



**KTH Industrial Engineering
and Management**

Revision Of The Aircraft Engines Preliminary Design Platform Of First Level

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Abstract

In the highly competitive aerospace industry, engine manufacturers must react very quickly and precisely to any demand emerging from aircraft manufacturers if they want to be positioned on the offer. This is especially true when answering to Requests For Information (RFI) based on preliminary design investigations of first level. In order to reduce the time needed to perform these costly operations while improving the performances achieved, Snecma wishes to develop tools for dimensioning the engine and also for assessing key parameters such as mass, emissions, fuel burn, costs, etc. Unfortunately, the set of tools and the process used at the present time for preliminary design investigations of first level are not sufficient to meet the high standards sought-after by the company in terms of time and performances. As a consequence, efforts must be spent on redefining the whole process and the tools it is based on; here is the mission that has been conferred upon me.

Multiple exchanges with performances engineers and specialists allowed to draw the current process for preliminary design investigations of first level and raise all the associated concerns. At the same time, a status of the existing tools (called modules in this report), mainly developed under Excel, has been realised in order to identify the range of action for today's investigations. A prototype has been developed under SDK Python with the aim of proving the feasibility of a solution to a difficulty that shows up in the process for each new investigation: the one of generating the workflow on the optimisation software Optimus. A target process has finally been discussed considering all the information collected, and would allow dividing by five the time needed to perform investigations compare to now. The prototype developed lead to interesting results and this solution could thus probably be integrated in the target process as it would allow saving one day of work for an engineer for each study to be carried out.

Solutions have been proposed to all the concerns identified in the process and they will have to be discussed with many actors and investigated further in the near future in order to set the target process that will allow meeting the final objective of answering all types of RFIs emitted by aircraft manufacturer in a very short time with a high level of confidence in the results.

Preface

Within the scope of my double degree in aerospace engineering performed at the Royal Institute of Technology (KTH), I realised my master of science thesis at Snecma - Villaroche - between March, 31st 2014 and August, 29th 2014 in the Mechanical Preliminary Design Section, part of the Methods and Tools for Integration Department, included in the Integration of Propulsive Systems Division of the Technical Direction.

Performing my master thesis in a company was important for me as I turn towards an engineering career in the industry rather than in pure research. It was also an excellent opportunity for me to complete my general knowledge of companies' organisation and to comprehend the interactions between the different services in a development project.

I decided to join Snecma as it is one of the world's leading manufacturer of aircraft and rocket engines which develops considerable activities at the present time. Moreover, in the past few years I had the opportunity to get a first insight into the high technology group Safran that Snecma is part of, through the realisation of two internships at Messier-Bugatti-Dowty, another company of the Safran group. The wide range of the group's activities has been fascinating me since then, and made me wish to continue exploring it.

The purposes of this professional experience were first to complete the general understanding of turbomachines I acquired at KTH with a more cross-functional vision of it, to understand how design choices are made for developing a new engine, and finally to get acquainted with some tools used for preliminary design. I found this master thesis particularly attractive in the sense that it called at the same time for the knowledge I acquired at KTH in aeronautics and for the knowledge I developed at Centrale Marseille in project management.

Acknowledgements

I am using this opportunity to express my gratitude to all the people who guided me and kept me on the correct path throughout my internship.

I express my deepest thanks to Matthieu Perrier and Alix Lejeune who supervised me during these five months. Their advice and explanations on various topics have been of precious help to me.

I also address special thanks to Arnaud Quenardel and Fabrice Chevillot, respectively chief of the Methods and Tools for Integration Department, and chief of the Mechanical Section of the same department, who in spite of being extraordinarily busy with their duties, took time out to hear, provide guidance and take part in useful decisions.

This thesis would not have been possible without the numerous exchanges with Ludovic Granillo and Hugo Larcher, performances engineers and main costumers of my project.

I would like to thank Didier Escure, Christian Vessot, Clément Leenaert, Hervé Rolland, Guillaume Godel and Yoann Mery, who as specialists, gave me valuable information about their respective activities.

I choose this moment to show my gratitude to Pierre-Yves Pamart and Damien Smadja for their precious help in programming with Pyhton, as well as Benoit Frossard for his support in the use of the Optimus software.

I am really grateful to Jens Fridh who accepted to be my supervisor for KTH. He gave me interesting advice during my internship.

Lastly, I offer my regards and blessings to all of those who supported me in any respect during the completion of the project, and to all the members of the Methods and Tools for Integration Department for their welcome.

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List of Acronyms

Acronym	English Meaning	French Meaning
APIs	Application Programming Interfaces	Interface de programmation
CAD	Computer Aided Design	Conception assistée par ordinateur
DOC	Direct Operating Cost	Coût direct d'exploitation
EGT	Exhaust Gas Temperature	Température des gaz d'échappement
EPNL	Effective Perceived Noise Level	Niveau de bruit perçu
EROC	Engine Reliability Operating Cost	Coût d'exploitation lié à la fiabilité moteur
ESA	European Space Agency	Agence spatiale européenne
FB	Fuel Burn	Consommation de carburant
FETT	First Engine To Test	Premier moteur à tourner au banc
FTB	Flying Test Bed	Banc d'essai volant
GE	General Electric	General Electric
GUI	Graphical User Interface	Interface homme-machine
LEAP	Leading Edge Aviation Propulsion	Propulsion aéronautique de pointe
MDO	Multidisciplinary Design Optimization	Optimisation multidisciplinaire
MOU	Memorandum Of Understanding	Protocole d'accord
MRO	Maintenance, Repair and Overhaul	Maintenance, réparation et révision
OAP1	Pre-projects tool of 1 st level	Outil Avant-Projets de niveau 1
OAP2	Pre-projects tool of 2 nd level	Outil Avant-Projets de niveau 2
RFI	Request For Information	Demande d'information
RFP	Request For Proposal	Appel d'offres
RIM	Design review	Revue Interne Métier
SDK	Software Development Kit	Kit de développement logiciel
SFC	Specific Fuel Consumption	Consommation spécifique de carburant
SOA	State Of the Art	Etat de l'art
WYSIWYG	What You See Is What You Get	Ce que vous voyez est ce que vous obtenez

Introduction

Preliminary design investigations are of paramount importance in the development of a new jet engine as they set the major technological choices for the engine and gives the frame for the conception phase. The first level of these preliminary design investigations can be considered even more important in the sense that they are carried out in order to give answers to Request For Information (RFI) emitted by aircraft manufacturers. Reactivity, accuracy and competitiveness are keys words that rule this phase of development if the engine manufacturer wants to get a chance to win the project. The information requested at this stage are usually an estimation of the mass, the size of the engine, thrust performances, the Specific Fuel Consumption (SFC), noise , emissions as well as costs. As a consequence, preliminary design teams must perform highly multidisciplinary investigations. From this perspective, in the early 2000's, the preliminary design office of Snecma came up with the idea of implementing an optimisation platform that integrates multiple modules that allow the calculation of the most important aspects related to the development of a new engine previously mentioned. The purpose of this platform was clearly to converge faster on an optimised engine's architecture based on Multidisciplinary Design Optimization (MDO) studies.

This platform was thus developed few years ago, but unfortunately it could not be sustained properly over time, leading to a considerable reduction of its capacities. Moreover, a certain number of concerns contribute to slowing down the current process. As a result, investigations have become rather long and some interesting results are not in measure to be extracted at the present time. The mission of redefining a whole new process and new tools for the preliminary design investigations of first level has logically been conferred upon the Methods and Tools for Integration Department which I am part of. The overall idea is to rethink entirely the way in which these investigations are performed; more actors should be involved in the process, the flexibility of the platform should be significantly increased, its use must be facilitated and a great care must be attached to the consistency of the results obtained. In order to meet these objectives, a user-friendly platform with a high degree of modularity must be built; it would allow engineers to answer aircraft manufacturers' RFI in a very short time.

As the project of rebuilding the platform is considerable and is just starting, there was absolutely no chance that I managed it entirely. As a result, the mission that has been conferred upon me during my 5-month master thesis was to conduct the first phase of the project, that is to collect the needs that originate from various actors for the future platform. In order to perform this task, a considerable investigation of the current process and a status of the existing modules had to be carried out, in line with an activity of prototyping.

Note that due to the public nature of this report, a considerable amount of sensitive information could not be presented, especially concerning the results of my investigations. Nevertheless, the methodology followed to perform each activity has been extensively discussed in this report.

Chapter 1

Safran Group and Snecma

1.1 Safran Group

Safran is a leading international high-technology group with four core businesses: Aerospace Propulsion, Aircraft Equipments, Defense, and Security. In 2013, the group had 66.300 employees worldwide and generated sales of 14.7 billion euros. The various activities, markets and main companies of each core business are briefly developed in the next paragraphs.

- **Aerospace propulsion:** Safran develops, produces, markets and supports engines and propulsion systems for civil and military airplanes and helicopters, ballistic missiles, launch vehicles and satellites. More information will be given in the section dedicated to Snecma, the lead company in this domains.
Main companies: Snecma, Turbomeca, Herakles, Techspace Aero.
- **Aircraft equipments:** Safran also provides a wide range of systems and equipments for civil and military airplanes and helicopters. Its main markets are engine nacelles, braking and landing systems, the electric green taxiing system, avionics, power transmission, etc.
Main companies: Aircelle, Messier-Bugatti-Dowty, Hispano-Suiza, Labinal Power Systems, Sagem.
- **Defence:** Operating in the optronic, inertial guidance, electronics and safety-critical software markets, Safran offers today's armed forces a complete range of optronic, navigation and optical systems and equipments for use in the air, on land and at sea.
Main company: Sagem.
- **Security:** Safran offers state-of-the-art solutions to meet the evolving security requirements of individuals, businesses and governments, based on multi-biometric technologies, smart cards and secure identification and travel documents. The detection of dangerous substances is also a key activity of Safran.
Main company: Morpho.

1.2 Snecma

1.2.1 Activity

Snecma is one of the world's leading manufacturers of aircraft and rocket engines, part of the international high-technology group Safran. The company designs, develops, produces and markets, alone or in partnership, engines for commercial and military aircraft, launch vehicles and satellites. It also offers a complete range of engine Maintenance, Repair and Overhaul (MRO) services to airlines, armed forces and other operators. The company's efforts to reducing engine noise and emissions to meet today's pressing environmental challenges is particularly commendable.

In 2013, Snecma had more than 14.600 employees worldwide, working in the 35 plants of the company. It generated sales of 5.6 billions euros.

1.2.2 Divisions



Figure 1.1: High-bypass ratio turbofan engine, CFM56-5C.

Snecma is also a partner to GE on several large turbofans, namely the CF6, the GE90, and the GP7200, which power long-range widebody jets. The company is currently developing the Silvercrest, a new jet engine designed for business aircraft. In the regional aircraft market, Snecma and its partner NPO Saturn of Russia develop and produce the SaM146 engine for the Sukhoi Superjet 100 regional jet, through the joint subsidiary PowerJet.

Military engines

Snecma designs, develops, produces, markets and supports engines (both jet engines and turboprop engines) for 20 different types of military transport, training and combat aircraft, deployed by the armed forces of 40 countries. Its flagship products include the M53-P2 powering the Mirage 2000, the M88-2 (Figure 1.2) for the Rafale, and the TP400 developed through the European alliance Europrop International to power the Airbus A400M transport.



Figure 1.2: Dassault Rafale afterburning turbofan engine, M88.



Figure 1.3: Ariane 5 first stage rocket engine, Vulcain 2.

Space engines

Snecma designs, develops and produces propulsion systems and equipments for launchers, space vehicles and satellites. As supplier of the Vulcain®2 (Figure 1.3) and HM7B™ cryogenic engines for Europe's Ariane 5 ECA heavy launcher, Snecma is the global leader in cryogenic propulsion. The company is also the European leader in plasma propulsion with the PPS®1350 thruster, already proven on ESA's Smart-1 lunar probe.

Services

Snecma offers a complete range of MRO services for both commercial and military aircraft engines, used by airlines, armed forces and other operators. The company invests a large share of its budget in R & D for new repair solutions, while also taking responsibility for the spare parts supply chain and managing engine maintenance contracts.

