

A case study of aeronautic product life cycle management in the (conceptual) design phase

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1. Introduction

Aircraft are complex products consisting of many components from many suppliers and with a life time measured in decades. Therefore an aircraft is a textbook example for Product Life cycle Management (PLM). To provide a big picture of the domain consider the following characteristics. The Airbus A380 has 445 suppliers [1]. The production period is long, the Airbus A300 was launched in 1969, entered into service in 1974 with the last aircraft being delivered after 33 years in July 2007 [2]. The long production times of aircraft are complemented by long usage times of aircraft and consequently long maintenance periods. For example the A380 has been subjected to fatigue tests covering 25 years of use [3]. A quarter of all Boeing aircraft currently in service have exceeded their minimum design life of 20 years [4]. Compared with consumer domains, like cars or electronics, production volume is low. For the A320 family, which entered into service in 1988, current deliveries stand somewhat above three thousand [2]. Such extensive aircraft production times and subsequent prolonged in-service times inevitably imply changes to the supply chain and changes to the components used in a specific aircraft design. In case such new replacements cannot fully comply with the original specifications, well structured and easily accessible design information, including relevant engineering information from the detailed design phase, is needed to evaluate the impact of the change.

During the prolonged lifetime of an aircraft design, it is inevitable that user requirements will evolve. This results in the need for the design of aircraft variants, which is referred to as the aircraft family concept, depicted in Fig. 1.1. For the design of such variants it is advantageous to extend existing PLM-use. This way design information from earlier design phases of major subsystems, like an aircraft wing, is captured. As a result, this paper addresses aeronautic product lifecycle management by describing the results of a case study. This study was performed on the feasibility of capturing design data from early wing design phases, like conceptual design, into a high-end PLM system, as used in the aircraft industry. Actual results as obtained in a large European programme [5] will be discussed.

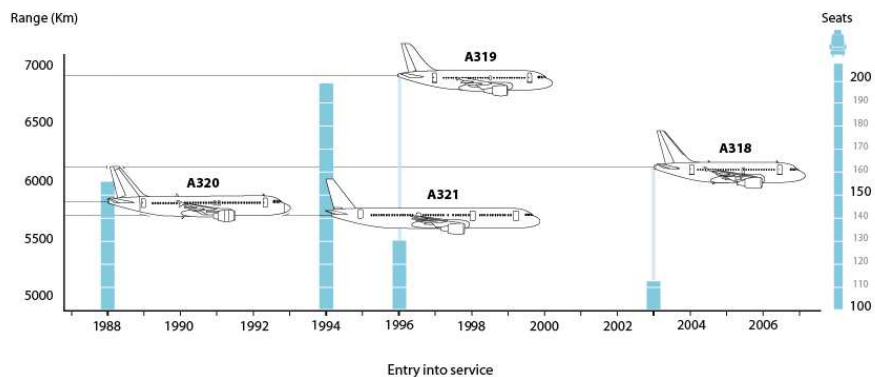


Fig. 1.1 Airbus A320 aircraft family, providing the range, the number of seats and the entry into service year, illustrating the need for extending product life cycle management with engineering information.

The next chapter elaborates the industrial need to manage design data from earlier design phases. Chapter three provides a concise overview of the wing design capability in order to improve the understanding of the wing Multidisciplinary Design Optimisation (MDO) - PLM study

described in chapter four. The implementation and obtained results are given in chapter five, before arriving at the conclusions in chapter six.

2. Using PLM functionality in early design phases

Complementing the information of the introduction, the design of aircraft, from the first activities in the feasibility phase until the entry into service, can take up to a decade. In contrast, according to Moore's law, computer hardware doubles its calculation capacity in 15 to 18 months [10]. Moore's law is expected to hold for at least one decade [11]. As a result computer hardware usually lasts for 5 to 8 years at most. The increasing hardware power results in Commercial Off The Shelf (COTS) software to experience a major update well before the decade has passed. The old version of the COTS software might not necessarily run on upgraded hardware, or even be supported on new hardware. The result is that already by the aircraft entry into service, the software originally used for the design, might not run anymore.

