CONCEPTUAL DESIGN METHODOLOGY OF HALE UAV

How Onera deals with complexity and applies its tools to innovative concepts

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OVERVIEW

Due to numerous potential applications, UAV have become a major field of investigation in aerospace science and technology. Being a system-oriented research centre, Onera has been involved since the 90s in many conceptual design processes of UAV. Through the example of HALE systems, and after briefly introducing their two levels of complexity (large span of applications, many scientific and technological topics involved), this paper illustrates Onera's efforts to face engineering challenges: how to coherently benefit from distributed expert knowledge, how to define a robust design process, how to introduce powerful system optimization techniques.
The paper introduces HALERTE, which is an advanced research tool that aims at helping designers in defining a HALE UAV that fulfils operational requirements, and shows how this methodology has been applied to the design of a blended wing HALE UAV in the frame of the FP5 European CAPECON project.
A large focus is then made on the most recent UAV project at Onera, the design of a multi-mission air-launch system in the field of space transportation, called Dedalus (studied under Cnes contract). The overall design methodology is described, the 22-tons composite configuration designed is detailed as well as the performances on the launching, freighter and surveillance missions. The final section shows how further works planned on this project could benefit from Onera's important effort in MDO, regarding problem formulation, complex analysis integration and optimisation tool suites choices.

1. HALE UAV DESIGN, A COMPLEX APPROACH THAT REQUIRES NEW ENGINEERING TOOLS

Before developing and illustrating Onera's approach on the case of high altitude, long endurance (HALE) UAV systems, this chapter introduces on the one hand the system complexity of HALE UAVs, and on the other hand the engineering challenges one has to face to achieve an efficient design process.

1.1. HALE systems

Rather than considering only the aerial segment, one would preferably talk about a complex system that comprises at least the carrier, the payload, the ground segment and the data link system, and may interact with other systems, as shown on fig. 1

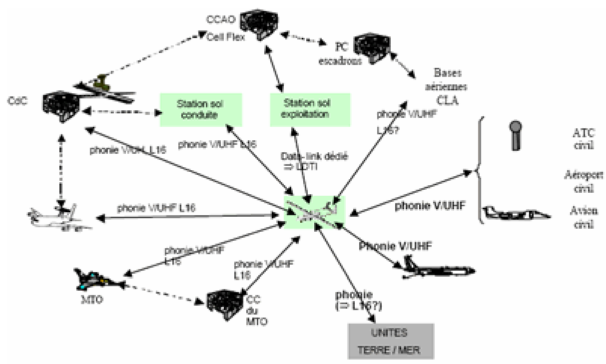

FIG 1. Global HALE system architecture

The variety and complexity of such systems can be drawn by introducing the large span of potential applications and disciplinary analysis involved.

1.1.1. Civilian and military applications

UAVs have been for long time identified by the military field as an efficient way to achieve difficult missions, with lower risk and cost concerns. Tactical UAVs are already operational for survey or even strike missions. But some specific needs also appear for HALE systems, among them:

- Theatre surveillance, for example to ensure permanent ballistic missile alert capability,
- Responsive deployment of a communication relay,
- Interception of enemy communications,
- …

All these missions have in common the requirements for a large field of view and an extended loitering capability, which match well with HALE UAV characteristics.

More recently, it has been put forward that HALE systems could also be convenient for a large amount of civilian applications. Within the scope of the FP5 European thematic network UAVNET (in which Onera took part), many civilian missions have been identified, and summarized in a roadmap:

- Pollution assessment and monitoring,
- Remote environmental research,
- Fire-fighting management,
- Security e.g. border monitoring,

- Scientific missions,
- Agricultural and fisheries applications,
- Oceanography,
- Communication relay for wideband applications.

For a lot of them, HALE UAVs could be adequate technological solutions, as shown on fig. 2 for emergency applications:

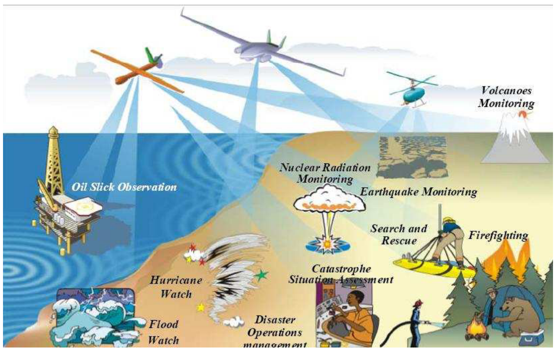

FIG 2. Civil UAV emergency applications

For both military and civilian applications, HALE requirements are very diverse and many configurations can be envisioned. That is a first level of complexity that has to be addressed.

1.1.2. Disciplinary analysis involved

High altitude flight with long endurance capabilities makes it necessary to reach a high technological level on each part of the whole system (vehicle(s), payload, ground segment, data link). Thus, high skills and tools are required in the following disciplines (corresponding to Onera's field of investigation, but not necessarily exhaustive):

- Aerodynamic characteristics estimation of the airframe,
- Aeroelastic behaviour of high aspect ratio wings,
- Engine performance evaluation,
- Structural sizing and weight breakdown assessment,
- Handling qualities analysis,
- Mission performances assessment,
- Payload design (SAR, instruments for atmospheric analysis, radar and optronic sensors,…),
- Data link feasibility and ground equipment design (antenna, data storage, data flow,…).

At a preliminary design level, it is also recommended to include such concerns as technology maturity, cost or international cooperation constraints.

This large span of disciplines involved and the specific requirements they have to cope with in the case of HALE UAVs brings the second level of complexity.

1.2. Engineering challenges to deal with complexity

Because of these two levels of complexity, HALE UAV systems are a perfect example of the new challenges engineers have to face, which are also valid for other aerospace vehicles (e.g. civil airplanes, launchers, rotorcrafts, missiles…). More and more cooperation between experts is required, as well as sophisticated multi-disciplinary optimisation techniques, in order to achieve better overall performances and design time reduction.

