MATED – Improving ESA's Model and Test Philosophies

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Today's space activities are characterised by growing cost and schedule constraints, often combined with greater technical/industrial complexity. This impacts on the Assembly Integration and Verification (AIV) process that is a fundamental step in the development cycle of any space system. The question then is, how can the process be improved to reduce the duration and cost of the AIV process whilst still maintaining the necessary quality and an acceptable level of risk?

The ESA-developed Model and Test Effectiveness Database (MATED), and its associated methodologies, is proposed as a viable tool for supporting such an initiative. This article describes the prototype database, the types of data that can be shared, the proposed analysis methodologies, and the potential benefits.

Introduction

In the last decade, the pressure from the space market to shorten the development time from system concept to launch has continued to grow, with the aim of reducing development time and cost without jeopardising mission success. The Assembly, Integration and Verification (AIV) process makes up an important part of the space system's development cycle, constituting typically 20-30% of the costs and 60-70% of the schedule. The model and test philosophies that form the basis of the AIV process are therefore important cost drivers.

The existing standards and industry practices that define the requirements to be applied in the preparation of test specifications and procedures are generally based upon tradition and need to be improved in the light of the latest modelling and test-effectiveness criteria.

It was against this background that an ESA study on 'Improving the Effectiveness of the Model and Test Philosophy Applied by ESA Programmes' was contracted to an industrial consortium led by Alenia Spazio SpA, with Astrium GmbH as subcontractor. The study's main objective was to develop a Model and Test Effectiveness Database (MATED), together with the associated methodologies, to serve as a repository for AIV, Non-Conformance Report (NCR) and Flight Anomaly (FA) data to be shared between European industry, agencies and space organisations. This novel resource should foster a continuous improvement in the AIV process itself, the related model and test philosophies, and the associated verification and testing standards.

The MATED concept

The main functions of MATED are to:
– archive data on anomalies encountered during the ground testing and flight operations of different spacecraft
– archive data on the AIV processes for different spacecraft, with particular emphasis on the cost-driver-related activities
– provide data-analysis functions that support identified methodologies for test-effectiveness evaluation and AIV programme-optimisation purposes
– ensure security of data, remote and multiple access, and flexibility of installation and utilisation.

MATED's architecture (Fig. 1) is based on a commercial Relational-Database Management System (RDMS) with a client/server approach compatible with the World Wide Web (Fig. 2). The study objectives were to:
– assess the state-of-the-art in the model and test-effectiveness domain and the available data sources
– analyse the AIV process as defined in the European (i.e. ECSS) standard, identifying cost drivers and improvement trends
– identify the methodologies for the analysis of the associated AIV data
– realise a prototype database that archives on-ground and in-orbit anomalies and other AIV-related space-project data
– populate the database with inputs from several projects in development and in operation (both applications and scientific missions)

