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OBSERVATIONS DURING VALIDATION OF SIDE IMPACT DUMMY MODELS - CONSEQUENCES FOR THE DEVELOPMENT OF THE FAT ES-2 MODEL

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Abbreviations:	FAT: German Association for Automotive Research SID: Side Impact Dummy FE: finite element
Keywords:	FE Dummy Simulation, Side Impact, ES-2, USSID, EUROSID, FAT, Validation

ABSTRACT

Detailed finite element side impact dummy models of the USSID and EUROSID have been developed in cooperation with the German Association for Automotive Research (FAT) during the last 5 years. Both models are validated using tests at material and component levels as well as fully assembled models. The development of the LS-DYNA dummy models has been performed by the authors. Both models are used by nearly all car manufacturers worldwide which use LS-DYNA for occupant safety simulations.

EuroNCAP (European New Car Assessment Program) announced recently a modified testing protocol for side impact assessment using the ES-2 dummy instead of the EUROSID-1 dummy. The ES-2 dummy is identical in many parts with the EUROSID-1 dummy but shows different behavior in experiments. Hence, the development of a model for the ES-2 dummy is of great interest for the automotive engineers working in the field of passive safety.

The FAT has launched a project similar to the previous one to develop an ES-2 model. Due to urgent need of the model in the industry a tight schedule is given for the development. The first release of the model is already available. DYNAmore GmbH is responsible for the developing the LS-DYNA models. This paper summarizes experiences gained during the validation of the EUROSID-1 and USSID model and describes the tests performed to validate the ES-2 model. Finally, the performance of the first version of the ES-2 model and the schedule for the project is presented.

INTRODUCTION

The EUROSID-1 was developed in the 1980s in an effort by the European Commission to improve the passive safety in side impact crash scenarios. This model is now incorporated in ECE Regulation 95. Simultaneously, the USSID was developed in the USA by NHTSA. Thus, the current regulatory situation is such that there are two different side impact tests and two different side impact dummies. The ISO has initiated the development of the new side impact dummy WorldSID in order to replace the existing dummies. However, the realistic time frame for the development and evaluation of this dummy may be up to 10 years before it can be introduced into legislative test procedures. The development of the ES-2 was driven by the idea that starting from an existing dummy which is already used in regulations, interim harmonization could be reached much quicker. The ES-2 is designed to address the important shortcomings of the EUROSID-1 while biofidelity is maintained. The EEVC report (WG12 August 2001) summarizes that both goals are achieved with the new dummy. Figure 1 shows the finite element dummy model of the ES2 and the parts which differ from the EUROSID 1. Geometric differences from the EUROSID-1 can be found at the spine, rib module, the upper legs, the clavicle, the shoulder foam cap and in the upper femur area. Furthermore, the EEVC report states that the overall test results in full-scale tests have shown that some critical dummy measurement values for the ES-2 have increased when compared to the EUROSID-1. This holds true particularly for rib reflection and the Viscous Criteria. The same tendencies are observed in sled tests performed for the development of the ES-2 model. Figure 2 shows the rib intrusion of the middle rib of the EUROSID-1 and the ES-2 for two different barrier speeds. The barriers are plane and considered as rigid.

Beside the regulatory situation many car manufacturers use the consumer organization assessment programs to determine criteria for passive safety performance of the vehicles. EuroNCAP announced recently that a new assessment will be established for the lateral impact vehicle safety. One modification is that from January 2003 on the dummy ES-2 will substitute the EUROSID-1 dummy. NHSTA and EEVC are considering to adapt the regulations such that the ES-2 will replace the USSID and EUROSID-1, respectively.

The above described harmonization activities lead to a project to develop a finite element model of the ES-2 dummy by the German automotive industry. In the past, 2 dummy models for the EUROSID 1 and the USSID were developed successfully chaired by a working group of the FAT, the German Association for Automotive Research. The authors are responsible for the development of the LS-DYNA models. The new project on the development of the ES-2 model is also chaired by the FAT. Representatives of Autoliv, Audi, BMW, DaimlerChrysler, Karmann, Opel, Porsche, TRW, and Volkswagen meet regularly to define new experiments, to discuss further general proceedings and to guide the development.

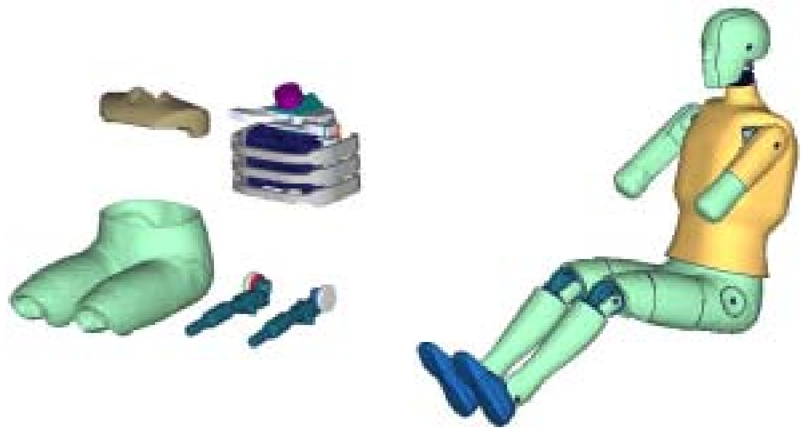


Figure 1: New parts of ES-2 compared to EUROSID-1 (left), the ES-2 model (right).

As partners for the automotive industry software suppliers have been selected to develop the dummy models for the 2 considered crash codes LS-DYNA and Pamcrash. The models for the two software packages are based on the same experiments but differ in modeling aspects.

DYNAmore GmbH takes responsibility for the development of the ES-2 model in LS-DYNA. The LS-DYNA models of the ES-2, EUROSID-1 and USSID are commercially available from DYNAmore GmbH and the local responsible LS-DYNA distributors. All models will be updated on a regular basis according to further regulations and knowledge.

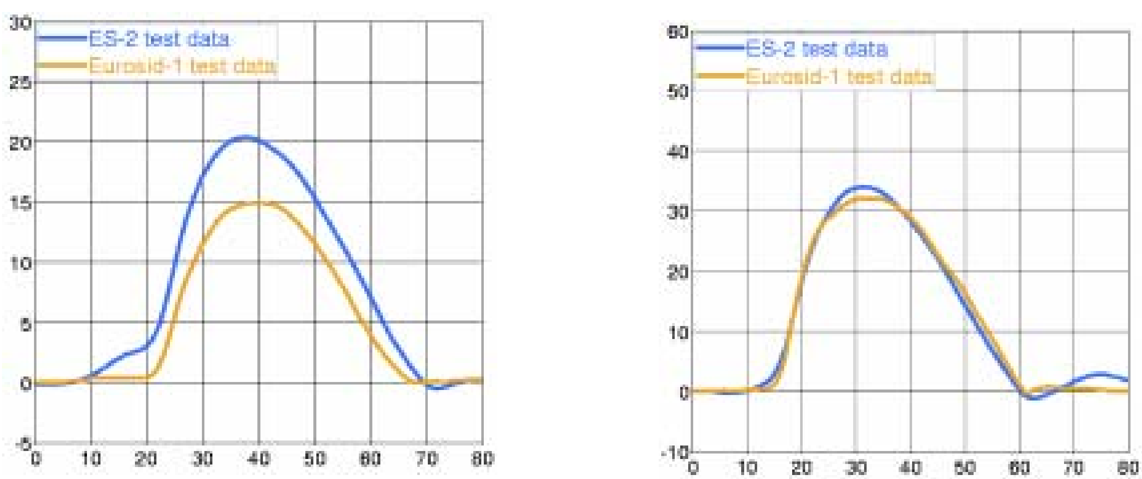


Figure 2: Middle rib intrusion of ES-2 and EUROSID-1: Lower barrier speed (left), higher barrier speed (right).