1.2.1. A network of experts

Conceptual or preliminary design processes often used to be performed by a centralized team of expert engineers that would use their experience and low-fidelity analysis tools. But two tendencies introduce the need for a distributed network of experts:

- Within a company or Research Centre, the needs for high level of skills and tools (as well as the variety of configurations to be assessed) mentioned above force to introduce disciplinary experts early in the loop, providing databases and various fidelity models,

- Because of the "system" aspect, design processes are likely to involve different companies, sometimes located in different countries (case of European cooperation), and something better than a phone or e-mail advice is required in the design process.

But in this network-oriented approach, some obstacles have to be overcome:
- Heterogeneous models have to share a common protocol of communication,
- Disciplinary experts might wish to protect the core of their knowledge and share only inputs and outputs of their models,
- Security aspects in the data exchange must be taken into account.

Chapter 2.1 will show how Onera addresses this question towards the HALERTE tool.

1.2.2. A robust definition process

In a conventional approach, the system definition process begins with the establishment of a set of requirements, induced by end-users needs. But at this step, if no information is available about what is achievable and what is not, three parasitic phenomena might occur:

- The requirements are too severe with respect to the needs. In this case, the cost will be much higher than expected, or a long refinement process will be necessary,
- The requirements are only based on "on the shelf" technologies. In this case, the system will lack of ambition and be rapidly out of date,
- The requirements are insufficiently precise and refined throughout the design process. The convergence to an optimal or at least satisfactory system is then far from being ensured.

That is why an iterative process has to be implemented, as shown on fig. 3 below.

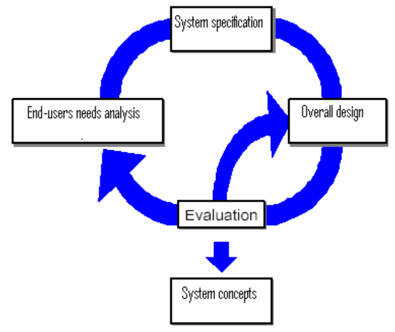

FIG 3. Iterative process to generate system concepts

The main difficulty is then to introduce the adequate level of tools in the evaluation of concepts. They must be at a sufficiently macroscopic level to deal with the large variety of configuration assessed, but accurate enough to provide data for a multicriteria selection of concepts.

Then, it is necessary to organise this formal knowledge collected in databases, design rules and calculation codes in a multi-disciplinary design process that allows cycles of analysis at several levels of detail and depth. It makes it possible to acquire sufficient knowledge on the concepts to establish a robust set of requirements.

In chapter 2.2 and 3.1, two different HALE design processes performed by Onera (one within the frame of the FP5 European project CAPECON and the other for an original air-launch system) will illustrate the use of such an integrated toolset.

1.2.3. A set of optimization methods and tools

MDO (Multidisciplinary Design Optimization) has become during the last ten years a major field of investigation in engineering science. Basically, MDO includes the aspects introduced in the 2 previous chapters (integration of distributed various fidelity analyses, integrated design process and exploration of the design space) and adds the problem of complex optimization strategies. More than a mathematical or formal procedure, MDO can be seen as a design organization philosophy that addresses the following topics:

- Design formulations and solutions: it includes the design problem objectives choice and formal decomposition, as well as the optimization procedures and issues,
- Information management and processing: it includes the software environment in which the process is implemented and the way to manage data flows and design space visualization,
- Analysis capabilities and approximations: breadth and depth requirements, inclusion of high fidelity analysis, geometric modelling, response surface models, sensitivity analysis capability,
- Cultural implementation: how this new design methodology impacts the industrial organization and what are the benefits and costs.

Since 2004, Onera has made an important effort to evaluate these techniques, and apply them to various aerospace design processes. As they are perfectly suitable for HALE UAV design, chapter 3.2 will describe how they are to be used to refine the design process of the air-launch system Dedalus.

2. HALERTE AND CAPECON, HOW METHODOLOGY LEADS TO EFFICIENT DESIGNS

UAV system design and assessment is one of the core application-driven fields of research at Onera. By the end of the 90s, this field, especially the HALE application, was chosen as the frame of an important method & tools development called HALERTE, which was soon after used in the CAPECON project.

2.1. HALERTE, a multidisciplinary engineering methodology

2.1.1. General principles of HALERTE

HALERTE is an advanced research tool modelling a HALE UAV conceptual approach by formalizing a method of analysis and evaluation of systems. Its aim is to help designers in defining a HALE UAV which fulfils operational requirements.

In a global design process that goes from end-user needs to the system definition and experiments (see fig. 4), HALERTE is located at the top and uses a high level of reasoning.

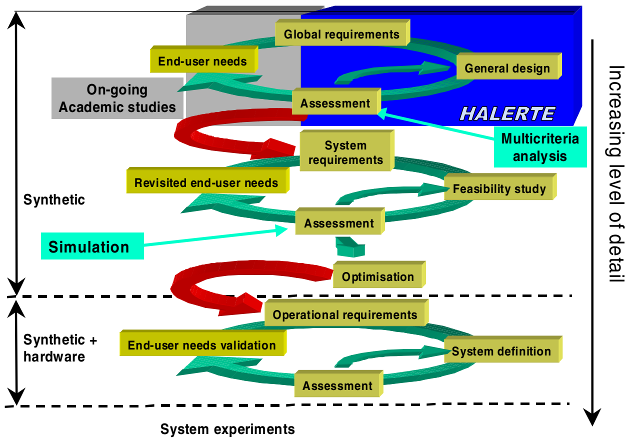

FIG 4. Overall design process

The function of the tool is to provide several system solutions and select the “best” ones thanks to a multicriteria analysis (based on various criteria such as operational performance, cost effectiveness…).

To achieve this function, two methods are implemented:
- Models of knowledge, that are provided by experts and allow disciplinary analyses,
- A specific design methodology that gathers and organizes this knowledge, using system level tools.

2.1.2. Implementation of the tool

The basis of HALERTE consists in a suite of elementary local tools that come from experts distributed in the different Onera geographic locations. These tools represent an elementary field of knowledge by the way of in-house software, databases, knowledge bases…The disciplinary analyses taken into account in HALERTE are those described in chapter 1.1.2: aerodynamics, aeroelasticity, engine performances, structural sizing and weight breakdown, handling qualities, mission performance, SAR and other radar and optronic instruments, datalink feasibility.

