SOFTWARE TOOL FOR RAPID EVALUATION OF MARINE ENGINE PERFORMANCE IN SERVICE

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ABSTRACT

In a previous publication, the methodology for evaluation of the performance of a marine engine in service was presented. This methodology involves the comparison of measured data from the “service report” from the ship, to “expected values” of the various parameters, obtained via simulations, using a thermodynamic model adapted and calibrated for the specific shipboard engine. The process of producing “expected” performance values using the model is somewhat complex and time consuming. A software tool is presented here, which uses the methodology as foundation, but allows rapid, almost real-time, evaluation of engine performance by comparisons of “measured” and “expected” values. If the model of the specific engine is set up and calibrated with the engine shop test data and then validated with the ship trials data, then it can be used to produce predictions by simulating any engine load point at any operating conditions. The range of possible operating conditions of an engine (load, speed, fuel type, environmental conditions….) is well defined. Thus, the model can run parametrically a-priori, for all the possible combinations (factorial) of the operating conditions. The total run-time for all permutations is obviously large, but the runs can be performed unattended. The volume of results is also rather large, but can be handled efficiently with a database application (e.g. for a set of 300,000 combinations, which can be considered a HYPERCUBE of performance data, it is about 150MB per engine). Then, , for any set of operating conditions of the engine, the extraction of “expected” values of performance parameterscan be performed by successive interpolation in this Hypercube, which only takes a few seconds! Thus the comparison of the “observed” (measured) values included in a service report and the “expected” values at the same operating conditions, is almost instantaneous and immediately indicates the engine parameters which are within allowable limits, as well as those which are off-limits and in need of further scrutiny. The tool can be integrated with existing systems for producing and archiving service reports on-board, or at the main office of a shipping company. The software tool, as well as examples of applications for the main engine of vessels, are presented.

1. INTRODUCTION

Engine performance evaluation can be accomplished by comparison of monitored data to some reference. However, the monitored data are not always reliable (e.g. due to sensor or monitoring system malfunctions, as well as human errors in recording and reporting) and the available reference data are often not appropriate for comparisons due to the fact that these reference data correspond to operating conditions - shop tests and/or sea trials - different than those reflected in the “service reports” and any correction may introduce further errors.

A procedure for engine performance evaluation was developed, involving the use of process models to produce reference data, which can be reliably compared with the measured (observed) ones, as both refer to the same operating conditions.

The developed procedure uses detailed engine thermodynamic simulations and can be applied to any ship, any engine using any fuel, independently of the existing shipboard monitoring system. The engine performance is evaluated by comparisons of measured (observed) data to simulation predictions (expected). If significant differences are discovered, these are further analyzed in order to monitor the emergence of possible components degradation.

2. PERFORMANCE EVALUATION PROCEDURE

The procedure for performance evaluation of a specific marine engine, as originally presented in [2], [3], consists of several steps, as shown schematically in (Fig. 1):

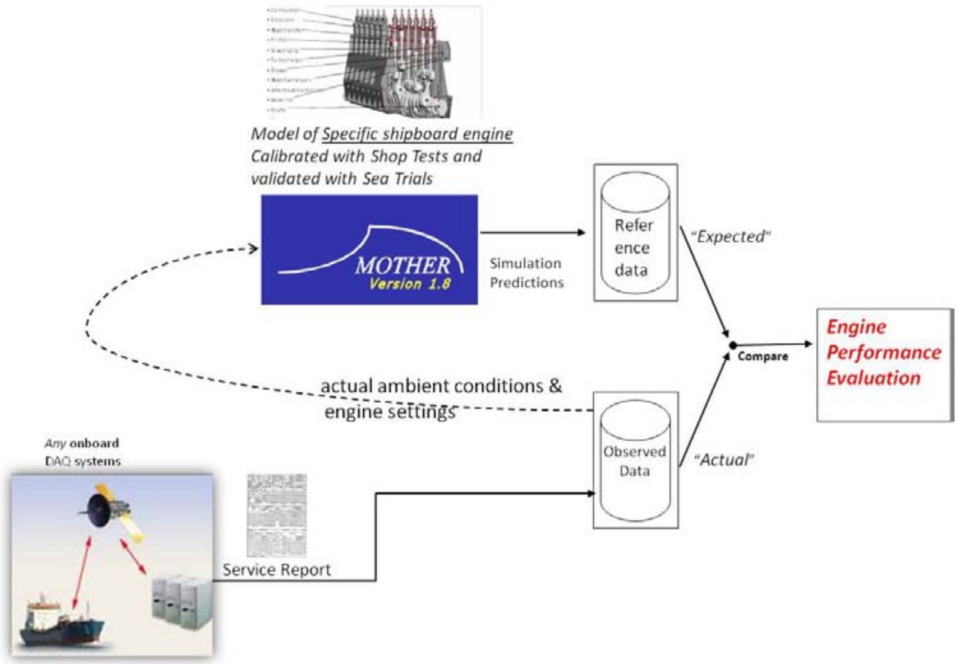

Fig. 1: Performance evaluation procedure

2.1 Engine model setup

For each ship and each engine under consideration, the specific engine's geometry is used for the set-up of the specific engine's simulation model. The model is calibrated / tuned on the basis of the specific engine's Shop Tests.