A major new software release, whether proprietary or COTS, with more advanced models and/or calculations is not guaranteed to reproduce the original results. Current solutions include re-assessing the original design with the current (i.e. updated) software and hardware. The resulting re-calculated baseline design is subsequently used for further design exploration.

Together these observations reinforce the need for comprehensive storage of the design information in a PLM system. The expected advantages include long-term traceability of decisions to the original data. Another advantage is the opportunity to store additional information on choices made, e.g. which design parameters to vary and why certain values for other design parameters are chosen. The PLM system should store all relevant design information of each discipline in a manner which is independent of the software tools used.

Summarising, the PLM system should capture all relevant design data for each participating discipline in the design, the analysis of the results and the system should allow for storing of justifications of the choices made. Furthermore, user friendly retrieval of such information over extended periods of time, spanning several generations of the supporting hardware and software, should be allowed. Ease of retrieval from various non-predefined perspectives is crucial as changes, e.g. in safety or environment, cannot be predicted, so neither can their future requests.

Apart from the PLM functions mentioned above, another important feature of a PLM system is the ability to capture a process in a workflow. In the case of an extended enterprise the collaborative engineering process between geographically dispersed companies should be captured in a workflow, executable through the internet. Once the workflow is defined, it becomes possible to automate part of the workflow. In our case, this means that the design workflow incorporates part of the analysis processes, running at a different site than the PLM system. So during the design phase, when all design software is operational, effort and time-to-market are saved by automating parts of the design workflow and making it available through the internet.

In general, as aircraft design and manufacturing move towards the virtual enterprise paradigm, the disciplines involved, the partly proprietary tools and the people will all be geographically dispersed and work for different organisations. This observation increases the importance of capturing all design information, because people, organisations and tools might change.

3. Example of engineering data from design phase: wing design

The wing characteristics provide an important contribution to the total aircraft performance. Consequently significant effort is spent on wing design by experts from different disciplines including aerodynamics and structures. During the wing design the interactions between the

disciplines needs to be taken into account. To increase the understanding of the wing design process before elaborating the wing MDO-PLM case study, this chapter provides a cursory overview of the wing multidisciplinary design analysis and optimisation capability.

Fig. 3.1a depicts the top-level view of the wing Multidisciplinary Design analysis and Optimisation (MDO) capability. Below the main components of this top-level are briefly described. The geometry generation component (see Fig. 3.1a, the top left labelled “variant generation”) uses, amongst others, a wing sweep angle and wing semi span (detailed in Fig. 3.1b) to define a consistent wing geometry description for the different analyses. The generated geometry (produced by the part labelled “geometry generation” in Fig. 3.1a) represents the wing external geometry, for aerodynamic analyses, and the internal wing geometry represents the internal wing structure, as used in the finite element based structural optimisation. For the engine sizing, labelled as such in Fig. 3.1a, a scalable engine model is used to determine the engine weight and the corresponding fuel consumption from the (maximum) mission thrust requirement as evaluated at take-off condition. The structural optimisation component is based on Commercial Off-The-Shelf (COTS) software. For a +2.5g manoeuvre load case, the optimal thicknesses of the wing’s primary structural elements, such as spars and ribs, are determined. The structural thicknesses are minimised while maintaining local Von Mises stress below its allowable value. The structural optimisation result is shown in the part labelled as such in Fig. 3.1a. For the aerodynamics cruise component, an NLR proprietary simulation system is used. A full potential/boundary layer Computational Fluid Dynamics (CFD) simulation of the wing-body configuration is performed. The considered critical design case is the Mach 0.8 cruise condition as this flight phase determines a significant part of the flight’s total fuel consumption and thereby the flight’s environmental impact of CO₂ emissions. Fig. 3.1a, lower left part (labelled “aerodynamics”) depicts the result. It is typical for MDO that critical loads, which size the aircraft, for different disciplines are experienced in different conditions and flight phases. The next component in Fig. 3.1a is mission analysis. This component combines and translates some key characteristics of the wing design, as obtained from the previous components and stored in the integrated design model, into the Breguet range of the wing design. The Breguet range is obtained from a formula which approximates the range of an aircraft design. More information on the Breguet range can be found e.g. in [7] and [9]. This aircraft range is used as an objective for subsequent wing design optimisation, as depicted in the part labelled “optimisation” in Fig. 3.1a. More information on the wing MDO capability can be found in [6], more information on the optimisation methods is provided in [7].

