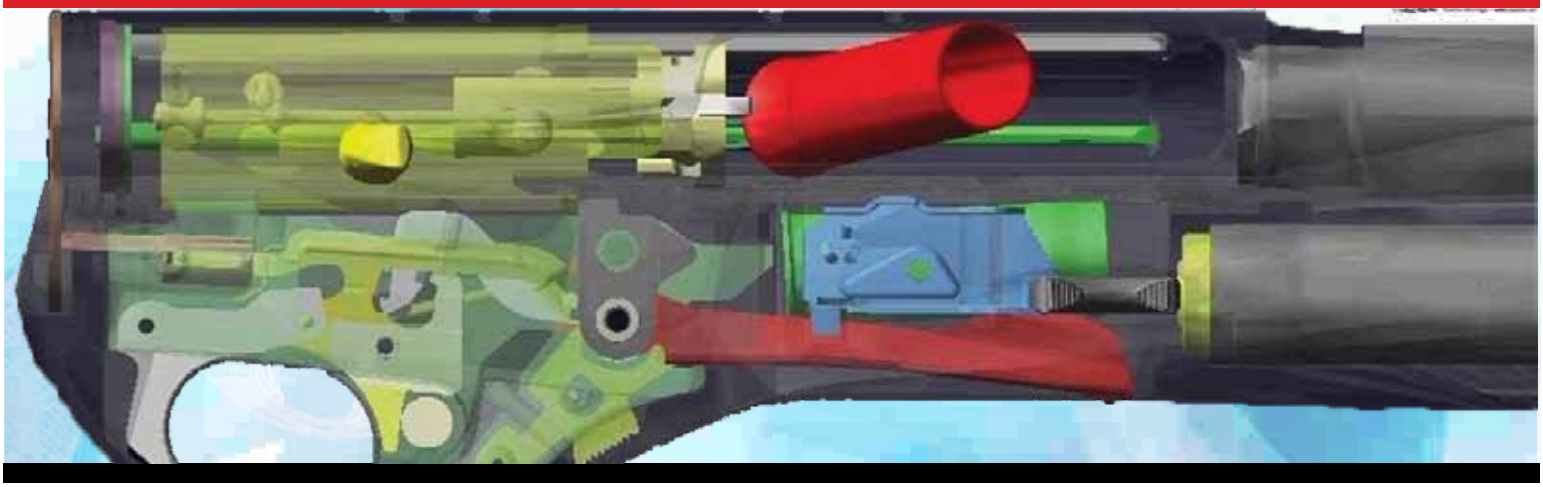
MSC Software

CASE STUDY

MSC Software: Case Study - Benelli Armi S.p.A.

Developing New Customizable Armaments

Virtual Prototyping Accelerates the Design Process of a new Modular Based Weapon



Virtual Prototyping Accelerates the Design Process of a New Modular Based Weapon

With the revolutionary VINCI shotgun, Benelli Armi developed a conceptually new semi-automatic inertial weapon, designed according to a patented modular system that allows the end user to reconfigure and customize the weapon by switching the modules without the use of tools.

This case study shows the process of virtual prototyping applied in the development of the VINCI project. After experimentally characterizing the phenomenon of the shot, a complete multibody model of the gun was built using MSC Software's Adams™ to determine a satisfactory configuration of the weapon. This configuration was then used to develop the first physical prototype, on which kinematic and dynamic parameters were measured in order to calibrate its behavior with respect to the Adams multibody model. The fine-tuned model was then used to virtually optimize all the different functions of the weapon through the use of the DOE. Finally, using the parameters optimized with Adams, the necessary physical prototypes were built to test the reliability and durability of the weapon.

The use of virtual prototyping in the development process of the new VINCI has contributed to the reduction in the number of physical prototypes and tests thereby reducing the time and cost of project development. The VINCI was awarded the prestigious "Shotgun of the Year Award 2010" in the United States.

