Quigley Scientific Corporation

• Applied & Computational Mechanics • Analytical Analysis, Design, & Development •

Corporate Objectives

Quigley Scientific Corporation provides solutions to difficult industrial problems involving technical and scientific research, analysis, modeling and software development. The primary objectives are to provide, creative, innovative, and robust solutions to client companies. Our approach involves focusing concentration at solving our client's current needs while developing a proprietary knowledge base for our client. The ultimate result of this proven and successful approach has established new core competencies for our client. This has led to new methodologies, processes, products, shortened delivery times for re-engineered products and new product deliveries.

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Project Experiences

The following sections illustrate typical projects completed by Quigley Scientific. For a full description of capabilities you are invited to our web site at http://www.qscorp.com.

• A detailed ***thermal system review*** was completed on a computer controlled manufacturing system. The client company was attempting to accelerate production rate for a next generation machine. Thermal efficiency and thermal loading was reviewed and recommendations provided.

• A design review was completed of an innovative dynamic chair system for an inventor. The advanced design of the chair has significant and position consequences on the comfort, health and healing rate of patients that use the chair. The dynamic nature of the chair involved a gravity fed ***dry particle flow*** system that required no outside energy to operate. Due to the nonlinear and chaos theory aspect of the system, a scientific experiment was designed for materials selections and calibration to provide a performance response consistent with the health aspect of the chair concept.

• A detailed design review and brainstorming meetings were completed on a water driven concept for ***endoscopic and dermal surgery***. This project involved "back of the envelope calculations" to quickly provide performance predictions in a concurrent design effort. The support to the client company included design review, business planning for ***design for maintainability***, review of the manufacturability and performance of the prototype designs, and brainstorming sessions for next generation products. Specific analyses focused on component sizing for vibration isolation and design support for structural consequences of machine failures.

• The ***dynamic fracture*** of a polycarbonate medical ampoule device was studied. An extensive test program was designed with the client to investigate the possible correlation of mold pressure at fixed temperature on the fracture toughness of the design. The study involved ***photo-elastic analysis*** of 1000 molded specimens under various molding conditions. A presentation of the large graphical database of digital scans of the photo-elastic images was completed as a customized web site for the client. The project increased the understanding of the influence of the ***mold core design*** to the temperature gradient induced residual stresses in the molded parts. The organization of the large graphical data set facilitated communications between the US and Europe based offices.

• An ***analytical viscoelastic analysis*** of a ***composite spring*** was completed for a tolerance sensitive design. The analysis included temperature dependent material property modeling to track the use of the spring part through production, assembly, storage and final use in an automated test machine for the ***medical industry***. The initial phases of the project include a detailed design and manufacturability review of the spring concepts developed by the client company. The analyses included functionality and features analysis and supported by the risks and benefits of the design.

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• The design of high cycle fatigue structures as typically seen in the plastics molding industry may not immediately seem apparent. However, with the increased needs of high volume part productions and decreased mold cycle time, the molding pressures on ***thin walled deep parts*** becomes a high cycle fatigue concern. The cost associated to premature fatigue failure typically results in unplanned and unexpected costs to the molding company. The utility of engineering fatigue calculations for ***mold core design*** was implemented to complete detailed comparison between two alternate designs involving 1-gate or 3-gate designs. The detailed issues of vent and retaining pin locations and geometry features was combined with details of the core manufacture. The ***original design knowledge*** of the mold cores was shown to exist, and for what reasons, and was not reduced or changed in the list of additional design recommendations. The engineering fatigue evaluation involved **MoldFlow™** calculations as provided from the clients analysis team with methodologies provided by Quigley Scientific. The fatigue calculations used a full range of strength reduction factors applicable to this industry and illustrated the management of these factors, hence manufacturability, would increase mold core durability. The reliability of the fatigue predictions was computed to be consistent with the internal product quality standard.

• An analysis of a structural plastic product that needed to be ***assembled by the consumer*** was completed. The design review provided suggestions on how to improve the product before the final tooling was completed. In many cases by wearing an ***"analyst hat"*** can provide timely suggestions to the design process. An analytical contact analysis was completed and delivered to the client for the axle bearing loads, plastic wheel contact loads for a number exceptional loading cases in the design. A novel analysis method was applied to estimate the ***rolling loads*** for rolling over carpeted floors and over low thresholds in office and home applications.

