DEVELOPMENT OF CFD CAPABILITIES IN XACTLIFE

MARKET AND COMMERCIALIZATION REPORT

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EXECUTIVE SUMMARY

This report accompanies the "Development of CFD Capabilities in XactLIFE" Technical Report LPTi Report No 160.

- Improve the accuracy of the residual life assessment of turbine components using prognostics based XactLIFE™ system to enable the Canadian Forces to assess and manage the risks related to fleet maintenance more effectively.
- Select turbine components from the legacy and the more recently acquired fleets operative within DND and perform different CFD (Computational Fluid Dynamics) simulations for testing and comparison purposes.
- Modify existing solvers in open source to enable accurate conjugate heat transfer (CHT) and Combustion simulation.
- Implement CFD capability within the existing XactLIFE™ prognostics system by integrating Open source CFD solvers to enable CHT analyses and combustion simulation to significantly improve its temperature prediction capabilities and accuracy.
- Compare the temperature prediction accuracy of different CFD solvers for complicated component geometries possessing different cooling features including convection cooling with turbulent flow features, impingement cooling and film cooling features.
- Compare the accuracy of temperature, pressure and velocity predictions of different CFD solvers for modeling combustion in the combustor chambers of different turbines and predicting the combustor nozzle plane temperature, pressure and gas velocity profiles.
- Integrate CFD solvers in the XactLIFE™ system and develop an integration framework for a heterogeneous environment.
- Improving the temperature prediction capability to be within (±4%) of actual measured metal temperature to get a more accurate Residual life assessment of the turbine parts

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COMPANY AND PROJECT INFORMATION

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Project Title:

Development of CFD Capabilities in XactLIFE

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1. HISTORY

LPTi is a 100% Canadian owned company. The company was incorporated in the Province of Ontario in March 1998 by Dr. Ashok K Koul, who also serves as the President and CEO of LPTi.

LPTi provides the services of its patented physics-based XactLIFE™ prognostics system for gas turbines that incorporates material engineering based rules and accounts for off-design engine operating conditions to analyze the effects of mission and damage accumulation variability on component life. This predictive maintenance system helps turbine users to significantly reduce turbine maintenance and downtime costs. LPTi's services for life cycle management of gas turbine components covers the aerospace, defense, power generation and oil & natural gas sectors. LPTi markets its services globally. Given the highly technical nature of LPTi products and services, it demands the involvement of LPTi's senior engineers in marketing its services. Markets outside Canada, notably India, China, Middle-east and USA are served by local tie-ups and representations.

The LPTi organization is run by individuals who possess extensive experience in the field of gas turbine engineering and life cycle management of turbine systems. Dr. Ashok K Koul serves as the President and CEO of LPTi for day to day operations of the company. The financial management of the company is done collaboration with a local Chartered Accountants company, MKP Professional services. LPTi also has an Advisory Board that provides advice to the CEO on a regular basis for current as well as future requirements.
The LPTi technical team also consists of professionals who are experienced in formulating life cycle management strategies, developing expert databases and systems for the life cycle management and life extension of gas path as well as critical turbine parts in aging engines. LPTi uses its patented XactLIFETM prognostics system for the residual life prediction of all parts for user specific engine operating environment and devising inspection based life cycle management strategies for all rotating components that are operating in aero engines or power plant units where equipment parts may not be visually accessible for routine inspection or may have exceeded their design life or may be cracking prematurely due to a variety of reasons during service.
The technical team comprises seven engineers with Ph. D. level qualifications in different engineering disciplines including thermodynamics, computational fluid dynamics, heat transfer, structural analysis, materials engineering and systems engineering. Other technical staff members include software development professionals and applications engineers. Most of the senior R&D staff members are operating at the leading edge of their individual engineering disciplines.

LPTi has developed one of its kind advanced prognostics system – XactLIFE™. The framework of the prognostic system is patented both in Canada (CA 2604118/20) and US (US 8,116,990 B2). LPTi provides case based customized Life Cycle Management service for gas turbine components and has been working with Department of National Defence (DND), Canada to implement ESIP in their fleet. Besides that LPTi is also working with other organizations across the globe in applying the patented technology to service exposed engines.