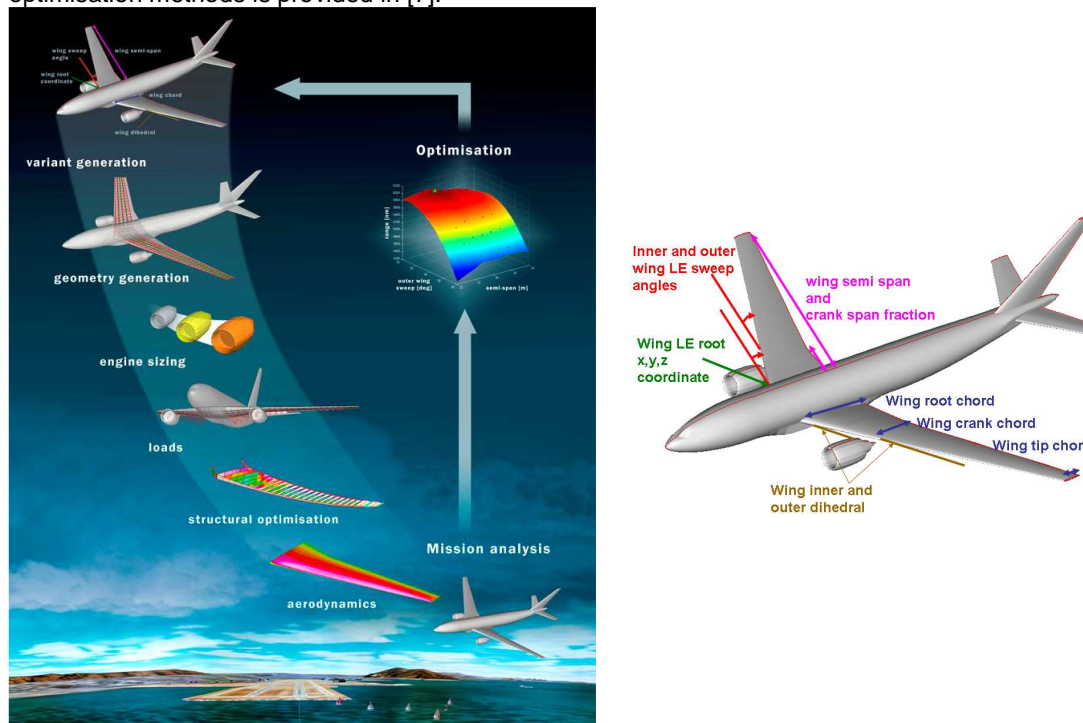


Fig. 3.1 a (left) Top-level wing multidisciplinary design analysis and optimisation capability
b (right) Wing design parameters

4. Concept of the wing MDO-PLM case study

The wing MDO capability as described above can be applied, for example, to assess existing design data and create variations of an existing aircraft family, during the conceptual re-design phase. During the long life cycles of aircraft, such studies can be motivated by fluctuations in the aircraft market needs. Maintenance and overhaul, new aircraft versions, freighter conversions or special versions like VIP versions, require being able to retrieve the justification of each major design decision taken for the original aircraft. Therefore, as an example, the wing MDO design study capabilities have been integrated within a PLM system. The objective of this integration is demonstrating the applicability of PLM in aircraft conceptual design.