Chapter 2

Context

2.1 Gas turbine engine development

2.1.1 General development process

Developing a new engine is a complex mission that can be divided into several steps, ranging from the definition of the engine specifications to the delivery and commissioning of the very first engine. Although each engine manufacturer uses its own roadmap for the design of gas turbine engine, a general representation of the design process can be found in [1] and is displayed in Figure 2.1 below:

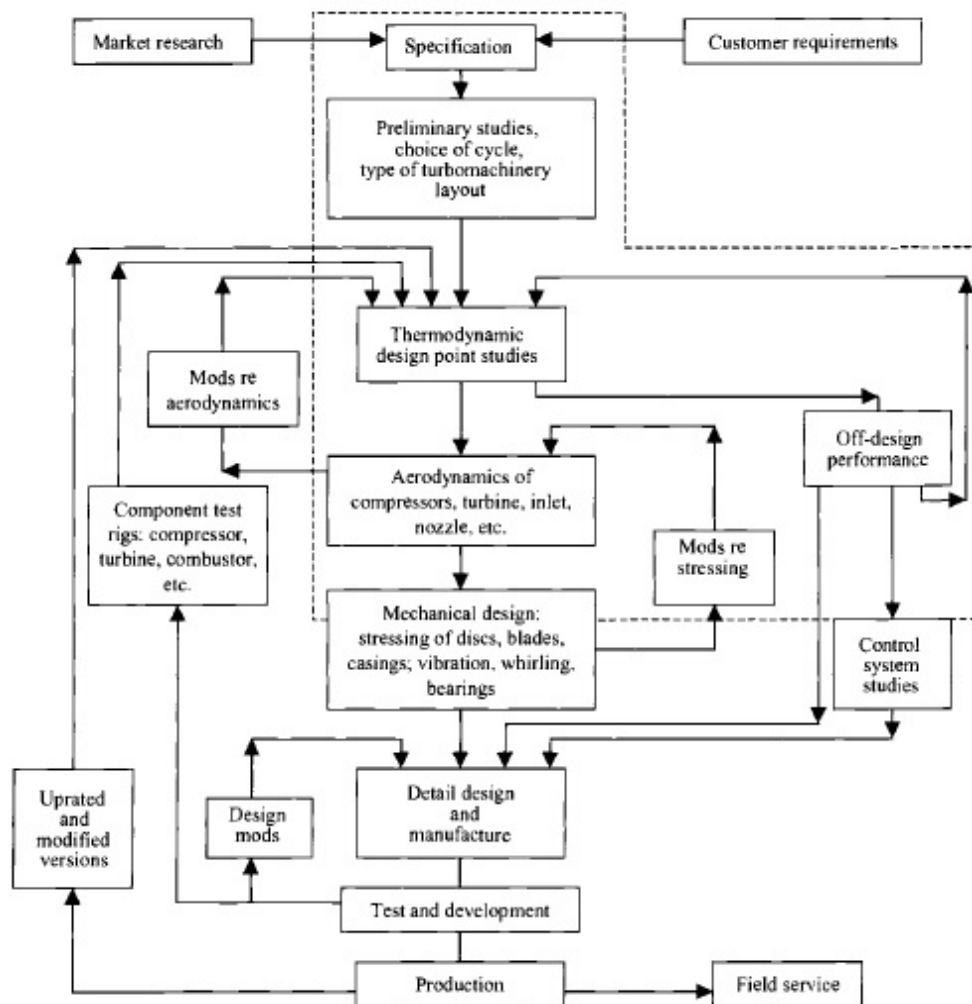


Figure 2.1: General design process for gas turbine engines.

At Snecma, the development process is organized around the following four major phases:

1. Preliminary design.
2. Definition.
3. Conception, industrialisation and validation.
4. Commissioning and product support.

Note that all these phases are strung out along multiple validation steps in order to guaranty that each activity's goals are fully reached.

The very first stage begins when an aircraft manufacturer emits a Request For Information (RFI) with the aim of obtaining a first answer to its needs. In general several engine manufacturers are approached and enter in competition in order to get the development project at stake. The customer challenges the engine manufacturers to provide the best trade-off between Specific Fuel Consumption (SFC), mass, thrust levels and several other key parameters. No precise values are required by the aircraft manufacturer but obviously it has expectations resulting from the State Of the Art (SOA). Indeed, given the evolutions displayed by all the engines over time (in terms of mass, specific fuel consumption, emissions, etc.) the aircraft manufacturer expects at least engine performances to be in compliance with the trend or even better.

Consequently, the preliminary design teams carry out the necessary investigations of first level so as to provide answers to what the aircraft manufacturer is interested in. The information requested at this stage are usually an estimation of the mass, the SFC, the size of the engine, the location of its center of gravity, its noise and emissions as well as its thrust performances. Several successive RFI can be sent to the engine manufacturer in order to converge on a precise definition gathering the aircraft manufacturer's expectations.

If the answer of the engine manufacturer to the RFI suits the aircraft manufacturer, then the latter expresses a Request For Proposal (RFP) which is a demand more detailed than the RFI previously emitted. An example of a typical RFP for an Air-to-Air fighter can be found in [1]. At the reception of this request, the preliminary design teams refine their studies by performing investigations of level 2 this time.

Following this, the aircraft manufacturer can decide to commit to the engine manufacturer on the project through the signature of a Memorandum Of Understanding (MOU). This signature marks the real beginning of the project.

Then comes the second phase during which thorough multidisciplinary investigations are carried out. The various teams of engineers such as the ones specialised in mechanical design are progressively involved and bring their contribution to the project. In the end, they are in measure to deliver a complete definition of the engine's architecture.

At this particular stage, the engineers of the Modules Division come into play and finalize the conception of the engine. Then, the manufacturing of the pieces is addressed, as well as the engine validation. This latter implies ground testing performed on the First Engine To Test (FETT) installed on a test bench followed by flight tests with the engine mounted on a Flying Test Bed (FTB). The FTB corresponds to a special aircraft which is of a different type than the one the engine under test is made to power. Note that only one engine under test is mounted on the FTB, all the others are regular engines.

Finally, during the fourth phase, the first engines are delivered to the aircraft manufacturer with the associated support.

2.1.2 General preliminary design process

It is important to mention here that the preliminary design teams perform highly multidisciplinary investigations, encompassing technical studies, for instance in the field of mechanics, thermodynamics, aerodynamics or acoustics, as well as financial studies related to production and maintenance costs for example. Although each engine manufacturer has its own way of conducting preliminary design, a general representation of the sequence to be followed has been extracted from [1] and is displayed in Figure 2.2.

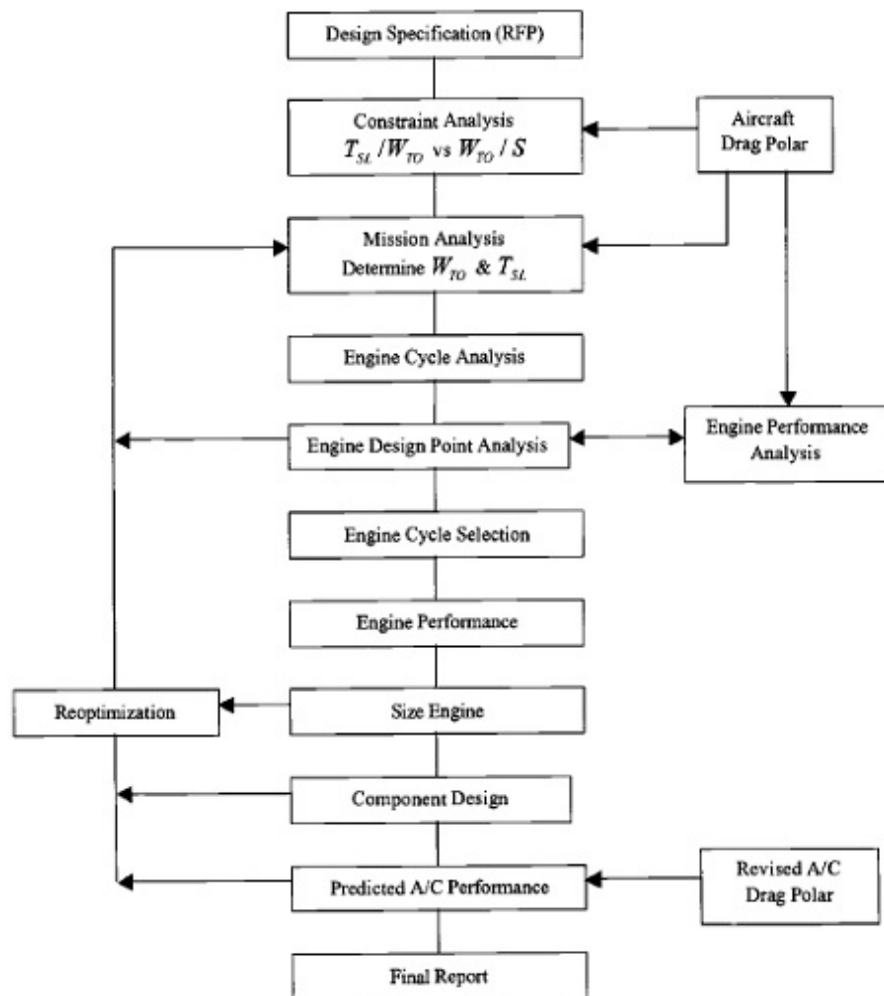


Figure 2.2: General preliminary design sequence for gas turbine engines.

For an extensive discussion of these steps the reader is recommended to turn to [1].

As one can notice the first step is to perform a constraint analysis. Basically, it consists in converting the design specifications (for instance: take-off from a runway of given length, flight at a given altitude and required speed, turn at a given altitude, speed and required rate, etc.) into relationships between the minimum thrust loading at sea-level take-off (T_{SL}/W_{TO}) and the wing loading at take-off (W_{TO}/S). Note that T_{SL} represents the installed sea level static thrust, W_{TO} the gross take-off weight and S the wing area of the aircraft. In order to achieve this phase, reasonable assumptions for the aircraft lift-drag polar and the engine thrust with flight altitude and Mach number first have to be made. Many solutions are acceptable at that stage even though performance constraints tend to limit the range of loading parameters available. Note that the selected design point is very sensitive to the application and the preferences of the designer.

Once the constraint analysis phase has been conducted, the next step is to establish the scale of the aircraft by assessing its gross take-off weight W_{TO} . In order to achieve this, a simulation of the aircraft flying over an entire typical mission has to be conducted so as to determine the weight fraction W_f/W_i for each flight phase, with W_f and W_i respectively the aircraft weight at the end and at the beginning of the flight phase. Once W_{TO} is obtained, it is possible to determine S and T_{SL} thanks to the two ratios previously chosen.

Now that T_{SL} as well as the assumed behaviour of thrust and specific fuel consumption with altitude and Mach number are known the idea is to translate these performances parameters in terms of design limitations (such as maximum allowable turbine temperature and attainable component efficiencies), flight conditions (ambient pressure, temperature and Mach number) and design choices (such as fan pressure ratio, compressor pressure ratio, bypass ratio, etc.). This phase corresponds to the parametric cycle analysis. It makes it possible to examine trends in engine performances with changes in design variables and to begin narrow the desirable range for each design parameter for a particular application.

Once the design choices have been made, it is time to conduct the performance analysis in order to assess how the selected engine performs at all possible operating conditions within its flight envelope. The variable parameters that are used at this stage are the flight conditions, the throttle settings and the nozzle settings. The performance of several different promising engines can be compared at that stage and makes it possible to ultimately find the engine design point (where it will spend the most time) that has the best balanced performance over the whole mission spectrum. Key parameters that define the overall engine performance have been identified in [2]; among which one finds:

- Net thrust: almost always the fundamental goal for the engine design. It is evaluated from the overall cycle calculation.
- Exhaust gas power: output power that would be produced by a power turbine of 100
- Exhaust temperature: a high value of this parameter is vital in maximising overall efficiency. However, there exists a higher limit due to mechanical integrity considerations.
- Exhaust mass flow: indicates the overall thermal efficiency.
- Specific power or specific thrust: amount of output power or thrust per unit mass flow entering the engine. This parameter allows to approximate effectively the engine weight, frontal area and volume.
- Specific fuel consumption: mass of fuel burnt per unit time per unit of output power or thrust. Minimising SFC is of paramount importance when the weight or costs of the fuel are significant.
- Thermal efficiency: rate of addition of kinetic energy to the air divided by the rate of fuel energy supplied. It generally increases as pressure ratio and turbine stator outlet temperature increase together as this results in a higher jet velocity for a given energy input.
- Propulsive efficiency: corresponds to the useful propulsive power produced by the engine divided by the rate of kinetic energy addition to the air. In order to obtain a high value for this parameter, a high engine mass flow must be coupled with low jet velocities.

Note that many other parameters of interest are looked upon at that stage concerning the engine, such as its noise, emissions, costs, deterioration. The idea is to extract the thermodynamic cycle that offers the best performance compromise possible.

The next step in the design process is to size the engine. Pay attention to the fact that mounting the engine(s) on the airframe inevitably induces forces on the external surfaces that increase the total drag, and that this phenomenon has not been considered up to this point. Indeed, the presence of the engine and its inlet, nozzle and exhaust stream actually influence the flow and pressure distribution over the entire aircraft. As a consequence, the engine designer should be in measure to influence the external surfaces that directly interact with the engine; this is especially true when dealing with turbofan engines and their associated nacelle.

Once the engine has been sized, many teams of experts are in charge of designing the engine's components such as the fan, the low and high-pressure compressors, the burner, the high and low-pressure turbines, as well as the engine's subsystems that include the nacelle, the fuel delivery system, the shafts and bearings, the accessory gearbox, the lubrication and cooling systems, etc.

2.2 Service integration in the company

Due to the considerable number of engineers working at Snecma Villaroche, the company had to organize its activities around several levels. The order starting from the most general level and progressing to the finest one is as follow: directions, divisions, departments, sections, and teams. My placement was performed in the Technical Direction, Integration of Propulsive System Division, Methods and Tools for Integration Department, Mechanical Section, Preliminary Design Team.