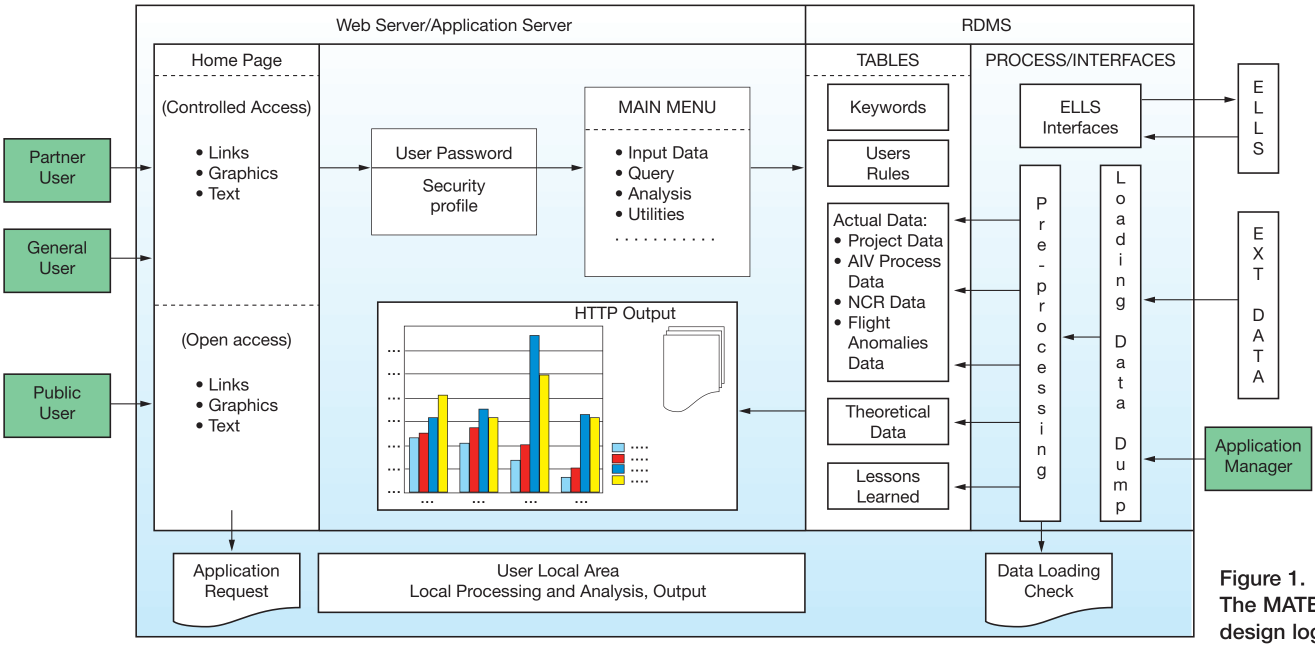


Figure 1. The MATED design logic

– carry out a first set of analyses to demonstrate the validity of the concept and the associated methodologies
– recommend methodologies for using the analysis results in updating and maintaining the European standards
– evaluate future development towards an operational system.

Access to the MATED data loading, reading and analysis functions is regulated by a password system based on user-specific prerogatives. Free user access to the welcome, news and information pages is also foreseen.

The MATED data

On the basis of the study findings, the foreseen analysis needs, and the industrial consortium's experience, four categories of data have been defined: Project Data, AIV Process Data, NCR Data and FA Data (Fig. 3). The innovative