Inertia Semiautomatic Shotguns: State-of-the-Art

The inertial semi-automatic shotguns exploit the recoil energy to power all aspects of automatic reloading. These are all the operations that follow the shot and the mechanism of the weapon must automatically perform to fire a new shot:

- The new shotshell is in the chamber, with the cocked hammer and closed bolt, Pressing the trigger releases the hammer which, pushed by its spring, strikes the firing pin, priming the cartridge.

Key Highlights:

Industry

Defense

Benelli

Challenge

To develop a conceptually new weapon designed as a modular system and an integrated system of recoil reduction.

MSC Software Solutions

Adams to determine a configuration of the weapon and to calibrate its behavior.

Marc to ensure the mechanical strength of the weapon

Benefits

- Optimize the Parameters
- Test Reliability and Durability
- Time and Cost Reduction of Project Development

"The use of MSC Software solutions has contributed to the development of a conceptually new design based on a modular system, reduced the number of physical prototypes and experimental tests; and reduced the overall time and development costs of the project."

Loredana Banci, Research and Development Manager, Benelli Armi

- The explosion of the cartridge pushes to the bullet that leaves the barrel at supersonic speed, causing the recoil of the weapon. The spring interposed between the locking head and the bolt is compressed and accumulates enough power for the bolt to accomplish all the different automatic reloading operations (shellcase extraction and ejection, compression of the bolt recovery spring and return of the bolt in closed position with the introduction of a new round in the chamber).

The New Project: Modular Inertia Semiautomatic Shotgun

The primary objective of the new project, VINCI (modular inertia semi-automatic shotgun), was to develop a conceptually new weapon designed as a modular system, allowing the end user to be able to reconfigure and customize by choosing new components of the shotgun from alternatives available in the market. Another objective was to create an integrated system of recoil reduction with particular attention to ergonomics. The weapon also had to be reliable with the full range of both high and low energy cartridges, according to the high Benelli quality standards.

To achieve these objectives it was necessary to develop a compact inertia system capable of concentrating all functions (closing, opening, shellcase ejection, reloading and returning to a closed configuration) that are required for a proper operation of the weapon within a single module, in order to make sure that all other independent and interchangeable modules could be replaced without the use of tools.

The Virtual Prototyping Process

Following are the steps of the virtual prototyping process applied during the development of the new VINCI project:

Analysis of shooting test: In the semi-automatic shotguns, the phenomenon that governs the shot is the recoil, since it determines the kinematic-dynamic behavior of the weapon. Therefore, the virtual prototyping process started from the characterization of the firing phenomenon in Benelli Armi ballistics laboratory by measuring the following values on a gun taken from series production: pressure in the chamber, force of recoil on the shooter's shoulder and bolt/shotgun displacement.

Construction of the multibody model: The construction of the complete multibody model of the gun has been realized using the simulation software, Adams, including all CAD components and relevant material properties.

The loads and constraints, both internal: joints, contacts, springs..., and external: DOFs of the weapon, cartridge pressure, gravity... were then applied to the model. Simulations with different types of cartridges (different pressure curves) have been performed in order to verify the efficiency of the weapon with different energy levels: the verification of relative displacements and velocities of the bolt with respect to the weapon makes it possible to monitor the functioning of the weapon with the full range of commercial cartridges used for hunting.