Within the divisions, there exists the Modules Division which is responsible for the development of all the modules of the engine (such as the compressors, the turbines, the fan, etc.) and the Integration division which deals with the engine as a whole. The latter is especially responsible for the preliminary design investigations, the overall dynamic and aero-thermal studies as well as the ingestion risks considerations. Dimensioning the system to attach the engine to the aircraft is also one of its key missions. As for the Modules Division, it conducts the detailed design of each component.

The purpose of the Methods and Tools for Integration Department is to support the activities of the Integration Division. More precisely its principal missions are to develop and maintain entirely new tools or new functionalities on existing tools, and new conception processes that will be used by the Preliminary Design sections of the Products Innovation Department. Theses tools' main objective is to benefit the conception work in terms of time and performances.

Indeed, time is a precious aspect in the development of a new aircraft engine, particularly in the preliminary design phase when the engine manufacturer wants to position itself on the race to be chosen from the aircraft manufacturer to carry out the project. Thus, Snecma designers must have from the very first stage of development, rapid and powerful tools at their disposal so as to set the major technological choices for the engine and determine its first rough geometry. Note that this work is performed under two different levels of details:

- **Level 1:** Rough investigation performed in "0D" (mainly calculations based on charts from experiment), chiefly used in answer to RFI emitted by aircraft manufacturers. No engine cross section is drawn at that stage.
- **Level 2:** More advanced studies involving 2D and 3D drawings and answering to RFP from aircraft manufacturers.

2.3 The preliminary design platform of first level - OAP1

2.3.1 Context and scope

As it has already been mentioned, the aerospace industry is highly competitive, which means that engine manufacturers must react very quickly and precisely to aircraft manufacturers' RFI if they want to get a chance to win the engine development project. In that sense, the preliminary design phase is of paramount importance. Moreover, it sets the major technological choices for the engine and gives the frame for the conception phase that follows if the engine manufacturer is chosen to carry out the project.

In order to reduce the time needed to perform the costly preliminary design operations and to improve the performances achieved, Snecma wishes to develop tools for dimensioning the engine and also for assessing the mechanical feasibility of the project as well as costs (production cost, maintenance cost, etc.).

From this perspective, in the beginning of the 2000's, the preliminary design office of Snecma came up with the idea of implementing the OAP1 platform ("Outil Avant-Projets de niveau 1") to operate in the very first level of a new engine development. This IT platform is intended to be multidisciplinary, integrating multiple modules that allow the calculation of the most important aspects related to the development of a new engine, such as its performances, mass, nacelle, Fuel Burn (FB), emissions, noise, cost of production, maintenance cost, Direct Operating Cost (DOC), as well as its feasibility and a lot more. The purpose is clearly to converge faster on an optimised engine's architecture that not only matches the aircraft manufacturer's specifications in terms of specific fuel consumption or maximum thrust for instance, but also that is competitive considering all the previously mentioned criteria simultaneously. The way in which this optimisation is conducted is based on the analysis of the Pareto front. As such, the stakes of this platform are considerable for the company.

An important consideration that needs to be kept in mind is that the thermodynamic cycle that optimizes the engine efficiency is not necessarily the one that optimizes costs, mass or other parameters. It can also lead to a solution which is not mechanically feasible. As a consequence, the interest of the platform lies in its capacity to extract the best engine configuration when taking into account all the important parameters characterizing the engine as well the feasibility of the project. Thus, the objective was to replace the previous one-vision investigations by a fully Multidisciplinary Design Optimization (MDO) study. MDO allows designers to incorporate all relevant disciplines simultaneously in a single investigation, and as a result its use increases significantly in a large number of industries such as aerospace or automobile. More information about MDO can be found in [3].

2.3.2 Objectives and gains

The main objectives of the OAP1 platform are the following:

- Increase the reactivity in proposing thermodynamic cycles and optimized engines architectures in response to RFI.
- Assemble multi-competences (about 10 disciplines) without having to perform inappropriate complex modelling since the very beginning of the development of a new jet engine.
- Approach the optimal design since the early stages of the project for a better positioning related to customers' needs and be sure that this solution is viable.
- Perform sensitivity studies. For instance what will be the impact on the mass of the engine if a FB reduction of $X\%$ is desired?

Resulting gains from the use of the OAP1 platform are expected to be obtained in:

- Delivery time in response to RFI
- Work load
- Consistency of the results
- Quality

2.3.3 Structure of the platform

The OAP1 platform is developed under Optimus, a Process Integration and Design Optimization software which bundles a collection of design exploration and numerical optimization methods. It offers a complete visualisation of the process, including all relevant data, connectivity of the process, simulation programs involved, as well as all input and output parameters. Results can easily be looked at thanks to a wide range of visualisation tools. An example of workflow is given in Appendix A. Note that this example is absolutely not taken from the OAP1 platform but is only here in order to give the reader an idea of how objects are connected to each other on Optimus. More information about the content of each object will be presented in Chapter 5.

Before going any further, it is important to mention that Snecma makes use of powerful codes that allow the calculation of the thermodynamic cycle of an engine and its associated geometry given some parameters such as pressure ratios, the maximum thrust, etc. This basically corresponds to the process that has been developed in section 2.1.2. Part of such a thermodynamic cycle can be seen in Appendix B. Unfortunately, data had to be removed for confidential reasons but it is interesting to notice that a considerable number of parameters (pressures, flow rates, rotational speeds, etc.) are calculated for several design points such as cruise, take-off, top of climb, etc.

Given a thermodynamic cycle, interesting engine characteristics can be calculated through the different modules of the OAP1 platform. The overall idea is to perform a considerable number of iterations which requires that calculation times must be short. These modules usually run calculations through Excel files or other executables and use meta-models based on experience. The noise emitted by a civil aircraft with a twin turboprop at take-off can for example be assessed depending on its gross take-off weight as suggested in [4] based on the analysis of the Effective Perceived Noise Level (EPNL) at take-off recorded in a database of turbo-propelled aircraft. In the same way, the mass of a turbofan engine can be assessed from its fan diameter.

The outputs obtained from each module can be used as inputs in other modules. For example, from the thermodynamic cycle it is possible to determine the flow paths in the engine, from which one can extract the characteristics of the nacelle. The drag associated to the combination engine plus nacelle can then be calculated, allowing in turn the determination of the fuel burn considering the aircraft characteristics. By combining the FB with the maintenance costs (calculated from the production costs), one can extract the DOC which corresponds to the cost per flying hour for the airline.

Thus, preliminary design investigations of first level are always performed around a thermodynamic cycle. Given a reference thermodynamic cycle previously determined and the SOA (that states the technical solutions that will be available in the future), the interest of the platform is to perform optimization by acting on several key design parameters of the engine such as the fan diameter for a turbofan engine for instance. Obviously, acting on these parameters has an influence on the thermodynamic cycle which has to be recalculated for each new design. In the end, the thermodynamic cycle that corresponds to the optimized situation among all the feasible solutions can be extracted and will be the new reference for the more advanced preliminary design investigations of level 2 that will follow.

Note that due to the interdependency between modules, several iterations must be performed before the results converge on their final values.

The overall principle of the OAP1 investigations is presented in Figure 2.3.

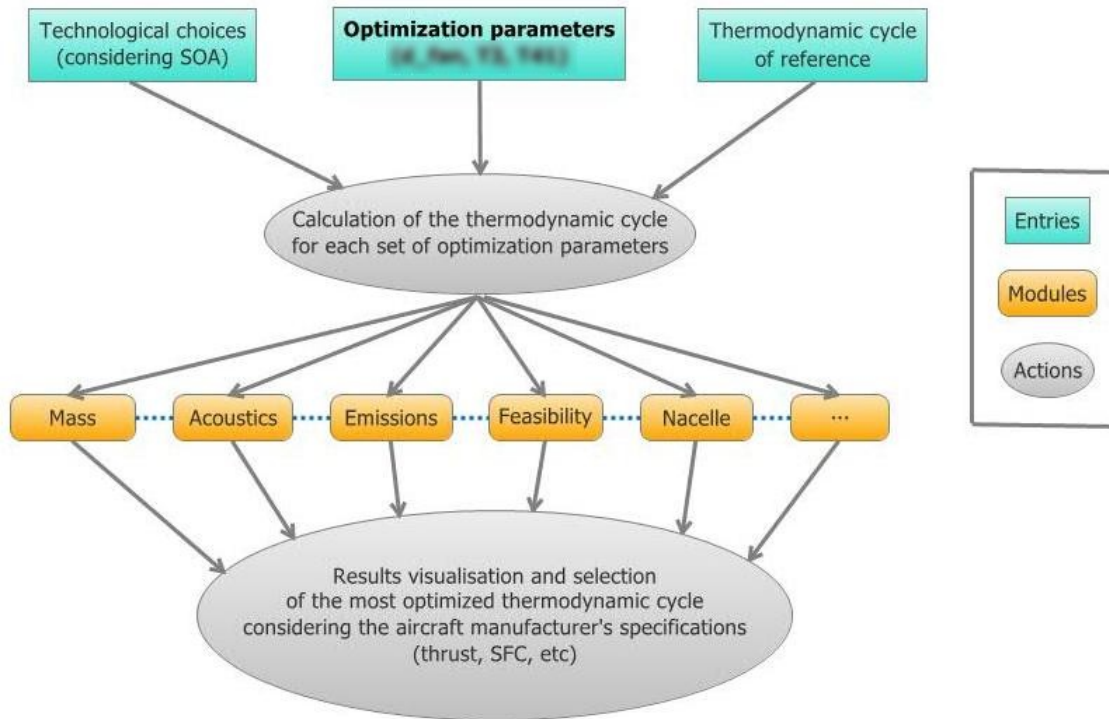


Figure 2.3: Principle of the OAP1 investigations.

2.3.4 Today's way of performing OAP1 investigations

At the time being, the preliminary design investigations of first level are chiefly centred around the Performances Section of the Products Innovation Department in relation with specialists whose mission can be seen as delivering modules for the OAP1 platform. The management of all the created modules' versions is however a point to be improved. Indeed, many modules' versions have been developed by different specialists during the past few years but due to a lack of documentation it has become hard sometimes to know whether they can still be used or not and for which application. Moreover, once more advanced studies have been performed, it happens to notice that the modules did not deliver trends accurately. As a result, among the existing modules, few have been ruled out of studies. Thus, the sphere of operation of the preliminary design investigations of first level is today not as extended as Snecma wishes it to be.

Furthermore, for each new investigation of first level, the specialists of the modules still in use are contacted by the engineers of the Performances Section and are asked to adapt their modules according to the study on course. As the validation of the modules is not always sufficient, it turns out that problems may show up during the optimisation phase, which imposes that several iterations are performed between the specialists and the performances engineers. This is only one example of the concerns and troubles that affect the process for preliminary design investigations today.

From this short description it becomes clear that actions need to be undertaken so as to improve the way in which preliminary design investigations of first level are performed.

Chapter 3

Mission and Objectives

3.1 Evolution of the OAP1 platform

The overall idea is to rethink entirely the way in which the preliminary design investigations of first level are performed. More actors should be involved in the process, and a great care must be attached to this involvement. The main purpose for the coming development of the platform is to increase significantly its flexibility, its ease of use and the confidence users can have on the results obtained. It should be in measure to gather all the interesting aspects of a new engine development and at the same time it should allow each specialist to perform post-treatments on its own domain of competences only. Thus, the idea is to build a user-friendly platform with a high degree of modularity that will allow engineers to answer aircraft manufacturers's RFI in a very short time.

The main operational requirements for the new platform are the following:

- Be functional for the various engines architectures (classical turbofans, geared turbofans, regional turbofan, open-rotors, turboprops, military engines, mixed flow engines).
- Include a large number of modules dealing for example with the calculation of mass, feasibility, nacelle, acoustics, emissions, fuel burn, costs, etc. A particular care must be attached to the associated configuration management.

3.2 Tool's general development process

Every single project consisting in developing a new tool at the Methods & Tools for Integration Department must follow strictly the process described in Figure 3.1 below.

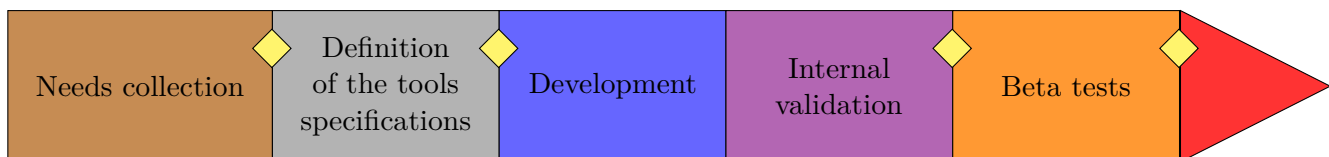


Figure 3.1: General process to develop a new tool in the Methods and Tools for Integration Department.

Before passing from one phase to the following, the tasks performed must be validated by a design review called a RIM (Revue Interne Métier). Each RIM is symbolized by a yellow diamond in Figure 3.1. The objectives of each step and the associated RIM are the following:

- **Needs Collection:** Understand the needs, iterate with the customer division to come up with a finalised expression of needs, and estimate the project's gains. This phase ends with a RIM of specifications.
- **Definition of the Tools Specifications:** Translate the needs into tools specifications, investigate different development solutions, identify the risks, generate a development schedule, write a validation

plan and choose test cases. Prototyping is the essential activity that drives this phase which ends with a RIM of definition and validation plan.

