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NEW THERMAL POWER PREDICTION METHODS FOR MARS EXPRESS AFTER 14 YEARS, UNDER RADICALLY NEW OPERATIONAL CONDITIONS. - MACHINE LEARNING TO THE RESCUE

Abstract

Mars Express (MEX) has been orbiting Mars, since 2004; generating great science and many discoveries for 15 years. Over the course of mission life, predictive tools have been developed based upon basic engineering knowledge and empirical data. The MEX thermal power model is an example of such a model, predicting average thermal power demand. It is 'tweaked' and refined every year to incorporate and reflect spacecraft telemetry.

The MEX thermal subsystem is one of the larger power consumers on the spacecraft. It has a large influence on the total power demand. The predicted thermal power demand is used for resource management, in particular power budgeting. Careful power budgeting ensures there is enough power available for platform operations and thermal power and science operations both in sunlit periods and eclipses when MEX is reliant on battery power. Proper power budgeting balances spacecraft safety and maximises science return.

As a spacecraft ages, components degrade and operations may need to change. Notably for MEX, the Li ion batteries and the gyroscopes are extremely degraded.

At this late stage in the mission the batteries retain less than 50% of the Beginning of life (BOL) capacity. These lithium ion (Li ion) batteries are the sole source of power during eclipses. While their capacity reduces, the eclipse durations and the eclipse seasons are lengthening. This means the power demand during the eclipses is increasing as the battery power available is decreasing. As MEX ages accurate power budgeting becomes more and more critical.

In 2017 MEX's gyroscopes had degraded so much that they were approaching End Of Life (EOL). To save the mission a fundamentally different operational mode was developed and implemented in 2018. This new 'gyroless' flight mode reduced gyroscope usage by 90% and extended both gyroscope and mission life.

Gyroless flight caused dramatic changes in the thermal subsystem. Every electrical unit dissipates heat when in use. With the gyroscopes switched off 90% of the time, the heaters had to compensate.

Not only did thermal power consumption increase, but the behaviour of the thermal subsystem changed completely. Furthermore, other constraints for gyroless flight lead to the use of new spacecraft orientations, illuminating areas of the spacecraft which had previously been in the shadow and vice versa. Areas previously illuminated and exposed to the Sun now required active heating by the thermal subsystem. All these factors rendered the previous thermal power model much less reliable.

Gyroless flight presented the following thermal modelling challenge; how to predict and quantify the thermal power for power budgeting in gyroless flight with radically different thermal behaviour with no empirical data?

In 2016, during gyroscoped flight, a highly accurate Machine Learning (ML) predictive model had been devised. In 2018, in desperation the MEX Flight Control Team (FCT) dared the ML team. How accurately could an ML model based on gyroscoped flight predict the thermal power demand for gyroless flight, and could it provide insights to the changed behaviour?

Unsurprisingly the performance of the ML models in the gyroless period is worse compared to the performance beforehand. However, the difference in performance is not substantial nor significant and therefore such models can be still utilised for accurate prediction of the thermal power consumption. Moreover analysis of the ML gyroless predictions also provided insights into the new thermal behaviour. By providing accurate predictions and feature analysis, the ML model allows for what if analysis

Understanding the thermal behaviour considerably aids the engineers. With greater understanding the engineers will be able to perform targeted 'what if' scenarios, e.g. what if instrument A is used, what is the impact on the power budget?

The ML model provides reliable predictions as well as enhancing engineering expertise which can be applied to power budgeting. In particular improved power budgeting during eclipses, enhances safety and reduces risk. This will make it possible to reduce safety margins and use that released power for science operations.

This paper describes the thermal power prediction challenges posed by implementing a new operational concept of gyroless flight to save the mission and how ML provided accurate predictions, at 15 minute resolution based upon old data for the new flight conditions. How ML clarified the new dominant factors and features in the thermal subsystems' behaviour is also detailed. This paper also portrays how the new ML model can be integrated into the existing structures for planning MEX operations and observations, enabling better management of available power to optimise science observations.