EXPERIMENTAL DATA FOR EUROSID-1 MODEL

An essential goal was to obtain experimental data close to the loading expected in real crash scenarios. The tests were performed within 4 years and are described in details in (Franz U., Walz M., Graf O., 1999). After a series of tests, simulations were used to define subsequent tests and the test results were used again to enhance the models and so on.

Material tests

Almost all specimens were taken from new parts delivered by FTSS. In order to get more general applicable data the specimen were chosen from areas where the materials appeared to be homogeneous. The following types of tests were performed: Static tension tests, dynamic tension tests, static compression tests, dynamic compression tests, relaxation tests, hydrostatic triaxial compression tests, static shear tests and dynamic shear tests. Emphasis was directed towards strain rate dependent foams used in many areas of the dummies. Details on specific material tests are presented in (FAT Schriftenreihe Nr. 150, 2000).

Component tests

For the project a large variety of component tests were performed as: Head drop tests, dynamic shear tests for the lumbar spine, pendulum tests for the lumbar spine, neck pendulum tests, drop tests for the damper, partial and complete thorax impact tests, pendulum tests for the abdomen, impact tests for the pelvis and impact tests for pelvis/upper leg, and impact tests for the shoulder foam cap. If possible, tests racks specified for dummy calibration were used. The tests were performed usually for a large variety of speeds and masses.

Pendulum tests on fully assembled dummy

For the development of the EUROSID-1 no pendulum tests on the fully assembled model have been performed.

Figure 4: Barrier shapes used for validation, EUROSID-1 model.

Barrier tests with fully assembled dummies
Many experiments were performed with rigid (rather stiff) barriers of different shapes. All impacting surfaces of the barriers were perpendicular to the impact direction. The barriers were decelerated after the dummy load approached zero; the impacting speeds ranged from 4 to 8 m/s with barrier masses above 1 t. The experimental data recorded was: Accelerations, force and intrusion. Furthermore, the dummies were equipped with contact foils to determine the moment of contact of different entities. The barrier shapes might be classified in two categories: one to apply loads comparable with a crash and the other to validate specific parts of the dummy (e.g. abdominal insert). The different barriers and the EUROSID-1 model are depicted in Figure 4. Furthermore, barriers equipped with unfolded pressurized airbags were used in testing.

OBSERVATIONS DURING VALIDATION

In the following the authors outline observations made during validation of the dummy model EUROSID-1 and USSID. Many of these experiences influenced the specification for the tests performed for validation purposes of the ES-2 model.

Soft foams
In the EUROSID-1 model the LS-DYNA material type 83, (Mat_Fu_Chang_Foam) is used for the soft foams. The main reason is that the model allows to use the test data from drop tests as material parameters without major modifications. Limitations of the material model to influence the hysteretic behavior were considered less important as the capabilities to model the complex strain rate behavior of the foams.

For open cell foam the rate effect is partly determined by the flow of the air out of the pores of the foam. Hence, the strain rate effect measured in a drop test is influenced by the shape of the specimen. This effect is amplified if the foam part is covered with a hull. In these cases the material parameters for the foam have to be adapted. Certainly, these adaptations can fit the material behavior only for a certain load range. Hence, the adaptations have to consider a test close to a real crash load. Figure 5 depicts on the left photo a shoulder foam cap damaged in a drop test by the outflow of the air.

Figure 5: Shoulder foam cap with damaged skin (left), cut through a pelvis (right).

Limitations due to element size

Pelvis openings allow to determine the exact position of the dummy and to dismount attached parts. To model the small opening many elements would be needed. The openings are covered with vinyl with a thickness of 3 to 4 mm. During impact these tubes are compressed and might buckle. A proper modeling of the tubes would need a huge amount of elements. The element size would be in no relation with the other parts of the dummy model. Figure 5 depicts on the right a cut through the pelvis of the USSID. A model without the openings does require that the neglected stiffness will be added somehow. In the model we used stiffer material properties for the pelvis foam. Hence, the material properties derived from a material test have to be adapted.

Limitations due to stability of elements

Many parts of the dummy consist of soft foams. Modeling the soft foam with the correct softness is essential for a good correlation of the model, in particular for the accelerations. In the dummy model sometimes soft foams are partly overlapping rather stiff parts and the two materials will be pressed together heavily during impact. At the edges of the stiff parts high deformation gradients and large element distortions appear in the foam material model. That may cause a termination of the simulation during the loading phase of the dummy model. To reduce this problem the foam material has to be modified. A modification of the material parameters of the foam has to consider which load should be modeled properly and where less accuracy is acceptable. For example the rib acceleration of a rib module in a component test will loose correlation due to artificially stiffened foam; the rib intrusion shows much less dependencies. For the final adaptations a load close to the crash is necessary for validation purposes.

Observations in component tests

For many components it is difficult to test them with loads comparable to loads in the assembled model. The reason is the interaction of the different parts that leads to complex load cases. The complex loading would require complex test set-ups. However, for these it is often difficult to have exact preserved boundary conditions. An example is the standard pendulum test of a spine used for calibration. In this test the spine is attached to a large pendulum at its top flange and with a mass at its bottom flange. During the test the pendulum is decelerated and due to the inertia of the mass at the bottom of the spine the spine bends with considerably large bending angles. Comparing the loads with the load in a real crash we observe that the 'real' load is more complex. It is a combination of bending, tension, shear and torsion, all loads resulting in small deflections. A model for the spine that would be based on a pure bending test as described above may fail to predict the behavior of the spine in a fully assembled model in a crash. A test set-up for an 'appropriate' load would be rather complex.

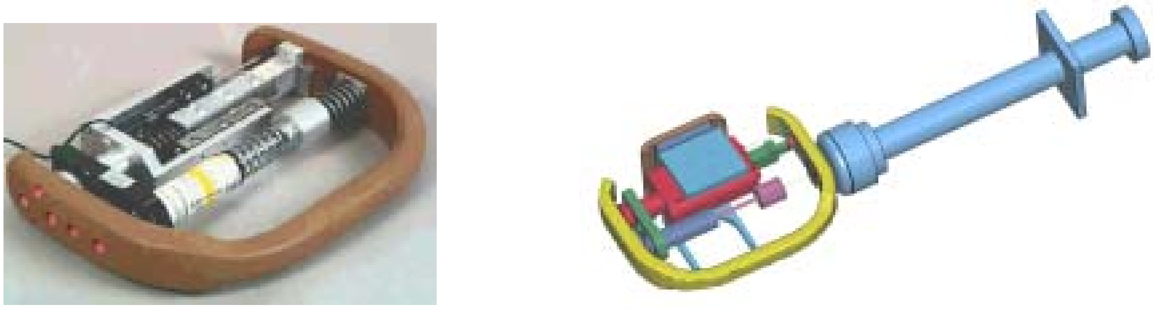


Figure 6: Rib module (left), rib module model in a component test (right).