• High temperature transient analysis for ***nitride bonded silicon carbide ceramics*** in over ***700 megawatt coal fired boilers*** was completed to identify the source of failure due to ***thermal gradient self-stressing***. The analysis attempted to design a lower cost solution to replace conventional steel designs. The project involved a retro-fit design limitation of the proposed ceramic part, and included fixed constraints based on the established flow characteristics of the burner. A proprietary finite element ***thermal-structural analysis*** was completed which included details of the air flow and coal particle system, effects on thermal loading due to the coal ash debris, effects of heat conduction, heat convection and thermal radiation from the flame front. The novel aspects of the analysis showed the competition between the heat conduction and convection effects that caused a severe self-stressing structural loading of the ceramic part. A new conceptual design using ***organic shapes*** was rendered and recommended to the client.

• A re-design based on a ***fast prototype dynamic response analysis*** for point of sale consumer station was completed. The benefits of fast prototyping is to validate many aspects of a new design, but the dynamic and structural response of the fast prototype does not indicate that of the final production version of the design. This project involved dynamic measurements of the fast prototype design and correlation to an analytical model of a ***spring loaded door opening***. The dynamic response of the final production version, with changes, was predicted and a custom coil spring design/specification was completed to provide a desirable dynamic response. Additional analysis support was completed with a nonlinear finite element analysis for the ***snap together design***. The calculation determined the peak force experienced for product drop test where the peak force had to cause ***disassembly without breaking***.

• A detailed ***finite element contact analysis*** of a sheet metal assembly was completed for a computer server application. The analysis model included detailed modeling for various connectors including ***line welds, plug welds, spot welds, pop-rivets and bolts***. The modeling included mechanical locking of the edge-to-edge contact and face-to-face contact in the assembly. The analyses were completed to complete the design process and provided tabulated summaries of the factors-of-safety for all key locations in the assembly. A design review provided recommendations for improving durability. A review of physically tested frames provided additional recommendations for data collection during physical tests and ***modes of failure analysis*** for the system.

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• Literature survey and fracture analysis of deep and long cracks in ***3" to 12" thick steel weldments***. Finite element modeling study was completed in full penetration welds to study the ***sensitivity of defects*** in the weld metal. The project lead to specific recommendations to the preheat, interpass and post heat conditions to build tough welds. Forensic analysis of photomicrographs indicated source and subsequent propagation from ***hot crack*** formed during the early solidifcation stage of the weld metal melt front. Acoustic stress waves were to cause the origin of the initial defect of a hot crack.

• Analysis of complex ***three-dimensional flat springs*** in automated testing equipment was completed. The project involved designing within specific geometric constraints for the compatibility with established parts and machinery. The springs were expected to provide adequate sealing force for the low temperature storage of the medical test specimens. The fatigue failure of the spring would cause major interruptions to the physical test and a durable final design was provided.

• An ***earthquake loading*** model for sizing of a assembly connectors for a ***telecommunications device*** was completed. Simple analytical models were generated to complete trade-off studies and what-if-scenarios for the design. The analyses were very practical to the fracture durability of the connectors to the level of ***first engaged thread stress*** from exposure to the loading defined by the ***Network Equipment-Building System*** (***NEBS) Requirements***, ***GR-63-Core*** specification.

• A very critical problem of a military sub-system would cause catastrophic failure at low temperatures. A ***temperature coefficient of expansion mismatch*** was found to be the issue leading to the failure. One in the field failure was unacceptable and solutions were provided to identify the cause and to correct the problem.

• In an ***ultrasonic welding*** operation of plastic parts, a system of internal electrical conductor strips were fatigue failing due to ***natural resonance excitation***. A detailed ***parametrically based model*** was created to optimism the dynamic response thus tuning the connectors. The model included a melt front model due to frictional heating at the connector-plastic interface. Correlation to physical test data was completed and fracture behavior identified resulting in redesign and improvement of the device.

• A stress, fracture and fatigue analysis depending on ***tolerance variation*** and stack-up analysis of a complex automotive application. The product involved a ***bolted assembly*** of stamped metal and composite parts. The fracture and fatigue analysis involved understanding the mechanisms in the fabrication that affected the durability and performance of the assembly. The loadings included random vibration at elevated temperatures as found in the ***automobile engine compartment***.