Following the calibration, the specific engine model's capability in predicting performance for all operating points of Shop Tests becomes satisfactory (Fig. 2). Then, the model constitutes a precise mathematical replication of the specific engine.

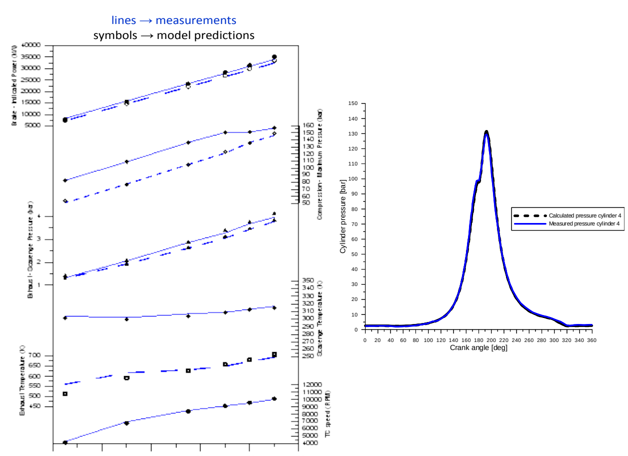

Fig. 2: Shop Tests: Measurements vs. model predictions

2.2 Data Filtering

Data included in the service report, which has been received at the main office, is passed through a validation filter, applying limit and range checks so as to detect and discard apparent erroneous recordings.

2.3 Performance evaluation

The engine model is fed with ambient conditions and operation settings from the service report, producing reference data for the specific engine at the specific conditions (i.e. how it is expected to operate). Service actual data (observed) are then compared to expected performance data.

If the percentage difference does not exceed 3% for all parameters, the condition of the engine is considered to be satisfactory. In case of exceeding 3%, for one or more parameters, further investigation is recommended. Sometimes percentage differences originate from inaccurate measurements (sensor, recording etc.). Furthermore, the variation of Δ (%) is also checked over a time period, in order to detect any apparent trend that can be precursor of a possible malfunction.

3. DEPLOYMENT PROCEDURE

Once the model of the specific engine has been setup and calibrated as described above, there are two principal ways of deployment (Fig. 3):

- **I.** The model is run many times up-front with combinations of engine operation settings to produce a multi-dimensional engine performance map (HYPERCUBE).
- **II.** The model is run with a specific operation setting of the engine, to produce the detailed "expected" engine performance parameters at this particular setting.

Deployment as per I is outlined in the following paragraphs 4, 5 and 6. Deployment as per **II** is outlined in the paragraph 7.