Figure 1: "Vinci" shotgun with compact inertia system

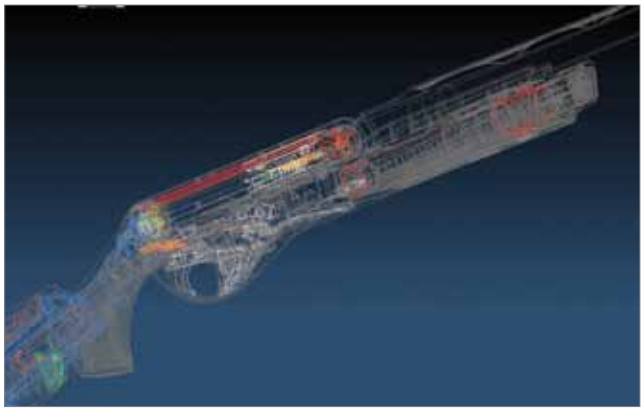


Figure 2: CAD model

Figure 3: Constraints and external/internal loads

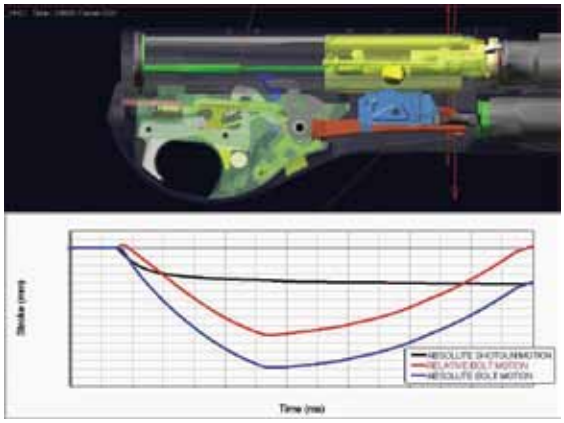


Figure 4: Multibody model

Calibration of the multibody model: Once a satisfactory configuration for the weapon was found, the first physical prototype needed for the calibration of the multibody model was built. All displacements, velocities and accelerations of the components that affect the kinematic-dynamic behavior of the weapon have been measured to calibrate the model by comparing with the Adams results. Through the support of physical prototype tests, engineers at Benelli Armi have calibrated various Adams parameters including, for example, the static and dynamic coefficients of friction of all contacts, the damping coefficients and the elastic constants of the reaction forces in order to obtain weapon/bolt displacement curves nearly superimposable with measurements (as shown in figure 5).

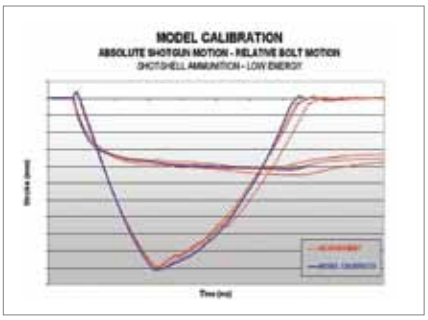


Figure 5: Calibration of the model by comparison with experimental measurement

Design optimization using simulation: Once the confidence in the results of the multibody model was acquired, the optimization of the different functions, extraction, ejection and loading enable was performed. in order to obtain a weapon characterized by an overall weight of 3.3 kg and reliable with the whole range of commercial hunting shotgun cartridges. Through the use of multi-level and multivariable Design of Experiment, the values of masses, springs, geometry, materials, etc.., were modified in accordance with design specifications (depth of blow, trigger load, maximum size, drop test according to NATO standards).

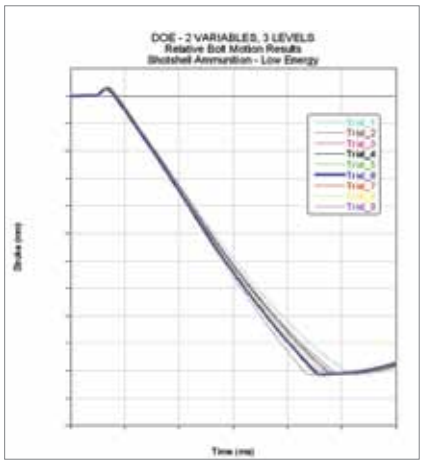


Figure 6: Optimization results

The use of DOE analysis on the virtual prototype enabled to evaluate in a clear, precise and rapid manner the effects of all variables involved and their interactions, by eliminating the intrinsic variability of the processes that causes, during the experimental trials, a high standard deviation of the measurements . Among the various functions of the weapon that have been analyzed and optimized through the Adams Design Evaluation tools, the following examples related to phase extraction and ejection of the cartridge case after firing (Figs. 7 and 8) are shown.