All these elementary tools are embedded in an integration environment that allows them to be ran on demand and linked together. The chosen software is ModelCenter from Phoenix Integration, whose interface is shown on fig. 5:

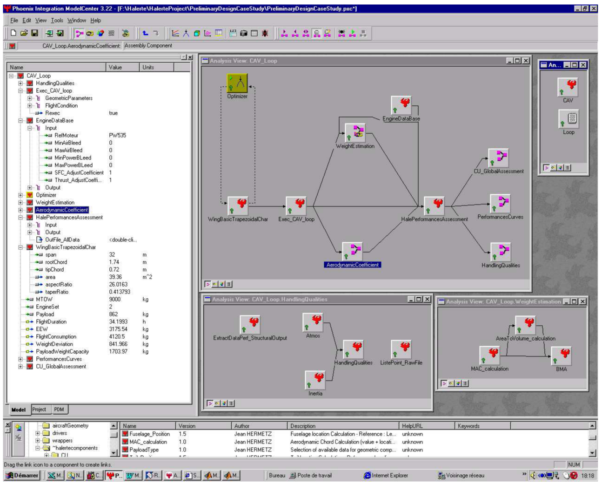

FIG 5. View of ModelCenter graphical interface

To integrate existing in-house software, an expert writes a wrapping file of its code in a specific scripting language that defines inputs, outputs and run procedure. The in-house software then becomes a component that can be published on the internet, using a client/server software called Analysis Server. This robust integration environment has many advantages:
- Heterogeneous (Fortran, C, Matlab, Excel,…), already existing calculation codes can be linked together,
- Each expert keeps the core of its knowledge and publishes only the chosen inputs and outputs in a distributed architecture,
- A lot of functions to link the different components, to interact with the design process (data storage, parametric studies, optimization loops using gradient or genetic algorithms), to visualize the design progress are available in the integration environment.

In addition to the elementary tools, HALERTE also uses some system level software applications that are partially embedded in the integration environment:

- CATIA CAD software to study some sub-systems geometric configuration,
- A knowledge capitalisation tool, to store the validated results obtained,
- A multicriteria analysis tool that implements various methods such as Topsis, Electre,…

2.1.3. HALERTE two-level design process

The typical design process in which HALERTE can be used is described on fig. 6. Before using the tool, it is assumed that a qualitative definition of concepts has been made by a group of experts.

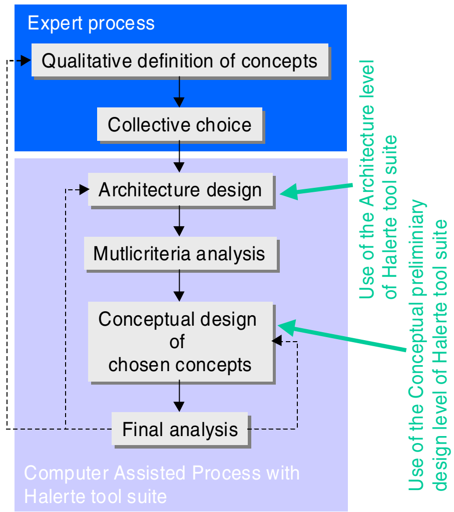

FIG 6. Overall process including HALERTE

Two levels of processes are implemented in the tool suite:

- The “Architecture level” is organized around a core module dedicated to flight performance estimation. It is linked to several modules that allow taking payloads into account in the overall performance estimation. The outputs of this level allow performing a multicriteria analysis based on performance of the vehicle and the payload, maintainability, reliability, cost, maturity of technologies, operability, logistic supports and so on.

- The “Preliminary conceptual design” step uses more calculation codes (distributed in different Onera locations, see fig. 7) and aims at the preliminary design of the system. The analysis involves airframe, propulsion (thrust and fuel consumption of high BPR turbojet), flight performance and handling qualities, payload characteristics (mainly weight and electric power consumption).

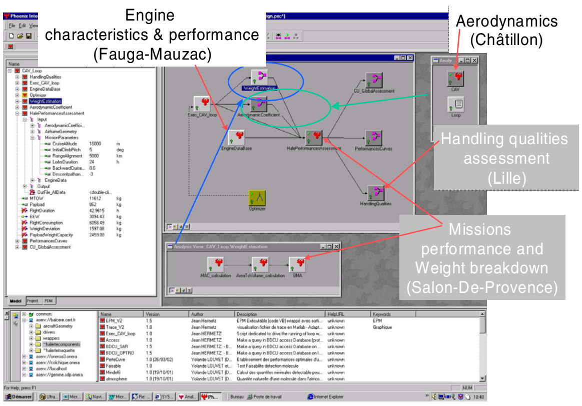

FIG 7. Preliminary conceptual design model

At the end of these two levels of assessment, an expert analysis concludes on the validity of the final concept and provides feedback to improve the design.

Abilities of the HALERTE tool suite have been successfully demonstrated towards the restitution of the Global Hawk system with respect to published data, and by following the overall process for a simplified panel of needs. The conventional architecture UAV found is illustrated on fig. 8 (from ModelCenter 3D view window).

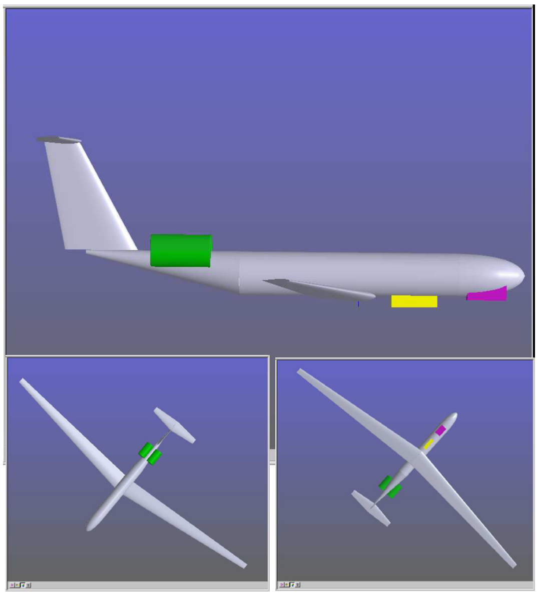

FIG 8. Example of HALE design performed by HALERTE

Chapters 2.2 and 3.1 will show that these methodology and tools can be applied to very diverse configurations.