From the PLM point of view the wing MDO design study is performed at three different levels, see Fig. 4.1, which defines the high-level workflow:

- The Project level.
At this level the high-level wing MDO study definition is performed. The problem is formulated, e.g. the design objective, the design parameters to be varied and the reference aircraft are identified. The obtained result: a validated input for the wing MDO design study is defined and released.
- The Collaboration level.
At this level the study input for the reference aircraft is transformed into a dataset for the MDO analysis. A breakdown of the study into details is performed. The wing design space determines the range of variants. All detailed data relevant to the different stages of the wing MDO design study are identified and stored. This data includes all design information of each evaluated variant, descriptions and versions of the used multidisciplinary wing analysis software, the derived optimal design, a description of the derivation process of the optimal design and the design validation.
- The Operational level.
At this level the actual multidisciplinary wing analysis calculations are performed for a specific wing variant. It requires a low-level interface with the multidisciplinary wing analysis software.

The different levels of the workflow in the PLM case study are revisited several times in the two phases of the study (see Fig. 4.1): first during the optimisation of the wing design and second during the validation of the optimal wing design.

The workflow returns to the Collaboration level to derive the optimal wing MDO design result. Due to the computational expense of a full multidisciplinary wing analysis, response surface modelling is used to find an optimum, which can (and usually is) located in between calculated design variants. More information on the response surface modelling and the optimisers used is given in [7].

In the validation phase the derived optimal design is evaluated at the Operational level. Subsequently at the Collaboration level the predictions of the wing MDO analysis software are compared with the full analysis results. Based on this comparison a final optimum is validated and presented at the Project level, thereby finishing the study.

The process is depicted in Fig. 4.1 below.

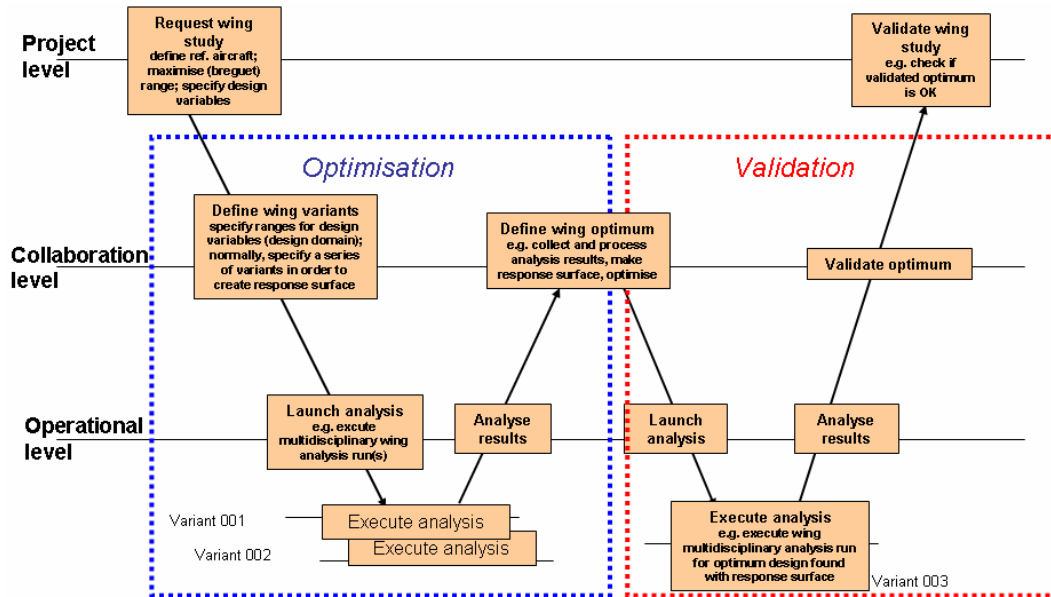


Fig. 4.1 Integration of wing multidisciplinary design analysis and optimisation capability with product lifecycle management resulting in the definition of sequence diagram of a typical process flow.