- **Development:** Realise the tool in compliance with the development choices exposed at the RIM of definition, and write a user and programmer documentations. Note that there is no particular RIM at the end of this step.
- **Internal Validation:** Follow the validation plan on the test cases, write a validation report. This phase finishes with a RIM deciding of the entrance of the platform into simulation.
- **Beta Tests:** Follow the beta tests with the customer division on the test cases previously defined. The cycle is ended with a RIM of commissioning.

As one can notice, the project does not only focus on the development phase but many other essential activities are implied, either upstream or downstream to it.

3.3 Description of my mission

As the project of rebuilding the OAP1 platform is considerable and is just starting, there was unfortunately absolutely no chance that I managed it entirely. As a result, the mission that has been conferred upon me during my 5-month master thesis was to conduct the first phase of the project, that is to collect the needs for the future platform. This task usually does not require that much time, but this project is a bit different from others in the sense that it does not consist in developing a "simple" tool, but the whole process of the preliminary design investigations has to be reviewed. As a consequence, the needs were far to be clearly defined yet as they originate from different actors: systems architects, performances engineers and several modules specialists.

As the main users of the OAP1 platform, the engineers of the Performances Section of the Product Innovation Department have been considered as the customers for the entire project, and thus I was often in relation with them. Nevertheless, my mission implied that I also be in contact with many other actors. Indeed, the general purpose and structure of the platform had to be discussed also with the systems architects (whom stand back and have the greatest expertise and overview on the entire jet engines developed at Snecma), and the features of the different modules to be integrated in the platform had to be reviewed with the dedicated specialists.

Concerning my mission, it consisted of the following main actions:

- Realising a status of the existing operational modules.
- Mapping the current process that guides preliminary design investigations of first level.
- Identifying all the concerns in the process.
- Proposing and collecting possible solutions to all the concerns previously identified.
- Clarifying each entity's sphere of operation and responsibilities.
- Thinking about the target process and proposing a partial solution.
- Developing a prototype aiming at investigating the feasibility of automating the creation of an Optimus workflow adapted to the study desired.

Chapter 4

Methodology

As this internship required considerable exchanges with various actors within the company, the actions described in this section had to be conducted in parallel, mainly according to the availability of each actor. Logically, the mission should have started with identifying the current process for OAP1 investigations (4.1) and drawing up a status of the existing modules (4.3) in order to orientate towards a target process (4.2) and to decide where to take action. Regrettably, proper interactions could not be made with the performances engineers who conduct preliminary design investigations of first level, until the middle of my internship which led me to work on a solution to an identified problem (4.4) even before the steps 4.1 and 4.2 were achieved.

4.1 Identifying the current process for OAP1 investigations

It was essential to get a good insight into how the preliminary design investigations of first level are performed at the present time. In order to meet this objective, I organised several meetings with the engineers working at the Performances Section. During these discussions, I chiefly focused on:

- Understanding the purpose of OAP1 investigations.
- Identifying the sequence of all the tasks to be done considering all the possible situations.
- Associating a mean duration to each task, or group of tasks.
- Listing all the concerns that show up in the process.
- Collecting suggestions on how to overcome the difficulties previously identified.

In parallel, I also met the specialists that develop modules for the OAP1 platform in order to know how they feel involved in the preliminary design investigations of first level, and to collect a list of concerns from their perspective.

It has been decided to map the current process for OAP1 investigations in the form of a flow chart presenting the connections between tasks and decisions, with the people in charge of it. This flow chart also displays the duration of each task or group of tasks, as well as a brief description of the difficulties associated to the tasks concerned. The details about each difficulty have been gathered in a summary table with their associated consequences. These concerns have been classified following the process logical progress.

4.2 Orientating towards a target process for OAP1 investigations

By analysing the tasks that present difficulties and their consequences on the duration of the process, it made it possible to decide where to take action. Moreover, at that stage it became necessary to interact with systems architects who are especially in charge of analysing demands from aircraft manufacturer, determining the outline design solutions and commanding detailed design solutions to the appropriate services. In the end, they are the ones who validate all the solutions chosen. Because of these interesting responsibilities, they will be the future people at the head of the whole OAP1 process.

The purpose was to define part of the whole new process for the future preliminary design investigations of first level. This implied that several decisions be made concerning solutions to the previously identified concerns in the current process.

In the end, there should not remain any concern in the process and tasks should be performed one after the other without the appearance of any unforeseen events; the time needed to conduct the whole process should be decreased considerably. In addition, it should be simple to integrate new modules or new versions in the platform to deal with technology changes.

4.3 Drawing up a status of the existing modules

As mentioned earlier in this report, various modules have already been developed by specialists in the past few years. However, due to a lack of documentation, it has become hard sometimes to know whether a version of a module can still be used or not and for which application (engines architectures, validity range for each variable, etc.). As a consequence, some modules were put aside and are not used any longer by the performances engineers although they could be used.

As a result, a large investigation had to be carried out in order to draw up a status of the existing modules that could be used today. This was achieved by contacting all the specialists in charge of the development of these modules. The purpose was to get for each module information about:

- The engines architectures that it can deal with.
- The input variables and their validity ranges.
- The output variables.
- The tools used.
- The calculation time.
- The degree of uncertainty that comes with the results.
- A description of how the module works.
- The users.
- The development prospects.

From these interviews, it was possible to create most notably a table that shows which modules are available today for each engine architecture.

4.4 Developing a prototype that generates an Optimus workflow

4.4.1 Presentation of the whole prototype

One of the difficulty that was put forward even before the mapping of the current process for OAP1 investigations was achieved, is the fact that a new Optimus workflow has to be generated for each new study. In order to adapt simulations to new engines, users have to generate the corresponding Optimus workflow by modifying manually one of the existing workflow developed in the past for an other study. This is long (almost one day), tedious, and represents also a considerable source of errors due to the considerable number of variables involved.

A solution to this problem would be to automatically generate the Optimus workflow corresponding to the study the user wants to perform. In order to achieve this, a prototype has been developed in SDK Python; a library that allows to interface the widely used general-purpose, high-level programming language Python to Optimus. Considerable help for programming in Python has been found in [5] while [6] has been used extensively for the interfacing between Python and Optimus.

It has been decided to first generate a Graphical User Interface (GUI) from which the user can select his choices of study. It gathers the choice of engine architecture, the choice of investigation to perform depending on the modules available for the architecture previously chosen (for example mass, emissions, fuel burn, etc.), and the choice of the program to use for the calculation of the thermodynamic cycle among the three available, with the associated choices of model and initial set of parameters.

The graphical features of this interface has been generated using QtDesigner; a WYSIWYG (What You See Is What You Get) Qt's tool for designing and building graphical user interfaces. The complete interface and the actions hidden behind choices have been created in SDK python thanks to the Pyside's modules QtCore and QtGui. Figure 4.1 presents the interface that appears when the program I developed is run.

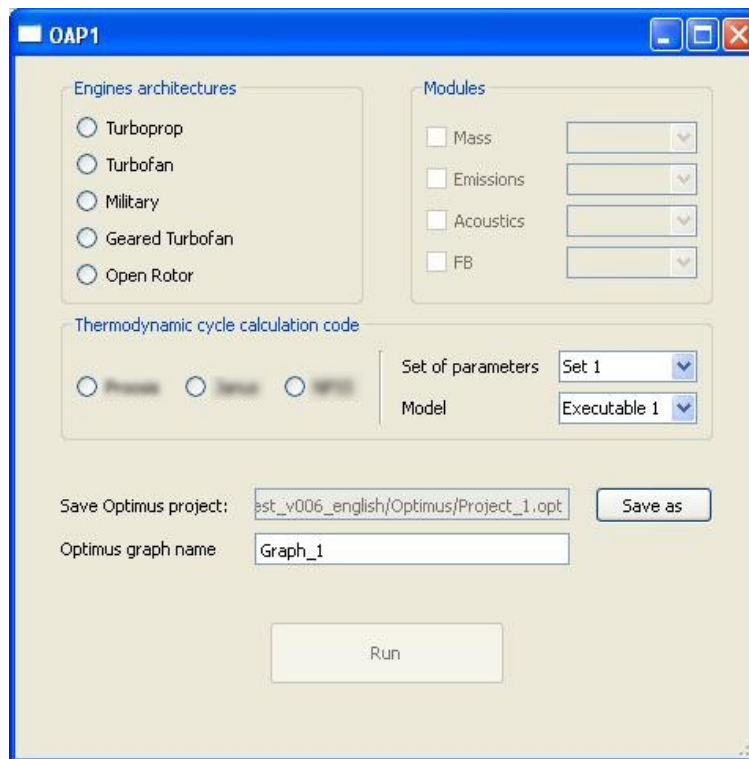


Figure 4.1: GUI to choose the OAP1 study to perform.

The interface is itself generated from an xml file that contains for every module, the different versions available, and for each version it states the engine architectures that it can deal with. The xml file that I created for a demonstration purpose is displayed in Appendix C.

The principal advantages of using this xml file are the following:

- For each engine architecture, only the available modules can be selected, as illustrated in Figure 4.2. This prevents users from running not appropriate studies.
- The xml file can easily be modified and the GUI will be automatically updated in consequence. This allows for example to regularly take into account the creation/suppression of a module's version.

Moreover, note that this xml file could also be used in order to store more information concerning the different modules' versions, such as their validity domains, an estimation of their uncertainties, etc. However, these points were beyond the scope of the prototype.

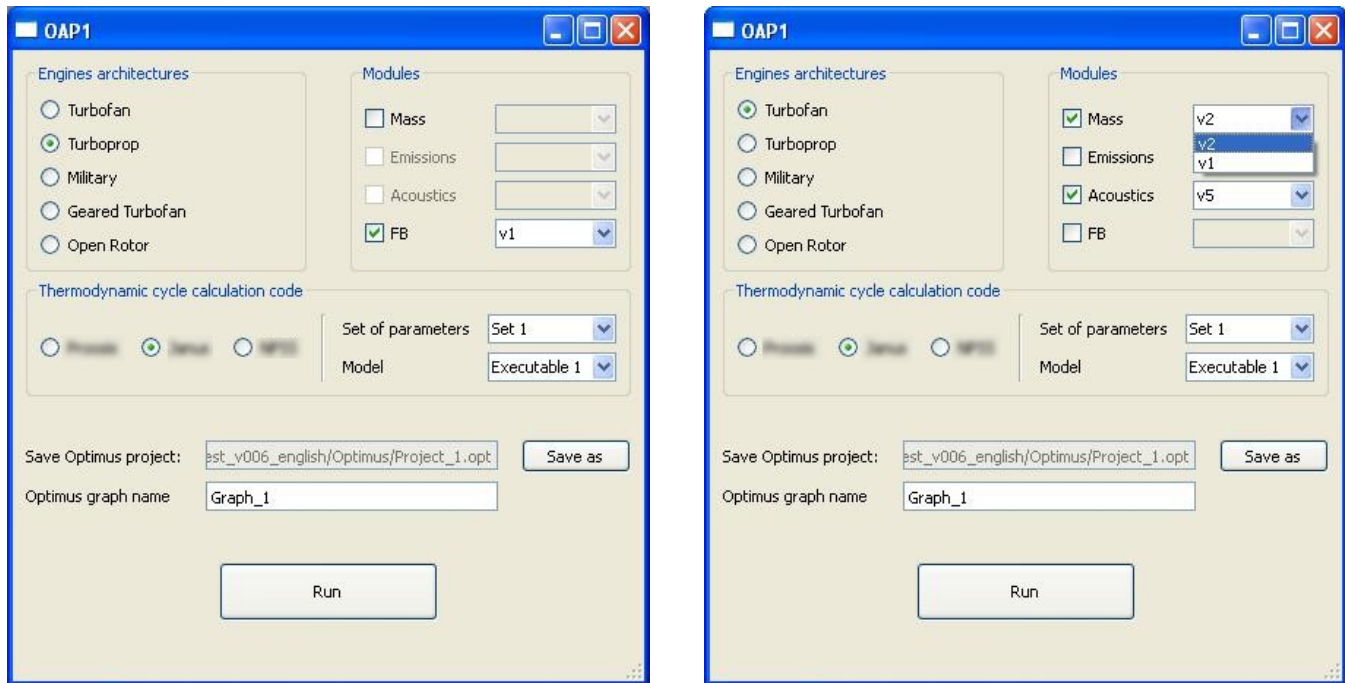


Figure 4.2: Demonstration of the xml file's interest when selecting the study to perform on the GUI.

Once the user has selected his choices of study on the GUI, the corresponding Optimus workflow is automatically generated by simply clicking on the push button "Run" at the bottom of the GUI and the project is saved on the location the user specified on the interface. All this work has been made possible thanks to the development of numerous functions in SDK python.

4.4.2 Files required for the workflow creation

In order to get a better understanding of this section that focuses on the prototype I developed, the reader is advised to first go through Chapter 5 which gives a brief introduction to the Optimus software.