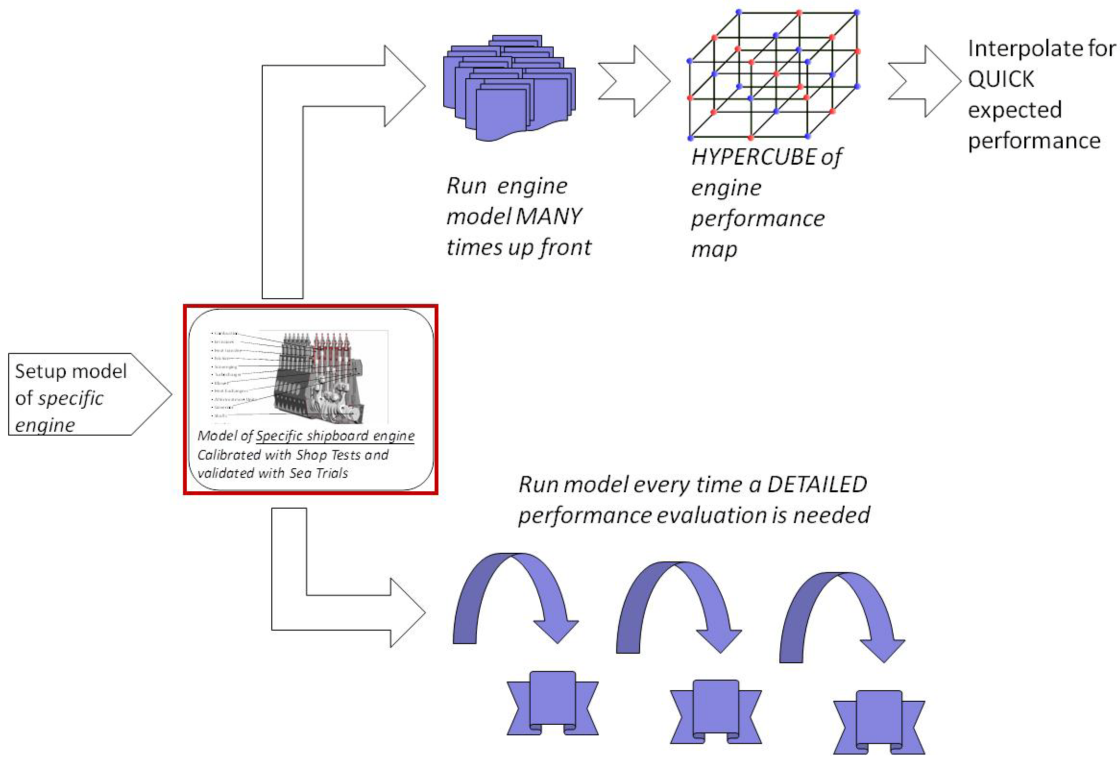

Fig. 3: Deployment of assessment procedure for specific engine

4. HYPERCUBE

A set of typical input parameters (operating conditions) that is used to perform a single simulation run of the engine model are shown below:

- Engine speed
- Fuel pump index
- VIT index
- Ambient pressure
- Ambient temperature
- Cooling water temperature
- Piston cooling temperature
- Lower Heating Value

If the variation range for each input parameter is defined and for each range the interval (partitioning) is sufficiently small, then the combinations (sets of values) of input parameters can be defined and the model can run for each set. For some parameters it has been found that a very fine interval is needed for sufficient accuracy of results, while for others a coarser partition is sufficient. Such optimizations are needed so as to reduce the total number of runs and hence the total volume of results, which are stored in a database, the so called “Hypercube”. Thus, for any input set, a point corresponds in this Hypercube map consisting (as a minimum) of the following parameters

- Indicated power
- Fuel consumption
- Maximum cylinder pressure
- Compression cylinder pressure
- Specific fuel consumption
- Scavenge receiver pressure
- Scavenge receiver temperature
- Air cooler pressure loss
- Turbocharger speed
- Compressor delivery temperature
- Exhaust receiver temperature

It must be noted that the actual number of output (engine performance) parameters of the simulation model exceeds 50, but for reasons of storage space only the type of performance parameters that are usually included in a service report are filed.

A typical number of runs to produce a Hypercube database for a specific engine are about 300,000 and the size of this number of output points and associated performance parameters for one engine is about 150 MB.

Then, if the engine performance for any arbitrary set of input parameters is required, a routine for successive interpolations is applied to the Hypercube database, it locates the data values in the vicinity of the point of interest and interpolates for the performance parameters.

The process is very fast and only takes a few seconds! (Fig. 4)

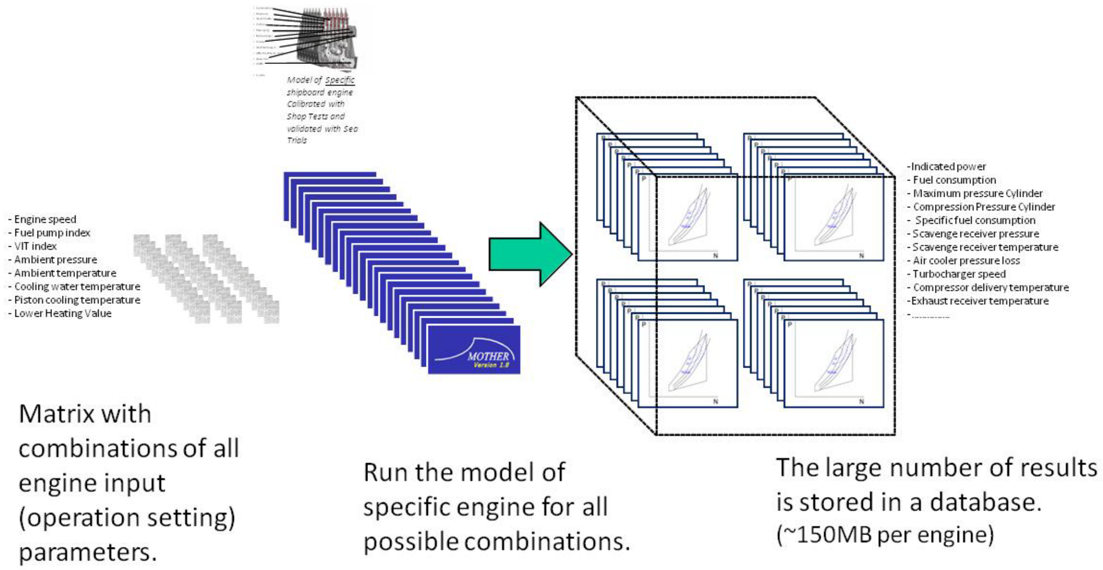

Fig. 4: Creation HYPERCUBE engine map

5. APPLICATION OF HYPERCUBE

The HYPERCUBE database which is created for a specific engine of a specific ship is delivered to the shipping company and can be integrated to its system for producing and archiving service reports from the ships. (Fig. 5)