2. INTRODUCTION

The main objective of the project was to replace the empirical thermodynamic modeling within the XactLIFE™ system with more advanced Conjugate heat transfer (CHT) based CFD system in order to predict an accurate temperature profile over the gas turbine component as a function of engine usage. The main objectives for the project are summarized below.

- Improve the accuracy of the residual life assessment of turbine components using prognostics based XactLIFE™ system to enable the Canadian Forces to mitigate the risks related to maintaining their fleet more effectively.
- Select turbine components from the legacy and the more recently acquired fleets operative under DND and perform different CFD simulations for testing and comparison purposes.
- Modify existing solvers in open source to enable accurate conjugate heat transfer (CHT) and Combustion simulations.
- Implement CFD capability within the existing prognostic XactLIFE™ system by integrating Open source CFD solvers to enable CHT analyses and combustion simulation to significantly improve its prediction capabilities and accuracy.
- Compare the temperature prediction accuracy of different CFD solvers for complicated component geometries possessing different cooling features including convection cooling with turbulent flow features, impingement cooling and film cooling features.
- Compare the temperature, pressure and velocity prediction accuracy of different CFD solvers for modeling combustion in the combustor chambers of different turbines and predicting the combustor nozzle plane profiles of temperature, pressure and gas velocity.
- Integrate CFD solvers in the XactLIFE™ system with the development of an integration framework for heterogeneous environment.

2.1 Scientific results

The primary achievement of this project was to replace the empirical thermodynamic modeling in the existing XactLIFE™ system with CHT based solvers. This results in accurate metal temperature prediction based on actual engine usage. Although the initial goal was to include an Open Source code, OpenFoam, into the framework but there are still a few limitations inherent in this software and the work is still in progress. In the interim a more robust CFX solver has been integrated in to the framework. With the addition of the CFD solver the system can now perform the mission profile analysis, engine modeling and conjugate heat transfer (CHT) based computation fluid dynamics (CFD) analysis to compute the usage based component assembly temperature profile for a complete mission as opposed to a single point analysis. With non linear structural analysis and microstructure based damage modeling being part of the overall framework, LPTi's XactLIFE™, can effectively simulate any change in the engine usage to compute the accumulated damage in the turbine component.

The integrated system was tested on a helicopter engine with a mocked up mission profile, Figure 1. The results of the improved off design engine modeling at different sections of the engine as a function of engine usage are shown in Figure 2. The Off design engine modeling provided the boundary conditions for the CFD solver integrated into the system. The CFD results are shown in Figure 3. The CFD temperatures were mapped on to the FEA mesh for FEA analysis and the FEA results were fed into the damage models to compute a combined creep-fatigue crack nucleation life of the component as a function of change in engine usage. The crack nucleation life profile over the component is shown in Figure 4.