A certain number of files are needed in order to run the prototype; some are used for the whole project, while others must be created for each modules' version. Note that the prototype has been developed only for actions that call Excel files to run calculations as it is the most common in the OAP1 platform today. Other executables could have also been called in the action files with some adaptations in the SDK program but it was not the point of the demonstrator. In the same way, the modules for the calculation of the thermodynamic cycle have been considered exactly as the other modules although this is not exactly the case. Indeed, they don't call Excel files but other executables with different arguments possible that correspond to the combo boxes "model" and "set parameters" that one can see on the interface in Figure 4.1. These considerations have not been taken into account in the prototype I developed as the principle of the automatic generation of the workflow remains unchanged.

In addition to the python files created for building the prototype, the files that are used for the whole project are the following:

- An initialization file (.ini) specifying the path to the directory containing the resources and the path to the Optimus software.
- An xml file to generate the GUI.
- A text file containing a list of variables that need variables from different modules to be calculated. The corresponding formulas are also given in this file. It will be seen later that these variables are added to the Optimus workflow when possible.

As for the files needed for each modules' version, here is the list:

- A text file containing all the inputs of the module (names only).
- A text file containing all the outputs of the module (names only).
- A file "input.tpl" to fill the input file in Optimus.
- A file "output.tpl" to fill the output file in Optimus.
- An Excel file with two sheets: one gathering the inputs (names and values) and the other one gathering the outputs (names and values).

As a reminder, only actions that call Excel files are treated in the prototype, which means that minor adjustments should be made in the files structure to account for other executables.

With all these files, and the extensive use of dictionaries in the SDK Python functions that I created, it becomes possible to generate automatically a workflow with the right connections between objects and with objects properly filled. Nevertheless, a great care has to be taken so as to avoid that variables be duplicated in the workflow; this will be discussed in the next section.

4.4.3 Management of different scenarios

In order to avoid that variables be duplicated in the workflow, the following scenarios and the associated solutions have been considered:

- **Input proper to a module:** if an input is used as entrance parameter by only one module, and that it does not correspond to the output of another module nor to an output variable calculated from the combination of several objects, then it is added to the input variable array dedicated to the module. Note that if a module has no proper input, then no proper input variable array is created for this module in the workflow.
- **Input common to several modules:** if an input is used as entrance parameter by several modules and that it does not correspond to the output of another module nor to an output variable calculated from the combination of several objects, then it is added to a common input variable array.
- **Output used as input in one or several other module(s):** in this case, the variable is not created as a new input but a connection is generated between the output variable array in which it is contained and the input file(s) of the module(s) that use(s) it.
- **Output calculated from the combination of variables from several objects:** the output is created in the workflow with the associated connections only if the other variables it needs to be calculated are available in the workflow. For instance, a variable that needs an output from the mass module in order to be calculated, won't be created in the workflow if the mass module is not considered in the study.

4.4.4 Test case

In order to demonstrate that the automatic generation of the workflow in Optimus was feasible, it has been decided to try on a test case. It consisted of defining randomly for each module a list of inputs and a list of outputs. The first objective was to prove that connections between objects were created correctly and that no variable was duplicated. The second objective was to prove that calculations could be performed without any problem, thus revealing in particular that input files and output files were filled properly.

The test case is presented in Figure 4.3 and has been built so as to test all the different scenarios mentioned in the previous paragraph. Note that the lists of inputs and outputs for each module have been chosen randomly which means that the connections that exist between objects on the test case represent on no account the reality. Moreover, the connections between modules have been realised manually in this figure with the aim of facilitating the comparison with the workflow generated automatically in Optimus with the prototype.

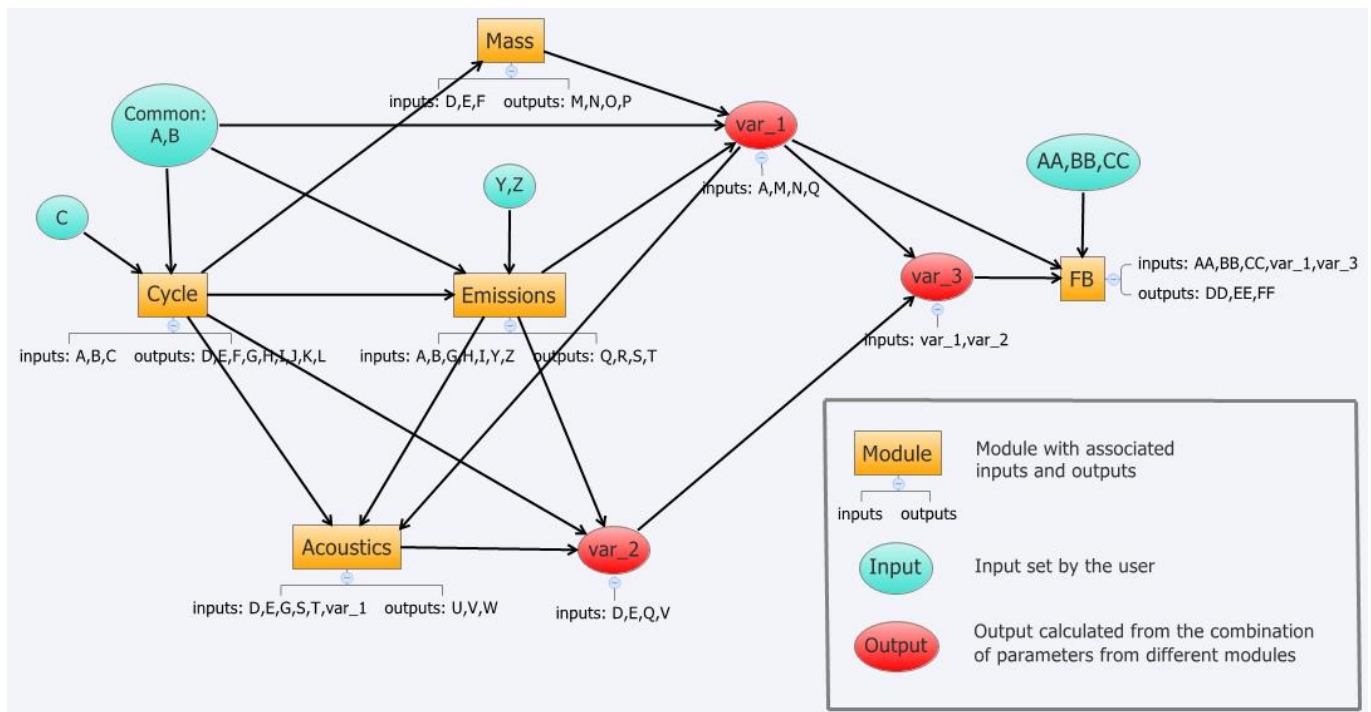


Figure 4.3: Test case build in order to prove the feasibility of the automatic workflow creation.

Before being able to run the model on the prototype, it was necessary to create all the files mentioned in section 4.4.2 for each version of all the modules. As this is only a prototype, the files used in all the versions of a module were exactly the same as it would not have brought anything interesting for the project to make distinctions between them.

Chapter 5

Introduction to the Optimus software

5.1 General content of an Optimus workflow

In this section, a basic Optimus linear workflow is presented in order to give the reader brief explanations about how the software works.

First of all, the meaning of each object is given in the example workflow displayed in Figure 5.1. One can see how objects are connected between each other.

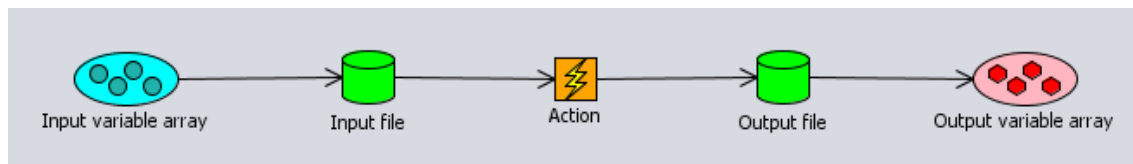


Figure 5.1: Example of a simple linear Optimus workflow.

By double clicking on each object, one can access to its content. All of them are going to be presented quickly in the next pages.

5.2 Input variable array and output variable array

The input variable array and the output variable array simply list the inputs and outputs respectively. The windows that appear when the user double click on them are shown in Figure 5.2 and Figure 5.3 respectively. Different features can be selected but this is beyond the scope of this brief presentation.

Name	Comment	Type	Range	Relaxed	Nominal	Low	High	Step	List
1 Input_1		Real	Low/High	<input type="checkbox"/>	0.0	-1	1	1.0	
2 Input_2		Real	Low/High	<input type="checkbox"/>	0.0	-1	1	1.0	
3 Input_3		Real	Low/High	<input type="checkbox"/>	0.0	-1	1	1.0	

Figure 5.2: Design input array properties window.

Name	Comment	Value	Temp	Default value	Treat as failed	Low	High	Target	Weight	Scale
1 Output_1		999	<input type="checkbox"/>	1.0	<input checked="" type="checkbox"/>	0	0	0	1	AUTO = 1,0E-6
2 Output_2		999	<input type="checkbox"/>	1.0	<input checked="" type="checkbox"/>	0	0	0	1	AUTO = 1,0E-6
3 Output_3		999	<input type="checkbox"/>	1.0	<input checked="" type="checkbox"/>	0	0	0	1	AUTO = 1,0E-6
4 Output_4		999	<input type="checkbox"/>	0	<input checked="" type="checkbox"/>	0	0	0	1	AUTO = 1,0E-6

Figure 5.3: Design output array properties window.

5.3 Action file

In the action file, the application to be run is specified and requires the input file name and the output file name as arguments. In the example chosen, the action calls Excel. This corresponds to the line "OptimusExcel.exe \$Input file\$ \$Output file\$" in the action window presented in Figure 5.4. What the other lines do will not be developed here.

The choice to call Excel in this example has been made because almost all the modules used in the OAP1 platform use Excel files to perform calculations. Note that other executables could have been called using the same syntax.

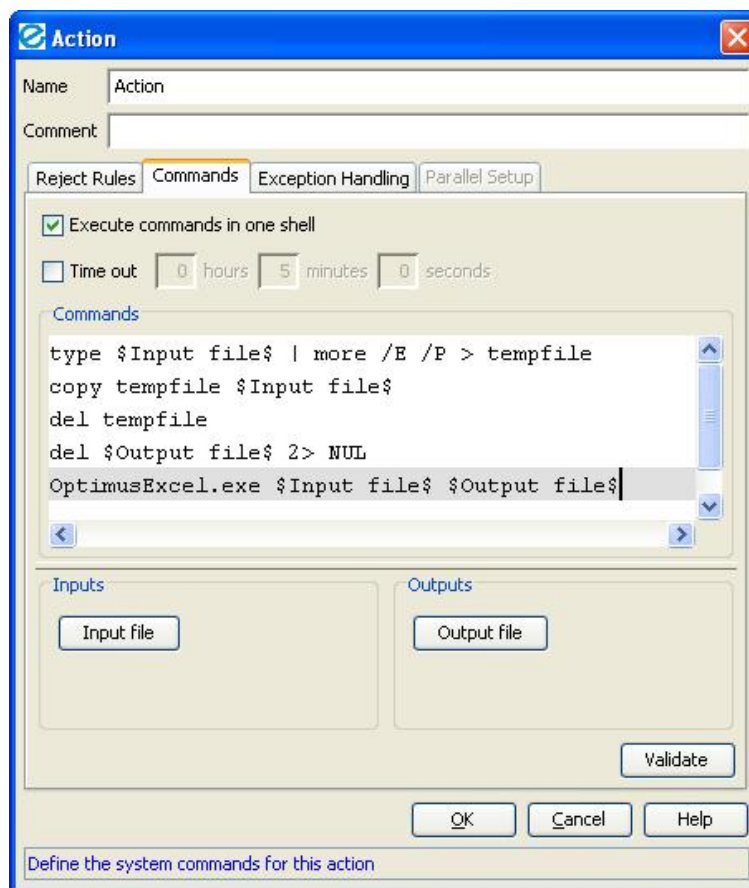


Figure 5.4: Action properties window.

5.4 Input file

All the actions to be performed in the Excel file are gathered in the input file. As a consequence, the input file has to be created in line with the Excel file called. One can notice on the template input file presented in Figure 5.5 the main actions available: opening an Excel workbook, activating a given sheet, putting values in defined cells, running a macro, reading values in particular cells, saving and closing a workbook.

The overall idea of this file is to put the input values, indicated directly by the user in Optimus when running an experiment, into a given Excel sheet and then to extract the corresponding output values after calculations or macros have been run in the Excel sheet.