2.2. CAPECON configuration

The first detailed study in which the HALERTE benefits could be put forward is a HALE UAV design process in the frame of the FP5 project CAPECON (Civil UAV Applications & Economic Effectivity of Potential CONfigurations solutions).

2.2.1. Requirements and project organization

The aim of the CAPECON project was to identify all potential operational civilian applications of UAVs and to design suited configurations of such systems. 8 concepts were initially planned to be designed to further determine which matches best to each identified application.

Among them was a HALE configuration satisfying the following set of requirements:

- Nominal operational mission, detailed in terms of flight profile (typical egress/ingress bound of 1000km with 24h loiter at 60000 ft, use of conventional runway),

- Payload requirements (typically a SAR radar and EO/IR sensors), in terms of weight (500kg), volume, main constraints such as angle of view, electric consumption.

Onera as the task leader and Warsaw University of Technology (WUT) were the two main partners in this design process, in which IAI (Israël Aircraft Industry - performance analysis) and UNINA (University of Napoli – FEM analysis, reliability and safety assessments) were involved. The study followed a two-iteration process as shown in fig. 9 and resulted in two configurations, one proposed by WUT and the other by Onera.

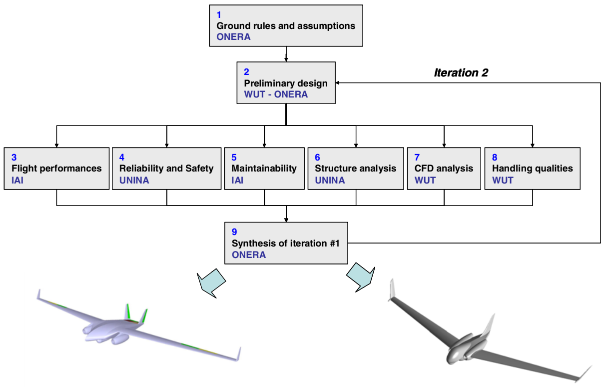

FIG 9. Project organization

2.2.2. Design process of Onera configuration

Onera was in charge of defining a blended wing UAV configuration that satisfies the top level requirements mentioned above. In this case, a large part of the tools introduced in chapter 2.1 was reused, following the overall methodology shown in fig. 6:

- The expert process: the background knowledge of experts and a qualitative analysis led to a baseline configuration, with the following characteristics:
 * Blended wing aerodynamic configuration
 * Twin engines to increase reliability
 * Engines located in nacelles for maintainability
 * Equipments in the central part of the wing
 * Two vertical tails for lateral stability
 * No horizontal tail
 * Conventional landing gear

- Then, the "Preliminary conceptual design" level of the HALERTE tool was used to assess and adjust a first configuration. Contributions from other partners were added to the process.

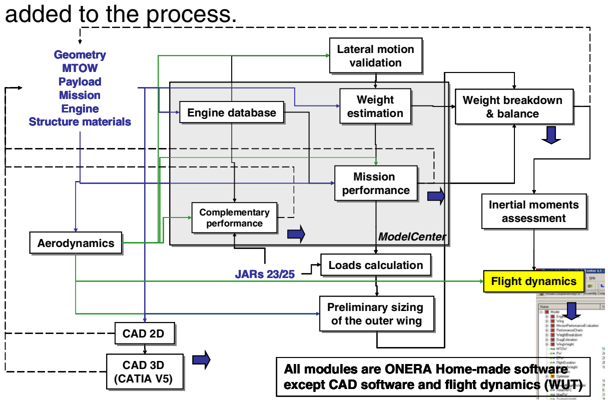

FIG 10. Dependencies diagram between analysis modules

- A final expert analysis was made, that pointed out the need for a refinement of the aerodynamic configuration. After selecting the best wing profile and planform through a parametric study, the “Preliminary conceptual design” phase was performed a second time to converge to the final configuration.

2.2.3. Results obtained

- After the first iteration of “Preliminary conceptual design”, the configuration, called OBW-01, had an overall span of 34.5 m for an overall length of 7.8 m. It weighted 7 tons and was powered by 2 Pratt & Withney PW 535 turbofan engines.

- This configuration appeared to be oversized, and it was decided to modify the aerodynamic shape to keep the performance level for a lighter and smaller configuration. A parametric study was performed, wich led to new sweep angle and longitudinal position of the wing.

- The final configuration, called OBW-02, has a MTOW of 5.4 tons and is powered by two Rolls-Royce Williams FJ 44-2E certified for high altitude flight. The figure 11 shows a 3D view of this configuration.

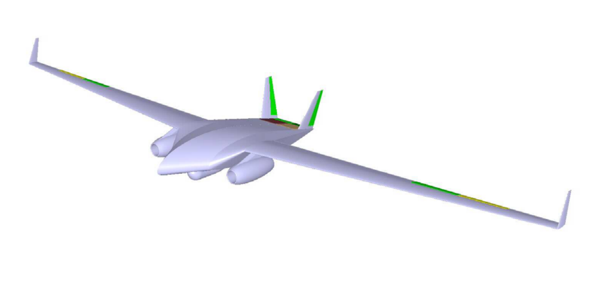

FIG 11. OBW-02 configuration

A view of the main equipments internal arrangement is shown on fig. 12, and a comparison between OBW-01 and OBW-02 is given in table 1.