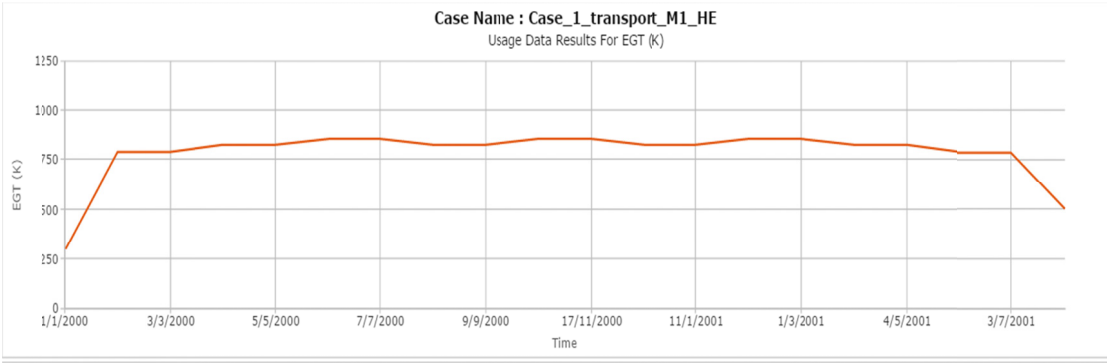
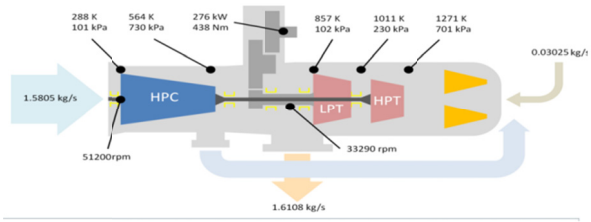
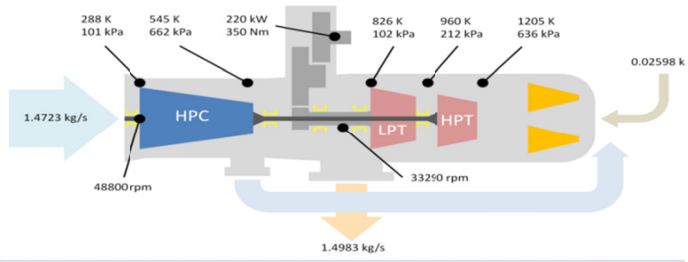


Figure 1 A mockep mission showing variation in Engine usage (EGT) with Time



Off design condition 1



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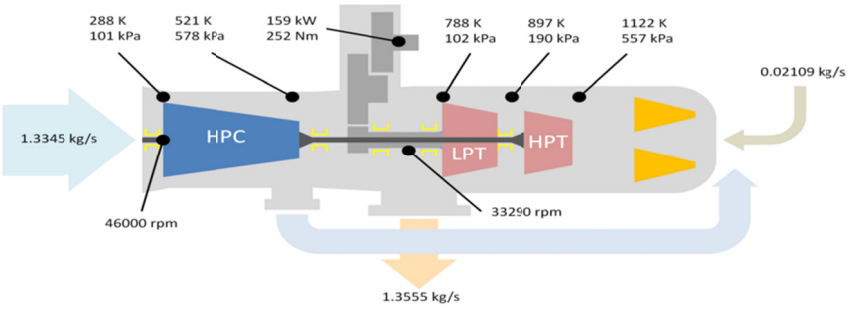
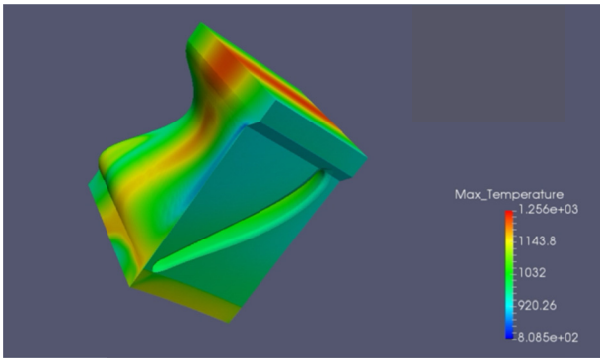
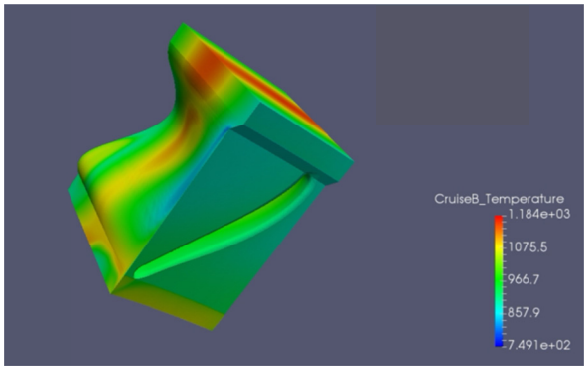


Off design conditon 3

Figure 2 Off design engine modeling results for 3 off design conditions determined through operation data filter