• Assembly analysis of consumer product involving ***multistage locking device***. The study included stress and sudden loading analysis for an aluminum frame attached to the locking device. Failure of the device would potentially cause liability issue for the start-up company.

• Fracture analysis of ***cracked high speed rotating devices*** was completed as part of an ***Air Force SBIR*** (Small Business Innovative Research Program). An innovative parametric analysis method was develop to complete a consistent convergence study. The final mesh models were designed to capture the correct physics occurring in the rotating and crack solution fields. A design sensitivity analysis was completed in a detailed form to produce an ***analytical variance*** of the performance and fracture toughness of the system. A state-of-the-art understanding was created that produced new knowledge on the ***true discriminators*** in rotating body performance.

• Drop analysis and day-to-day handling analysis and design review of point of sale scanning device. A critical design review and forensic analysis was completed on the device performance. Several recommendations were generated and implemented. The analysis involved relating the peak dynamic stress loading to critical regions in the device. The finite element study related to the ***thread root level*** of stress concentration of a critical component.

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• A ***nonlinear locking device*** for an adjustable ice hockey helmet was reviewed and analyzed for stress, deflection, and shock analysis. A significant number of "what if" scenarios were formed, discussed and analyzed to increase durability and strength required for the serious athlete.

• An very new and ***innovative ski boot*** concept was reviewed and analyzed. A state-of-the-art method for ski boot design and efficiency was involved to improve the athletes controllability and performance. A number of alternate conceptual designs were created and analyzed.

• Detailed technical and ***literature review*** of a metal forming process specific to the client's product was completed. A worldwide search was involved to bring the client technical background and reference data to state-of-the-art in their industry. Many related subjects were identified to provide support to current and future product developments. The worldwide search was completed with computerized search services, patent and literature paper recovery, direct investigation and research, paper review, and generating a ***technology plan*** for the use of the discovered information.

• The selection of transparent, durable and strong materials for the design of a deep well ***pipe inspection system*** was completed. Long time fatigue and fracture behavior of ***fused silica*** and ***sapphire*** was considered due to the high temperature and high pressure environment. A design review of the support structure and sealing methods of the tool was completed to improve tool life.

• Impact analysis of an automotive application involved a ***passenger compartment shift handle*** for a ***first–tier supplier*** to the automotive industry. The study was a preliminary analysis of the nonlinear aspects of a collapsing shift handle and its internal complex design features. The total ***energy absorption and peak loading*** to the passenger was computed and compared to the allowable and acceptable limits. Nonlinear finite element analysis involving plasticity, finite deformations and developing/evolving self-contact analysis was completed.

• An extensive mathematical development is underway for a metal forming process that contributes in a core manner to an engineered product that produces over ***1000 product variations***. The mix and match aspect of final product assemblies requires engineering feasibility studies to be completed during the design to specification for unique, one of a kind, product deliveries. The mathematical aspect of the product is being developed with semi-analytical functions to a deep level. The development was implemented in the ***Mathematica™*** computerized system for mathematics. The resulting design and analysis function will provide code functions to provide design and sensitivity directives. This work effort will lead to developing a ***core competency*** for the client company in critical aspects and timely development of new product deliveries.

• In an oil field application a conceptual design and feasibility evaluation was completed to identify robotic solutions for tractoring wire cables into deep horizontal wells. Several design concepts were discovered and evaluated from the standpoint of feasibility in the hot and abrasive environment of wells. ***Fail-safe designs*** were investigated to limit the possibility of irrecoverable tractor failures. Energetic requirements for tractor operation and ***automatic recovery system***s was investigated and analytical calculations generated to support the design considerations.

• Analytical development support of an innovative ***inline skate blade*** sporting goods product line was completed from concept, through design and analysis, and manufacture. This project involved working with the lead design engineer at the client company to develop a totally new concept for ease of use and maintainability of inline skate blade wheel and chassis mountings. The final design resulted in a minimal set of parts and configurations that produced three actual products for the market and for addressing the needs of the inline skate blade customer and rider. This project has lead to Quigley Scientific's first ***World Patent*** application with the client company by invitation.

