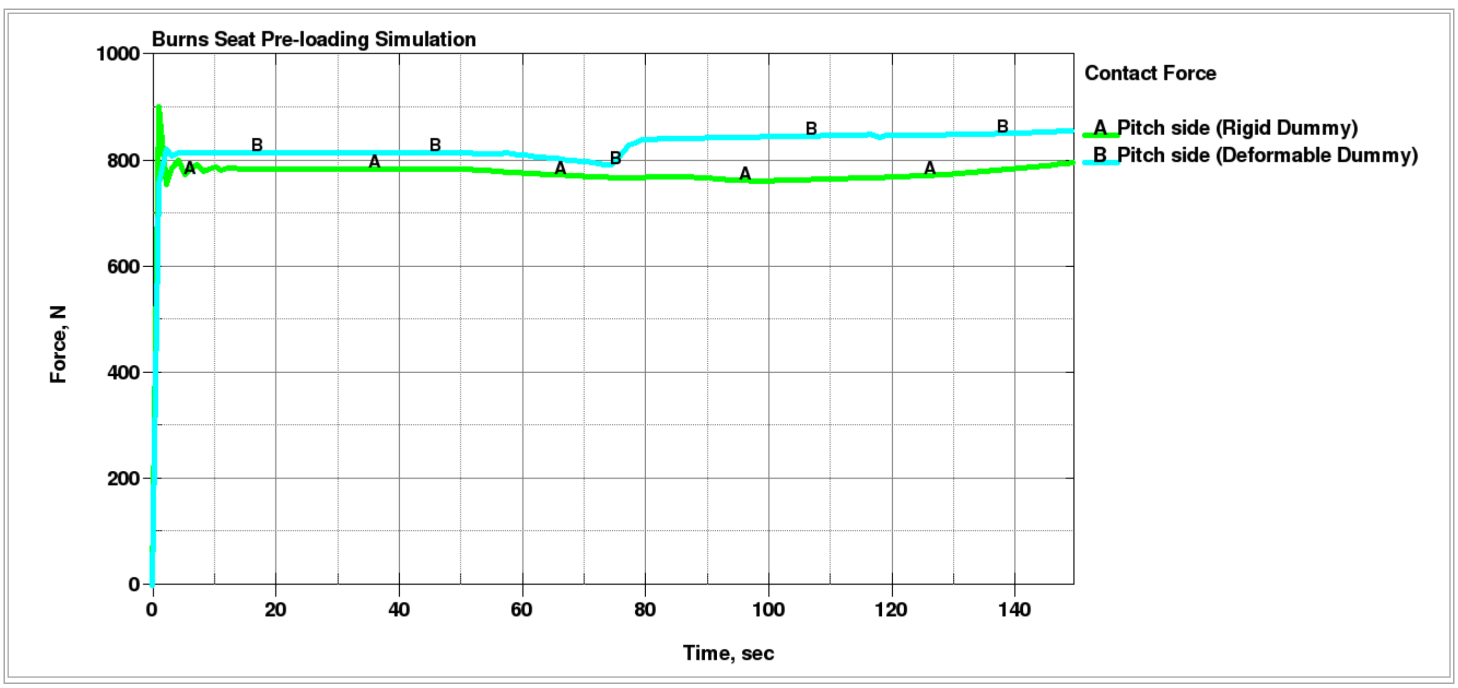

Fig 7. Contact force between the dummy and seat on the pitch side

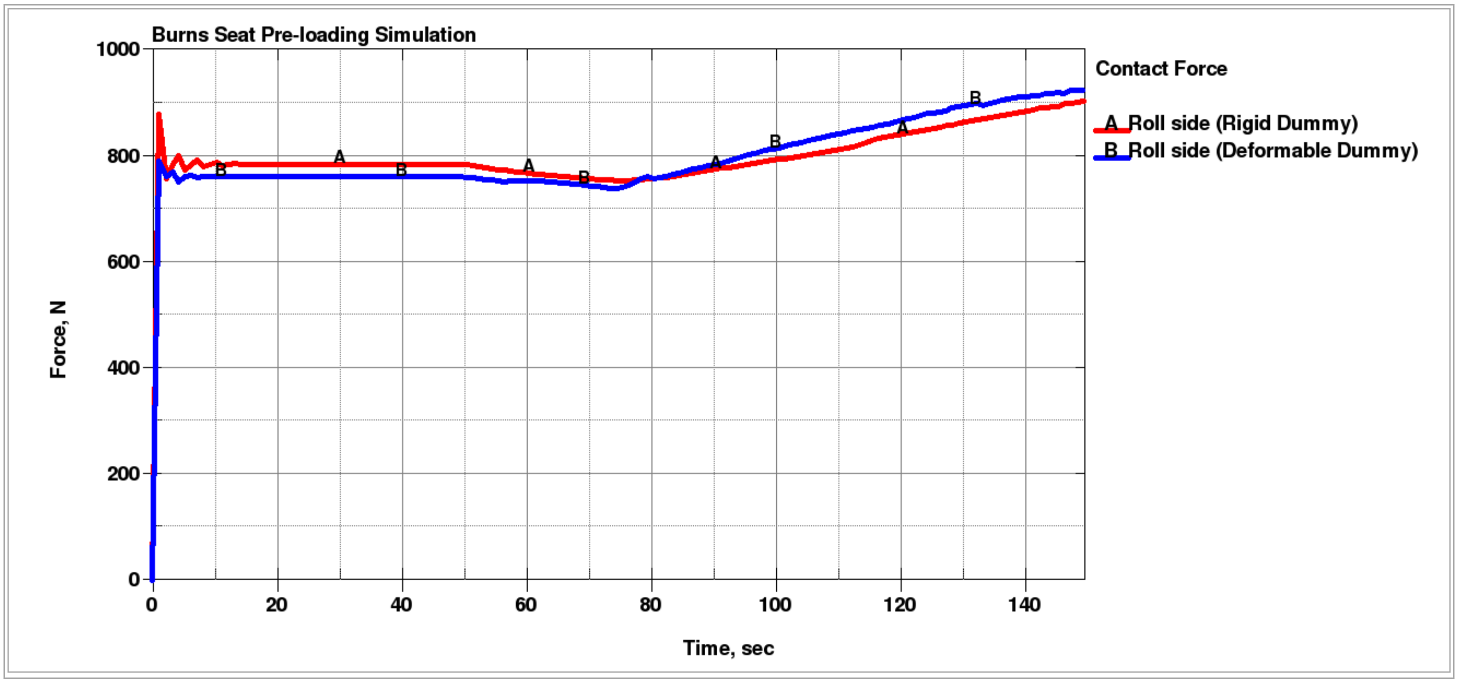

Fig 8. Contact force between the dummy and seat on the roll side

This gives the flexibility to the analyst the choice of dummy they want to use for their work. Once the pre-loading part of the simulation is complete, we can use a more detailed dummy model for the explicit solution, where the floor is subjected to a 16G deceleration pulse.

The Burns Seat model used in this study along with the dummy input will be made available on AWG's website, please contact the site's moderator to gain access to these inputs.

References

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