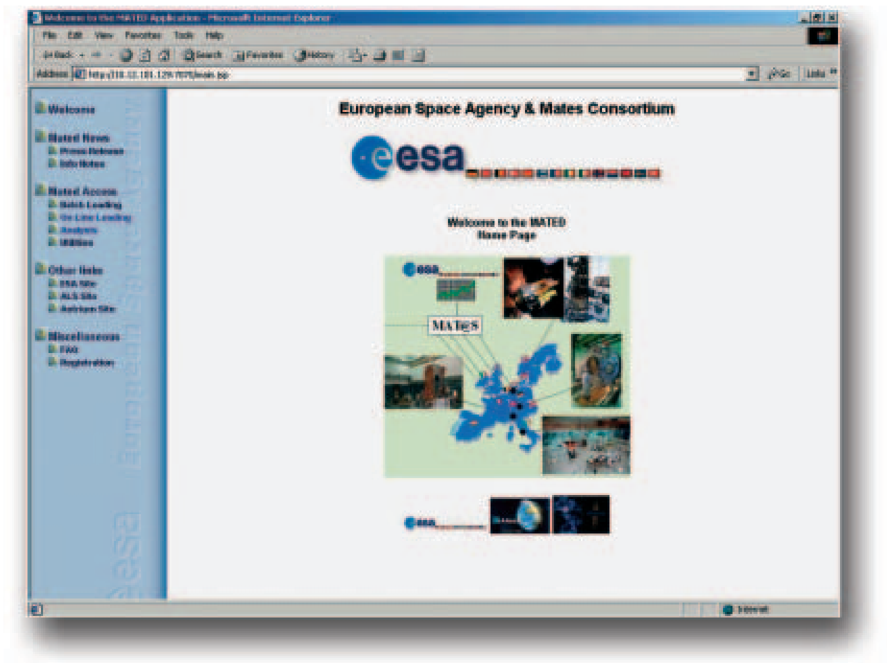


Figure 2. The MATED web site

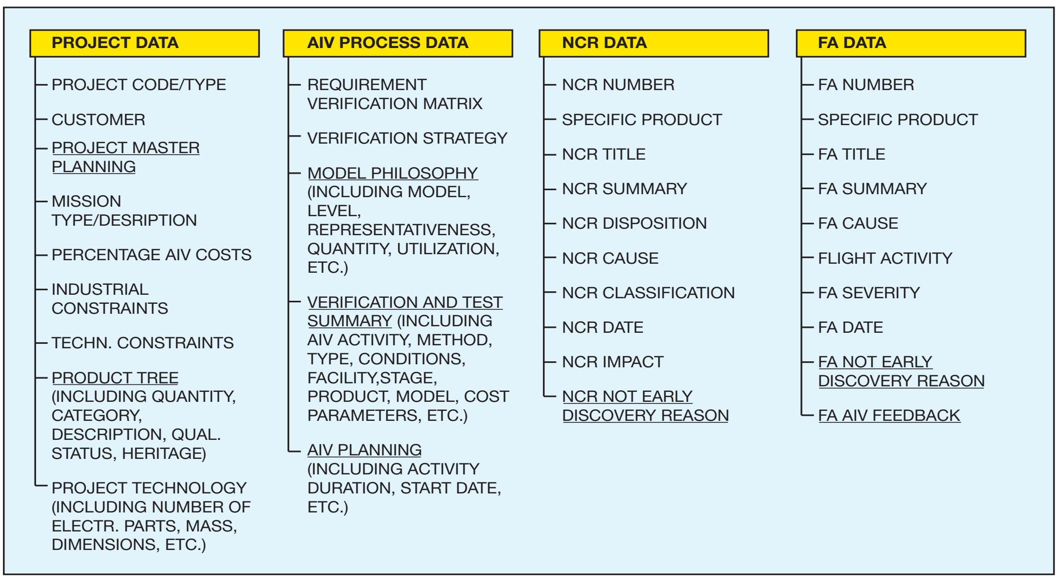


Figure 3. The MATED data tree

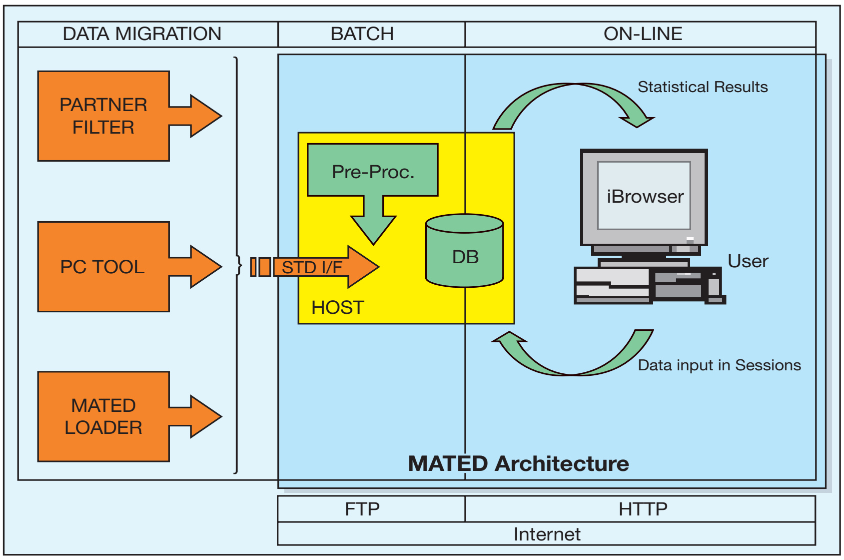


Figure 4. MATED data-collection scenario

feature of MATED compared with existing systems is the linking of the project products to the respective AIV activities, ground failures and flight anomalies. The associated time and cost aspects of the AIV process are also documented, albeit in relative values for reasons of confidentiality.

Data can be loaded into MATED using both the batch-loading and the on-line-loading capabilities of the system. In the case of batch-loading, a simple ASCII interface table can be generated either by a commercial PC tool, by filtering existing company databases, or by using a dedicated 'MATED loader'. The data currently collected in the MATED prototype consist of: 7 projects (both applications and scientific missions), 24 models, about 800 products, more than 300 AIV activities, about 400 NCRs and 50 FAs. The system-level data are substantially complete, while additional lower-level data will be collected during the next phase together with new project data.

