Helicopter Life Cycle Cost reduction through pre-design optimisation

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Executive summary

This paper presents the work currently performed on the helicopter preliminary design to cost optimisation within the Improvement through a Virtual Aeronautical Collaborative Enterprise (VIVACE) program. The objective and planned activities are discussed. A description of the NLR analysis tool SPEAR "SPEcification Analysis of Rotorcraft", the Eurocopter preliminary Life Cycle Cost model and the integration of this cost model in SPEAR are given.

Abbreviations

DMC	Direct Maintenance Cost
EC	Eurocopter
MDO	Multidisciplinary Design and Optimisation
LCC	Life Cycle Cost
SPEAR	SPEcification Analysis of Rotorcraft
VIVACE	Value Improvement through a Virtual Aeronautical Collaborative Enterprise

Introduction

The pre-design is normally driven by performance requirements. Other important requirements, such as maintenance cost, non-recurring cost, weight and specific customer requirements, are not treated in the same manor. Also a formalised decision process for the assessment of different design solutions by trade-off analyses often is missing.

However, the goal is to find the optimum helicopter design which not only reaches the required performance requirements, but also satisfies the customer’s requirements at lowest possible costs. Several customers will use the helicopter, and they are likely to perform missions, both different in type and characteristics. In contrast to fixed wing operators, helicopter operators will often use the same helicopter for a diversity of missions. So, the helicopter should not only be optimised for the performance requirements matching the most demanding mission, but also to have the lowest cost while performing a diverse mix of missions. These costs are influenced by the different mission characteristics (flight hours, flight profile, payload, etc.), but also by the maintenance policies applied. This requires a multidisciplinary optimisation approach at the preliminary design phase.

Currently, the most demanding missions are identified by market analysis and the design choices are based on the cost estimates involved with those missions. So, the market as a whole is taken into account, but not the specific mission diversity of the various customers in the market.

VIVACE activities

In order to find an optimal technical solution for these multidisciplinary customer requirements a methodology has to be developed to find an optimal compromise between the “driving” design parameters. This requires the identification and evaluation of those driving parameters by the assessment of the sensitivity of the design to each of these parameters by trade-off analyses.

Such a methodology can also improve the efficiency of the helicopter design process by reducing the number of iterations during the design process.

In the Value Improvement through a Virtual Aeronautical Collaborative Enterprise (VIVACE) “Multidisciplinary Design and Optimisation” (MDO) Use Case, the following activities will be performed:

- evaluation of existing (pre-design) methodologies/technologies and tools,
- development and integration of a Life Cycle Cost model in a pre-design sizing tool,
- identification of the cost driving parameters and performing the sensitivity analysis,
- development and implementation of a methodology to find a multidisciplinary design solution to optimise Life Cycle Cost.

Eurocopter is developing a helicopter Life Cycle Cost (LCC) model which reflects the impact of both the major technical parameters and the major categories of customers and missions.
NLR will integrate the LCC-model Eurocopter develops into it’s helicopter analysis tool SPEAR "SPEcification Analysis of Rotorcraft" and develop a sizing optimisation methodology to enable a multi-mission design to further LCC optimisation.

SPEAR

NLR has developed a methodology for the analysis of specifications for a rotorcraft that should be capable of fulfilling a set of flight and mission tasks. The methodology has been implemented in a computer program called SPEAR: "SPEcification Analysis of Rotorcraft". This program is able to estimate the size and minimum mass of a rotorcraft capable of fulfilling a specified set of operational (flight and mission performance) requirements. The program determines the rotorcraft gross mass, the main dimensions, the installed engine power, the fuel capacity and the mass breakdown for the main vehicle components. The consequences of operational requirements can be analysed, trade-off studies can be performed, and the effects of technological developments on optimal rotorcraft mass and size can be assessed. The computer program uses the flight and mission performance calculation routines from EMPRESS (Ref. 1) and contains a large amount of information on historical and current helicopter designs. Extensive use is made of databases for major helicopter design relationships, major component characteristics, etc. Different kinds of graphical representations for the produced helicopter design results are included. The program basically includes the potential for Life Cycle Cost optimisation or trade-off studies.