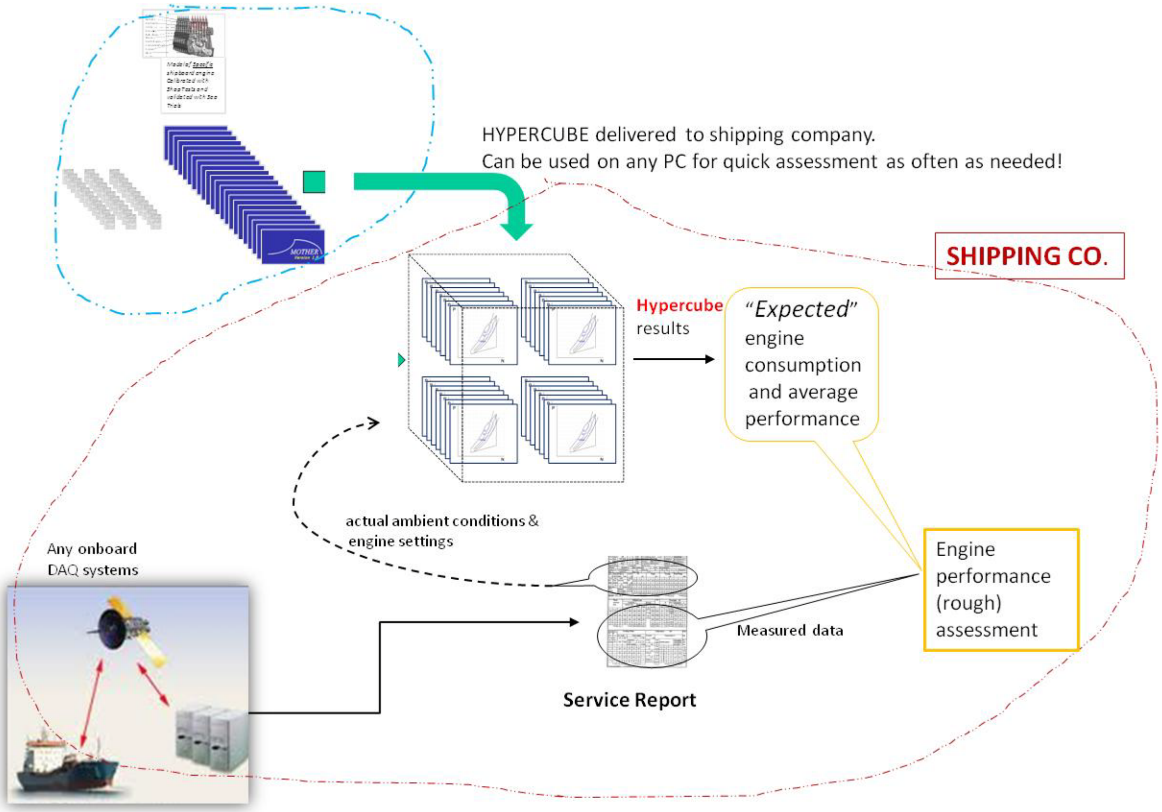

Fig. 5: Creation of HYPERCUBE and Deployment in shipping company

When a Service Report is received, some engine operation data (load settings and ambient conditions) are retrieved to be used for input to the HYPERCUBE database. This retrieval can be manual or more often automatic, if the Service Report is in electronic form (e.g. excel file)