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• A design sensitivity study was completed to increase the buckling strength of a ***boot binding*** in the snow sport industry. The occurrence of a binding failure may lead to serious rider injury. The design variables significant to the design were identified and an appropriate nonlinear finite element model was developed to model the ***kinematics of the locking device***. The effects of process variations, composite material variations, molded part tolerances, and justification of dimensioned parts in the binding assembly were incorporated in the study. Several design recommendations were provided through the product design and re-tooling efforts. An experimental test designed by the client was modified based on the finite element findings which lead to high correlation to the analytical predictions. This work effort has lead to developing a core competency for the client company in the critical aspects of binding design, engineering and development.

• The electronic slider switch and internal contacts were designed for the **SpotLiter™** product. The design was completed analytically in ***Mathematica™***. The work included a model for the nonlinear snap-through of the switch and the multiple states that the switch was to endure. The design was based and motivated from earlier work completed and the constraints and methods developed on the **SnakeFan™** project list below.

• Detailed forensic and mathematical analysis of the importance of ***edge effect*** in laminated composite structures was researched. The forensic analyses involved microscopic investigation of the effects of manufacture process and how the resulting ***insitu geometry*** influences the edge effect response and product strength.

• Detailed analysis of a laser "piping" system for beam delivery applications for ***laser based manufacturing***. The analysis involved detailed analysis to obtain critical alignment information for the laser delivery system in terms of beam translations and rotations through the reflected system. A comprehensive modal analysis was completed and the frequencies and modes discussed in physical detail. A ***stochastic analysis*** was completed based on the power spectral density (PSD) anticipated in the manufacturing site. The analyses were completed concurrently with the
manufacture of the system and delivered before the laser system was installed at the client's customer site. Design recommendations were completed to improve system dynamics and stiffness.

• ***Drop analysis*** of a bolted plastic assembly on the housing of a portable electronics device was calculated. The analytical method involved the combination of numerical methods that allowed for energy transfer through the part interfaces of the assembly. The peak dynamic forces and stresses were identified through the assembly and were completed concurrently with the design team efforts.

• Mathematical development of a ***stochastic tolerance analysis*** was designed for high precision indexing rotary tables. The development was implemented in the ***Mathematica™*** computerized system for mathematics. The base equations of the machine analysis included nonlinear kinematics, nonlinear finite element analysis combined with analytical contact stress analysis. The design variables and system level variables were considered in the study.

• The analysis and redesign of a ***circular knitting machine*** sinker component was completed for the highest speed machine in the world. The sinker component in combination with the knitting needle completed the knitting operation. Detailed finite element analysis and fatigue analysis were completed to produce ***design curves*** for existing design variables and machine clearances. A new design was obtained from the historical data on previous design considerations by the client. The study reproduced the best attributes of the earlier designs and combined them to provide the required machine durability to exceed $\mathbf{10^9}$ **cycles**. Forensic studies from a surface scanning electron microscope were applied to the analysis. An in-house experiment was designed for validation. The viability of the analysis based design solutions included specific ***manufacturablity specification*** in terms of ***tolerances on clearances*** to ensure the machine's required fatigue durability.

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• A detailed analytical stress and fatigue analysis was completed for a juvenile high chair. The project involved the validation of experimental/quality testing of a field-fix kit and a new design for the product. The final review of the Quigley Scientific findings were presented to the **Consumer Product Safety Commission** (CPSC) in Washington, D.C. The work by Quigley Scientific contributed directly to a national press release announcement concerning the product.

• The ***fretting fatigue analysis*** of a large crank shaft was modeled for a 200 ton metal forming press. Forensic data of a failed system was correlated to the stress analysis for investigating the possible reasons of the failure. Studies were completed for various combinations of loads and third-party accessory equipment.

• A review and discussion was completed on ***engineering design and analysis methods*** for a large metal forming press company (over 200 tons). The review involved complete review of engineering drawings and consistency to the overall design and analysis methods in place. The root of the investigation was the beginning of long discussions on how to achieve consistent definitions of factors-of-safety for open discussions among the company's sales, marketing, design and engineering groups. The cost of quality and reliability of prescribing quality standards resulted.

• An electronic slider switch was designed for the **SnakeFan™** product. The design was completed in ***Mathematica™*** that included a model for the nonlinear snap-through of the switch. The design replaced a prepackaged design that was previously designed into other products. The slider switch design included an extensive design and analysis of the switch to balance a variety of constraints including: human factor analysis for the allowable force for turning on and off, stress relaxation of the nickel plated phosphor bronze material used in the switch, material yield limits, and the required electrical contact force for ensuring good contact. The preliminary work leading to the final design involved the rapid development of twelve conceptual designs for the switch. The final design and sizing was arrived at by detailed analytical stress analysis and balancing ***design for assembly*** and ***design for manufacturability*** concepts.