The rib module is a very good candidate for a useful validation on component tests. If the spine is fixed in space the behavior of the component can be explored excellently with impactors targeting at different locations and with different speed, angles, and masses. Figure 6 depicts a rib module on the left and on the right the rib module model impacted by a pendulum. Occasionally, effects in component tests appear which can hardly be observed in the fully assembled model. It is sometimes questionable if all effort spent in the calibration on a component level is necessarily important for the assembled dummy model. As an example for an effect that can not bee seen in a sled test, but does appear in a component test, the rib module in the component test is chosen. In particular, the influence of different modeling techniques of the attachment of the bearing with the steel inlet of the rib is examined. The steel inlet of the rib is screwed to the massive aluminum piston of the bearing. Between both parts the rubber like cover of the rib foam is clamped. Figure 7 depicts 3 different modeling techniques of this connection. The upper model has a slightly deformable connection between the parts, in the second model the rigid piston is connected to the steel inlet of the ribs by sharing the nodes, in the third model the steel inlet is considered as rigid in the area of the flange of the piston and is merged with the piston. The three models give significantly different answers in the component test whereas in a sled test the models give almost the same answer. Figure 8 shows the intrusions in pendulum test on component level for the three models on the left, the right graph depicts the results in a sled test for the three alternatives.

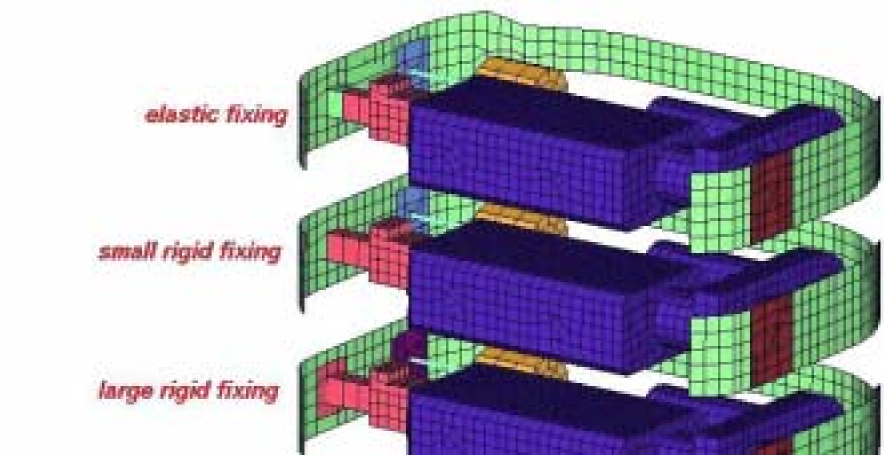


Figure 7: Different ways of modeling the connection of bearing piston with the steel inlet of rib. Colors: Light gray for deformable parts, medium gray for rigid piston of bearing, dark gray for fixed part of bearing.

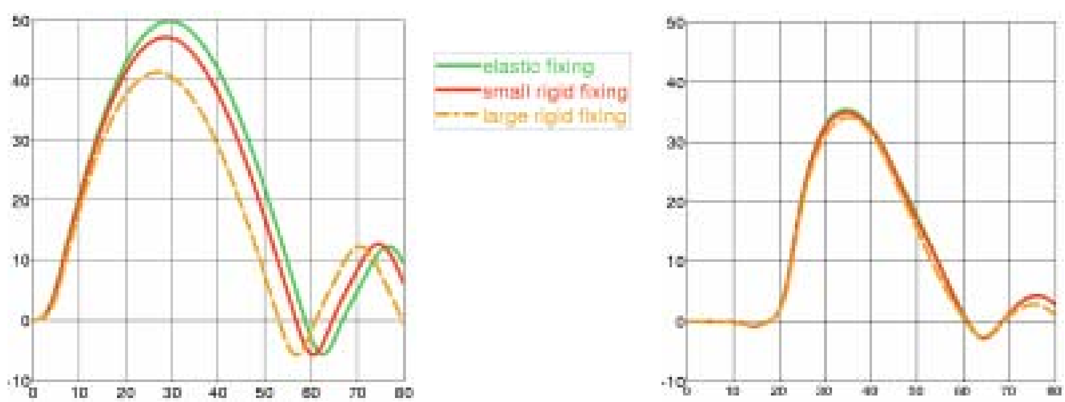


Figure 8: Different rib intrusions in component test (left) and rib intrusion of middle rib in a sled test (right), based on alternative modeling of the connection of bearing piston with steel inlet of rib. Graphs show deflection [mm] vs. time [ms].

Sled test with fully assembled dummies

For the dummy performance friction, slacks, global movement and interaction of parts, in particular the arm, have a significant influence. Hence, many modeling details can be addressed only in a test close to the load case in a vehicle. Defining a test close to a real crash seems to be the crucial demand for tests used for validation. In (Franz U., Graf O., Hirth A., Remensperger R., 2001) the loads of dummies in two vehicles are considered and compared with the loads during impact of rigid barriers, it seems that the barriers give comparable loads. As example for a signal determined by the interaction of many parts the acceleration of the pelvis is illustrated. The signal is determined by the interaction and material properties of the pelvis, the pelvis plug, the iliac wings and the upper femur and subsequently the legs. Figure 9 depicts the parts of the dummy (left) and the model (right). Another example is the rib intrusion during impact. The ribs show a high dependency on the movement of the arm and subsequently on the frictional parameters of the dummy itself and the dummy with the barrier. Figure 10 depicts the influence of the friction for the intrusion of the middle rib in a simulation of a sled test with the plane barrier; on the left the frictional parameters of the interior contact were modified, on the right the influence of the friction with the barrier is depicted.

Figure 9: Parts interacting in pelvis area, dummy and finite element model.

Figure 10: Influence of frictional parameters on rib intrusion of middle rib in simulations of barrier test. Different frictional parameters in the self contact of the dummy (right); different friction in contact with barrier (left). Graphs show deflection [mm] vs. time [ms].

From our experiences the type of barriers designed to load specific parts are of minor importance for the development. It is very difficult to load one part separately, because the barrier usually contacts the arm as well. Additionally, it is difficult to obtain a decent load in the dummy by loading one part separately with a barrier that weights more than 1 ton with a representative impact speed. It seems more reasonable to use pendulum tests for such purposes. Furthermore, costs for pendulum tests on the fully assembled dummy are much lower than tests using heavy sleds.

Initially, a few experiments were performed with airbags mounted on the barriers. The airbags were unfolded and pressurized in advance. Due to the difficult determination of proper initial conditions these tests have not been considered at a later stage.

Geometry of model

For the foam parts the available CAD data describes the surface of the mold of the vinyl hull. A model based on this data would have many penetrations, because the real parts shrink due to the manufacturing process, and during assembly many parts are deformed by neighboring parts. Furthermore, the geometry of the model is influenced by gravity loading and deformations during positioning. Hence, non-unique assumptions have to be made to obtain a representative model.

EXPERIMENTAL DATA FOR ES-2 MODEL

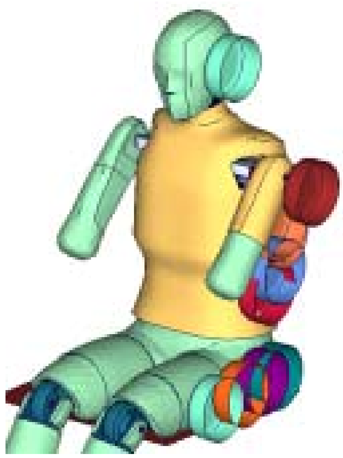
For validation purposes of the ES-2 model the following tests were initiated by the FAT.

Material tests

Due to the large conformity of the materials of the ES-2 with the materials of the EUROSID-1 very few material tests were performed. The new tests include the upper and lower foam of the upper leg, the back plate and the clavicle material.

Component tests

The majority of component tests were performed for modeling the rib module. Different masses, different speeds and impact locations and angles were considered. Aside from the standard measurement, the motion of the damper piston was measured. Furthermore, pendulum tests were performed for the neck and lower spine. Compared to the former project much fewer component tests are specified.



