Publishable Summary for the 1st reporting period 18 months after the project start

Summary of the context and overall objectives of the project

The main aim of the DevTMF project is to characterise TMF behaviour of two superalloys to allow for more accurate prediction of design lives of present and future gas turbine components. The ultimate goal is to enable further increase of operation and service life, which will subsequently provide environmental and economic benefits. Together, the team plans to deliver significant technical innovations in following major topics:

1. Improvement and development of advanced standard and non-standard cutting-edge TMF experimental methods and harmonisation of the test methods to enable standardisation across the field by performing comprehensive studies into the phenomena for a range of representative parts,
2. Advanced metallurgical assessment of structural disc alloys taking into account the effect of multiple critical variables (e.g. R-ratio, phase, environment, dwell) to determine active damage mechanisms that control the life under TMF operating conditions, and
3. Physically based coupled models, with experimental validation, capable of predicting TMF initiation and propagation lives of components subjected to complex engine cycles and suitable for implementation in the computer programmes used to predict component lives.

Two business opportunities are addressed by this work: (i) at the end of the project the materials understanding and lifing models will be used to optimise/uprate the performance of existing individual aero engine components (thus enabling improvement of specific fuel consumption by allowing them to run at higher temperature and pressures, thereby increasing engine efficiency and reducing CO_2 emissions without hardware modifications) and (ii) over a longer timescale influence the development of new disc alloys and ultra-efficient future designs. DevTMF will therefore provide key-enabling technologies for achieving the requirements mentioned above without compromising mechanical integrity, reliability and safety.

Work performed from the beginning of the project to the end of the first period

During the first 18 months of the project, work has been performed on to characterise static and dynamic thermal gradients for the validation of both TMF crack initiation and propagation test methods. Thermal gradients were measured with thermocouples, pyrometry and thermography across and along the gauge length. It was found that infrared thermography (IT), which is a non-invasive temperature measurement technique, combined with Rolls-Royce HE23 black thermal paint to provide a stable emissivity value, gave consistent accuracies within ±2 ^{o}C to type N thermocouples (TCs). Pyrometry have proven accurate for temperature control and monitoring provided specimens are heat treated before testing but still there is a problem as emissivity changes during long duration tests. TCs have shown to be sensitive to cooling air displaying faster cooling rates and lower temperatures than those observed by the IT. They also absorb heat energy during tests and as result faster heating rates are observed with peak temperatures exceeding the target temperature by as much as 10 ^{o}C. Further, a comparison between isothermal CP tests run with different heating methods were studied to determine their effect on CP rates and crack monitoring techniques in order to establish a framework for the larger test programme (Figure 1). Finally, the effect of static and dynamic crack tip heating in induction field was studied to provide more in-depth analysis as high heating rates and good accessibility for crack monitoring techniques make induction heating the preferred heating method for TMF tests in this programme. However, the possibility of localised heating near the crack tip due to an increased surface area was questioned and required investigation to allow for confidence in induction coil testing and consequently in the testing methods.