• ***Drop analysis*** of an ABS plastic housing of the **SnakeFan™** product was calculated. A method that involved the combination of finite element analysis and a nonlinear constraint expression for the dynamic event was applied. The finite element analysis included finite deformations of the housing and plasticity analysis for the material response. The analyses considered the worse possible loading case for the drop analysis to ensure the highest design safety for the consumer.

• Stress analysis of a large four wheel drive articulated off-road vehicle. The frame of the vehicle was constructed as a weldment of sheet and channel stock. The durability of the weldment assembly and bracketry was analyzed for a variety of loads. Final assessment of the original design produced four new designs for the critical region in the frame.

• Large scale ***tapered threaded systems*** were analyzed for applications in the oil field. The analyses involved convergence studies for mesh modeling using complex load combinations and contact analysis for all threads in the system. Plasticity analyses and durability calculations were completed with the classical fatigue relationships and fatigue crack growth modeling. The project resulted in extending the state-of-the-art for threaded connection analysis.

• Crash and impact analysis of an automotive bumper application for a ***first–tier supplier*** to the automotive industry. The study involved the detailed analysis of a proprietary material application involving a triple-ply metallic laminate composite and analytically based competitive analysis to current material systems. Nonlinear finite element analysis involving plasticity, finite deformations and contact analysis was completed. Detailed analysis for the solutions features found in the crash analysis of automotive bumpers was completed. Correlation to physical data for ***5 mph crash*** was used to verify the analytical modeling. The first level analysis was successfully used to ***predict the viability*** of an alternate material system that had not been manufactured at that time. Analysis and comparison to traditional bumpers showed the effectiveness of the new material system.

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• Analysis of a two-stage speed reducer used in satellite tracking for an **MIT Lincoln Laboratory** application. The study involved internal stress path calculations using a detailed Hertz contact stress analysis for a complex conforming ball-bearing system with material tradeoff studies involving plastic and metal combinations. The analytical study was completed in ***Mathematica™***.

• Acted as a consultant for **Advanced Research Projects Agency (ARPA)** project titled: *Precision Speed Reducer for Robotics and Manufacturing (TRP-93-009).* Analytical development of mathematical methods for modeling of the SYNKdrive**™** speed conversion technology was completed. The analytical studies were completed in mathematical formulations defining the internal kinematics and load transferring capabilities for various configurations. The mathematics of contact mechanics, strength of materials approaches and machine kinematics were applied.

• Analysis and design of light-weight, compact, ***high-torque powered wrench*** application exceeding 14,400 lbf-in of delivered torque was completed. Experimentally based bearing load-life calculations were applied to studies to estimate reliability/feasibility for ***design space constraints***.

• Analysis of a consumer product created by an ***industrial design*** firm. The analysis was completed for a four-bar linkage system including fixturing, mechanical stops, steel cabling, aluminum tube resizing, manufacturing feasibility analysis and ***human factor analyses***.

• Research, development and implementation of an ***interactive mathematical notebook*** within the ***Mathematica™*** system based on computerized algebra. The project included characterization of a novel mechanical system for speed conversion and provided a design and analysis functionality to the client. The effort included a kinematic solver and a nonlinear finite element formulation for general six-point contact analysis. The implementation included many new ***Mathematica™*** functions in approximately 1.5 megabytes of programming. An interactive help utility and automatic programming templates were included. An implementation of an interactive slide presentation including text and animated graphics was used for marketing and development by the client.

• **Expert Consultant** for the Defense in: Ball Corporation, Plaintiff, versus American National Can Company, Defendant, in the United States District Court Southern District of Indiana, Indianapolis Division, Civil Action No. IP91 434C, and qualified as Expert Witness in this case. The case involved a patent infringement claim on the manufacturing process of a thin sheet aluminum can top product. Contribution to the preparation for the trial and trial materials involved: research, engineering theory, analysis and evaluation, deposition preparation and attendance, interviews, reviews of expert consultant/witness studies of the Plaintiff, generation of studies, and strategic analysis and planning. The jury determined non-infringement, for the Defense, and the suit of over **$180M** was defended successfully.