5. Implementation and results of the case study

Although, in principle, it is possible to apply PLM functions stand-alone from the wing MDO capability, the many manual actions required make this error prone as well as costly. Fig. 5.1 shows how the wing MDO capability and PLM capability have been integrated into a combined capability supporting the wing MDO design study objectives in the context of an extended enterprise. The wing MDO capability has been extended with a web interface allowing automatic operation. More information on the wing web can be found in [8]. The Commercial Off The Shelf (COTS)-based PLM has been extended with a wing MDO-PLM design connection. Both capabilities have been connected using a standard Internet-based IT infrastructure. As the purpose of the wing MDO-PLM integration is to build a functioning prototype, standard security solutions have been used. A separate part of the work, the VIVACE – TSCP cooperation, addresses the security issues. The Transglobal Secure Collaboration Program, or TSCP [12], is a government – industrial partnership developing secure and interoperable solutions for, amongst others, the aerospace domain. Information on VIVACE – TSCP cooperation is provided in [13].

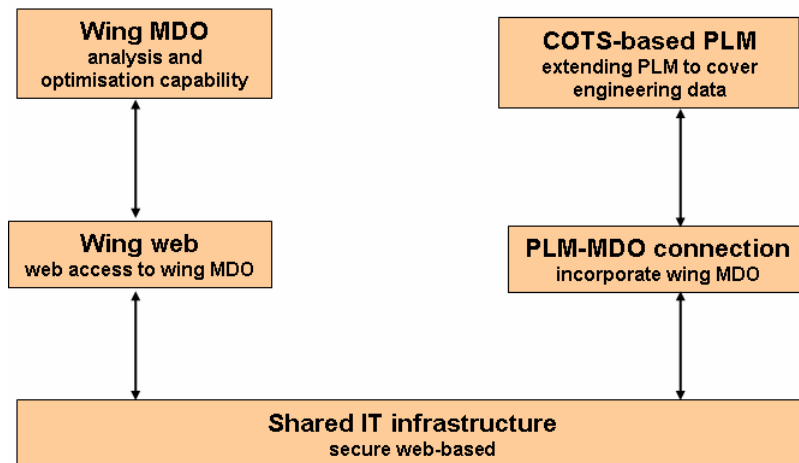


Fig. 5.1 Integration of wing multidisciplinary design analysis and optimisation capability with product life cycle management.

The integration of the wing MDO analysis capability into a PLM system is performed using a COTS-product, common in the aeronautical domain: Windchill. The wing MDO software runs on a combination of a Linux server and a Windows platform, and communicates with the PLM server using a Java programme.

Reflecting the conceptual wing MDO-PLM workflow set-up (Fig. 4.1) within the wing MDO-PLM implementation (fig. 5.2), three objects have been defined for the integration.

- The Study object.**
 It has a link to one or more reference aircraft objects. It contains design study targets (e.g. range maximisation) and design study parameters (e.g. wing semi span, wing sweep angle depicted in Fig.3.1) with the ranges of variation for the design space considered. It contains the key results obtained (e.g. maximum range found, optimum wing semi span and wing sweep angle values) and visualisations of the design. Furthermore, it contains metadata of the analysis like software tool version identifications and analysis dates.
- The Reference aircraft object.**
 This object contains design information that relates to the aircraft family, e.g. number of engines, maximum take-off weight, values for all wing design parameters, like wing chord (see Fig. 3.1b) and reference values for the design study parameters wing sweep angle and wing semi span. It also contains detailed information that relates to the multidisciplinary wing analysis evaluation of this design, including the Breguet range.
- The Variant object.**
 This object contains a link to one Reference aircraft object. Furthermore, after the multidisciplinary wing analysis run has been performed the Reference aircraft object contains the values of the varied wing MDO design parameters (e.g. wing semi span, wing sweep angle.) and the calculated key results (e.g. range). Also additional detailed design information and results of the calculation (like design visualisations) are stored in this object. A screen dump of the implemented Windchill workflow is given in Fig. 5.2 below.