Specification of requirements

In order to be capable of performing needed missions, an operator has to specify a set of vehicle related requirements. These can be broken down into three parts, being the:

- rotorcraft configuration,
- flight performances,
- mission performances

The rotorcraft configuration contains data that describe the general layout of the rotorcraft plus some (aerodynamic) efficiency parameters. The flight performance and mission performance parts contain the data for respectively the specific flight performance requirements and mission profile(s) that the rotorcraft must be capable of fulfilling. The mission equipment package is taken into account by means of a mass provision complemented by an additional parasite drag area for any external equipment.

Methodology

The methodology applied in SPEAR is largely based on (Ref. 2). The task of the computer program is to establish feasible rotorcraft dimensions that comply with the set of flight and mission performance requirements for the given rotorcraft configuration. Valid solutions are those that comply with the flight performance requirements and for which available fuel equals required fuel to fulfil the most demanding mission, see figure 1. The optimum solution is defined as the one that achieves these objectives at the lowest gross mass. As suggested in (Ref. 2) other criteria may be defined for the optimal solution, e.g. one that achieves the lowest Life Cycle Cost.

SPEAR determines the main rotorcraft parameters: the main rotor dimensions, the gross mass, the installed engine power and the fuel capacity. In addition, and derived from these quantities, other detailed rotorcraft design data are estimated.

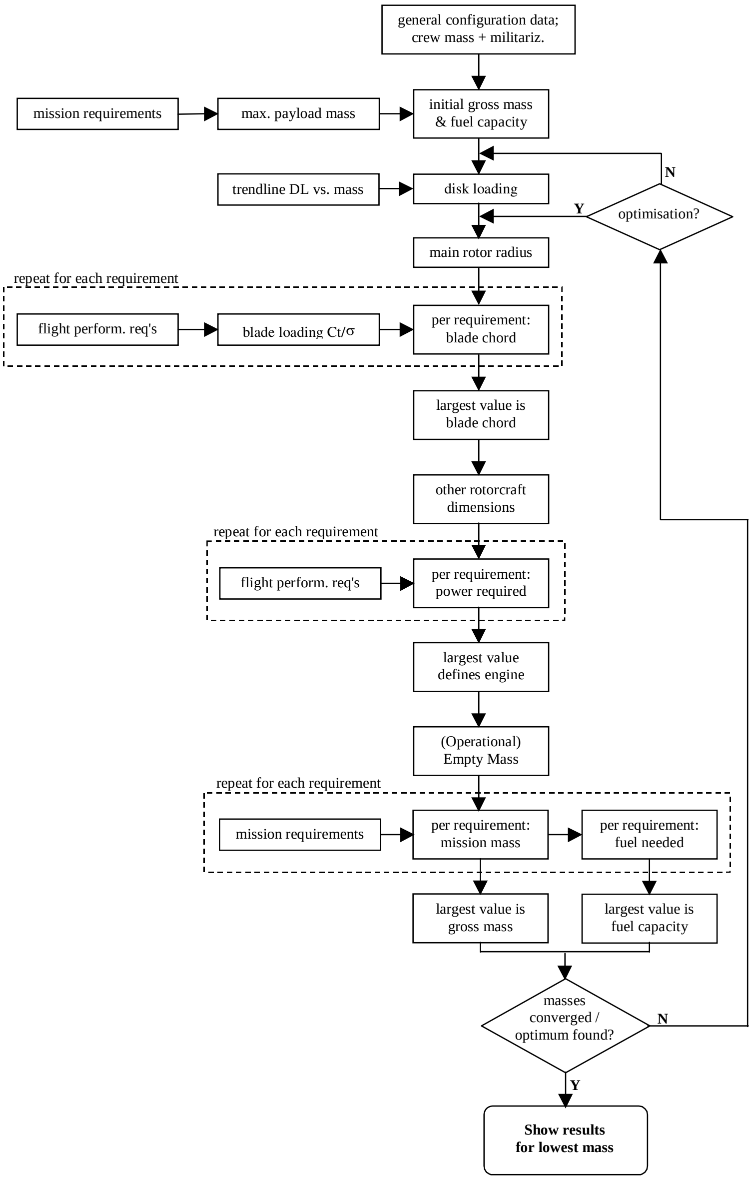

Figure 1 Flow chart for the SPEAR calculation routine

Functionality

An analysis in SPEAR can be carried out at three levels with an increasing amount of input data and possibilities:

Basic

The Basic analysis will determine the gross mass based on the provided rotorcraft configuration, operational requirements and a user selected main rotor tip speed value. Historic data is used for fuselage drag, specific fuel consumption and tail rotor diameter. The engine is either compliant with the specified rotorcraft requirements or automatically selected from a database.