Off design condition 1



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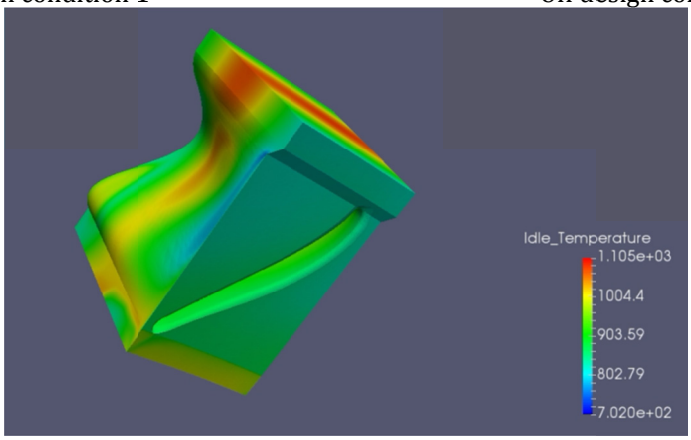

Off design condition 3

Figure 3 CFD based CHT results showing the fluid domain results as a function of change in off design condition

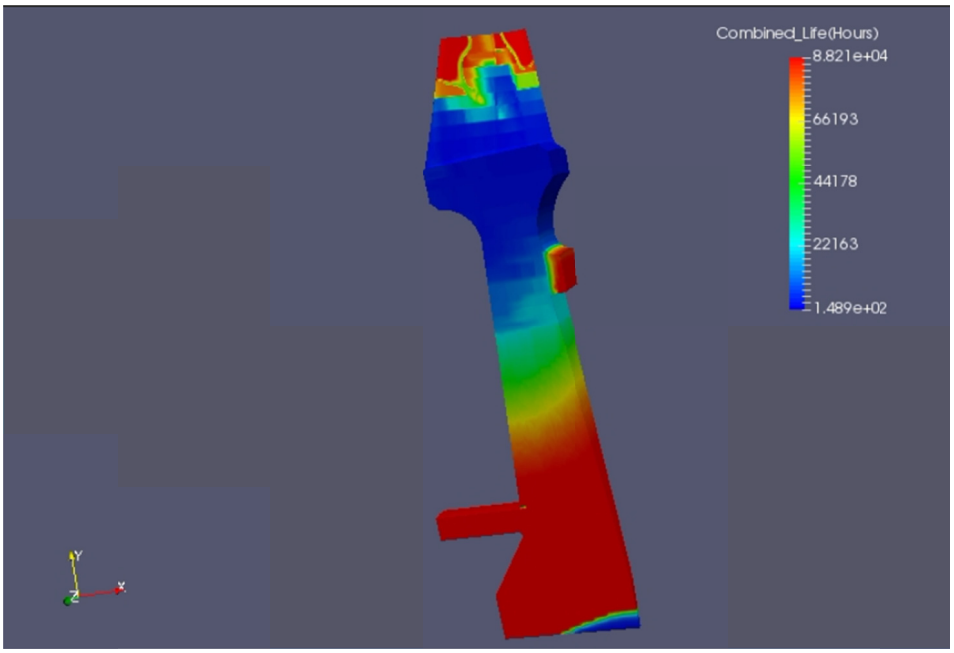

Figure 4 A combined (Creep + Fatigue) cumulative life profile as a function of usage

The figures above demonstrate an entire flow of the XactLIFE™ prognostics system with advanced capabilities of temperature prediction as a function of engine usage.

3. AREAS OF COMMERTIALIZATION

LPTi is currently custom building an engine specific XactLIFE™ GT platform using the LCM-ES framework for DND for their T56 Fleet for C140. The software shall be installed at one of their R&O bases and shall enable DND personnel to enter the mission data for the engines flown and the system shall predict the fracture critical locations for the parts of interest and their remaining useful life.