Construction of the optimized prototype: Once all parameters related to each function (extraction, ejection, loading, ...) have been optimized, the necessary physical prototypes were built to test reliability and durability of the weapon.

Validation of the multibody model: The qualification tests of the prototypes were made in the Benelli Armi ballistic laboratory, where, thanks to sophisticated measuring instruments (high-speed camera, laser, accelerometers, piezoelectric sensors, etc..) the correspondence between the results provided by the Adams simulation model and the experimental measurements was verified.

In addition to the kinematic-dynamic simulations made with Adams, on all safety components of the new VINCI project a series of structural checks were carried out with Marc in order to ensure the mechanical strength of the weapon.

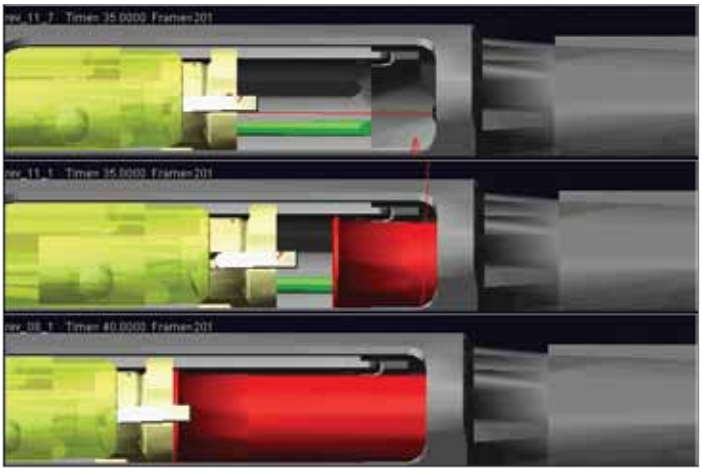


Figure 7: Comparison of different DOE simulations to evaluate the combination of relevant parameters that allows for an efficient extraction.

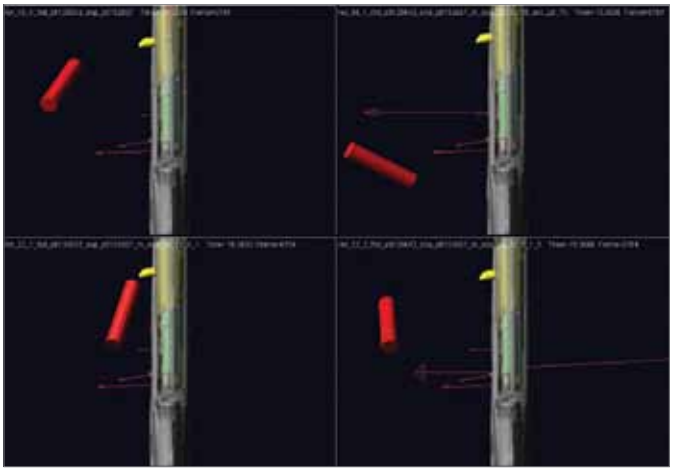


Figure 8: Comparison of different DOE simulations to evaluate the combination of relevant parameters that allows for an efficient expulsion.

Conclusions and Future Developments

The use of MSC Software solutions (Adams for kinematic-dynamic simulations and Marc for structural analysis), has contributed to:

- Develop a conceptually new weapon based on a modular system.
- Reduce the number of physical prototypes and experimental tests.
- Reduce the time and development costs of the project.
- Register three new patents (locking and recocking assembly, quick coupling for stock, modular portable weapon).