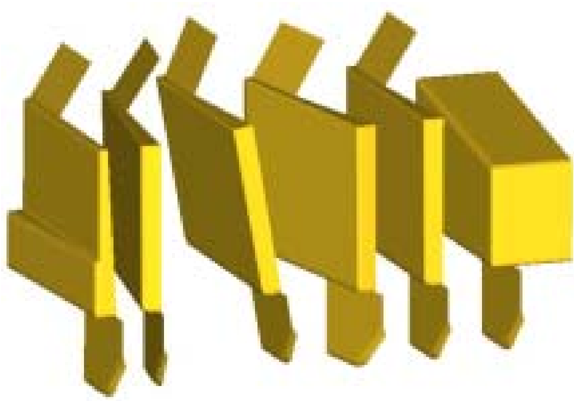


Figure 11: Pendulum impact locations (left) and barriers (right) used in tests for validation of ES-2 model.

Pendulum tests on fully assemble dummy

Many pendulum tests on the fully assembled dummy were performed to validate specific parts of the dummy. Figure 11 depicts on the left the ES-2 model and the different impact locations. Usually 2 different speeds of the impactor are considered.

Barrier Tests with fully assembled dummies

Many experiments were performed with rigid (rather stiff) barriers. The speed varied from 4 to 7 m/s with barrier masses above 1 t. The dummies were fully instrumented, recorded quantities are: Accelerations, forces, moments, and displacements. Furthermore, the dummies were equipped with contact foils to determine the time of contact between several parts. All shapes of the barriers were designed to have comparable loads to a vehicle test. No barrier shapes were designed to validate specific parts of the dummy model. The different barriers shapes are depicted in Figure 11 on the right. The impacting surfaces are inclined for some barriers.

MODEL DESCRIPTION

The first commercially available release of the ES-2 model is version 0.1. The model is based on the EUROSID-1 model release 3.5. The geometry is adapted based on CAD data from the dummy manufacturer FTSS. The rib module of the ES-2 model is extensively validated on component test basis. Furthermore, the release correlates with the most important sled test, the plane barrier and pendulum tests on the thorax of the fully assembled dummy. The release 1.0 is scheduled for autumn; it will include many adaptations gathered during validation of the dummy model in respect to the pendulum tests on the fully assembled dummy. Release 2.0 will be available in spring 2003, and will have the full set of tests as validation basis.

Release 0.1 consists of approximately 60,000 nodes, 100,000 brick elements (mainly 3-noded tetrahedron elements) and 54,000 shell elements (mainly Belytschko-Tsay elements) and a couple of discrete elements and beam elements and more than 150 part/material definitions. Figure 12 depicts the clavicle box and the thorax of the finite element models. For modeling the foam materials usually material type 83 (Mat_Fu_Chang_Foam) is used. The foam parts of the upper arms are modeled with material model 62 (Mat_Viscous_Foam). For modeling the vinyl coverings mainly material type 6 (Mat_Viscoelastic) is chosen. The rubber femur stoppers use Material law 76 (Mat_General_Viscoelastic). Other rubber parts are modeled with material type 62 (Mat_Viscous_Foam). The majority of the iron or aluminum parts are modeled with material type 20 (Mat_Rigid). One major single surface contact (Type 13, Automatic_Single_Surface) with the soft constraint option is used to model the contacts in the dummy. The rather fine mesh of the rib foam is ‘glued’ to the much coarser mesh of steel inlet of the ribs with Contact_Tied_Shell_Edge_to_Surface (Type 7). All solid elements are covered with shell elements. All other contact parameters are default settings. The recent model uses the stiffness based joint definition in combination with the generalized joint option. Global damping is not applied. The models run with LS-DYNA version 960 upwards on computers with SMP and MPP architecture.

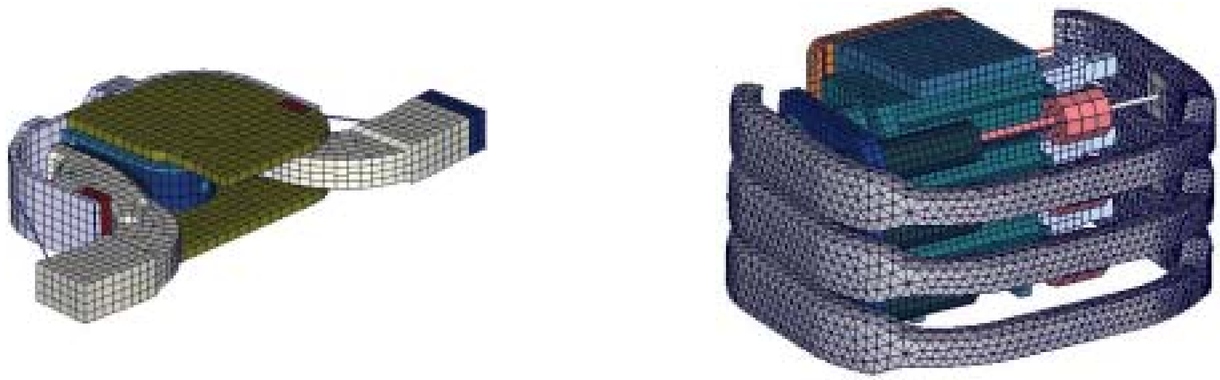


Figure 12: Details of ES-2 model: Clavicle box (left) and thorax (right).

CORRELATION IN PENDULUM TEST

The correlation of the simulation with a pendulum test is presented in the following. In the test the fully assembled dummy is impacted laterally by a pendulum in the thorax area. Figures 13 to 15 depict the performance of the ribs and the spine. Other signals, like pelvis acceleration are considerably low in this test.

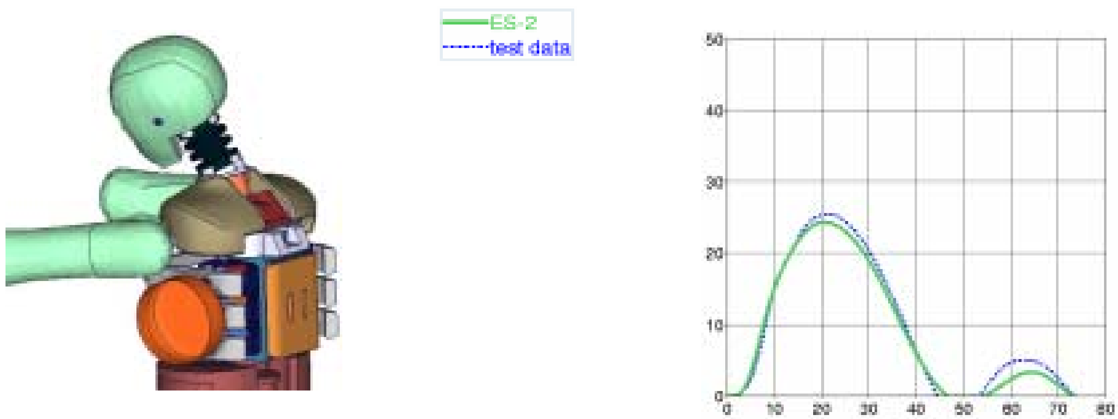


Figure 13: Dummy model during impact (left) and performance of upper rib (right). Graph shows intrusion [mm] vs. time [ms].