The MATED analyses

As shown in Figure 5, four levels of analysis have been defined:

- L1: on-ground, in-orbit and combined failure statistics
- L2: technical and financial test-effectiveness evaluations
- L3: model and test-effectiveness-index evaluations and time/cost parameter simulations
- L4: risk assessment, risk/cost comparison, sensitivity analysis and optimisation.

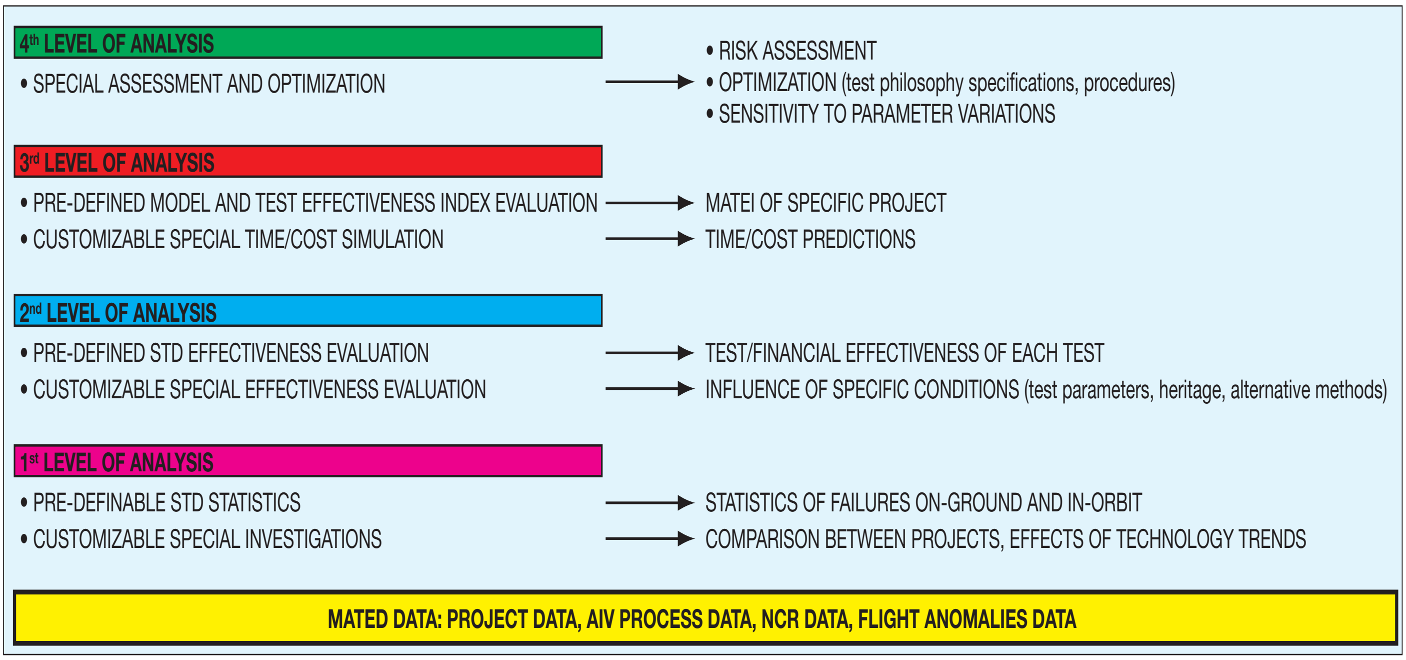
The higher-level analyses are based on the results of the lower-level analyses, and the L1 and L2 analyses are also customisable in the sense that other selected parameters can be introduced. The MATED analyses can be applied to the entire database or just a subset of it (i.e. investigation field), considering only certain projects or limited ranges of the different key parameters. The system allows one to select the applicable investigation field (Fig. 6).