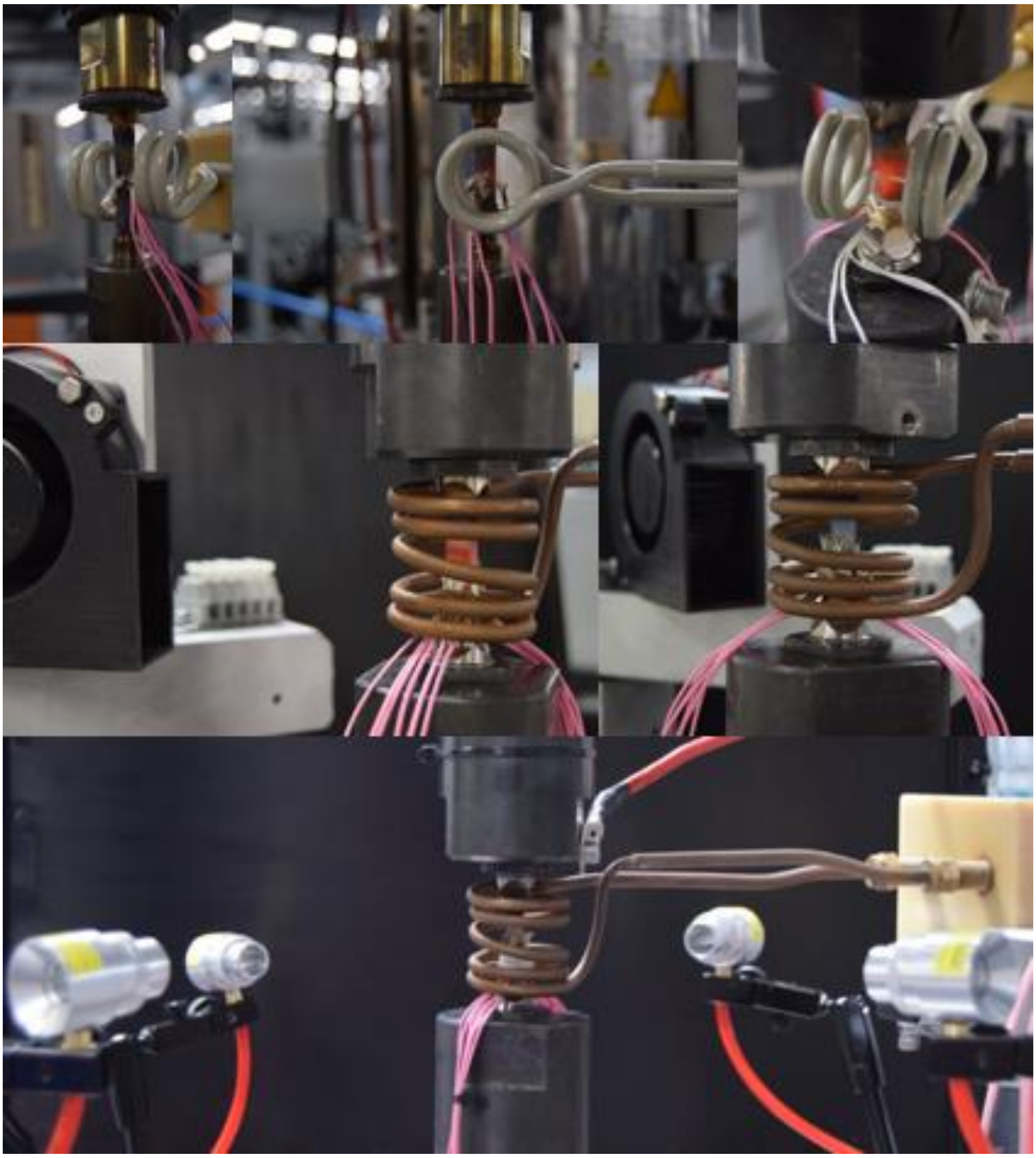

Figure 1: Investigation of a range of coil designs and setups

At present sets of temperature dependent material parameters have been determined for the material investigated and corresponding interpolation functions fitted (with temperature as the argument in these functions) allowing both isothermal and an-isothermal cyclic behaviour to be estimated over the majority of the test range and the corresponding plastic strain increment quantified at the onset of damage (along with various other material/loading history dependent quantities). Various damage functions are explored in order to estimate tertiary material softening and crack initiation, Figure 2 (note that hysteresis loops presented in (a) are not from the actual material). Development of hardening parameter evolution equations (back and drag stress) is expected to yield notable developments due to the presence of heavily temperature dependent phenomenon (for example, isotropic hardening at low temperature and isotropic softening at high temperature). The Forman model is currently used for the estimation of CP due to fatigue loading, with extensions in the near future looking to add creep enhancement and oxidisation/acceleration/retardation terms. Initial results are promising. Particular emphasis is being placed on the development of fatigue/creep damage interaction laws (replacing the simple linear Miner's rule variants that are often applied in the literature). Further, an-isothermal cyclic plasticity models have been developed and incorporated into MATLAB codes (for uniaxial loading validation) and UMAT subroutines (for Abaqus FEA implementation). Initial validation of these codes and the corresponding material coefficient functions is underway using standard TMF (cyclic plasticity) data.