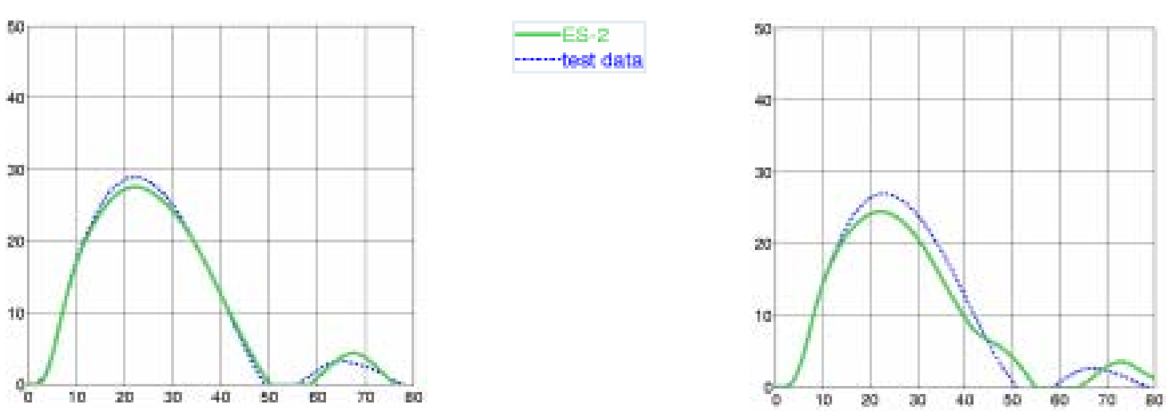


Figure 14: Rib performance: Middle rib (left) and lower rib (right). Graphs show deflection [mm] vs. time [ms].

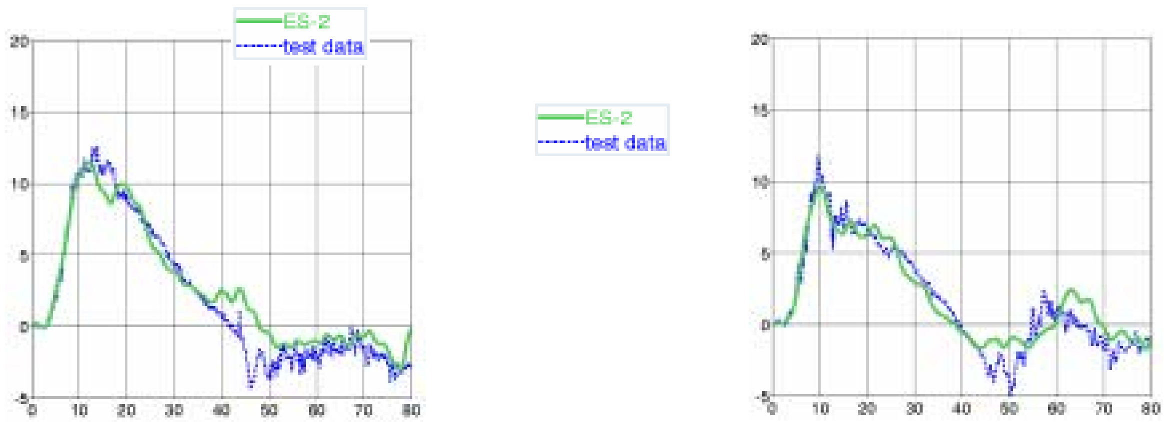


Figure 15: Spine performance: Upper spine T1 (left) and lower spine T12 (right). Graphs show acceleration [g] vs. time [ms].

CORRELATION IN BARRIER TESTS

The performance of the fully assembled model impacted by a planar rigid barrier is presented in the following. Figure 16 depicts on the left the model before impact. Figures 16 on the right and Figures 17 to 20 depict the correlation of the dummy model.

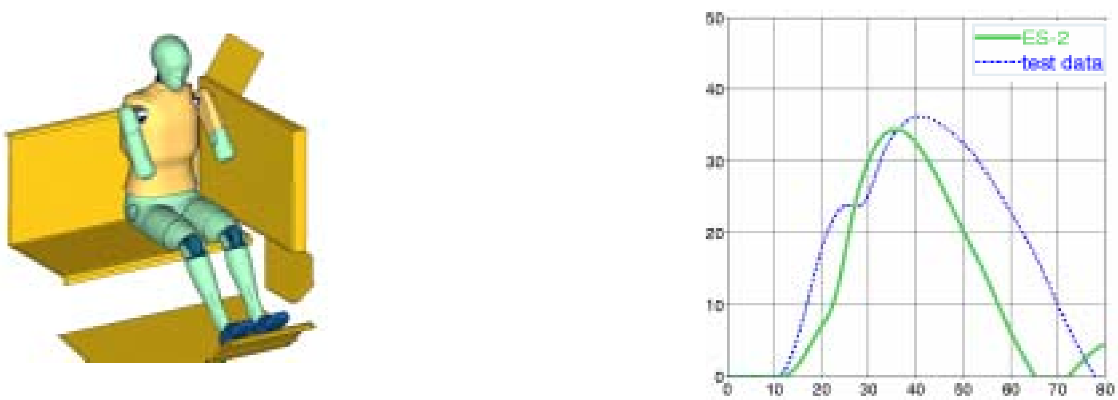


Figure 16: Dummy model during impact (left) and performance of upper rib (right). Graph shows intrusion [mm] vs. time [ms].

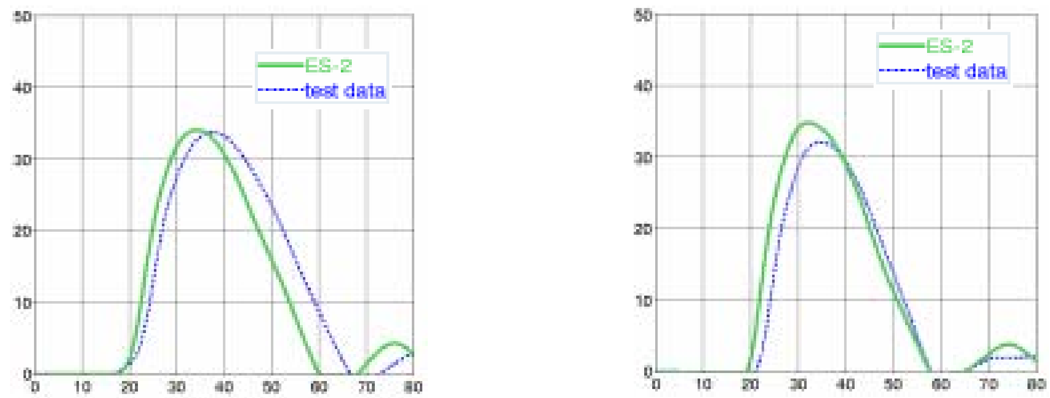


Figure 17: Rib performance: Middle rib (left) and lower rib (right). Graphs show deflection [mm] vs. time [ms].

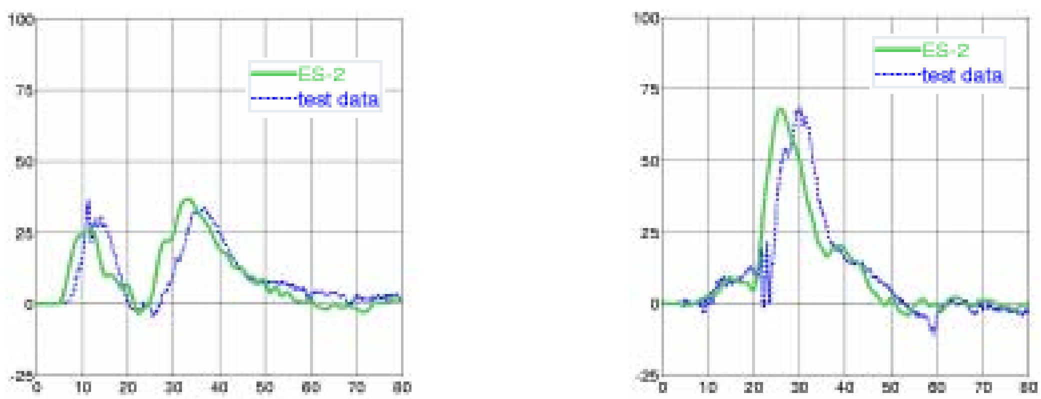


Figure 18: Spine performance: Upper spine T1 (left) and lower spine T12 (right). Graphs show acceleration [g] vs. time [ms].