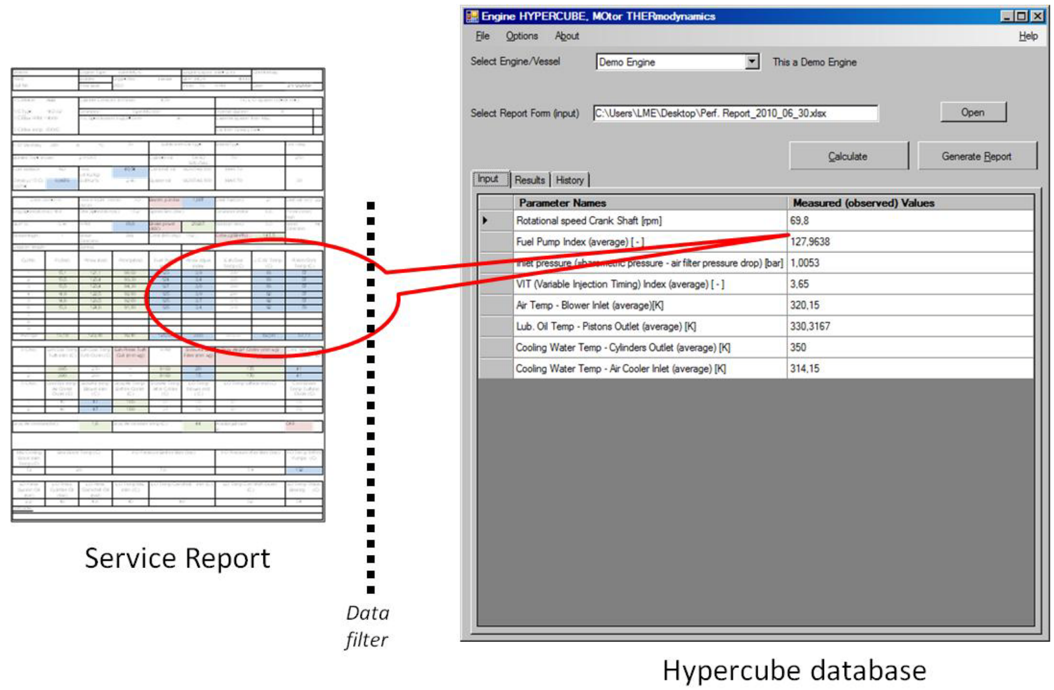

Fig. 6: Using operation data from Service Report to enter HYPERCUBE

A filter is used to ensure the “observed” data (logged load settings and ambient conditions) in the Service Report are within acceptable ranges and to highlight erroneous readings. Then the Hypercube application is used to calculate the “expected” performance for the same specific conditions of engine operation.

Another data filter with preset limit and range checks for all “observed” (measured) parameters in the service report, is used to detect any possible inaccuracies in measurement sensors or errors in reading or recording. Subsequently, all the “observed” (measured) performance data are compared with the “expected” performance. Any deviation between “observed” and “expected” above some preset divergence limits is highlighted, for the user to take note. (Fig 7)

The divergence limits can be adjusted as needed, but in general it has been found that a 3% difference is a good compromise for fidelity without ambiguity in assessment. In this way, only the parameters deviating from normal need to be attended to, instead of scrutinizing all the data included in the Service Report. For any highlighted parameter, a history can be obtained with graphs and histograms of past values and deviations, to ascertain any pattern or possible component degradation issues or process problems (Fig. 7)