Potential of MATED results

MATED analyses can answer such questions as:

- Which tests are discovering more NCRs? At which stage and what level?
- What are the most critical subsystems or equipment items in the ground testing?
- Which AIV activities are more impacted by design or workmanship failures?
- Is there any correlation between failures and time into test?
- Is an alternative verification method more effective?

Figure 5. MATED analyses



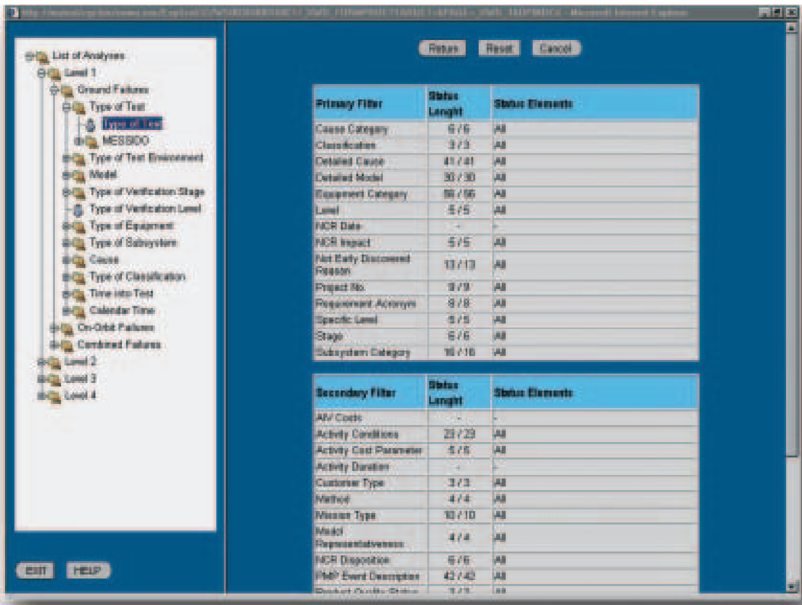
- Which subsystems/equipment items are more critical to operations?
- What is the technical and financial effectiveness of a test?
- How we can compare two model and test philosophies?
- Which test is the most likely candidate for deletion?

In terms of L1 Ground Failure (GF) statistics, MATED allows one to derive distributions of the numbers of NCRs, in absolute or relative terms, normalised to the number of electronic parts (to take into account project complexity), as a function of several key parameters. Figure 7, for instance, shows the distribution of NCRs vs type of test, with the ranking of the different tests highlighted. The distributions can also be customised to include a selected third parameter.

In terms of L1 In-Orbit Failure (OF) statistics, similar distributions can be derived as a function of the key parameters and are also subsequently customisable. Figure 8 shows the customisation of the failure-analysis distribution vs type of severity with respect to the 'FA AIV feedback' parameter, where the anomalies with the severest consequences (partial loss of functionality and redundancy switching) suggest the need to improve EMC, end-to-end communication, functional and performance, life and thermal-vacuum testing.

In terms of L2 Test-Effectiveness Evaluations, the Technical and Financial Test Effectivenesses (TTE and FTE indices) can be calculated. The TTE corresponds to the number of NCRs in the test of interest, divided by the sum of the total NCRs plus the FAs in the early flight period. The FTE multiplies the TTE by the ratio between the cost of the mission and the cost of the test (i.e. for the same TTE, the FTE is greater if the test costs less). The TTE can be customised for a third parameter, such as different test conditions (e.g. number cycles in thermal vacuum). Figure 9 shows the TTE and FTE for an acoustic test.

In terms of L3 Model and Test-Effectiveness Index (MATEI) and Time/Cost Parameter Evaluation, a reference index as been defined corresponding to the level of completeness of a certain model and test philosophy with respect