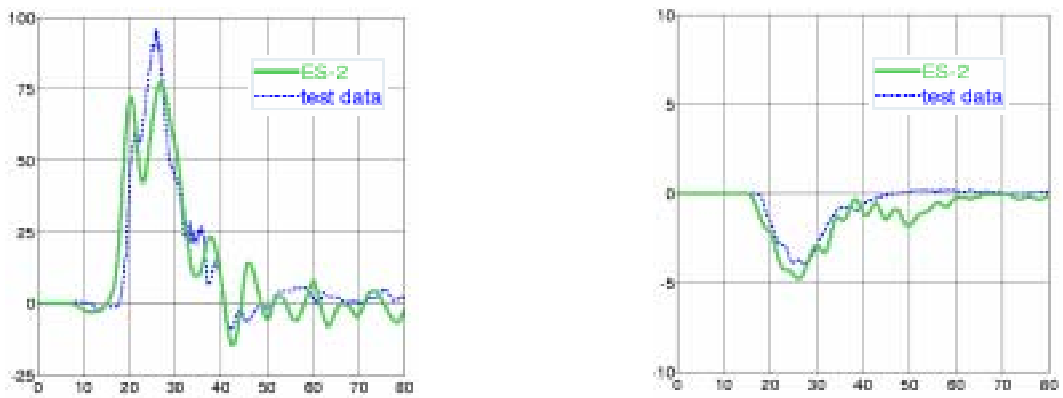


Figure 19: Pelvis performance: Pelvis accelerations (left) and pubic sympysis force (right). Graphs show acceleration [g] vs. time [ms] and force [kN] vs. time [ms], respectively.

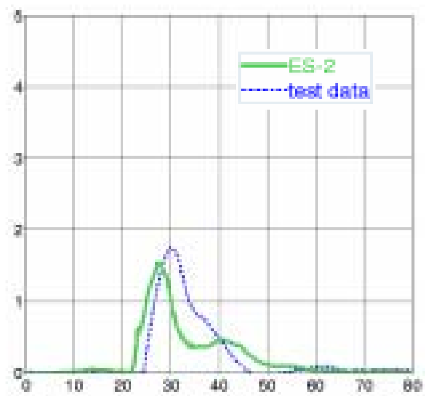


Figure 20: Abdominal resultant force. Graph shows force [kN] vs. time [ms].

CONCLUSIONS

The schedule of the project and the performed tests for the ES-2 model are presented. The indispensable need of both, component and sled tests is explained using simple examples. Experiences and suitability of the different types of tests for validation purposes are discussed.

For the development of the ES-2 model a wide range of experimental testing has been performed by the FAT. The models rely on many new features in LS-DYNA to describe the occurring effects. The ES-2 model developed by DYNAmore under the chair of the FAT is capable to capture efficiently many details with very high complexity as can be observed in the comparisons between simulations and experiments presented in this paper. It is the aim of the FAT project to achieve an accurate and stable finite element model. This goal has been achieved so far. The release 0.1 of ES-2 model is already based on a selection of pendulum and barrier tests. The ES-2 model is commercially available in version 0.1 and will be updated regularly.

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- Width: 251 feet, flight deck at widest point
- Height: 20 stories, waterline to mast
- Displacement: 91,209 tons
- Propulsion: Nuclear
- Flight deck: 196,000 square feet
- Air wing: 9-10 squadrons, 80 aircraft
- Personnel: 6,000+

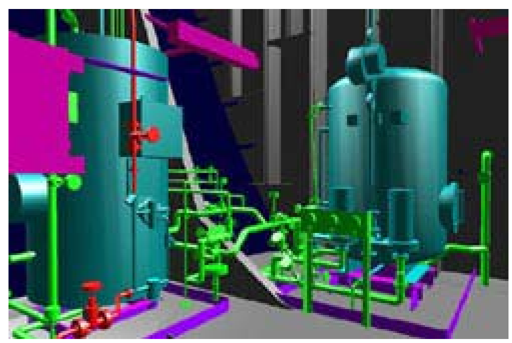
Today, Newport News employs more than 4,000 design and construction engineers, each integrally involved in the design, testing, and construction of aircraft carriers for the Navy. Their job is to develop, evaluate, and insert new technologies that reduce the total cost of ownership while enhancing the capability, flexibility, survivability, and combat effectiveness of the ship. The merging of Northrop Grumman, a defense electronics powerhouse in its own right, with Newport News, created an organization ideally suited to serve as the Navy's one-stop shop for nuclear aircraft carriers. The company's ability to provide concept-to-completion shipbuilding provides a twofold benefit to the Navy-lower acquisition costs and lower total cost of ownership throughout the life cycle of the aircraft carrier.

SGI workstations and high-performance computing systems have long been instrumental in helping Newport News reduce the total cost of ownership for Navy ships, specifically in areas of 3D solids modeling, finite element analysis (FEA), and the management of complex data.

Bow to Stern: The Seawolf-class submarine was the first Navy ship to be entirely designed by Newport News using 3D solids modeling. The move to full-blown 3D product model design for submarines and, later, for select aircraft carrier components, enabled Newport News to fully implement steel fabrication automation, maximize preoutfitting and neat-build processes, transfer digital design data to drive work-execution systems, and improve accuracy control, design quality, design validation, and configuration management.

When the Seawolf project was getting underway, Newport News was migrating its main FEA application, I-DEAS, from the mainframe to a workstation-only platform. SGI® Indigo® workstations were selected, in part, because of their support for I-DEAS and because they could also be used to handle 3D modeling of various project components.

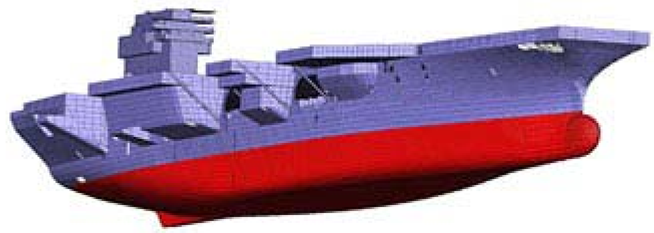
Moving Forward: In the years since the Seawolf project began, I-DEAS and VIVID tools and files were migrated to a single CAD tool-CATIA® software, a commercially available and continually upgradeable solution from Dassault Systemes that supports industry-accepted best practices. Moving to CATIA enabled Newport News to realize an overall reduction in software maintenance costs. The first of the next class of aircraft carriers, CVNX (carrier, vessel, nuclear, experimental), will be modeled using CATIA for all new design work.



Newport News' engineering visualization software of choice is PTC's dvMockup, which enables visual analysis, simulation, and real-time design collaboration of 3D CAD models across multiple machines in both LANs and WANs. Also now widely used at Newport News for supporting proof-of-concept studies and other R&D projects is Alias|Wavefront™, a comprehensive suite of 3D industrial design software applications.