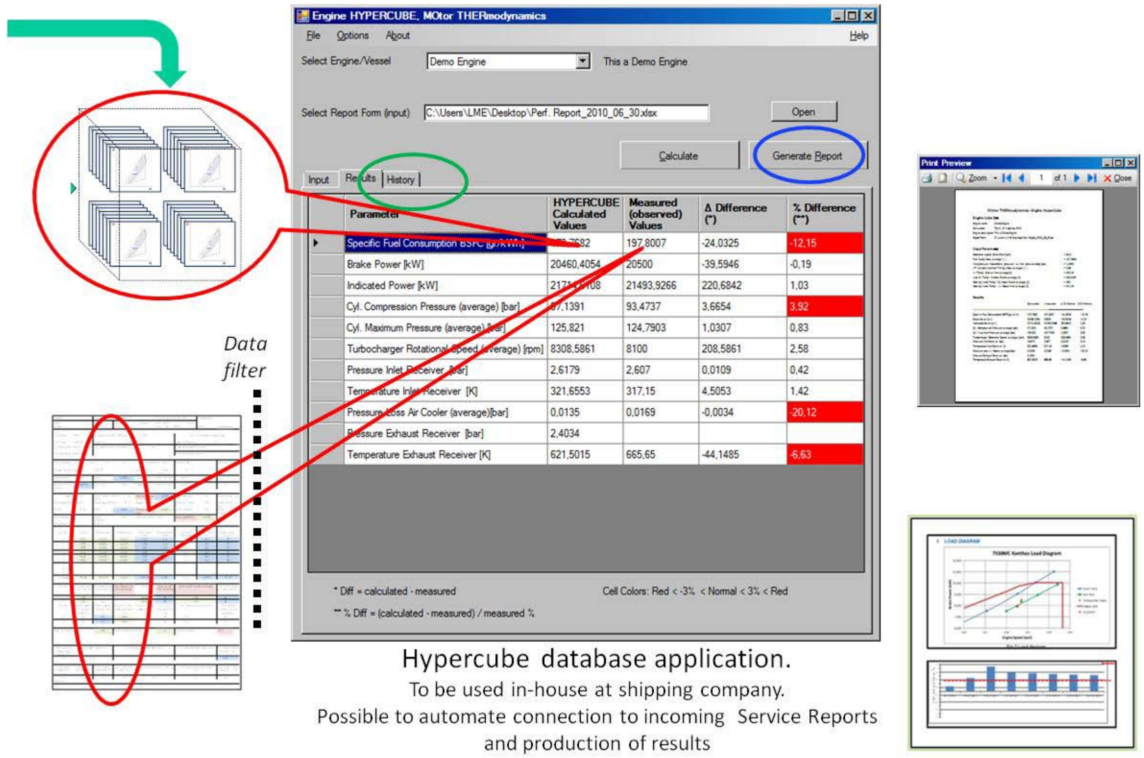

Fig. 7: Use of Hypercube database application

6. ADVANTAGES AND LIMITATIONS OF HYPERCUBE

The assessment procedure using the Hypercube application is fast and takes less than 5 seconds on a normal PC. It can be integrated with any in-house application for producing and archiving service reports, to automatically access data and produce a rapid assessment of engine performance.

Since the HYPERCUBE database is a complete map of performance of a specific engine, it can also be queried manually with any set of input data to produce a prediction of an expected performance at specified conditions. Such a facility can be used e.g. for largely different or “off-design” operating conditions, such as very low loads (super low steaming), to ascertain engine behavior, including expected fuel consumption, shaft torque, exhaust temperature etc., prior to actual operation. Another possible use is during the sea trials, where the “expected” engine performance can be obtained to be compared with the actual observations.

There are certain limitations that have to be considered. The HYPERCUBE is a map of engine performance which is pre-produced, using a very large number of combinations of engine load settings and ambient conditions, namely with prior assumptions for engine adjustments, components condition, combustion characteristics, valve timings etc. These are fixed prior to the simulation runs for the production of HYPERCUBE.

For example, in a multicylinder engine, all cylinders are normally considered equivalent and all geometry and settings, e.g. valve timings, injection settings, fuelling, compression ratio, are the same. The HYPERCUBE will then provide a performance map with these settings.

If, for example, the expected performance is required with one engine cylinder having reduced compression (e.g. due to piston ring blowby), then a new HYPERCUBE must be produced, since this cylinder “fault” will affect the performance of components downstream, e.g. exhaust receiver temperature, turbocharger boost and, in the end, the whole engine performance.

7. DETAILED PERFORMANCE PREDICTIONS

Although the procedure using the HYPERCUBE will be acceptable for the large majority of engine performance evaluation applications, there are instances where a more detailed approach is necessary.

This inevitably requires a fresh series of targeted runs of the engine model, possibly with careful adjusting of submodels. These instances invariably require a more detailed scrutiny of input data to be used in the simulations, a deep knowledge of the engine model structure as well as extensive engineering and thermodynamic knowhow to assess the results and adjust the model accordingly, so as to produce refined results.

In contrast to the HYPERCUBE application, which can run independently and automatically, being integrated within the shipping company IT environment, the detailed performance evaluation requires specialized expertise and has to be performed “offline” by experts. (Fig. 8)