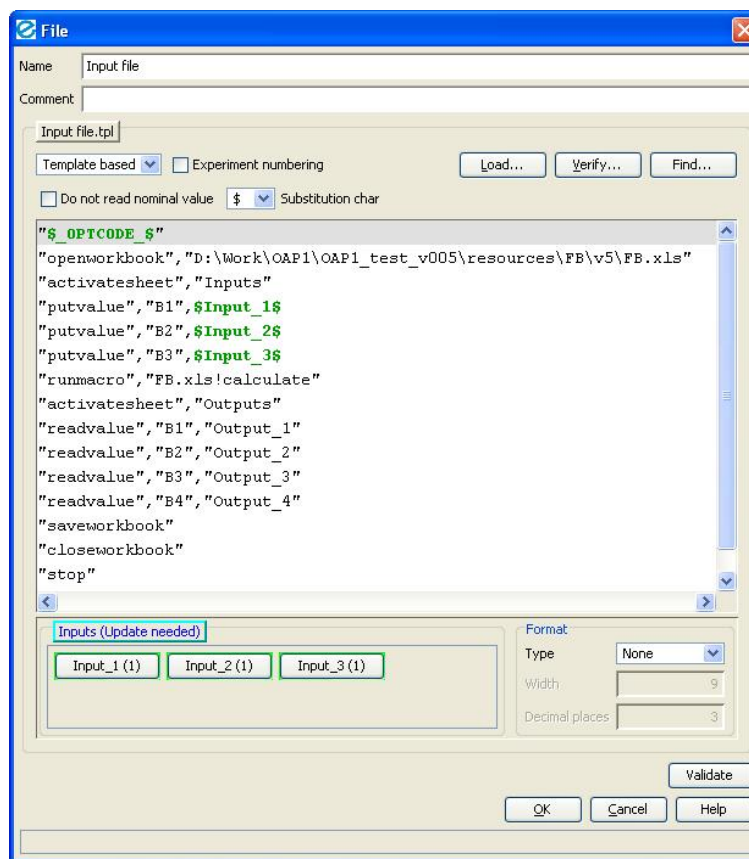


Figure 5.5: Input file template definition.

5.5 Output file

In the end, the output file is made to assign the extracted output values to the corresponding output variables in the Optimus workflow. These outputs can then be used by other objects in the workflow if needed. An output file template is displayed in Figure 5.6.

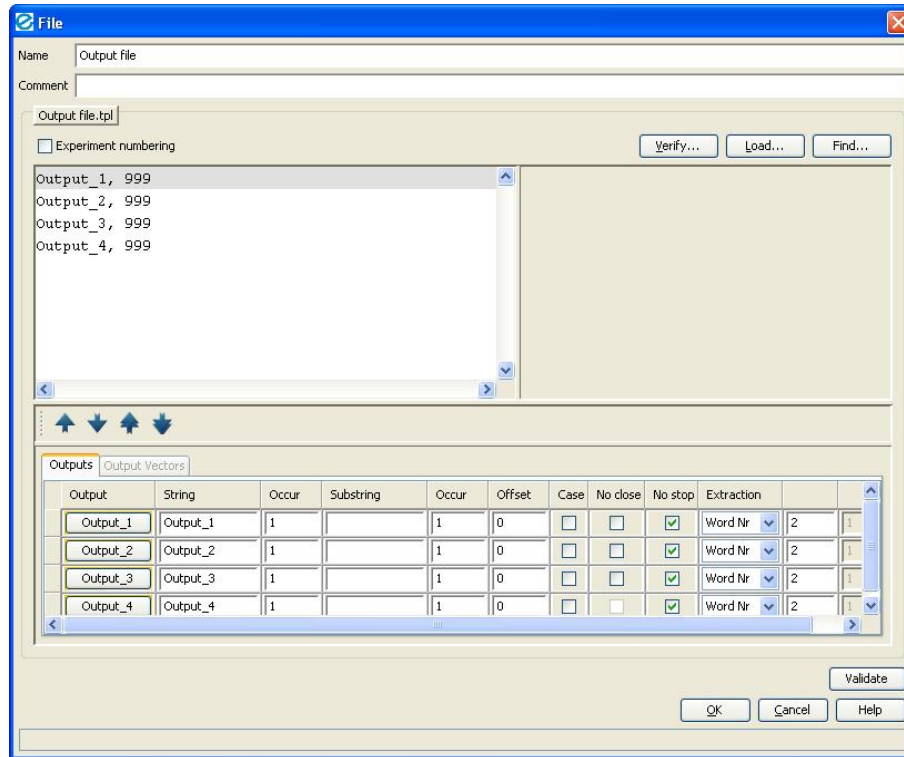


Figure 5.6: Output file template definition.

At this point the simple example workflow is completely defined. The purpose is then to run some design iterations and to visualise the results. Many possibilities exist at these stages, but it won't be developed here as it is beyond the scope of this report.

Please note once again that the case developed above was just a basic example of an Optimus linear workflow with the aim of giving explanations about how objects are connected between each other. The idea is then to couple several linear chains of this type in order to perform optimisation analyses.

Chapter 6

Results

6.1 Current process for OAP1 investigations

6.1.1 Mapping of the current process

The whole process of the current preliminary design investigations of first level has been entirely mapped with actions, decisions, durations and concerns. Regrettably, for confidential reasons it is not possible to display it in this report. Nevertheless, a flow chart example has been generated in order to present the logic and the formalism that have been used; it is presented in Figure 6.1.

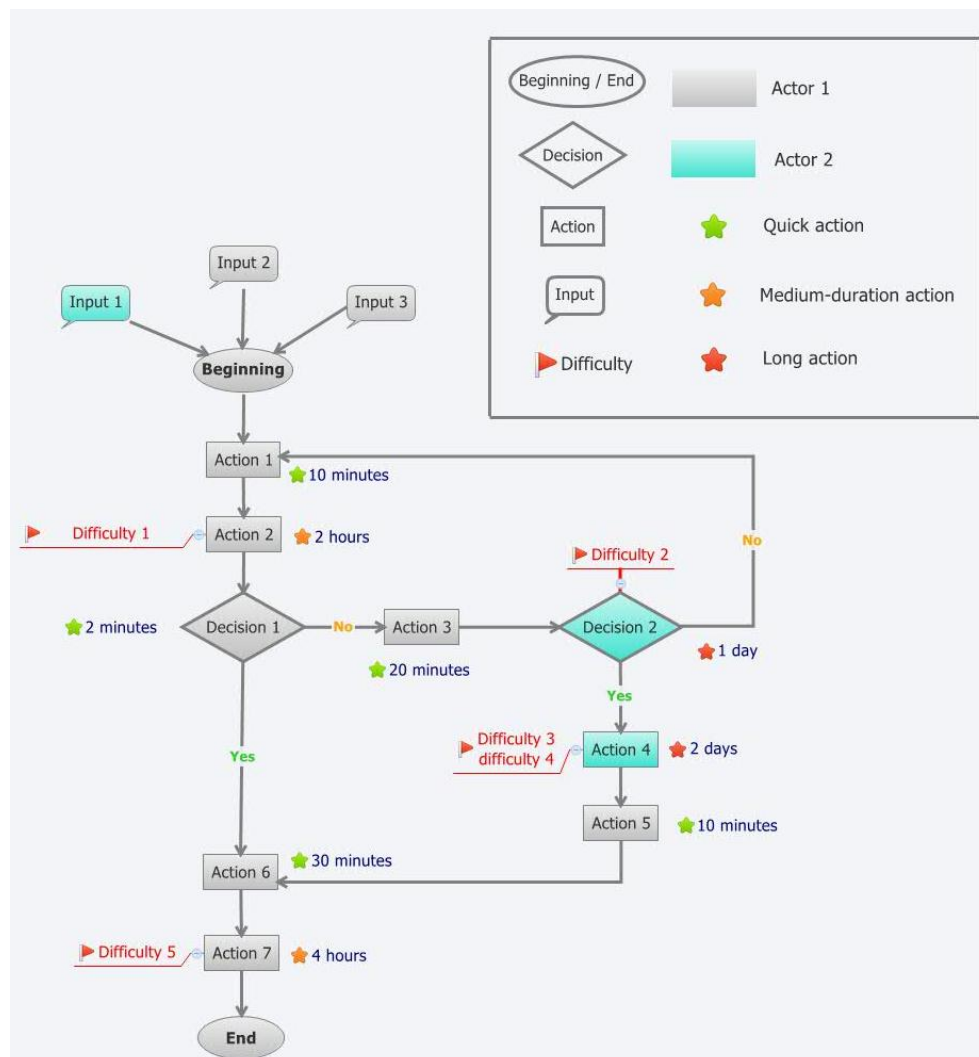


Figure 6.1: Flow chart model used to map the current OAP1 process.

From this model, one can see that actors of the different actions/decisions can be identified thanks to a color code, that the difficulties are symbolized with a red flag next to the related action/decision with a short description of the problems, and that the mean duration of each action/decision is given in association with a star which color depends on the duration.

6.1.2 Concerns and possible solutions

A table gathering all the concerns raised, in association with their main consequences, has been generated in complement to the flow chart mentioned in the previous paragraph. In total, a dozen of difficulties have been identified; few of them are presented in Table 6.1.

Irritants	Main consequences
<u>Lack of documentation about validity domains:</u> The domain of validity of a module's version is rarely specified, and the same applies to the uncertainty in the results obtained.	- It is sometimes difficult to know when a version of a module can be used and what are its limits.
<u>Lack of unity in the OAP1 modules:</u> There exists no standard tool for OAP1 modules (Excel, other executables written in various programming language), nor standard formalism among the same tools.	- It is difficult sometimes to find inputs, outputs, and to understand how they are related. - It makes the filling of the input files and output files long and complicated in Optimus, and represents at the same time a considerable source of errors.
<u>Optimus workflow generation:</u> The performances engineers must generate a new Optimus workflow for each new study. In order to so, they modify manually one of the existing workflow developed in the past for an other study. Basically it consists in modifying/adding/deleting objects, connections between objets, etc.)	- It leads to a loss of time. - It represents a considerable source of errors due to the large number of variables involved in the study.

Table 6.1: Part of the table of concerns and associated main consequences.

6.2 Target process for OAP1 investigations

Sad to say, no target process could be mapped during my placement period partly due to the considerable number of decisions to take. However, some directions for the future process to be developed have been given and will be discussed in the next chapter.

6.3 Status of the existing modules

Following the interviews I had with the various specialists, I was in measure to generate a table that sums up the modules that can be used today for each engine architecture in order to perform preliminary design investigations of first level. Unfortunately, for confidential reasons, this table cannot be displayed in this report. One thing that can be mentioned here, is the fact that some modules that were developed in the past are not used any longer by performances engineers as they have not been sustained properly. In addition, there also exists some modules that are not used by performances engineers even though they are considered functional by the specialists. This status was useful to visualise quickly the range of studies that can be performed today for OAP1 investigations. In any case, modules are almost exclusively used by performances engineers only, and not by the various teams of specialists.

Concerning the calculation times, it turns out to be almost instantaneous for all the modules, with the exception of one module for which calculations can take few minutes. This is in total compliance with the idea behind preliminary design investigations of first level, that is to perform optimisation based on a considerable number of iterations.

As for the tools used to develop modules, all of them are developed under Excel, except one which is a Fortran executable.

Output variables have been identified clearly for each module in contrast to the input variables which have been identified more vaguely. Indeed, specialists often content themselves with mentioning inputs from the thermodynamic cycle without specifying precisely each one of them. Concerning the validity range of inputs, nothing came up.

When discussing the degree of uncertainty of the results, it appeared that this was something really complicated to assess and only few specialists were in measure to give rough estimated values.

Finally, really interesting introductions have been made by all specialists in order to present their activities and how their modules work. The development prospects have also been raised.

6.4 Prototype to automatically generate an Optimus workflow

In this section, the workflows automatically generated with the prototype for two different investigations performed based on the test case introduced in section 4.4.4 will be presented.

The first investigation chosen regroups all the modules that appear on the test case. The GUI that permitted conducting this investigation is shown in Figure 6.2 and the corresponding Optimus workflow generated is presented in Figure 6.4.

The second investigation performed only contains two modules plus the thermodynamic cycle module. The GUI that permitted conducting this investigation is shown in Figure 6.3 while Figure 6.5 displays the corresponding Optimus workflow generated.

Note that the first Optimus workflow is a bit messy due to the large number of connections between objects. As crossings between connections can be avoided easily manually by clicking and dragging objects, or by using a library, no effort has been spent on this aspect. Pay attention to the fact that due to this modelling, some connection lines graphically intercept objects in between the two objects it connects but no connection exists with these intercepted objects.

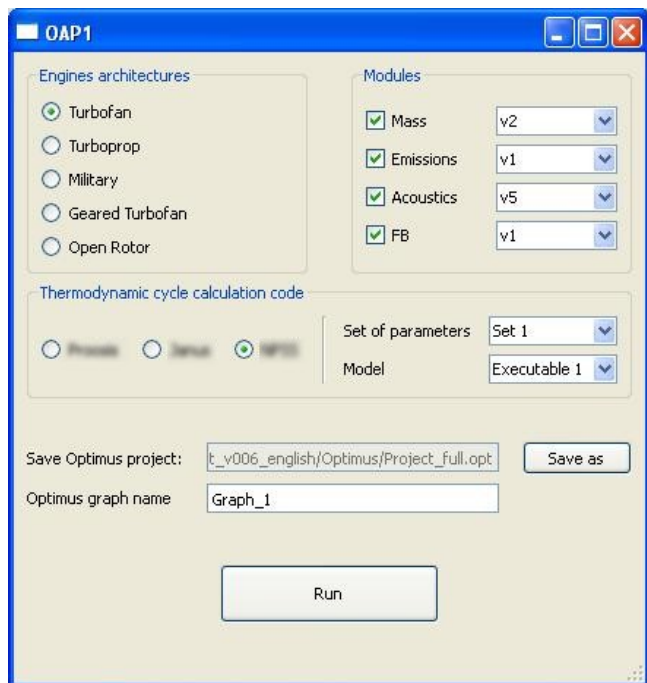


Figure 6.2: GUI displaying the choice of study for investigation number 1.