Parametric
The second analysis level provides more extensive options to further analyse the configuration proposed by the program. The effects of varying the following seven main rotor parameters can be analysed: diameter, blade chord, tip speed, rotational speed, disk loading, blade loading and solidity.

Graphical
The third analysis level automatically presents the results in a graph, for which four different types are available:

- design chart (power required or rotorcraft gross mass as a function of the disk loading),
- parameter analysis chart (one of several masses or power required as a function of one of the seven main rotor parameters),
- carpet[1] plot (one of several masses or power required as a function of two of the seven main rotor parameters),
- power curve (level flight power required for the calculated rotorcraft size as a function of airspeed for given values of gross mass, altitude and temperature).

Just like in the *Basic* analysis level, several options have been set to use historic data. This concerns the fuselage parasite drag area (assuming an 'average' drag level), the engine specific fuel consumption, and the tail rotor diameter.

User interface
SPEAR contains a Microsoft Windows compatible user interface, which makes the program easy to use. The SPEAR main window (see figure 2 for a screen shot) contains:

- a pull down menu bar that contains lists of commands to work with the SPEAR program; the menu items can e.g. be used to load or save a rotorcraft data file, to specify the analysis requirements, to run the program, and to view the results,
- a speed button bar that contains shortcuts to the most commonly used menu commands for the specification of the requirements (rotorcraft, flight and mission) and for performing the three types of analysis (basic, parametric and graphical),
- general information panels that show additional text information on the selected rotorcraft configuration, and the selected flight and mission performance requirements.

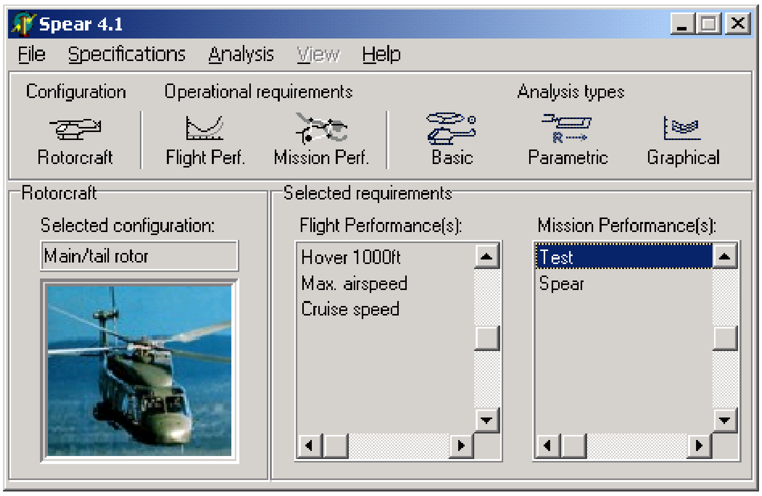

Figure 2 Screen shot of the SPEAR main page

[1] A carpet plot is a means of displaying data dependent on two variables in a format that makes interpretation easier than normal multiple curve plots. A Carpet Plot is often used in multi-dimensional parametric studies.

SPEAR runs on Windows NT/2000/XP Personal Computers, thereby taking advantage of the Windows features. The current version is SPEAR 4.4, dated September 2005.

Life Cycle Cost model

Eurocopter is currently developing a helicopter Life Cycle Cost model which reflects the impact of both the major technical parameters and the major categories of customers and missions. The preliminary LCC model delivered to the "Multidisciplinary Design and Optimisation" (MDO) Use Case takes into account civil operations and is composed of the following three calculation routines, Life Cycle Cost, rotorcraft acquisition cost, Direct Maintenance Cost (DMC).

Life Cycle Cost

This calculation routine aggregates mainly the rotorcraft acquisition cost (sale price) and the Direct Maintenance Cost of a fleet for a certain period. The major parameters related to the use of the helicopters (but not directly connected to the manufacturer), are also taken into account. The Life Cycle Cost is therefore based on the following estimated cost items:

- rotorcraft acquisition cost,
- cost of spare parts procurement,
- cost of documentation,
- Direct Maintenance Cost,
- insurance cost,
- pilot overall cost,
- fuel cost.

At the current preliminary level of the LCC model, the list of parameters has been limited while still allowing computation of a realistic result. This list will be refined to be consistent with the rotorcraft acquisition cost and Direct Maintenance Cost routines level of detail.