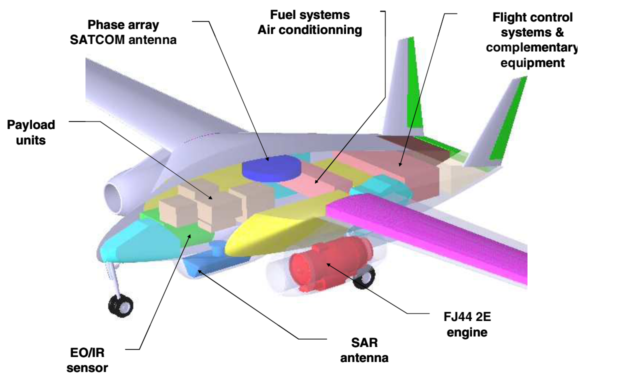

FIG 12. Internal view of OBW-02 configuration

Parameters	OBW-01	OBW-02
MTOW	7000 kg	5400 kg
Wing loading	117 kg/m²	105.22 kg/m²
Max LD ratio	27	32
AR	20	18
MMO	0.6	0.636
Initial Climb altitude	50 000 ft	55 000 ft
Absolute ceiling	63 000 ft	63 400 ft
Fuel (nominal mission)	3640 kg	2628 kg
Take off thrust (SLS)	28.5 kN	24.3 kN
Thrust loading	246	222
Payload/wing area	13	12
Payload/take off thrust	27	25

TAB 1. Characteristics of the two successive concepts

3. DEDALUS, AN AMBITIOUS HALE CONCEPT

More recently, in the frame of a study funded by CNES (French national space agency), Onera was given the opportunity to extend the range of HALE UAV application and configuration addressed by designing a multi-mission UAV, called Dedalus (Design of Dual-Use Air-Launch UAV System),primarily used for satellite launching. In the first phase, HALERTE toolsuite proved its efficiency for a new kind of configuration. The beginning second phase will benefit from Onera’s efforts in the field of MDO.

3.1. Conceptual design of a HALE air launch system

3.1.1. Context and global requirements

Within the frame of a common workshop with CNES, Onera is involved in investigations for advanced space transportation systems. Among the spectrum of possibilities, air-launch (conventional multi stage rocket launcher dropped by an aircraft) is a potential interesting technique, as it offers better rocket flight performance and has some advantages regarding operations.

Using an existing aircraft reduces development costs but has a major drawback: the aircraft must be adapted and ceases to be fully operational for the role it was designed for.. On the other hand, developing a new vehicle wouldn’t be economically viable if it is only dedicated to a few launches per year. Following these observations, Cnes and Onera proposed a concept of multi-mission UAV that could achieve more frequent missions (freight transport, surveillance) apart from the launch one.

Rather than a piloted aircraft, an UAV should be able to carry the launcher with a good reliability and robustness. Furthermore, it appears that the range of operations for the launch mission is close to the one of potential HALE missions such as long range freight carrying or surveillance.

The original requirement for the launch mission is to deliver a 10 to 150 kg payload on a 800km/98° low e arth orbit. This can be declined as follows on the UAV:
- Ability to climb in a given time and to deliver the rocket launcher above the commercial air traffic (at least 50000 ft),
- Payload weight compliant with the rocket launcher total weight,
- High degree of flexibility in order to attach and release

quickly the payload with a reduced operation time.

The secondary missions can be defined as follows:
- Freighter mission: carrying conventional containers on the longest possible range,
- Generic survey mission: conventional HALE missions such as fire forest detection, maritime patrol, telecom relay,…

In addition, several high level features in terms of reliability, logistics support, maintainability and affordability have been identified in order to define a consistent set of requirements.

3.1.2. General methodology

Because of its multi-mission ambition, among which one is quite unconventional, and because it is a composite vehicle comprising the UAV and the rocket launcher, the design process of this HALE system is a challenge. Nevertheless, the steps defined in the HALERTE methodology (see chapter 2.1.3, fig. 6) remains valid.

- **Expert selection of an adequate topology**: the launcher and the UAV can be considered separately.

Launcher assumptions:
* 3 stages,
* Solid propulsion for the 3 stages with a long ballistic phase between stage 2/3 propulsion phases,
* Winged first stage in a configuration similar to the Pegasus.

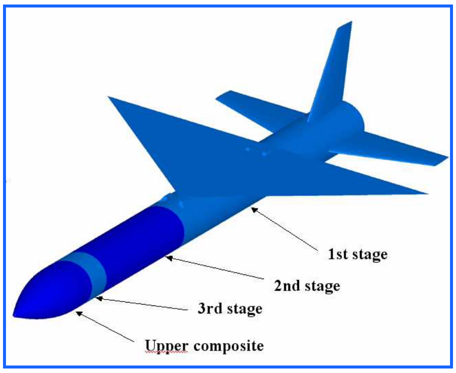

FIG 13. Baseline launcher configuration

UAV preliminary analysis:
On the basis of the requirements defined above, a preliminary analysis was performed, which led to the following choices of architecture:
* A conventional delivery of the launcher installed under the UAV was chosen, instead of an upper carrying,
* Conventional, canard and flying wing configurations have been investigated and the first one was selected on stability and freight logistics concerns,
* A twin engine configuration was selected for safety reasons.
The twin boom high-wing configuration finally selected is illustrated in fig. 14. The engines position was chosen to contribute to the vehicle balance and to keep free the space between the booms for the payload.

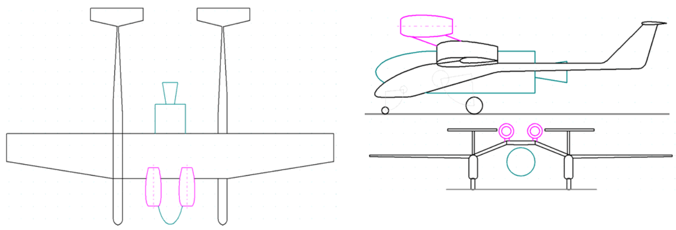

FIG 14. UAV baseline configuration

- **High level sizing of the system**: here comes the first obstacle to overcome in the design process. In fact, the two designs of the launcher and of the UAV are tied by a few coupling parameters (launcher mass which is also the UAV payload, altitude and speed of the delivery). That's why a 3-step process was used: two separate parametric studies were performed with respect to the coupling parameters, the best launch point was chosen, and then the two preliminary designs were made separately, as shown on fig. 15.

