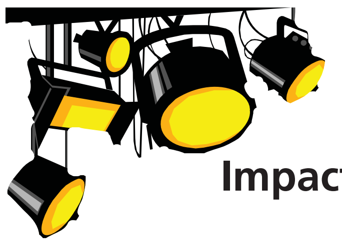

Spotlight on SBIRs

Impact Technologies, LLC Develops Integrated Rocket Motor Life Prediction Software System: mLIFE™

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Impact Technologies, LLC, of Rochester, New York, is a high-tech engineering consulting and health management system development firm that is dedicated to supplying advanced machinery diagnostic and prognostic solutions and software tools in the aircraft, land-based equipment, power, and defense industries. Impact has worked on SBIR programs since its inception in 1999 and has been awarded over $40 million in DoD R&D contracts in the areas of Monitoring and Diagnostics and Condition-Based Maintenance. In 2002, Impact was awarded a Tibbetts award for SBIR excellence. Impact has performed SBIR programs on topics ranging from embedded monitoring of lubrication systems to power assurance for rotorcraft.

Currently, Impact is under a Phase II SBIR contract with AMRDEC at the Redstone Arsenal to develop mLife, an integrated solid propellant rocket motor life predication software system. The objective of the system is to provide Army engineers with a tool to assess the effects of storage time, temperature and humidity on solid rocket motors and to predict their probability of successfully operating when called upon. This tool not only uses the legacy methods of damage analysis such as thermal stress-induced creep, but adds additional modules to incorporate finite element stress/strain analysis, nonlinear damage accumulation, propellant degradation effects, and probability theory. To manage this wide variety of analysis methods and models, the software is designed in a tiered format which allows updated modules (e.g., lifing models, fusion algorithms, data libraries) to be easily integrated into the software. Progress has also been made on the fusion and estimation of confidences associated with life predictions. Other features of the software include an intuitive graphical user interface which combines the tools for managing data (both inputs and outputs), input and results visualization. In addition to applications for rocket motor storage, this technology may be applicable to single-shot devices like vehicle airbags, ejection seats, emergency shutoff valves, and torpedo squibs that must work even after long periods of storage under varied environmental conditions.

The motivation for this program comes from the fact that solid rocket motors are manufactured and then stored for extended periods of time under uncontrolled environmental conditions. Temperature excursions during storage, around the world, can exceed 100°F in a year and humidity excursions often exceed 50% RH and can even approach 90% RH in severe cases. It is known that these temperature and humidity excursions can cause damage to the solid rocket motors from a variety of causes. This damage can affect the rocket motor's reliability. And, given the criticality of the application, the users cannot afford to have a rocket motor malfunction for any reason. There is a need to improve the state of the art in predicting the damage caused by environmental excursions on the rocket motor solid propellant and its affect, in turn, on the rocket motor's reliability.

There are legacy methods to provide an assessment of damage and reliability as a function of environment. However, these legacy methods are limited in their scope and difficult to use, by today's standards. The legacy methods are limited in scope as they only consider damage due to steady thermal stresses in the propellant as a function of time (creep damage). The legacy methods use a one-dimensional finite element approach to calculate maximum principle stress in the propellant as a function of the difference between the environmental temperature and the manufacturing (cure) temperature of the propellant. The maximum principle stress is calculated at each temperature and the damage for each time/stress combination is calculated. The damage fraction is determined as the ratio of time that the propellant sees a certain stress versus the time to failure for the propellant at that stress level.

The overall sources of stress in a solid rocket motor are thermal stress in the propellant due to difference in temperature between manufacturing temperature and environmental temperature, and difference in coefficient of thermal expansion (CTE) between the propellant and the casing; where the casing is made from a dissimilar material such as metal or a composite. Hence a steady-state temperature of both the casing and the propellant can produce stresses and strains in both the casing and the propellant.

The mLife program leverages modern advances in the theoretical approach and computational resources incorporating predictive algorithms for three time-dependent damage mechanisms: 1) creep damage in the propellant, 2) cyclic fatigue from strain cycles in the propellant due to the difference in CTE between the propellant and case and