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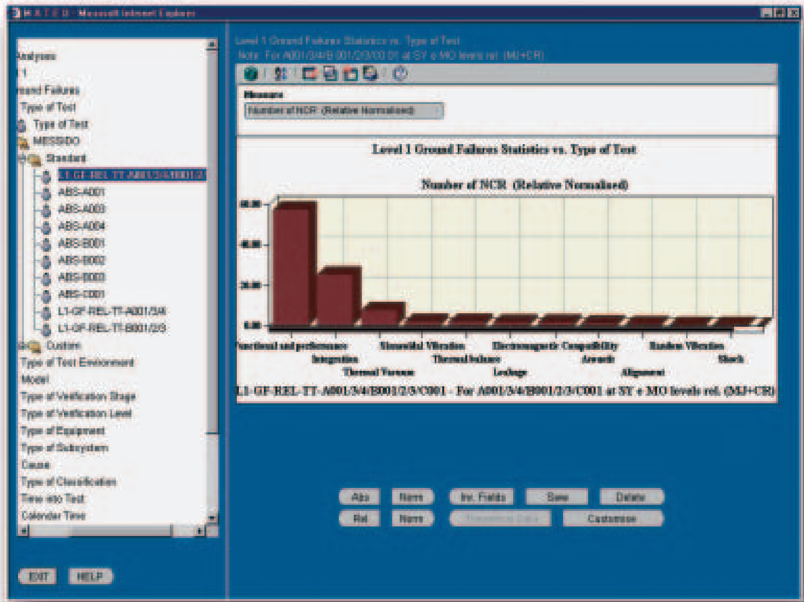

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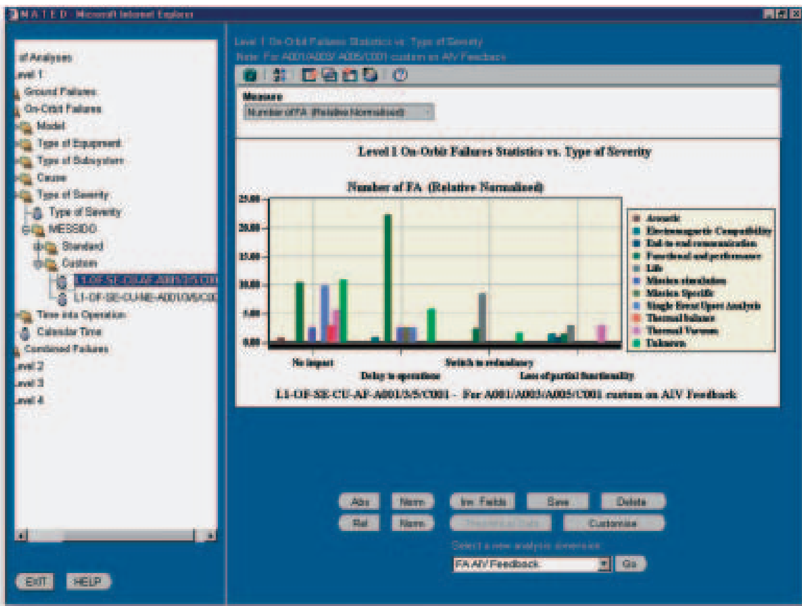

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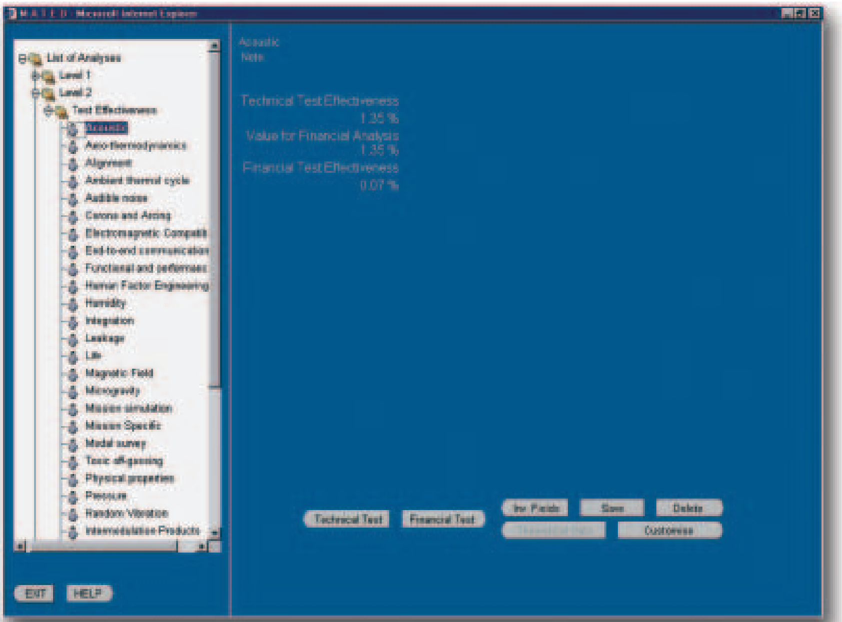
Figure 6. Investigation field selection