The newly improved XactLIFE™ GT platform can be custom built for DND or any other client in military, power generation and oil & gas sectors alike. The tangible benefits of using this system are as follows:

1. XactLIFE provides quantified basis for Predictive Maintenance that reduces maintenance the costs of engine ownership and improves asset availability. An improved XactLIFE™ with an integrated CFD solver provides higher prediction accuracy and reliability.
2. Accurate temperature prediction ability and life prediction of critical components using an improved XactLIFE™ shall enable quantified and informed decision making and maximize operational readiness.
3. The integrated CFD solvers in conjunction with the improved off-design engine performance analyser integrated non linear FEA solvers along with the capability of predicting both creep as well as fatigue damage makes LPTi's XactLIFE™ system a novel and complete package for life prediction. It makes it the only software package in the market that analyzes both hot gas path components as well as engine core components under real off-design engine operating conditions.
4. XactLIFE™ predictions are more accurate by around 40% against OEM recommendations, and around 45% against fatigue only predictions.

3.1. Target Arena

There is a pool of existing clientele who are being approached for the initial marketing of the standalone engine specific XactLIFE™ system. Previous test cases shall be embedded into the demo that can be accessed and analyzed by these clients. Their feedback shall be collected to continuously improve interface design, software development, and support services. These clients are from sectors including defense (DND, DoD-US, DRDO-India), aerospace and aviation (Standard Aero Limited, CAPI-China), power generation (EPRI-US, NTPC-India), and more. Targeted clients shall also include emerging OEMs in the developing countries.

Due to the nature of prognostics systems, users shall always look for validation and certificates. LPTi has conducted several test cases and validated its predictions with the field and rig testing as well as the test experience. Through the DIR/BCIP programs, LPTi shall work closely with TAA/DTAES under DND to validate and initiate the

certification process for the software. This will be a huge step forward for LPTi's national as well as international commercialization efforts.

3.2 Potential Share

Within Canada, LPTi is the only qualified ESIP vendor and the XactLIFE™ system will also be the only material physics prognostics software for gas turbines in the market. In a global context, the product offering is very unique and is unmatched in terms of the coverage of the different aspects of physics based modeling, material damage mechanisms as well as upfront reliability prediction. As such there is no fixed market for prognostics systems, as these are hi-tech innovative products that enables Predictive Maintenance.

The estimated market size of predictive maintenance system for gas turbine components in Canada is $1M-10M and globally is $100M to $1B, annually. There is tremendous return on investment for potential clients as maintenance/repair/overhaul and downtimes are very expensive. The target clients are owners of aging assets who face tough decisions concerning whether to continue using these assets, or make major capital investments. The proposed innovation shall provide them with quantitative, informed maintenance decision-making capabilities based on the actual turbine usage. For emerging OEMs, the prognostics capability shall enable upfront design verification without prototype testing.

3.3 Risk

During the commercialization rollout, risks may arise from the integration of the data flow from user's performance/operation data recording system into XactLIFE™ system. The major technology risks will lie in the inaccuracies in creating and modifying the configuration files that directly impact component life prediction. In the past, LPTi has conducted several studies on RACF/DND's legacy aircraft engines such as T56 and J85 engines. LPTi possesses a thorough understanding of these engines and their typical problems. It is proposed that the validation of the prediction can be done with the known service and field data which contain details of the component repair/replacement.

Financial Risks will arise from the uncertainties of quarterly revenues due to the changing volume in the sales of the engine specific XactLIFE™ licenses, which will likely be more prevalent during the initial stages of commercialization. The customization cost will be substantial and have to be recovered in the initial licenses of an engine specific version. Other risks include fluctuations in the operating cost due to changes in our own or competitors' pricing policies, costs related to deferred acquisitions and payments. LPTi plans to include a five year term contract for yearly renewable licensing to stabilize the fluctuations with the revenue generation.

Some of the market roll-out risks are identified and summarized below:

- Product might face problems in market acceptability (Probability of Occurrence-LOW; Impact-MEDIUM)
- Product reliability may be an issue (Probability of Occurrence-LOW; Impact-MEDIUM)
- Competition from products of similar functionality might pose a threat (Probability of Occurrence-LOW; Impact-LOW)

4. INCRIMENTALITY

During the course of the project, some of the technologies that were only used in engineering consulting services were transferred into a product. Two (2) full time positions were created one being a Senior CFD Engineer and another being a Jr. Software developer. LPTi is at an early stage of marketing its products and services to industrial (land) and aerospace engine users. The XactLIFE™ is a knowledge intensive product that LPTi has developed over a period of fifteen years with many person-years of R&D effort. The present operating costs of LPTi are over $1M/year. Without the funding provided by DND, it would not have been possible to complete the work.