Moreover, Benelli Armi is actively working to implement the process of virtual prototyping during the development of new products through the use of the new SimXpert simulation environment which will allow:

- The improvement of CAD-CAE integration ensuring two-way mapping between the various modules through direct import of native CAD formats.
- The solving of multidisciplinary problems through the integration of FEM and multibody.
- Automatic capture and reuse, through the creation of templates, all procedures for the construction of virtual models, in order to significantly reduce the time dedicated to the repetitive steps of model preparation and at same time to protect the corporate know-how.

Another area of development will be dedicated to the implementation of topological optimization in order to achieve even more efficient and effective conformation of the components of the weapon, thus reaching the predefined goals within the constraints of the project.

About Benelli Armi

Benelli Armi was founded in 1967 by the Benelli brothers and has been part of the Beretta group since 1983. Benelli Armi is present in 74 Countries with a capillary sales network allowing it to offer permanent product sales and service assistance. In the USA, the main overseas market, there is a direct sales branch, while in France and Spain the company is in partnership with the Beretta group. Benelli commands more than 20% of the global market for semiautomatic shotguns and in Europe leads the industry sector.

To satisfy the needs and characteristics of such a vast market, Benelli Armi has created the widest and most complete range currently available, comprising 135 semiautomatic models. Over the years, the image of Benelli Armi has grown from strength to strength in Italy and abroad, until finally achieving company quality certification according to ISO 9001 and NATO AQAP 2110 standards. For additional information, please visit **www.benelli.it**.

Figure 9: Complete physical prototype

About MSC Software

MSC Software is one of the ten original software companies and the worldwide leader in multidiscipline simulation. As a trusted partner, MSC Software helps companies improve quality, save time and reduce costs associated with design and test of manufactured products. Academic institutions, researchers, and students employ MSC technology to expand individual knowledge as well as expand the horizon of simulation. MSC Software employs 1,000 professionals in 20 countries. For additional information about MSC Software's products and services, please visit: www.mscsoftware.com.

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About Adams

Multibody Dynamics Simulation

Adams is the most widely used multibody dynamics and motion analysis software in the world. Adams helps engineers to study the dynamics of moving parts, how loads and forces are distributed throughout mechanical systems, and to improve and optimize the performance of their products.

Traditional "build and test" design methods are now too expensive, too time consuming, and sometimes even impossible to do. CAD-based tools help to evaluate things like interference between parts, and basic kinematic motion, but neglect the true physics-based dynamics of complex mechanical systems. FEA is perfect for studying linear vibration and transient dynamics, but way too inefficient to analyze the large rotations and other highly nonlinear motion of full mechanical systems.

Adams multibody dynamics software enables engineers to easily create and test virtual prototypes of mechanical systems in a fraction of the time and cost required for physical build and test. Unlike most CAD embedded tools, Adams incorporates real physics by simultaneously solving equations for kinematics, statics, quasi-statics, and dynamics. Utilizing multibody dynamics solution technology, Adams also runs nonlinear dynamics in a tiny fraction of the time required by FEA solutions. Loads and forces computed by Adams simulations improve the accuracy of FEA by providing better assessment of how they vary throughout a full range of motion and operating environments.

About Marc

Advanced Nonlinear & Multiphysics

Marc is a powerful, general-purpose, nonlinear finite element analysis solution to accurately simulate the response of your products under static, dynamic and multi-physics loading scenarios. Marc's versatility in modeling nonlinear material behaviors and transient environmental conditions makes it ideal to solve your complex design problems. With its innovative technologies and modeling methodologies, Marc enables you to simulate complex real world behavior of mechanical systems making it best suited to address your manufacturing and design problems in a single environment.

With the solution schemes that are smarter and designed to provide the performance that you need by taking full advantage of your hardware combined with an easy to use modeling solution, you can truly discover and explore nature's inherent nonlinearities. Whether your problems involve large deformation and strains, nonlinear materials, complex contact or interaction between multiple physics, you have reached the end of your search and with Marc, you can now focus on your improving your designs.

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