Figure 7. Typical L1 ground-failure statistics

Figure 8. Typical L1 customised in-orbit-failure statistics



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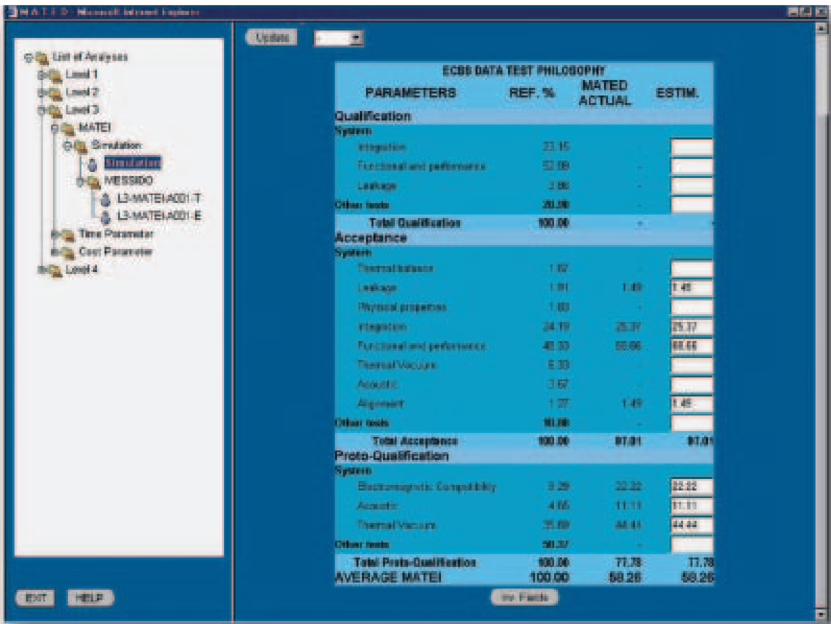

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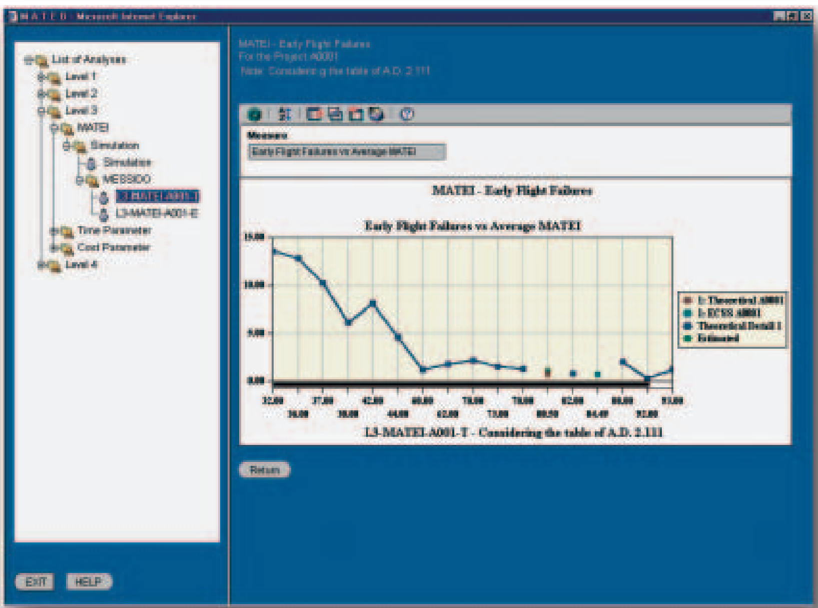

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to the ECSS (European Cooperation for Space Standardization) verification and testing standards. Figure 10 shows the MATEI ECSS Test Philosophy table.