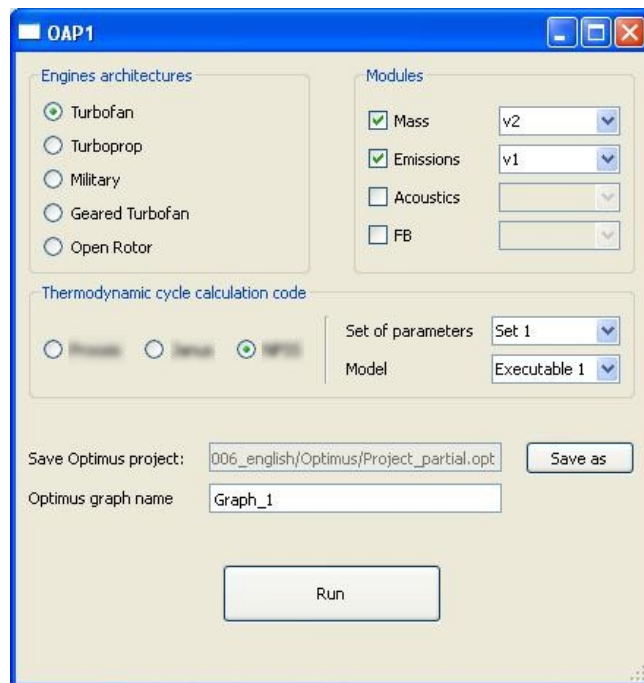


Figure 6.3: GUI displaying the choice of study for investigation number 2.

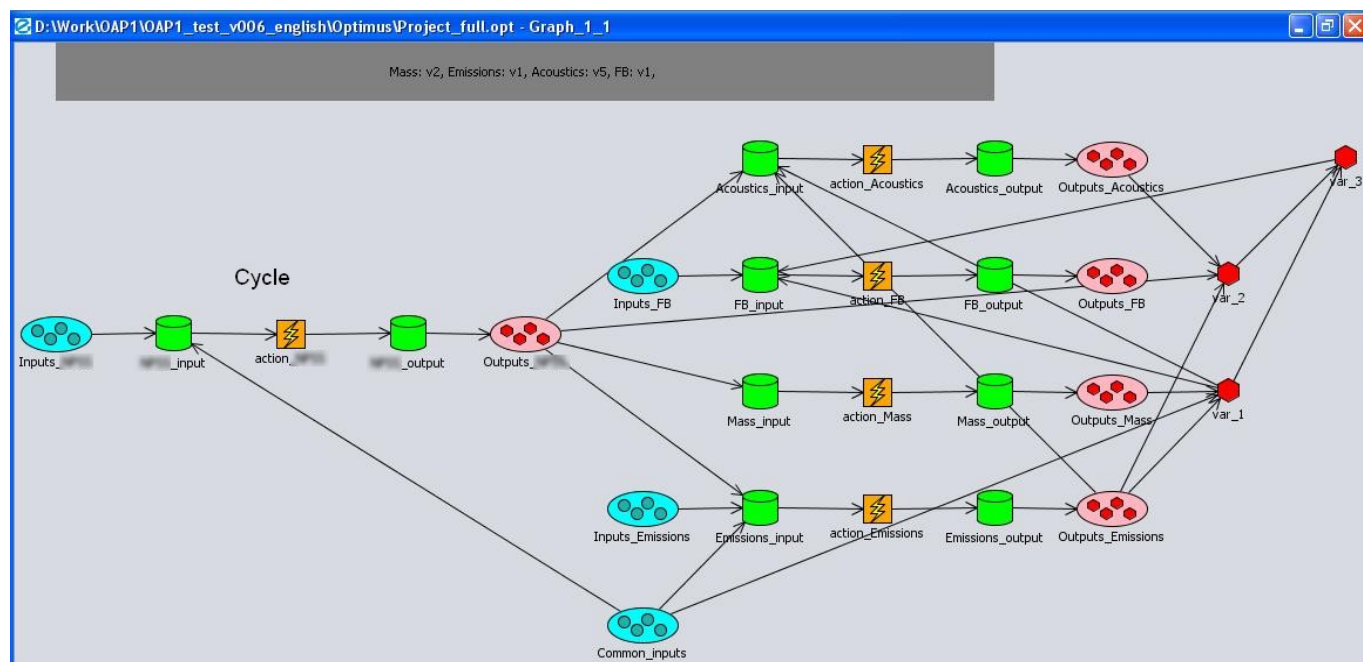


Figure 6.4: Optimus workflow generated for investigation number 1.

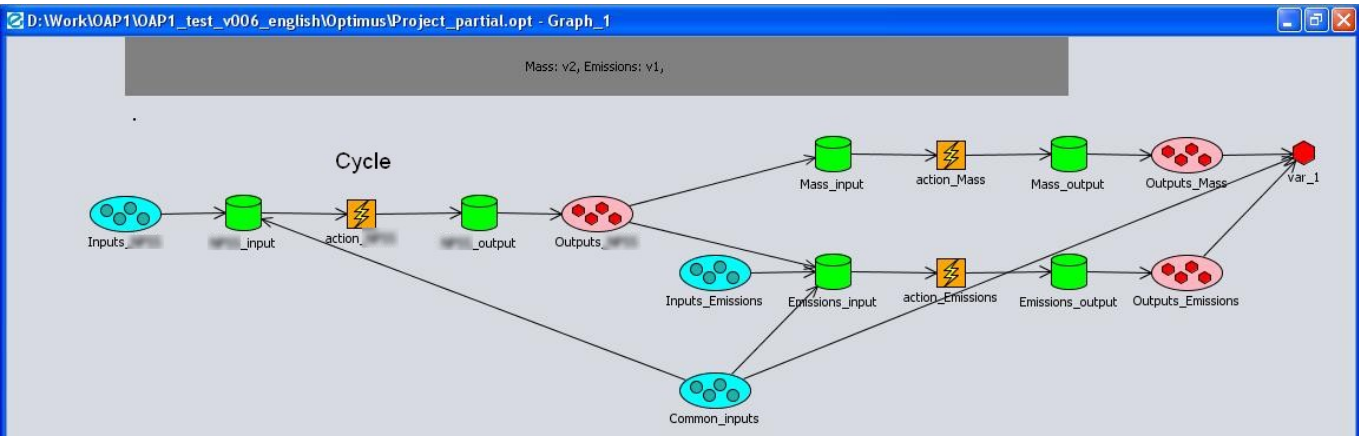


Figure 6.5: Optimus workflow generated for investigation number 2.

A study with several experiments has also been performed on the first investigation with random values assigned to inputs. The objective was to verify that all the objects of the workflow were filled properly and that it was possible to extract output values. Note that random formulas had previously been entered on each module’s Excel file in order to perform the calculation of the outputs. Part of the results are presented in Figure 6.6.

Exp. Num.	var_C	var_AA	var_BB	var_CC	var_Y	var_Z	var_B	var_A	var_D	var_E	var_F	var_G	var_H	var_I	var_J	var_K	var_L	var_U
1	8	7	6	5	4	2	2	1	11	16	10	6	3	2	25	6.25	21	10988
2	1	1	1	1	1	1	1	1	3	1	2	0	2	1	15	50	6	33
3	2	2	2	2	2	2	2	2	6	8	4	0	4	4	25	25	9	884
4	5	1	3	7	10	2	5	7	17	175	10	0	12	35	55	10	30	360122
5	4	4	2	2	3	1	7	2	13	56	11	-3	9	14	75	12.5	33	32420

Figure 6.6: Part of the results obtained with test case number 1.

Chapter 7

Analysis

7.1 Current process for OAP1 investigations

From the combination of the flow chart mapping current OAP1 investigations, the full table of concerns, and the status of the existing modules (which could unfortunately not be displayed in this report for confidential reasons), it was possible to identify the following main observations:

- The whole process is centred too much around the performances engineers; the various teams of specialists are not involved in a proper way on the OAP1 investigations.
- Not sufficient modules are functional so as to perform the advanced optimisation investigations Snecma wishes to conduct today.
- There is a lack of documentation, both from the performances engineers about their expectations and from the specialists about the modules they develop.
- The lack of uniformity between modules makes it complex to integrate all of them in the platform.
- The validation of the different modules' versions leaves something to be desired.

All these elements contribute to making the OAP1 process long, complicated, and incomplete compare to what Snecma would like to achieve. Troubles occur at the various stages of the process as revealed by the non-linear structure of the flow chart the reader does not have access to. Some of them imply that a considerable time be spent on rework, which is tragic. As a consequence, it takes almost 5 five times longer to perform investigations today than what it should if everything goes correctly. Thus, performances engineers spend a great part of their time doing tedious tasks rather than focusing on their core activity. This way of functioning is no longer satisfactory in order to meet the high standards the company established itself; actions need to be undertaken. In that sense, numerous discussions with the performances engineers and the modules specialists permitted to raise a list of possible solutions to each concern identified. Some of the solutions proposed to the difficulties presented in Table 6.1 are gathered in Table 7.1 next page.

Concerns	Proposed solutions
<p><u>Lack of documentation about validity domains:</u></p> <p>The domain of validity of a module's version is rarely specified, and the same applies to the uncertainty in the results obtained. As a consequence, it is difficult to know when a version can be used and what are its limits.</p>	<ul style="list-style-type: none"> - Impose specialists to write a complete documentation when creating a new version of a module, integrating its domain of validity associated to levels of confidence in the results. Several levels of confidence could be identified according to the parameters' range considered. - These information could be stored in an xml file in order to prevent the use of a module outside of its validity domain, and to get a good insight into the uncertainty in the results obtained.
<p><u>Lack of unity in the OAP1 modules:</u></p> <p>There exists no standard tool for OAP1 modules (Excel, other executables written in various programming language), nor standard formalism among the same tools (every specialist develops its on Excel file as he likes for instance, which makes it difficult sometimes to find inputs, outputs, and the relations between them). In addition to making the filling of the input files and output files complicated in Optimus, it also represents a considerable source of errors.</p>	<ul style="list-style-type: none"> - Impose one or several standard formalism(s) for all the modules developed. - Call the development of modules under Excel into question. If a clear layout can be used, it can be complicated to follow the calculations' flow-path. The ideal would probably be to integrate all the modules directly into the code that allows the calculation of the thermodynamic cycle, insofar as it contains a great number of numerical methods (that offer a greatest robustness than Excel's solver) and as calculations can be followed step by step easily.
<p><u>Optimus workflow generation:</u></p> <p>The performances engineers must generate a new Optimus workflow for each new study. In order to so, they modify manually one of the existing workflow developed in the past for an other study. This is long, tedious, and represents also a considerable source of errors due to the considerable number of variables involved in the calculations.</p>	<ul style="list-style-type: none"> - One solution would be to generate automatically the optimus workflow adapted to the study on course (cf prototype). - Else, if all the modules are developed and integrated directly into the code that allows the calculation of the thermodynamic cycle, then there would be no needs of using Optimus any more and problems related to the workflow generation would vanish. However, this solution would require that specialists learn the particular programming language used first, which is costly in terms of time and money.

Table 7.1: Part of the table of concerns and associated possible solutions.

7.2 Target process for OAP1 investigations

It has been decided that the OAP1 investigations process should be split into two distinct paths in the target process: one path for investigations in answer to RFI, and an other path for the development and validation of new modules. The overall idea is that modules be developed in anticipation to needs following the second path mentioned, ensuring that investigations in answer to RFI can be performed as quickly and smoothly as possible with all the modules of interest when aircraft manufacturers emit demands. In order to meet this objective, it is necessary for performances engineers to have access to many off-the-shelf modules that work perfectly.

Moreover, systems architects will become the ones leading the OAP1 process. They will especially be responsible for collecting the needs, launching modules' development and deciding investigations to be performed. At the same time more responsibilities will be given to specialists, in a way that OAP1 investigations becomes useful to them too; in addition to developing modules, they will also be involved in the post treatment of the results. In doing so, they could orientate investigations in a particular way and validate/invalidate results. In order to be able to assume these new roles, specialists should have time allocated to OAP1 investigations from now on.

From a more practical perspective, here are some of the actions that will need to be undertaken in order to orientate to the target process:

- Determine whether the Optimus software should still be used or not (ageing software, tedious results extraction, post-treatment in real-time not possible, problems when the network connection is lost, etc.) and if not, determine an other solution to replace it.
- Define a standard formalism for the modules, with general requirements clearly specified
- Define a way of determining the validity domain of the modules, as well as levels of confidence in the results depending on the range of parameters scanned.