Newport News' compute and visualization power recently grew when the shipbuilder refreshed its Silicon Graphics® Octane® workstations with 47 high-powered Silicon Graphics® Octane2™ visual workstations and an SGI® Origin® 3000 series system with 24 processors, eight of which are dedicated solely to FEA work. The remaining 16 processors handle 3D modeling and simulation. The SGI Origin 3000 series system's high-performance shared memory enables Newport News to perform complex computational tasks. By including SGI® InfiniteReality® series graphics, the system also enables advanced visualization. The ability to do these concurrently is unique among supercomputers and provides Newport News with a single-platform price/performance solution that can grow with the shipbuilder.

FEA Structural Analysis



The integrity of the structure of an aircraft carrier is infinitely essential to its survival. That means using SGI high-performance computing to conduct rigorous FEA analyses on every component of the carrier structure. Newport News puts carrier components through structural analyses (static, modal, transient) to test how the ship will react to every conceivable stressor once deployed. This includes load conditions such as hurricane-force winds, vibrations from routine maneuvers, explosions above and below the waterline, and a range of other war-type events. Everything possible is done to ensure that the FEA work results in the best structural engineering solution being applied to the final product.

The analyses are conducted in computer simulations to determine their validity. If the simulations are small enough (under 200,000 degrees of freedom) they are performed on the Silicon Graphics Octane2 workstations. The FEA-dedicated portion of the SGI Origin 3000 series system handles large-scale simulations, turning out results virtually around the clock. The results of each simulation are then given to the product modeler who, in turn, uses the new information to update the 3D model of the entire ship.

"You can expect to perform evaluations on several iterations of a typical model, depending on where you are in the design process," said Kevin Arden, senior project engineer for Northrop Grumman Newport News. "However, with the next class of aircraft carrier, CVNX, still in the earlier stages of development, the project engineers are conducting as many as five simulations a day just to keep up with the product modeler changes and then using the FEA results to make further design refinements almost daily."

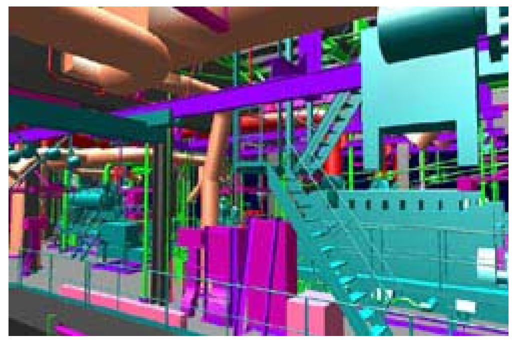
Typical FEA structural analysis applications used by Newport News include MSC.Nastran (MSC.Software), and LS-DYNA (Livermore Software Technology Corporation).

Visualization Technology

In 1998, Newport News committed fully to integrating visualization technology into its shipbuilding business model. According to Bill Kunz, Visualization Engineering Solutions project lead at Northrop Grumman Newport News, "We felt that in order to remain the world's most advanced shipyard we needed to up our competitive edge. To achieve our goal, and based on our previous successes using SGI products, we selected the SGI Reality Center facility. SGI was the only company that met all of our functional requirements. We also were quite impressed with the price/performance quotient."
SGI was responsible for the installation of the Silicon Graphics® Onyx2® workstation and the overall systems integration of the SGI® Reality Center™ theater.

SGI and Newport News then conducted a full-fledged trade study before finally selecting PTC DIVISION dvMockUp as the company's large-scale visualization tool, which could be optimized on SGI hardware. Kunz said, "Besides liking the 64-bit capability and large address memory space, dvMockUp's ability to import all CAD formats was a real plus. And it was highly customizable." At the end of the selection process, everyone involved felt that having and getting to work on the best visualization tools available would serve as a powerful incentive to the engineers.

"Our best example of putting visualization technology to work for us has been on CVNX," said Kunz. "In this program, visualization is an integral part of all Integrated Product Team (IPT) design/build meetings. The team also uses visualization collaboratively with our design partners and external customers, using it to bring them into the design process from the very beginning. Our IPTs use visualization to make movies of erection and build sequences as well as facility layouts that support preproduction planning. Future plans will support physics-based simulations as well as work and operational simulations. Ultimately we see visualization playing a huge role in life-cycle support for the ships we build."



Newport News also is very interested in the recently introduced SGI® InfinitePerformance™ scalable graphics subsystem and how it can further enhance the shipbuilder's visualization capabilities. InfinitePerformance graphics, with 16-way scaling available in fall 2002, will deliver a much-elevated class of geometry performance and will enable Newport News to visualize, interact with, and collaborate on even the largest of models and most complex simulations. The enormity of an aircraft carrier, and the number of files required to create a single, complete 3D model has, to date, kept view rates to about one to two frames per second. SGI InfinitePerformance graphics, with 16-way scaling and interactive graphics performance of up to 283 million triangles per second, will enable Newport News to achieve better frame rates and visualize their largest models in even greater detail.

Having a distributed visualization system also was part of the vision. Today, the SGI Origin 3000 series system located within the Newport News complex is connected directly to visualization centers located in four separate buildings. The facilities range from a large auditorium, a visualization center, and a design/build theater to a series of five small-scale visualization rooms. From a marketing and public relations standpoint, the SGI Reality Center installations help Newport News confirm its leadership role in the shipbuilding industry.

The Rewards: With the addition of the SGI Reality Center installations and through the use of SGI and other visualization software applications, Newport News looks to reap further time and cost savings in the area of physical prototyping.

While there are obvious time- and cost-savings opportunities to be realized through using digital prototyping, there are still some concerns that need to be overcome. Bryan Marz, enterprise project analyst for Newport News, had this to say: "Customer acceptance of a digital, design-only approval process isn't likely to happen as rapidly in shipbuilding as in other manufacturing arenas, due to customer concerns surrounding human interaction with the model."

"To facilitate acceptance, simulations in which ship personnel staff operations stations, perform casualty drills, and engage in operations that the ship is designed to perform must be created. Every design review is a proving ground for the validity and reliability of digital mock-ups."

Other areas in which digital prototyping inroads are being made, albeit at a slower pace, are the testing of dynamic events. However, Newport News' engineers will continue using the results of physical prototype testing to prove the validity of the digital model.

VASCIC: The Virginia Advanced Shipbuilding and Carrier Innovation Center (VASCIC), also located in Newport News, Virginia, is a state-of-the-art R&D integration facility managed by Newport News. The institution, which opened in 2001, brings together manufacturing, defense, and academia and serves as a collaborative proving ground for advancing visualization and other technologies that support Navy initiatives-future naval capabilities, total ownership cost reduction, and technology transfer. Newport News hopes to implement the technology advancements made through VASCIC directly into its aircraft carrier design and construction.

Into the Future: In the years and projects ahead, large-scale shipbuilders such as Northrop Grumman Newport News will continue to increase their reliance on visualization technologies as expressed through digital prototyping, visual mock-ups, and SGI Reality Center facility presentations to their customers. Because moving tremendous amounts of data forward to current technology platforms takes innumerable staff-hours to accomplish, the first fully digitally designed aircraft carrier is still some years away. However, there appears to be no doubt among industry insiders that it will happen.

To ensure that shipbuilders and manufacturers realize their visualization technology benchmarks, SGI will continue to design and develop robust workstations and high-performance computing solutions with optimum speed and graphics capabilities that will further improve upon the capability, survivability, and combat effectiveness of the backbone of America's defense.

For more information on Northrop Grumman Newport News visit its web site at www.nns.com.