Given a pre-determined model and test philosophy, it is therefore possible to estimate the MATEI and try to anticipate the number of early failures to be expected (Fig. 11). The validity of that MATEI can subsequently be checked/verified during the operational lifetime of that particular spacecraft or space system. An equivalent approach can be followed for cost and time-parameter aspects.

In terms of L4 Sensitivity Analyses and Optimisation, MATED offers the user the ability to carry out risk assessments, risk/cost comparisons, sensitivity analyses and optimisations for current and new projects. This type of analysis is usually supported by a suitable set of L3 and sometimes L2 analyses, as well as other offline investigations such as risk assessments. Figure 12 shows a typical result, where the data are expressed as percentage deviations with respect to the baseline.

The MATED operational scenario

The future application scenario foreseen for MATED, which could be made operational very soon, is as follows:

– ESA would serve as the MATED host and database administrator.
– The MATES Industrial Consortium would support ESA as applications manager for data loading, system upgrading, maintenance, special analysis and user feedback.
– Other European and world-wide companies, agencies and organisations would become ‘partner users’, providing data and statistics and receiving tailored access to MATED functionalities. They could also be supported by the MATES Industrial Consortium with suitable training and maintenance support.

Conclusion

Streamlining of the model and test philosophies for Europe’s future spacecraft and space systems is crucial to reducing the time, and hence the investment, needed for their development whilst still keeping the degree of risk under control. The proposed sharing through the MATED database initiative of the European space sector’s AIV knowledge and

Figure 9. Typical TTE and FTE evaluation

Figure 10. Typical MATEI ECSS test-philosophy table

Figure 11. Typical early-flight-failure diagram

experience accumulated over many years would represent a major step forward in this respect. The first results have already demonstrated the validity of such an initiative. The number of spacecraft developed in Europe is not so high in a global context, and the number of in-flight anomalies that have been experienced to date by ESA spacecraft is actually very low. For MATED to be a success, therefore, as many participants and inputs as possible are needed, in order for the results to be statistically significant. It is therefore hoped that the many companies, agencies and organisations both in Europe and around the World working in the space domain will be motivated to join in this initiative, which holds the promise of substantial mutual financial benefits for the participants.

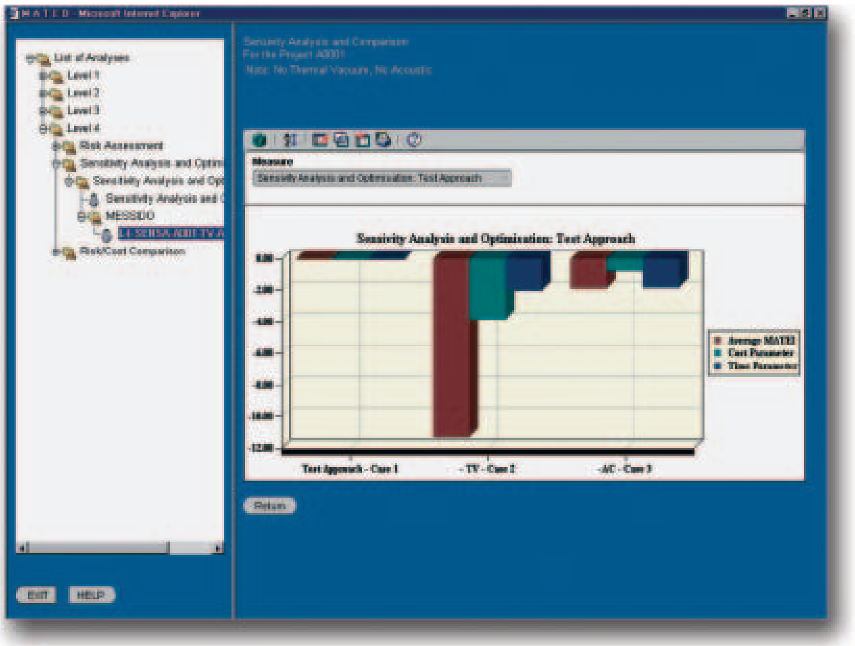

Figure 12. Typical sensitivity analysis and optimisation result