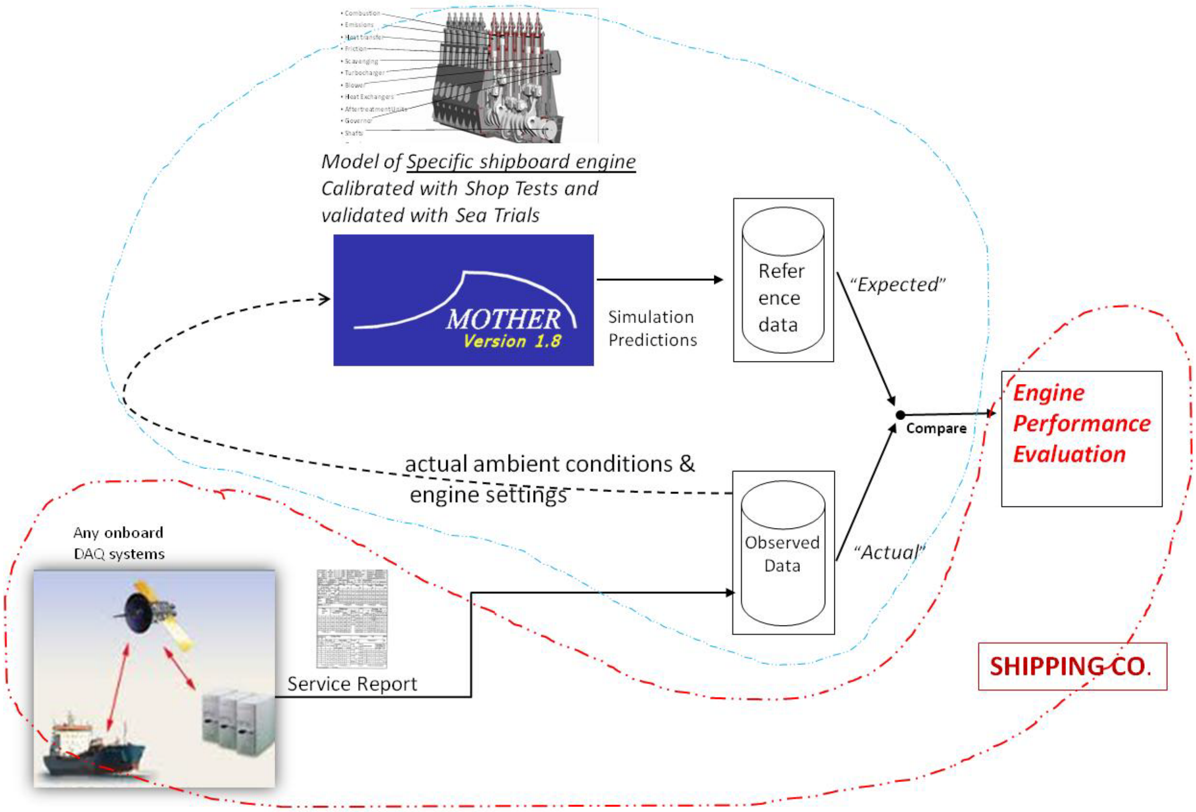

Fig. 8: Detailed performance predictions for particular investigations

Such a service performed by expert consultants, can be used for example to investigate any peculiar or unexpected performance differences (which may have been initially detected by use of the HYPERCUBE). Separate model runs may additionally consider any available in-cylinder measurements of pressures from indicating hardware on the engine (Fig. 9), detailed fuel quality analysis for combustion model adjustments, as well as involve parametric model runs to evaluate possible malfunction scenarios. Then, the very large number of prediction data that can be produced by the model (Fig. 10) has to be scrutinized by expert consultants. An evaluation report is produced, including comments on primary data, results of the simulations, evaluation of predictions versus observed data, comments and recommendations. (Fig. 11)

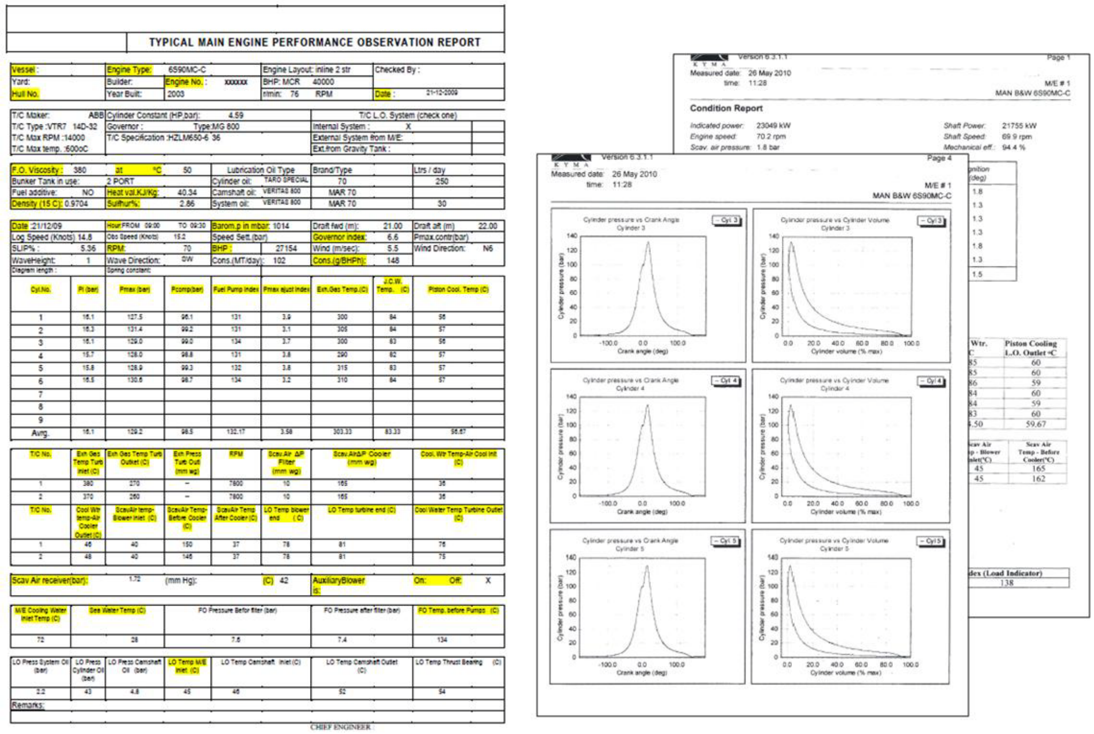

Fig. 9: Use of detailed monitored data, such as indicator diagrams, in conjunction with detailed simulations for particular investigations