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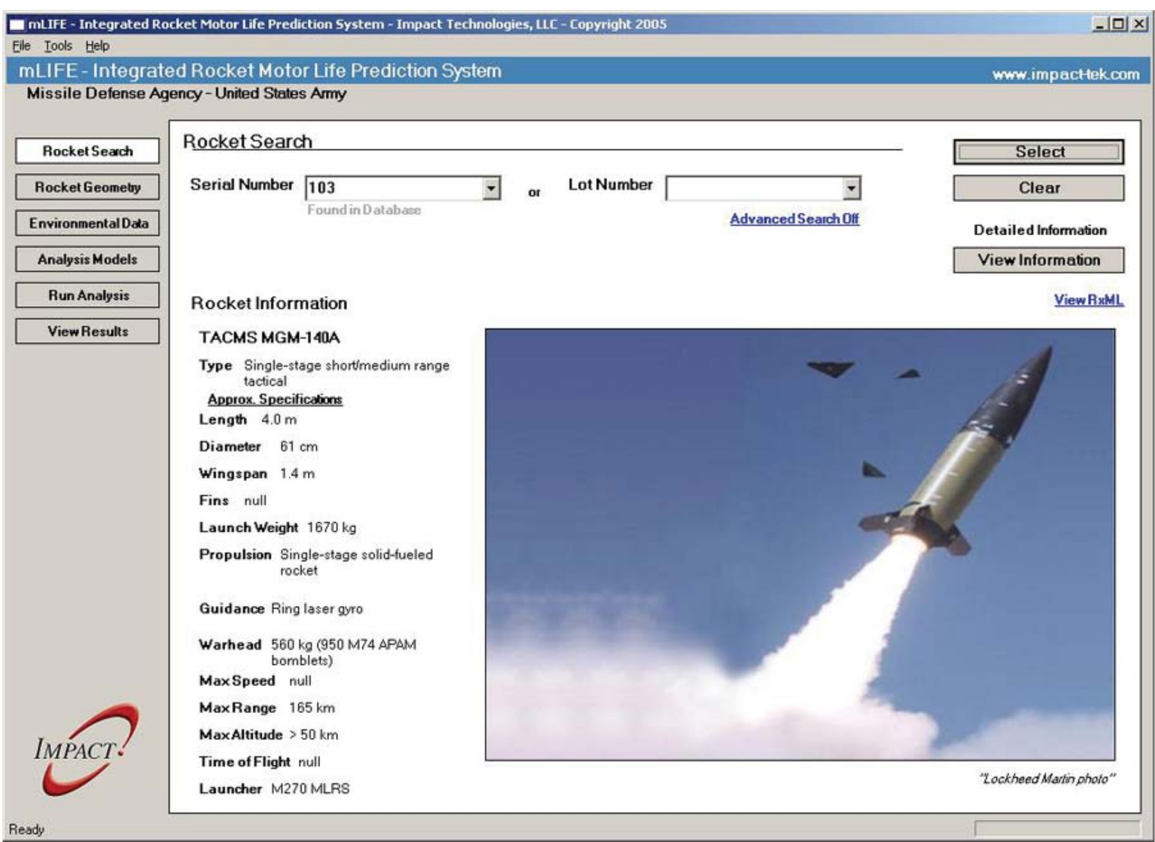
environmental temperature excursions, and 3) degradation of the propellant due to exposure to temperatures and humidity over time. The mLife program utilizes data fusion methods to combine these physics-based damage functions with historical and test data to provide the best estimation of reliability after various storage scenarios. This program also packages all the analyses into a user-friendly software package that runs on a desktop computer. The details of these improvements are as follows:

- Creep due to steady thermal stress – The legacy methods use one-dimensional finite element analysis to calculate stress within propellant over a given time increment. mLife uses three-dimensional finite element analysis to calculate state of stress and strain throughout rocket motor. With mLife the stresses due to the difference in CTE between the propellant and the casing are also taken into account for both creep and cyclic fatigue damage.
- Cyclic fatigue – mLife takes into account the strain range due to thermal excursions and computes the damage per cycle and the total accumulated damage. This method uses the Local Strain Approach with Rainflow cycle counting for accumulated damage
- Propellant degradation – mLife takes into account environmental effects on the degradation of the propellant.
- Creep-Fatigue interaction – mLife includes a software module for this combination.
- Damage mechanism fusion with historical data – mLife uses data fusion methods to fuse the results of the physics-based analyses (described above) with experimental and historical data to determine the best estimate of reliability.

The status of the current work and recommendations for future work in this area are as follows: The software is in place to cover a wide variety of damage mechanisms. The software reads parameters from data files making for easy updates. mLife requires parameters for material properties of the various propellant types. This is especially true of the parameters describing the behavior of creep and fatigue interaction and the interaction between mechanical damage and propellant degradation. Future work will center on obtaining the data parameters for the various propellant types and various analyses. Specifically the crack initiation properties to be used with the Local Strain Approach, for various propellant types, and the parameters to describe creep-fatigue interaction of the propellant materials will need to be quantified.

Finally, the goal with all SBIR programs is to commercialize the technology developed during the period of performance. Impact has an extensive track record in both commercialization and partnerships with large manufacturers. The plans for this program are no different, as Impact is currently developing a commercialization strategy involving the relevant military and manufacturing customers. Additionally Impact is leveraging the knowledge gained from the Rocket Motor Lifing program on related SBIR programs. When coupled with data collection and database systems the mLife software system will provide an end-to-end method for predicting the remaining useful life of rocket motors based on storage conditions.

For more information on Impact Technologies, LLC and various fields of expertise, visit the company website at www.impact-tek.com. Impact often publishes and presents its work at conferences and forums, and can provide whitepapers on many of its technologies upon request.



Screen shot of mLife Rocket Search.