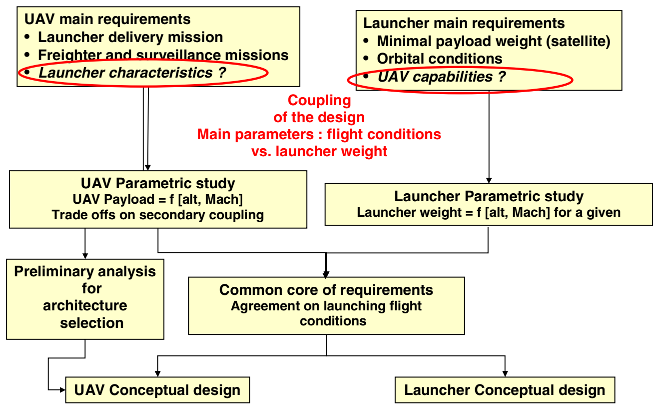

FIG 15. Joint UAV/launcher design methodology

The launcher part of the parametric study was based primarily on ΔV calculations, staging and trajectory optimization.

For the UAV part, the HALERTE tools and the knowledge acquired from CAPECON were used to find the maximum achievable payload for several launch conditions (altitude between 16000 and 20000 m, mach number between 0.6 and 0.8).
* The design variables were mainly the MTOW of the vehicle, the aspect ratio of the wing, the wing loading and the maximum lift to drag ratio in cruise/loiter conditions,
* The constraints dealt with take off, landing and climbing performances.
The simple optimization problem was solved using a SQP algorithm.

The best values of the coupling parameters retained for the next step of the process are an altitude of 16000 m, a launch mach number of 0.8, and a launcher weight of 13 tons.

- **Preliminary conceptual design**: this was performed using a higher level of assessment.

For the launcher part, the coupling of trajectory and staging analysis allowed to jointly estimate the 3 stages masses and the loss coefficients along the trajectory, while maximizing the satellite payload weight.

For the UAV part, the HALERTE tools and the process were updated and tailored in order to model the relevant peculiarities of the UAV configuration studied. The main adjustments are related to the estimation of the drag penalty generated by the payload, and to the secondary mission performance assessment.

The overall design process integrates at least 50 components and is illustrated on fig. 16.

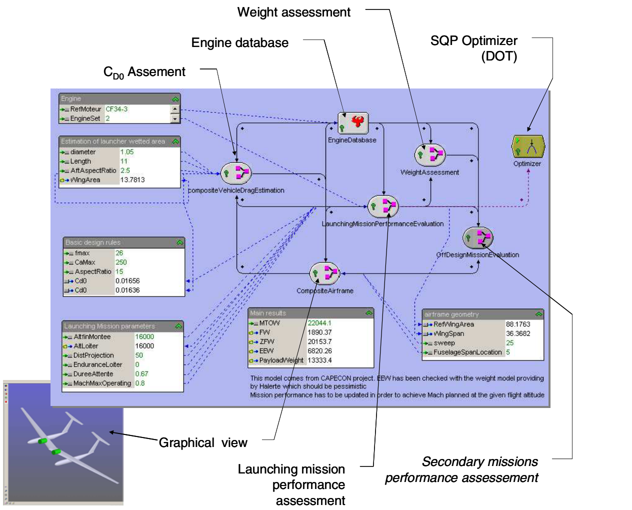

FIG 16. Main analysis view of the process in ModelCenter

3.1.3. Final configuration description and performances

This conceptual design process converged to a configuration that satisfies the initial requirements and functional constraints.

The designed UAV has a MTOW close to 22 tons for an overall payload (included fuel) of 15 tons. The twin boom with independent tails, high aspect ratio swept wing configuration is illustrated on fig. 17. It is equipped with two GE CF-34-3 engines. Fuel tanks are located in the wings and avionics bays in the booms.

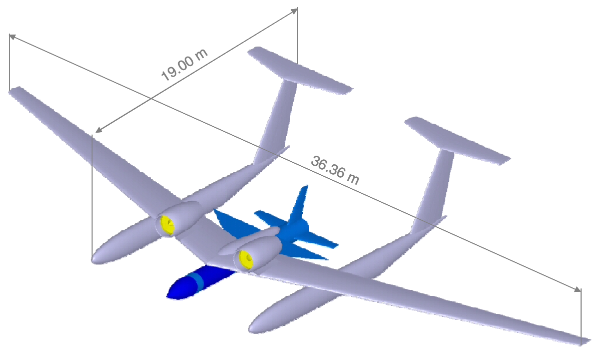

FIG 17. UAV system with the space launcher

The figures in tab. 2 summarize the design description.

Parameters	Dedalus configuration
MTOW	22000 kg
Empty weight	6800 kg
Maximum payload	15200 kg
Length	19 m
Wingspan	36.4 m
Wing loading	250 kg/m²
Wing loading (end of mission)	78 kg/m²
Wing sweep	25°
Max LD ratio	25
Aspect ratio	15
Thrust at sea level	2*4300 daN
Fuel capacity	10180 litres

TAB 2. System characteristics

- Launch mission performances:
* The Dedalus system can carry a 13 tons/3 stages solid propellant rocket launcher, which is able to put a 150 kg payload into a 800 km/98° low earth orbit,
* The launch point at altitude 16000 m, mach 0.8 is reached after 1h37 of climbing,
* The fuel consumption for this mission is 2000 kg,
* Take off and landing distances are compliant with conventional runways.

- Freighter mission performances: a freight pod able to carry 2 standard LD-11 containers (6.4 tons) or 3 standard LD-3 containers (7.3 tons) has been designed.

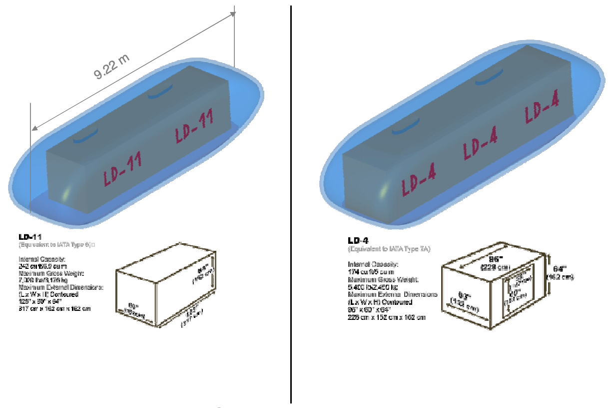

FIG 18. Freighter pod

The achievable range is 10600 km in the first case, 9000 km in the second case.

- Surveillance mission performances:
A conventional surveillance pod of 500 kg can be carried by the vehicle with a typical endurance of 26 h at 15000 m. Mission duration is then 31 h.