Only few points are mentioned here but many things must be determined. Before being able to take decisions, several studies will have to be performed in order to chose the best solutions. Regrettably, the limited duration of my internship prevented me from investigating all these different solutions.

7.3 Status of the existing modules

Given the status of the modules that has been carried out, it is clear that at the present time we are far from the sought-after concept of off-the-shelf modules ready to be used for preliminary design investigations. Once the standard formalism for the modules to be developed will be set and that other key actions will be carried out, there is no doubt that the objectives will be achievable.

Nevertheless, following the interviews I had with the various specialists, it came out that considerable efforts will have to be placed on determining modules' validity domains as well as levels of confidence in the results as these characteristics are often very difficult to assess. Serious investigations will have to be carried out around these points.

7.4 Prototype to automatically generate an Optimus workflow

In this section, the validity of the prototype developed will be assessed. Based on the two investigations conducted with the test case, it is going to be verified if:

- The modules contained in the generated Optimus workflow correspond indeed to the choices made by the user on the interface.
- All the different scenarios considered in section 4.4.3 are treated properly.
- Calculations can be performed with the generated workflow.

First of all, it is rather straightforward to confirm that the modules included in the workflow correspond to the ones selected by the user on the interface. Indeed one can see in Figure 6.2, that apart from the module calculating the thermodynamic cycle, the modules to include in the first investigation are mass, emissions, acoustics and fuel burn, and indeed all these modules appear in the generated workflow displayed in Figure 6.4. As for the second investigation, the modules to include in the study are mass and emissions according to Figure 6.3 and only these two modules are present in the workflow shown in Figure 6.5.

Now, in order to control the different scenarios previously mentioned, let us compare the test case presented in Figure 4.3 to the Optimus workflow generated by the first investigation shown in Figure 6.4.

- Concerning the common inputs, one can notice that connections are generated between the common inputs array and the input file of the modules cycle and emissions as well as with the output var 1 which matches with the test case.
- Concerning outputs that are used as input in one or several other module(s), this can be verified with the output array of the thermodynamic cycle calculation code cycle which is connected to the input files of the following modules: acoustics, mass, emissions.
- As for outputs calculated from the combination of variables from several objects, one can verify that connections are properly made in Figure 6.4 for var 1, var 2 and var 3. For instance, var 3 receive as inputs var 1 and var 3 and is used as input in the fuel burn module. Moreover, if one refers to the second investigation performed, the workflow presented in Figure 6.5 does not display var 2 and var 3 which is what was wanted. The reason for that is the fact that the acoustics module has not been selected for the study, and without this module it is not possible to calculate var 2; as var 2 is missing, then var 3 cannot be calculated either.
- Finally, concerning inputs proper to a module, one can notice in Figure 6.4 that every module has a proper input variable array except the acoustics and mass modules which matches with the test case.

From these verifications it turns out that objects are automatically connected properly with the prototype developed. The last verification consisting in running a calculation in order to assert that the objects are also correctly filled was also performed successfully as revealed by Figure 6.6 which displays part of the results of the analysis. Changing the values of the initial set of inputs changes the values of the outputs in consequence. The numerical results obtained with Optimus have been verified by performing the exact same calculations in an excel file and both match perfectly.

All these verifications confirm that the prototype fulfils all the functionalities it has been designed for. In the end, this prototype contributes to prove that an automatic generation of an Optimus workflow adapted to the preliminary design study engineers want to carry out, is conceivable. Obviously, one must keep in mind that this is only a prototype and that adjustments should be made in order to adapt the prototype to all the possible situations that may arise in reality. One difficulty that shows up for instance, is that each field of activity has its own codification for variable names. This means that a same variable physically, can be called with different names between modules. As a result, something would need to be done in order to adapt to this situation. One can imagine that a cross-reference table be created for example.

Nevertheless, the automatic generation of the Optimus workflow would allow to save precious time compare to now for each new investigation and gain in consistency of the results. Indeed, about 10% of the total time

needed today to perform OAP1 investigations could be saved by using this method. This gain in time would be even more important relatively once the difficulties related to the modules will be solved.

In the end, the prototype developed represents a first solution investigated with the objective of improving the process for preliminary design investigations of first level at Snecma. Other investigations of this type will have to be performed before the target process for OAP1 investigations can be fully determined.

Chapter 8

Discussion and Conclusions

The complete investigation of the current OAP1 process performed through many discussions with the performances engineers and specialists made it possible to raise a list of concerns. It proved that the way in which preliminary design investigations of first level are carried out today is not sufficient with the aim of achieving Snecma's expectations in terms of delivery time, workload, and content of the results.

The study of the current process permitted at the same time to collect the needs for the future platform to be developed. Possible actions to improve the process have been suggested, and the role of the different actors involved in the process have been redefined; more responsibilities will be given to specialists and systems architects will be positioned at the head of the process. On paper, these improvements would permit to divide by 5 the time needed to perform OAP1 investigations in answer to RFI, which is considerable with the intention of gaining new development projects for future engines.

However, before being able to take decisions, several studies will have to be performed in order to chose the best solutions for the target process. Unfortunately, the limited duration of my internship only allowed me to investigate meticulously one solution to an irritant: the one concerning the generation of an Optimus workflow adapted to the study desired. With hindsight, this was maybe not the first point to be tackled if one compares all the irritants that show up in the OAP1 process. However, as the performances engineers were extremely busy with work and that the main user of the platform among them went on paternity leave, I could only identify tardily the current process for OAP1 investigations and the list of irritants. Moreover, as the difficulties related to the generation of the Optimus workflow for each investigation was put forward since the very beginning of my internship, I have been directly orientated to work on a solution to this problem. Anyway, the prototype that I developed proved that an automatic generation of an Optimus workflow adapted to the preliminary design study engineers want to carry out is conceivable, and that it would save precious time compare to now. Obviously, one must keep in mind that this is only a prototype and that adjustments should be made in order to adapt to the real situation. As stated above, other investigations of this type will have to be performed before the target process for OAP1 investigations can be fully determined.

Regardless of the solutions chosen, it has been decided that developing modules in anticipation to future demands from aircraft manufacturers for new engines, will play a predominant role in the new process. Indeed, by developing the right tools before engineers actually needs it, significant reactivity will be gain in the preliminary design investigations. The overall idea is that engineers have access to many off-the-shelf modules that have been previously validated so as to conduct optimisation studies in the shortest time possible as soon as demands emanate from aircraft manufacturers.

Given the status of the modules that has been carried out, it is clear that at the present time we are far from the sought-after concept of off-the-shelf modules ready to be used. However, once the standard formalism for the modules to be developed will be set and that all the other solutions will be chosen, there is no doubt that the objectives for the new preliminary design platform of first level will be achievable.

From a more personal perspective, this internship was a great opportunity for me on several aspects. First of all, it allowed me to develop technical competences in programming with objects-oriented language, and completed my general knowledge of aircraft engines. I also discovered and got a good insight into preliminary design, and understood the considerable interest of multidisciplinary investigations. In addition, I acquired a sound knowledge in the process that guides any software development project.

Given the integration feature of my mission, I also developed general competences that will undoubtedly be useful to me during my whole engineering career. Indeed, I especially learnt how to organize and conduct meetings, how to set objectives, and how to write internal memorandum. This was also the opportunity to get acquainted with difficulties that can show up in large companies; troubles to know where to find a precise information, the fact that each department first sees its own interest although working with others on a common project, collaborators out of office for a certain time or overloaded with work, etc.

These difficulties made me realise the importance of planning in any project; point toward which I should have turned a greater attention during my internship. Finally, I also had the chance to observe during this 5-months period the real need for traceability in companies in order to ensure competences' sustainability.

Chapter 9

Future Work

In this chapter, the discussion will be primarily developed around the global development process of a new tool followed in the Methods and Tools for Integration Department, presented in Figure 3.1.

At the present time, the first phase concerning the needs collection has been achieved. The idea is now to investigate different solutions to all the irritants identified in the current process; this corresponds to the definition of the tools specification. Prototyping will be the essential activity during this phase. The main points here will be to determine the formalism that all modules should respect as well as the associated documentation, and to decide whether the optimisation investigations must still be performed under the Optimus software or not. These decisions will have to be taken in agreement with the various teams of specialists, the performances engineers, the systems architects and the engineers of the Methods and Tools for Integration Department. More accurate needs will emanate from these decisions, allowing to set clearly the tools specifications. Finally, the test cases will have to be defined.

Once these decisions will be taken, the future process for OAP1 investigations could be mapped entirely. In parallel, the development of the various tools will be conducted. On one hand, the various teams of specialists will be assigned the mission of developing new modules in compliance with the standard format newly chosen, and on the other hand, the engineers of the Methods and Tools for Integration Department will develop the overall platform that will integrate all these modules.

Finally, internal validation and beta tests will end the project.

An important consideration, is that new modules can be developed and validated regularly by specialists to face needs and that they can easily be integrated in the platform. In this way, the modules library would constantly be enriched allowing to preform more and more complete and accurate preliminary design investigations of first level.

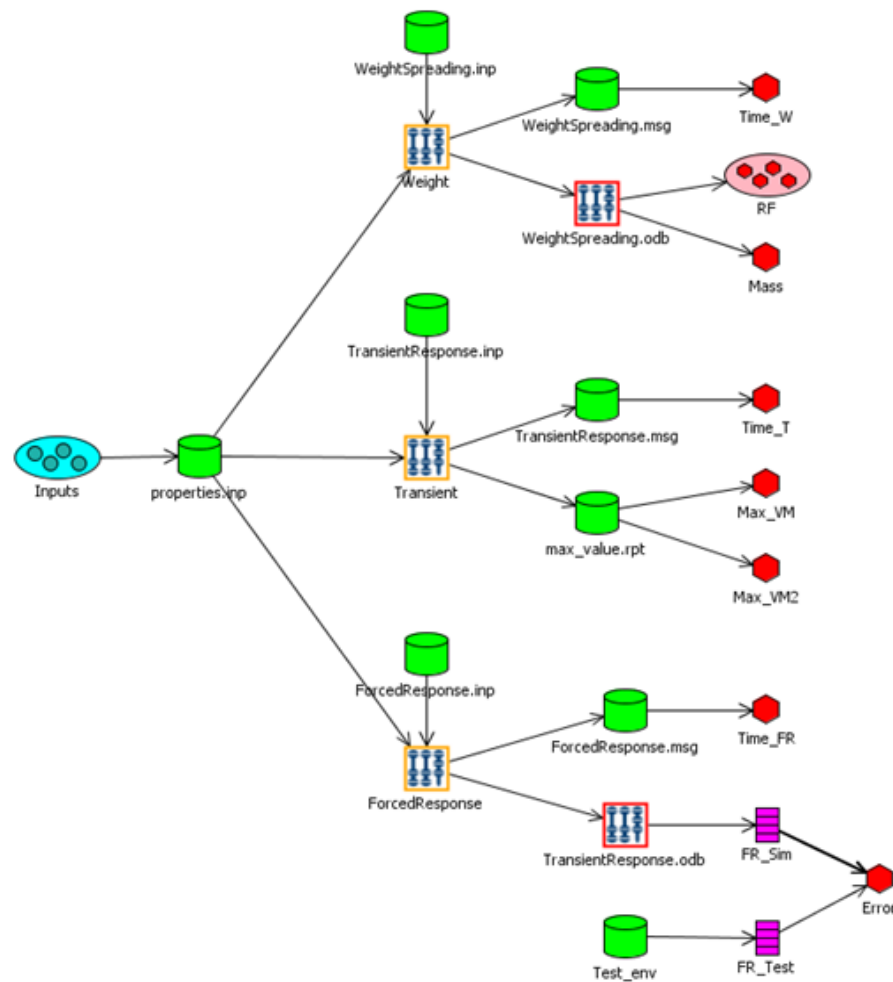
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Appendices

Appendix A

Example of an Optimus Workflow



Appendix B

Part of a thermodynamic cycle

Parameters	Units	Design points			
		Cruise 100%	T/O 0/0,25	TOC	Design 95%
POINT	unites	CONFIDENTIAL			
ALT	FT				
XM	-				
VTAS	KNOT				
DTAMB	K				
FNIN1	LBF				
SFCIN1	LBM/HR/LB				
WB15	LBM/SEC				
WB27	LBM/SEC				
PB27	BAR				
PWX4	HP				
ERAM1A	-				
P3Q2	-				
BPR	-				
W25R3	KG/S				
T3	K				
T41	K				
T49	K				
P5Q2	-				
P16Q56	-				
DIA2A	IN				
DSP2A	KG/S/M2				
UERFAN	M/S				
UPERIF	M/S				
XN12	RPM				
PCN12	%				
XN12R	RPM				
PCN12R	POURCENT				
XNU12	-				
P13Q12	-				
TAMB	K				
PAMB	BAR				
W2	KG/S				
T2	K				
P2	BAR				
W23	KG/S				
T23	K				
P23	BAR				
W25	KG/S				

Appendix C

Xml file used to generate the GUI.

```

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- <data>
- <modules>
- <module name="Mass">
- <versions>
- <version no="1">
- <architectures>
<architecture>Turbofan</architecture>
</architectures>
</version>
- <version no="2">
- <architectures>
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</version>
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- <versions>
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