Rotorcraft acquisition cost

This routine estimates the price of a helicopter according to its major physical parameters, such as the installed power, Max Take-Off Weight, rotor diameter, fuselage size, etc. The cost breakdown within the model is representative, but the total acquisition cost is scaled to represent the published sale prices.

The level of detail of the cost breakdown is consistent with the level of detail used by the preliminary design team in its first loop, see figure 3.

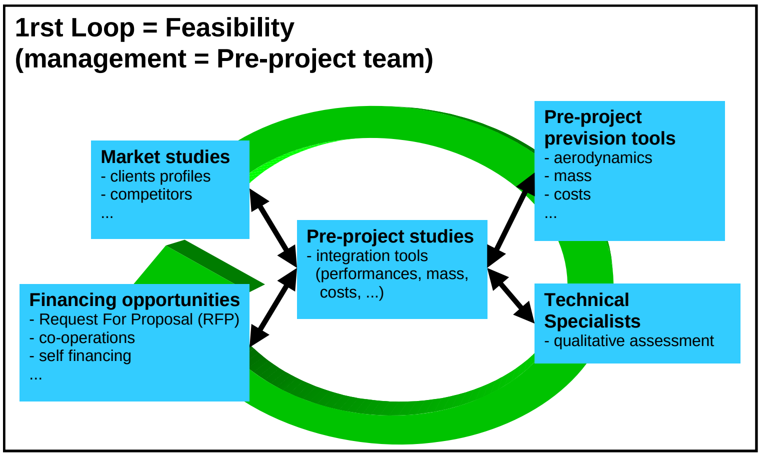

Figure 3 Feasibility phase (1st loop) of helicopter development process (Ref. 3)

The analysis of new helicopter cost data may modify the choices of the cost drivers. However, the cost driver parameters will be limited to the number required to reflect the impact of both the major technical parameters and the major categories of customers and missions.

An updated LCC model will also take into account the effect of the level of optional equipment. Optional equipment is generally applicable to heavy helicopters, while light helicopters are typically sold close to the baseline configuration with only very limited optional equipment.

Direct Maintenance Cost

This routine is quite similar to the rotorcraft acquisition cost routine, which means that the description given under rotorcraft acquisition cost is also applicable for this routine. The main difference with the rotorcraft acquisition cost routine is a much lower scatter of the results around the average as compared to the rotorcraft acquisition cost routine results.

The preliminary cost model equations will be updated based on the latest information.

LCC model in SPEAR

The Eurocopter (EC) provided preliminary cost model has been integrated in the NLR analysis program SPEAR.

It should be noted that the cost functionality is valid for the single main rotor configuration only, and therefore not valid for the co-axial rotor configuration.

An “Analysis Costs Input (EC model)” window has been created, see figure 4 to modify input data for the detailed cost estimation process according to the Eurocopter preliminary Life Cycle Cost model. This LCC model only takes into account civil operations. The input data is self-explanatory. All changes to the cost data will automatically be stored in the database.

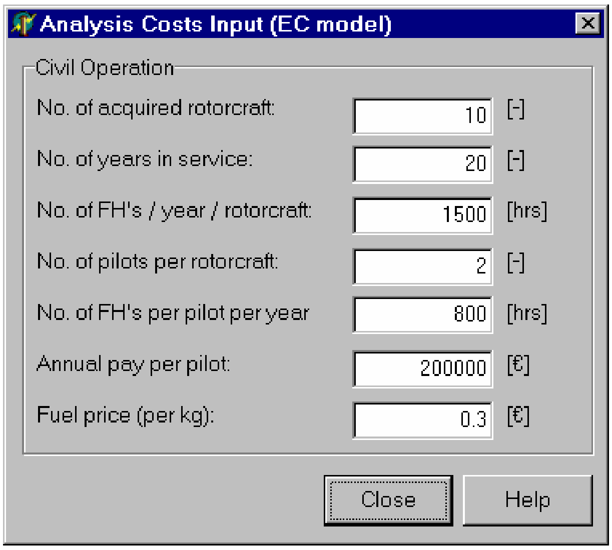

Figure 4 Analysis Costs Input (EC model) window in SPEAR

The “Calculated Cost Results (EC model)” window has been created. This shows the estimated life cycle cost, the sale price and the Direct Maintenance Cost (DMC) on three data tab sheets, see figure 5. The Eurocopter preliminary Life Cycle Cost model results are expressed in 2005 Euro’s.