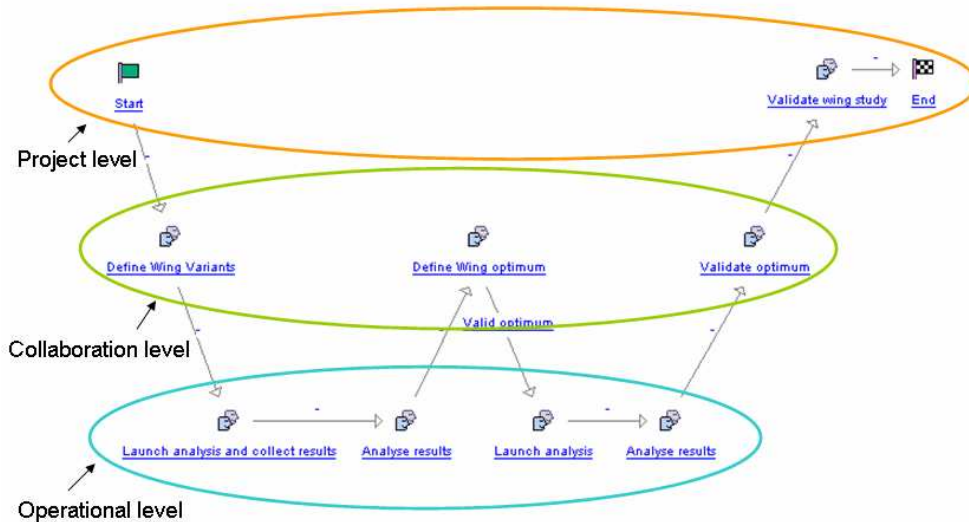


Fig. 5.2 Multi-role workflow of the PLM implementation of the wing MDO design study

The wing MDO-PLM case study involves a customer Company A that develops a new aircraft family member, e.g. a freighter version of the aircraft. In the context of this programme a wing MDO study is performed by Company W, which is specialised in wing design (Fig. 5.3). The study results in an optimal wing design, i.e. with maximal Breguet range.

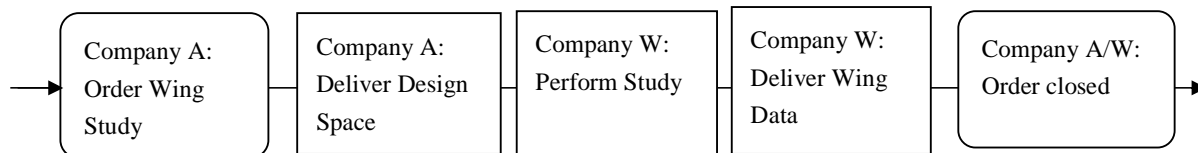


Fig. 5.3 Process diagram of wing case study enterprise

At the same time, following the context of an extended enterprise, technical experts (e.g. aerodynamics, structures, engines) of Company A are involved on the collaboration level during the execution of the wing study. They must review the optimal wing design calculated by Company W. Within Company W the roles within the wing study are sub-divided over

- A project manager, who has the organisational responsibility of the wing study project.
- A lead designer, who has the technical responsibility of the wing study project.
- An MDO operator, who performs the variant calculations and the optimisation.
- Various discipline experts (e.g. aerodynamics, structures), who evaluate the design results.
- An administrator, who maintains the software infrastructure of the project (e.g. sets up the workflow).

A possible picture of the virtual organisation, with the roles defined above, is given below in Fig. 5.4.