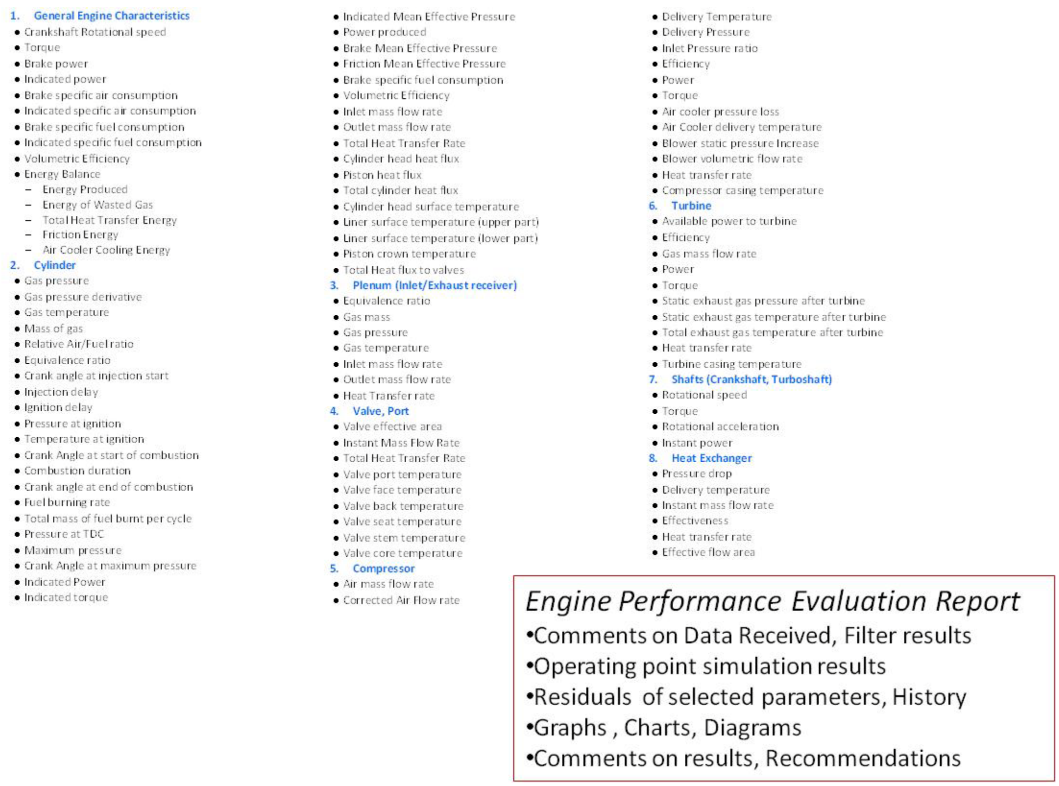

Fig. 10: The detailed simulations produce predictions for a very large number of parameters

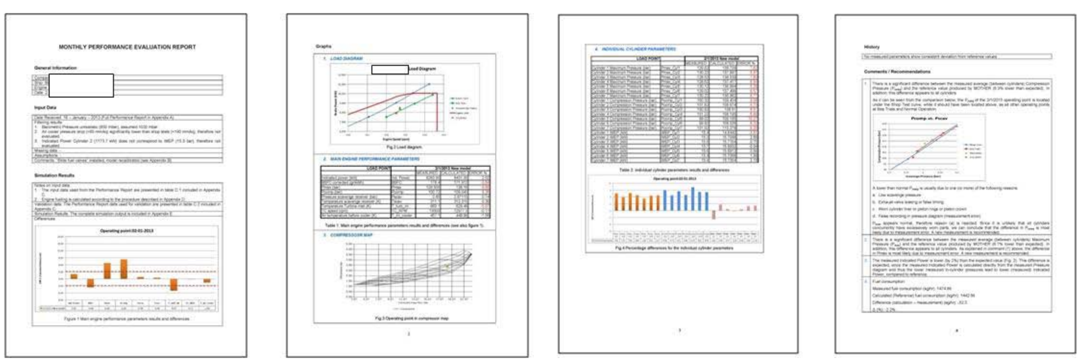

Fig. 11: Detailed performance evaluation report by experts

8. CLOSING REMARKS

A procedure for shipboard engine performance evaluation, using a thermodynamic model to generate reference data, has been under development and in trial use with several shipping companies for the last 3 years (the generic engine model itself is under development for the last 2 decades). The shipboard engine performance evaluation application, using the HYPERCUBE database, has been in testing for about six months with applications in shipping companies as beta prototype, with encouraging results.

The method and procedure provides a cutting edge technology solution to a complex and important issue in ship operations.

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