Feasibility of using different CFD solvers was evaluated and a procedure of integrating one solver was designed. At the same time, sufficient understanding was gathered to pursue the development and collaboration on an open source code for the longer term that would enable LPTi's XactLIFE™ to cost effectively enter the cloud computing sector. Finally an interpolation based temperature prediction approach was conceived and a proof of concept was also developed that has a potential to open new opportunities for XactLIFE™ to enter and excel in the real-time prognostics domain. During the course of the project new collaborations/contacts with area-specific research leaders, software partners as well as very motivated team at DND and PWGSC were also made.

5. MARKETING REQUIRMENTS AND STRATEGIES

LPTi's current business model is to provide engineering services based on its in-house expertise. However, based on preliminary market surveys, LPTi would like to commercialize its proposed prognostics system as a scalable, engine-specific standalone software. As part of the current DIR, LTPi has also conducted preliminary studies on the feasibility of using advanced surrogate modeling techniques to interpolate the part metal temperatures with respect to the engine operating points. This would require the CFD analysis over all the known engine operating points defined by an envelop and then use interpolation to predict the temperature for any other operating point within the envelop. Hence a real-time physics based prognostics can be partially realized by bypassing the need of time and resource consuming CFD simulations used in XactLIFE™ system. Further work shall be required in selecting the appropriate interpolation models, selecting optimal number of simulation points, verifying the accuracy of the proposed interpolation models , and extending similar technique for FE analysis.

LPTi has created a demo of an engine specific system that would allow the user to select different usage and predict life of some already populated turbine component models. This will allow the users to assess upfront the risk of turbine part criticality under certain usage scenarios, thereby enabling more informed maintenance decision-making. The end-users of the demo shall be provided with documentation that would include a user manual, input information required for creating user specific configuration files, and details of the different on-site training services. This would cater to end-users from the turbine owner to overhaul and design communities. Training and optional add-on modules shall also be provided for different levels of usage, which can be customized and selected by the end-users based on their needs.

There is a pool of existing clientele who are being approached for the initial marketing of the standalone engine specific XactLIFE™ system. Previous test cases shall be embedded into the demo that can be accessed and analyzed by these clients. Their feedback will be collected to continuously improve interface design, software development, and support services. These clients are from sectors including defense (DND, DoD-US, DRDO-India), aerospace and aviation (Standard Aero Limited, CAPI-China), power generation (EPRI-US, NTPC-India), and more. Targeted clients will also include emerging OEMs in developing countries.
Due to the nature of prognostics systems, users will always look for validation and certificates. LPTi has conducted several test cases and validated its predictions with field and test experience. Through a BCIP program, LPTi could work closely with TAA/DTAES under DND to validate and initiate the certification process for the software. This will be a huge step forward for LPTi's national as well as international commercialization efforts.

LPTi would like to embark on the commercialization path for rolling out the engine specific XactLIF™ GT prognostics systems with the integrated CFD solver. LPTi shall be licensing the standalone desktop versions for specific engines. A yearly licensing fee with software support and maintenance contract is being proposed as an anchor price. In addition, variable pricing will be applied if the software is being used for analyzing multiple engines of the same type. Moreover, optional on-site training and add-on modules shall be made available at additional cost. The product pricing has been calculated based on the software development, analysis, as well as on the potential cost savings and improved readiness. The configuration files for the specific engine and its components shall be created using LPTi's consulting team in parallel with the new software development, training, support, and marketing. This would enable the LPTi's existing personnel to support the proposed commercialization efforts as well as create opportunities for new employment and partnerships especially in software licensing and security. The successful commercialization shall lead to employment opportunities within as well as outside of LPTi.

6. REFERENCES

Life Prediction Technology, “Development of CFD Capabilities in XactLIFE” Technical Report LPTi Report No: 160.