FINITE ELEMENT MODELING: DESIGN MODEL

SRI International is performing research under contract to FAA to protect critical aircraft components against fragments resulting from uncontained failure of a turbine engine. As part of this program we are developing computational models to perform finite element analyses of fragment impact. The impacts are highly dynamic events, including strong nonlinear effects such as impact, penetration, and large deformation and failure of materials. We use analysis to guide and understand the impact experiments, and we use the results of the experiments to guide development of the models. To perform the analyses, we are developing a detailed material model for yarns and fabric, and a design model that is described here.

The design model that can be used as a tool for choosing or evaluating parameters for fragment barriers. Because it uses a simplified description of the fabric, the model runs very quickly (about 2 minutes on an SGI Origin 200 for the tests shown here) and easily allows evaluation of changes in size of fabric, number of layers, or yarn pitch. The design model implemented as a user-defined material in LS-DYNA3D uses shell elements with an orthotropic continuum formulation to model the fabric.

MODEL PARAMETERS

To calculate parameters for the shell material model, we use measured values for thickness and areal density of the fabric. From the measured value of strength for a single yarn (1.61e7 dyne [36 lb]), we calculate linear fabric strength (e.g. in dyne/cm) by multiplying the pitch (number of yarns/cm) by the strength of a yarn. We calculate the Young's modulus (dyne/cm2) in the two orthogonal directions along the yarns by taking the measured yarn load at 1% strain, multiplying by the pitch and distributing the load over the fabric thickness. The shear modulus in all directions is assumed to be 10% of the Young's modulus, and the Poisson's ratio is assumed to be zero in all directions. The fabric density is calculated by dividing the measured areal density by the measured fabric thickness. For multiple plies, the fabric thickness is simply the number of layers times the single layer thickness; the modulus and density values remain the same. This model assumes that for a multi-ply target the fabric yarns are all aligned in the same directions (e.g., 0 and 90 degrees).

Design Model Parameters

No. of plies	Pitch yarns/inch	Thickness (mm)	Areal density g/cm2	Force at 1% dyne	Modulus dyne/cm2	Density g/cc
1	30	0.15	0.0130	2.00e8	5.25e11	0.867
1	35	0.19	0.0158	2.33e8	4.84e11	0.832
1	40	0.23	0.0185	2.67e8	4.57e11	0.804
1	45	0.27	0.0219	3.00e8	4.38e11	0.811

FAILURE MODEL

The fabric material model is assumed to be elastic-plastic with linear hardening to failure in two orthogonal directions aligned with the yarns. The yield stress is set to 12.0e9 dyne/cm2 with 20%

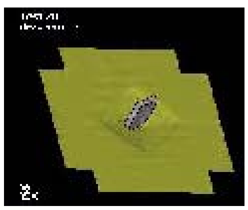
strain hardening. The failure criterion is based on accumulated plastic strains in the two directions both exceeding a specified limit. The limit values for strain, which depend on the number of layers, are listed below.

Failure Strain Values

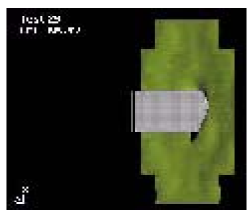
No. of Layers	1	2	3	4	5	6
Strain to failure	0.035	0.060	0.085	0.110	0.135	0.150

EXAMPLE SIMULATIONS

We performed simulations using the simplified model for 15 of the gas-gun tests . The calculated results of these calculations are listed in the table below. The test included Zylon targets covering the range from 30 to 45 yarns per inch, from one to 6 plies, gripped on two edges and four edges, with a range of pitch and roll angles for the fragment. Three of the simulations are shown in the animations below.



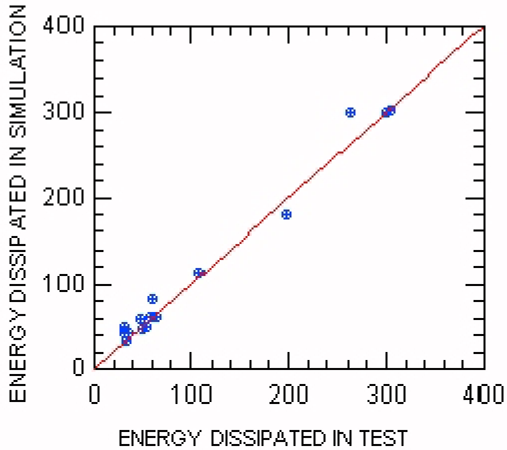
Test 20
1 ply Zylon
Gripped on 4 edges
25 g fragment



Test 29
4 plies Zylon
Gripped on 4 edges
96 g fragment

Test 58
1 ply Zylon
Gripped on 2 edges
25 g fragment

For each simulation we calculated the residual velocity of the fragment and from that, the energy dissipated by the target. For calculations in which the fragment did not penetrate the target the residual velocity was set to zero. The figure below shows a comparison between the calculated and measured energy dissipated for 15 of the gas gun tests. A linear fit through the data passing through the origin gives a slope of 1.03 and an R2 value of 0.98. The average of the errors in calculated energy dissipated for the simulations is +4.4% of the total kinetic energy of the fragment with a standard deviation of 8.7%. Although the design model does a good job overall, it tends to overpredict the dissipated energy for the tests with four edges gripped.



RESULTS FOR SIMULATED GAS GUN TESTS

SUMMARY OF DESIGN MODEL

The design model as implemented in LS-DYNA3D is very easy to use, with a limited number of physically-based input parameters, and runs in a few minutes on an 4-processor SGI Origin 200. It has done a reasonably good job for simulating the gas gun tests, but it has some obvious limitations in terms of modeling failure mechanisms such as yarn pull out. We need to investigate its utility for other applications such as fuselage impact tests.

For more information about this research, please contact:

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October 07

LSTC	Segment based automatic contact AVI 61
	LS-POST

October 14

CEI	Harpoon for mesh generation
AMD	A notebook with the AMD Athlon™ XP processor
DYNAmore	The First LS-DYNA Forum held by DYNAmore

October 21

FEA	AVI 62 Courtesy Cril Technology
ANSYS	ANSYS/MECHANICAL

October 28

MSC.Software	MSC.Linux the way to the future
JRI	JMAG-Studio a magnetic field analysis program
Altair – West	Altair Western Region

Events & Conferences

2002	
Dec 18 - 21	**HiPC 2002** will be held in Bangalore, India known as the Silicon Valley of India.
2003	
Feb 18	**Fujitsu LS-DYNA Seminar** at Makuhari System Laboratory
Feb 20-21	**2nd LS-DYNA Users Conference by GissETA** India Private Limited - dev@gisseta.com
May 19-21	**BETECH 2003** taking place at the Hyatt Regency Dearborn hotel in Detroit, USA - 15th International Conference on Boundary Element Technology
May 22 - 23	**4th European LS-DYNA Conference** will be held in ULM, Germany presented by DYNAmore (Germany), Cril Technology Simulation (France), ARUP (United Kingdom), Engineering Research AB (Sweden) and STRELA (Russia) Call for Papers & Registration - (PDF 472KB)
June 3-5	**Testing Expo 2003**, Stuttgart, Germany. A world's leading automotive test and evaluation exhibition & conference
June 17-20	**The Second M.I.T. Conference** on Computational Fluid and Solid Mechanics, taking place at Massachusetts Institute of Technology Cambridge, MA.,USA The mission of the M.I.T. Conference is: "To bring together Industry and Academia and To nurture the next generation in computational mechanics"
Oct 29-31	Hosted at the conveniently located Novi Expo Center in Detroit, Michigan, **Testing Expo North America 2003** will bring together, under one roof, leading test equipment manufacturers and test service providers.