The Life Cycle Cost page shows the estimated total operating cost for the number of acquired rotorcraft. The purchase cost is taken from the Sale price tab sheet, the direct maintenance cost from the DMC tab sheet. Finally the estimated operating cost per flying hour is provided.

The sale price page shows in detail the estimated costs of producing the individual major components. These add up to the sale price per rotorcraft.

The DMC page shows in detail the estimated Direct Maintenance Costs per flight hour for the individual major components.

The rotorcraft analysis is not (yet) influenced by the cost, and therefore a change in cost input data or technology factor could be taken into effect directly by clicking the 'Re-calc' button.

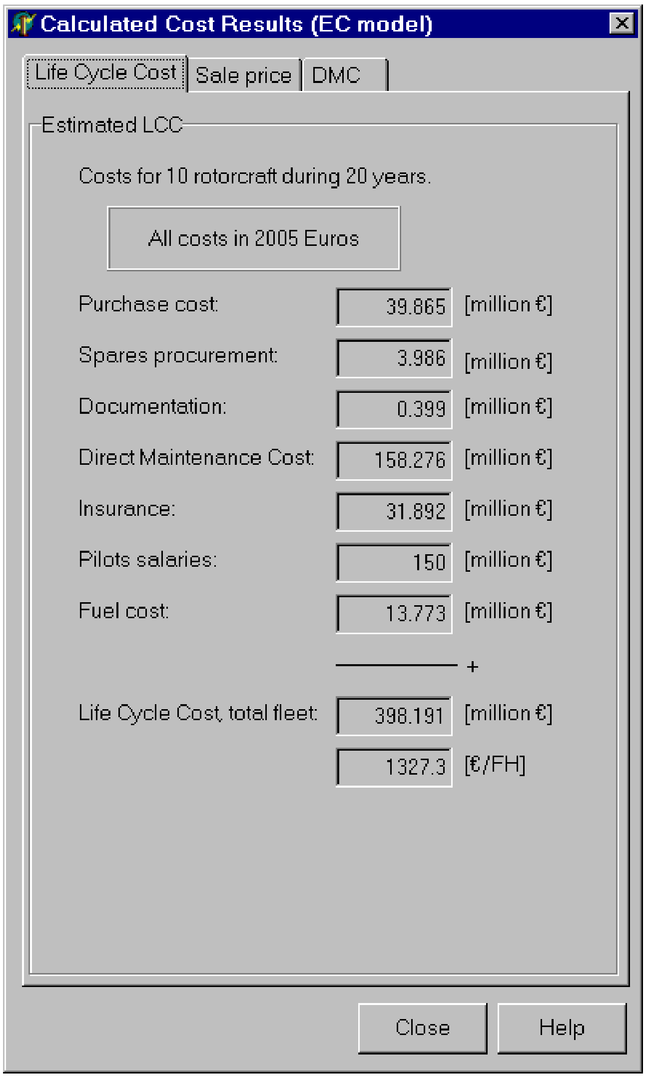

Figure 5 Calculated Cost Results (EC model) window in SPEAR

Concluding remarks

The pre-design is normally driven by performance requirements. Operators however, need cost effective helicopter designs, which not only reach the required performance requirements, but also satisfy their requirements at the lowest possible costs. Therefore a Life Cycle Cost model is being developed which reflects the impact of both the major technical parameters and the major categories of customers and missions.

In the VIVACE "Multidisciplinary Design and Optimisation" (MDO) Use Case, NLR has integrated the preliminary LCC model developed by Eurocopter into it's helicopter analysis tool

SPEAR "SPEcification Analysis of Rotorcraft" and is developing a sizing optimisation methodology to enable a multi-mission design for LCC optimisation. This helicopter analysis tool basically includes the potential for Life Cycle Cost optimisation or trade-off studies. A description of SPEAR has been provided. The cost model has been tuned to reflect the present sale prices of Eurocopter helicopters, but will be updated upon availability of new data. Dedicated Life Cycle Cost input and output windows have been added to SPEAR.

Eurocopter and NLR will continue the work respectively to improve the LCC model and to develop a pre-design optimisation method. The objective is that the LCC model will reflect the impact of both the major technical parameters and the major categories of customers and missions, and that the optimisation method will be enable a multi-mission design to LCC optimisation.

Acknowledgement

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