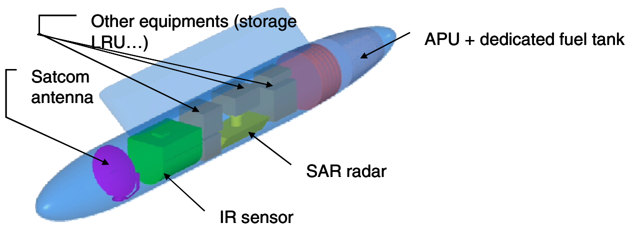

FIG 19. Autonomous survey pod

At the end of this design process, the technical feasibility of such a multi-mission HALE system has been demonstrated, with satisfactory levels of performance for the 3 different missions. Further work will be undertaken to refine some disciplinary analysis (mainly aerodynamics and weight assessment) and to get a first economical assessment. But it is also planned to improve the overall design process by reaching a higher level of integration between the launcher and the UAV and the use of MDO techniques.

3.2. Towards a coupled design using advanced MDO techniques

Since 2004, Onera has been devoting an important internal effort through an internal project called DOOM (French acronym for multidisciplinary optimization methods and tools). Its aim is to evaluate the different topics that enter the field of MDO and to spread them in the different families of aerospace system design processes. Further works about to begin on the Dedalus concept are intended to benefit from this knowledge, regarding design problem formulation, integration of complex analysis models and integration and optimization tool suites.

3.2.1. Design and optimization problem formulation

The first step to set up an MDO approach is to have a clear view of what your process is doing, what analysis are performed and what is the data flow between them. This process clarification can be formalized by establishing a “diagram of dependencies” (DD) that will show the different analysis modules with their inputs and outputs, as well as the forward or backward data exchange. An example of this type of diagram is shown on fig. 20, for a simplified SSBJ design process.

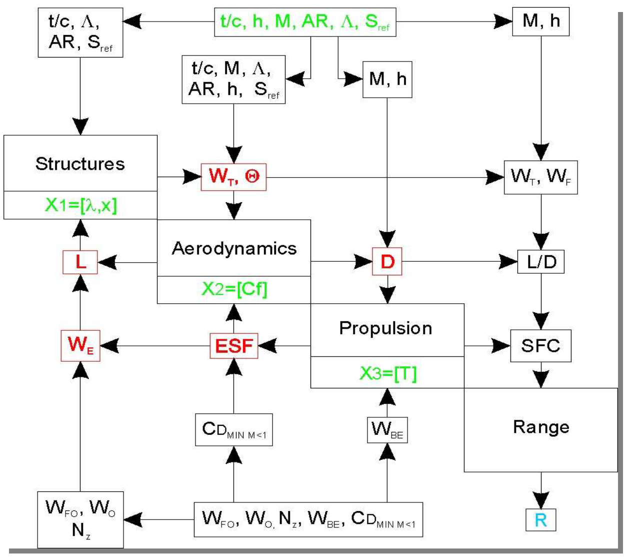

FIG 20. SSBJ diagram of dependencies

The following notations are used:
Xi: inputs that apply only to discipline i
Z: inputs shared by several models
Yi: outputs of discipline i
Yij: outputs of discipline i that are inputs of discipline j

This DD is often a simple translation of the traditional way to perform a design process. But Onera experiments have shown that there are several ways of establishing the DD, which may have different behaviours when you go to the optimization step.

Basically, the DD results from:
- The span of disciplines and phenomenon that are to be assessed,
- The parameterization level of the system (what parameters are intended to be modified during the design process),
- The different engineering rules that are introduced in the process to drive the solutions (sizing criterions, choices of preferred configurations,…).

There is an important degree of freedom regarding the design rules:
- If there is very few design rules, the process tends to be pure analysis. It allows a large exploration capability but may lack of robustness, authorizing incoherent designs,
- If there is a lot of design rules, the process tends to be pure guided design. The gain in robustness is balanced by certain rigidity in the design space exploration.

Once the DD is established, one has to set up the optimization problem by defining the objective function(s) and the different local or global constraints. A multidisciplinary design optimization problem is now ready to be investigated.

There is an important academic work on MDO formulations, that is to say the strategy used to solve the MDO problem. Onera has performed a systematic investigation of some of these formulations on the SSBJ test case shown on fig. 20. The main formulations investigated are:
MDF (Multi-Discipline Feasible): this is the traditional “all at once” optimization, considering the whole process as a black box.
IDF (Individual Discipline Feasible): this is a system level formulation that relaxes coupling variables.
CO (Collaborative Optimization): this is a multi-level formulation that implements local optimization, while trying to keep the consistency at system level.
BLISS (Bi-Level Integrated System Synthesis): this formulation performs a global sensitivity analysis on the system and is then able to optimize each discipline with respect to its contribution to the objective function.

In the case of Dedalus, the above described optimization process consisted in two separated MDF processes, with a quite low number of design variables. It is intended in the second part of the study to increase the parameterization level, to merge the two processes in a single DD and to implement a global MDO formulation. BLISS could be a good candidate to make the two sub-processes interact coherently.

3.2.2. Integration of complex analysis models

MDO aims at early acquiring the highest possible level of knowledge on the system. When increasing the level of parameterization or the required accuracy of assessments, it may be necessary to integrate high fidelity analysis models such as FEM or CFD computations. But two obstacles have to be overcome: the need for a sufficiently precise parametric geometry, and the time cost of such models preventing from using them in an optimization process.

Regarding the geometry modelling aspect, some preliminary experiments have been performed at Onera to integrate a CatiaV5 model in the design loop. Functional feasibility has been demonstrated, and some practical conclusions have been drawn (need of a specific implementation of the geometric model, availability of mass properties assessment, possibility to export the geometry in a chosen format, interest of element databases).