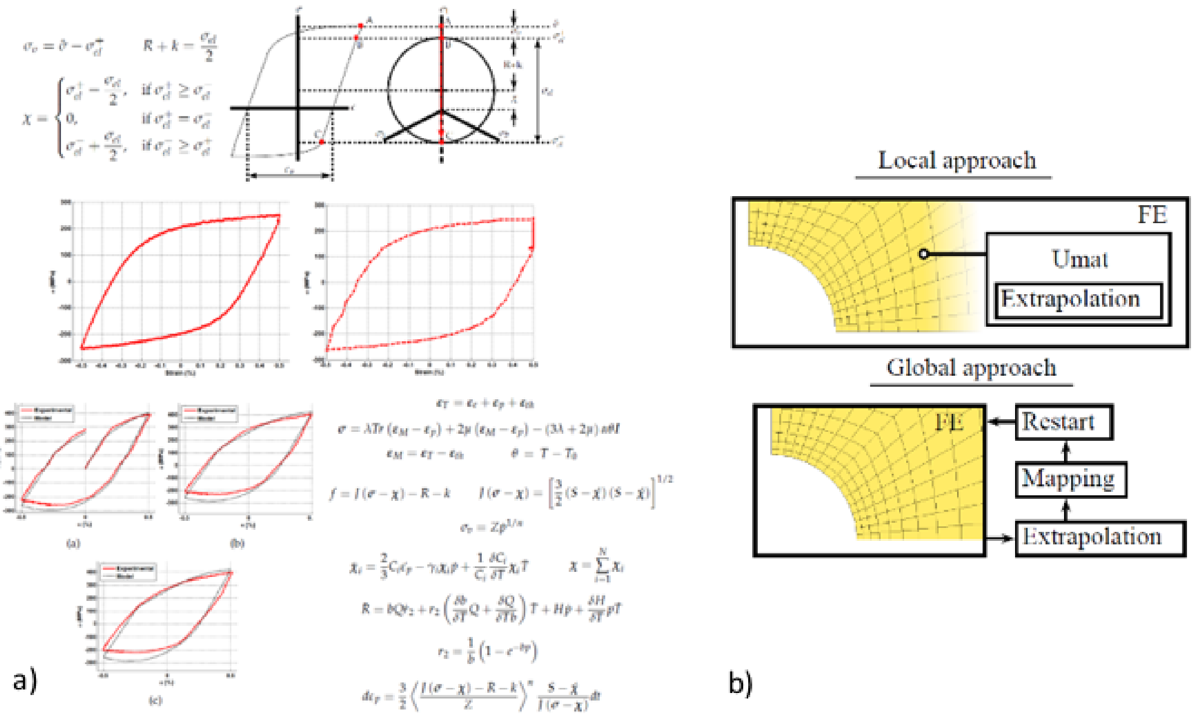

Figure 2: Cyclic plasticity model equations (a) and cycle jumping approaches (b). Note that hysteresis loops presented in (a) are not from the actual material.

Progress beyond the state of the art, expected results until the end of the project and potential impact

Two relevant outputs have been produced towards increased maturity of the TMF test techniques and future standardisation of TMF CP experimental method. The effect of heating method on TMF crack propagation rate is considered and in particular, induction heating is evaluated in detail, with orientation, setup and material type all considered. Through direct measurements using thermography and the comparison of CP data, no evidence of crack tip heating has been discovered, which has been considered in both nickel and titanium alloys. In order to accurately predict the life of components subjected to isothermal or TMF loading situations, it is of utmost importance to correctly predict the local stress-strain history. However, even with the computational power of today, a complete cycle-by-cycle analysis is generally far too time consuming, and therefore, efficiency of two different cycle jumping procedures have been evaluated in the project. It was found that the discrete material parameter modification cycle jumping procedure is, with margin, the fastest but not as accurate as the extrapolation method.

Improved temperature measurements techniques and heating methods will give us confidence in the structural test programmes to produce accurate TMF data, which will in turn give better prediction of service lives of new and existing aero engine components. This also includes extension and development of the TMF models.