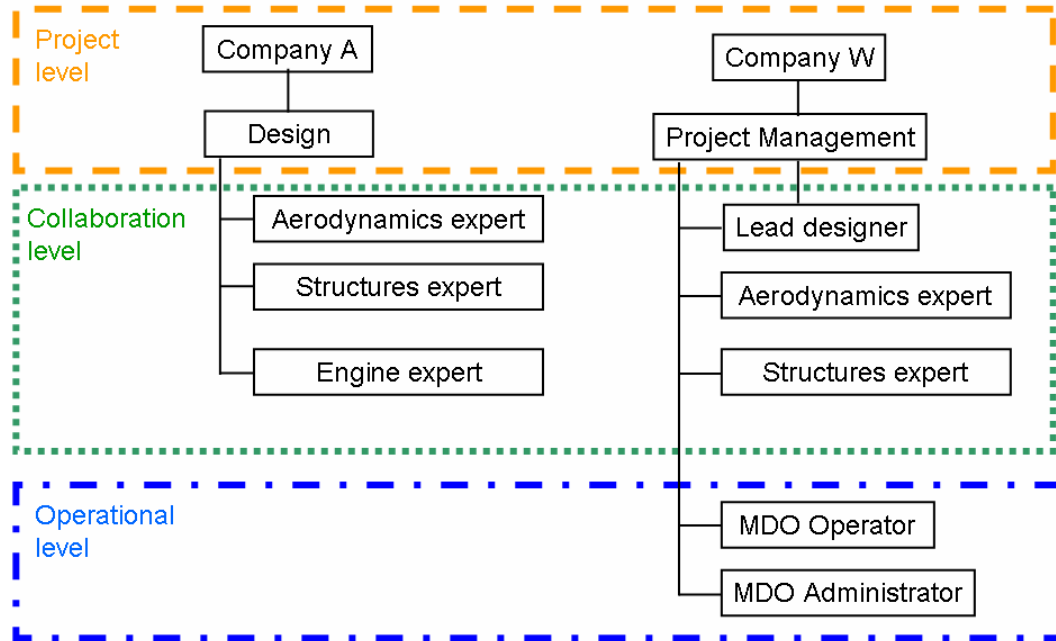


Fig. 5.4 Organisation diagram of roles within an extended enterprise wing study

After the wing study order has been agreed between the project management of Company W and Company A (Project level), the study is defined in more detail. The MDO administrator initiates the wing MDO-PLM environment, including the workflow, roles, data objects and software version descriptions. The lead designer defines the Reference aircraft object. Next, the lead designer defines a Study object, selecting the Reference aircraft object. The objective of the study is defined as maximising the Breguet range of the aircraft, while varying the wing semi span and sweep angle within the allowed wing design space. The current definitions of the Reference aircraft and the Study object are then reviewed by the technical experts of the customer Company A, on the Collaboration level.

As a next step, for each wing design variant to be analysed, a Variant object is derived automatically from the Reference aircraft object. It is added to the Study object. In our wing MDO-PLM case study, the wing sweep angle can be varied between 20 and 40 degrees and the wing semi span between 28 and 32 metres. Furthermore the versions and descriptions of the multidisciplinary wing analysis software are stored. Subsequently, on the Operational level (refer to Fig. 5.4), the MDO operator calculates all Variant objects using the multidisciplinary wing analysis software. After completion of all wing design evaluations, the MDO operator verifies the results. Based on the defined design objectives, the MDO operator performs the draft wing optimisation. Typically a single wing design variant analysis consumes significant computational resources. Therefore the draft optimum wing design is obtained using advanced techniques like response surface modelling (see Fig. 5.5). Usually such draft wing optimum design does not coincide with available variants (see Fig. 5.5). More information on this optimisation method is provided in [7]. Once the draft optimum design is found, the MDO

operator validates this result by evaluating it with the full precision multidisciplinary wing analysis capability. The optimum design is then presented to the technical experts (of both Company A and Company W) and the lead designer (Company W) for review (Collaboration level). If they reject the optimum wing design, the MDO operator has to perform a new design variant analysis, until an acceptable wing design is obtained. If the technical experts and the lead designer accept, the optimum wing design is then formally accepted by the project manager and the wing study order is closed (Project level).