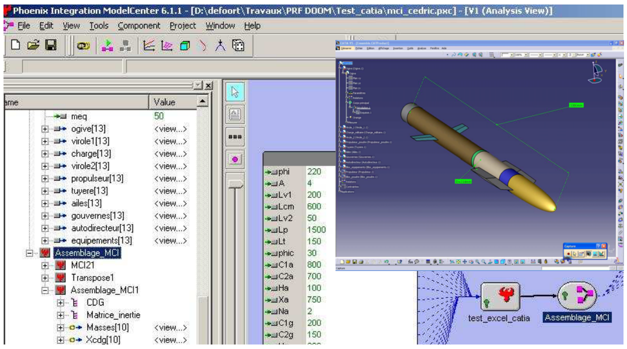

FIG 21. Integration of a CAD model in ModelCenter

This kind of interface could be partially used to link the existing Dedalus CAD model to the assessment models.

To deal with the time consumption of complex calculation codes, the non physical approximation techniques are a major field of investigation in MDO. That is why Onera has devoted an important part of its MDO work to study the theory of some known techniques (polynomial regression, Kriging interpolation, neural networks, support vector machines...) and their applicability to optimization problems. Some physical test cases have been implemented and the influence of tuning parameters put forward.

Depending on the assessment level that will be chosen, some of these techniques could help improving the MDO design process of Dedalus.

3.2.3. Integration and optimization tool suites

To capitalize knowledge, make experts communicate and get a suite of optimization algorithms and design space visualization, an integration environment is required. A systematic investigation of software solutions has been performed, using practical experience on some of the available software and formalizing it through qualitative criterions:
- Cost and support,
- Design process implementation,
- Distributed analyses integration capabilities,
- Data and history of design process storage,
- Visualization tools,
- Optimization and approximation techniques library,
- Interfaces with various analysis software.

Two families of tool suites can be put forward:
- Commercial solutions, generally robust, with different level of implemented functions, but often costly,
- Freeware elementary functions that can be linked together, but an important programming effort is required. Fig. 22 shows what could be the elementary pieces of a freeware MDO environment.

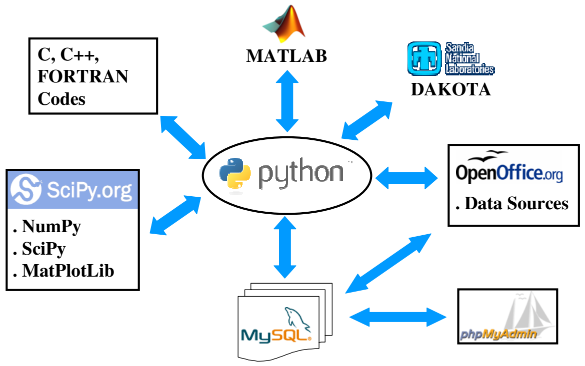

FIG 22. Freeware potential MDO environment

Interoperability of these families of tools is also under assessment, and could help setting up a common design process in the Dedalus application, as the UAV and launcher design processes use different integration environments and optimization techniques.

CONCLUSION

Through the example of HALE UAV systems conceptual design processes, covering various configurations and applications (from the blended wing surveillance UAV of CAPECON to the two-booms multi-missions Dedalus air-launch system), this paper aimed at illustrating Onera's continuous efforts to improve its skills in aerospace system engineering and to be ready for the upcoming design challenges.

In the field of HALE UAV, these methods and tools can be seen as a way to valuate the applied research in the different topics involved (from new aerodynamic configurations to advanced radar sensors), as well as a means to generate innovative solutions for a wide span of applications. They also pave the way for future European-scaled ambitious projects.

References

[1] *European Civil UAV Roadma*p, submitted on behalf of the European Civil UAV FP5 R&D program members, www.uavnet.com

[2] Joseph P. Giesing, the Boeing company, long beach, CA1, Jean-François M. Barthelemy, *A summary of industry MDO applications and needs*, AIAA Technical Committee, 1998

[3] Jean Hermetz, *HALERTE – a multidisciplinary tool for HALE UAV system concepts definition and evaluation*, UAVnet meeting, Eilat, Israël, 2002

[4] Claude Le Tallec, Jean Hermetz, HALERTE: a multidisciplinary engineering methodology for HALE UAV system conceptual design, Onera-DLR Aerospace Symposium, Toulouse, France, 2003

[5] Z. Goraj, A. Frydrychewicz (WUT – Warsaw), J. Hermetz, C. Le Tallec (Onera – Toulouse/Paris), HALE UAV platform optimized for a specialized 60-ft altitude patrol mission, 24th International Congress of the Aeronautical Sciences, 2004

[6] N. Bérend, M. Bourgaie, S. Defoort, J. Hermetz, C. Le Tallec (Onera, Paris/Toulouse), R. Bec (CNES, Evry), *Innovative Air-Launch System using a Multirole UAV*, 57th International Astronautical Congress, Valence, Spain, 2006

[7] N. Bérend, C. Le Tallec, J. Hermetz (Onera, Paris/Toulouse), R. Bec (CNES, Evry), *New perspective for air launch systems using unmanned aerial vehicles*, 7th International Symposium on Launcher Technologies, Barcelona, Spain, 2007

[8] J. Clément, J. Hermetz, N. Bartoli (Onera, Toulouse), M. Masmoudi (UPS, Toulouse), *Multi-disciplinary optimization methods studies*, EUCASS conference, Brussels, Belgium, 2007

Glossary

AR: Aspect Ratio
BLISS: Bi-Level Integrated System Synthesis
BPR: By-Pass Ratio
CAD: Computer Aided Design
CAPECON: Civil uav APplications & Economic effectivity of potential CONfigurations solutions
CFD: Computational Fluid Dynamics
CO: Collaborative Optimization
DD: Diagram of Dependencies
Dedalus: DEsign of Dual-use Air-Launch Uav System
DOOM: Démarche Outillée d'Optimisation Multidisciplinaire
FEM: Finite Element Model
FP: Frame Program (EU terminology)
HALE: High Altitude Long Endurance
HALERTE: Haute Altitude Longue Endurance des Robots Transportant des Equipements
IDF: Individual Discipline Feasible
MDF: Multi-Discipline Feasible
MDO: Multi-disciplinary Design Optimization
MMO: Maximum Mach of Operations
MTOW: Maximum Take-Off Weight
SAR: Synthetic Aperture Radar
SQP: Sequential Quadratic Programming
SSBJ: SuperSonic Business Jet
UAV: Unmanned Aerial Vehicle