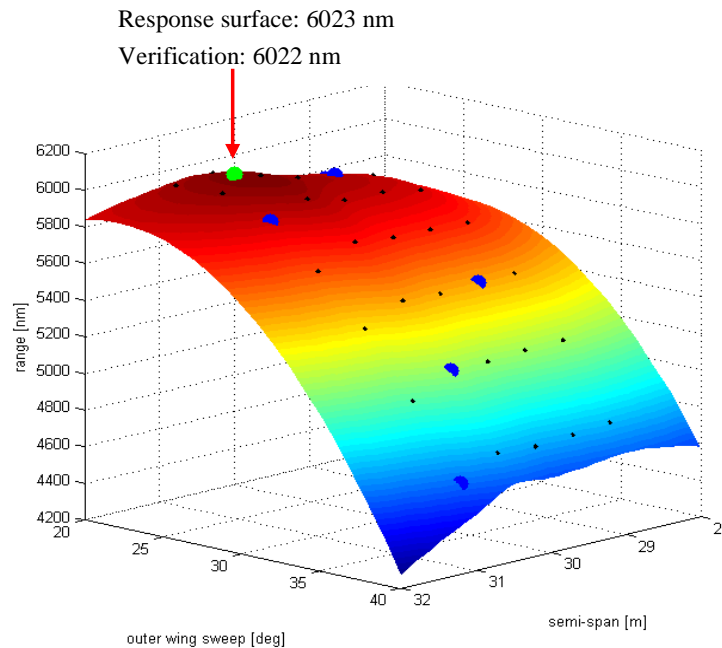


Fig. 5.5 Draft optimum found by response surface modelling, with the verification result.

6. Concluding remarks

For various reasons, including prolonged maintenance periods and extending an aircraft family with new aircraft versions, there is a need to use product life cycle management prior to engineering phases, like (conceptual) design phases. To assess the feasibility of this concept, a case study has been performed. The case study integrates an advanced multidisciplinary wing analysis capability, which already included a flexible optimisation tool suite, with standard COTS-based product life cycle management software, commonly used in the aeronautical domain.

A workflow has been developed using a wing MDO-PLM sequence diagram and corresponding role descriptions. The wing MDO-PLM concept has been implemented successfully using the standard COTS-based PLM software. Typical PLM advantages have been demonstrated, like

- A single workflow describing all design related activities, providing for increased transparency of the design processes and roles involved.
- A single workflow allowing automation of part of the process, supporting a reduction of the design analysis time. Automation can also help reducing the manpower effort involved.
- The capability to store design decisions, including their justification for later retrieval.
- By storing the integrated design model, a single and consistent description of the design, for all disciplines involved, has been archived.
- Long term storage and retrieval of information, independent of the COTS and proprietary software and supporting hardware that generated such design data. For COTS software vendor support falls short of the time scales required by aircraft. Proprietary software might not even be available to all partners. The hardware might have even shorter support periods than the software, justifying the need for the long term storage capability of PLM.

- Support of the virtual enterprise paradigm, with the PLM software and the wing multidisciplinary design optimisation software running in different and geographically dispersed organisations.

The above list demonstrates all functions described in chapter two. Hence, the prototype fulfils the requirements. Future solutions, like the prototyped wing MDO-PLM system, will even allow for the emergence of specialised organisations providing design services.

Acronyms

| | |
|------|--|
| CFD | Computational Fluid Dynamics |
| COTS | Commercial Off The Shelf |
| MDO | Multidisciplinary Design optimisation |
| PLM | Product Life cycle Management |
| TSCP | Transglobal Secure Collaboration Program |

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