TECHNOLOGY ASSESSMENT WITH MULTI–DISCIPLINARY AIRCRAFT DESIGN TOOLS ON THE NEXT GENERATION SUPERSONIC COMMERCIAL TRANSPORT

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1. Introduction

The challenge in the development of a very complex system like a supersonic transport is not only to achieve the required technology, but also to link a team of highly skilled experts. At Daimler–Benz Aerospace Airbus an industrial approach was introduced to integrate the individual departments with their specific knowledge into the design of a future supersonic commercial transport.

Different designs are analyzed with a modular synthesis model and compared on the basis of operating economy with specified performance and environmental impact. The analysis routines of the synthesis model are mainly configuration independent and represent fixed levels of structural, aerodynamic and propulsion technology. The specialist departments are responsible for the content of the routines, and later for verifying the design with more refined methods.

More than 200 variables describe the aircraft geometriy, engine characteristics, mission and the level of technology.

The level of technology is the key for fulfilling the market driven design requirements. This is especially valid for the next generation supersonic aircraft. The main difference to subsonic aircraft is the necessity of a high level of technology. It is essential for this kind of aircraft to choose and define the right and the level of technology far ahead of the configuration freeze.

In combination with the cost of technology programs, it may be a new area for multi–disciplinary aircraft design to introduce the level of technology as a free parameter variable for the design process.

The following chapters will describe the design process MIDAS, the necessity of technology for the next generation SCT and a proposal for an approach for technology assessment.

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2. MIDAS, a Design Process

Figure 1 shows the preliminary aircraft design process at DA, introduced for the project of the next generation SCT: Multidisciplinary Integration of DA Specialists

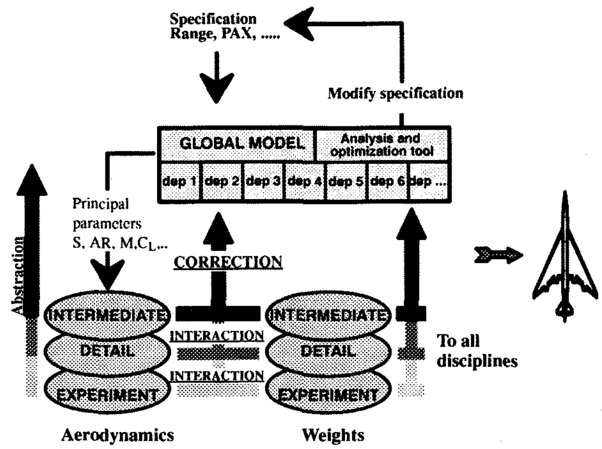

Figure 1.

On the highest level there exists a global model of aircraft performance and economy as a function of its specification and a set of design variables. The analysis routines in the global model are supplied by the specialists departments who have the final responsibility for their content. These global analysis routines connected in different ways to the intermediate / detailed calculation methods of the specialists departments. For use in the global model, where the aircraft design is handled multi–disciplinary, the routines are linked via a database.

The first step of the design process is the input of the aircraft specification to initiate sizing and the definition of the design parameter and constraints. After running a design loop with the global model, the resulting principal parameters will be delivered to the specialists departments. The predictions of the global models will now be checked with the more detailed calculation routines of those departments. If the deviation of the results is larger than acceptable, a correction of the global model is necessary and there will be a next run on the global level. This must be repeated until the difference in the results between the two working levels will be acceptable.

There is always the possibility that the design requirements are too optimistic. In that case the design requirements have to be changed in that way, that the design will converge under the assumed level of technology. This is necessary for a feed–back to the marketing teams, to show a possible design space.

3. Optimization, Constraints, Free Design and Fixed Parameters, Objective function

The most important and challenging point for the MIDAS process is the connection of the different main domains with its specialists during the initial design loop of a new aircraft.

Main areas	⇆	Analysis areas
•Aerodynamics		Performance•
•Structure incl. loads		Noise•
•Mass estimation		Sonic boom•
•Propulsion		Operating costs•
•Geometry		Objective function•

If this is done, a powerful analysis tool is available for single analysis runs, 1–dimensional sensitivity calculations or in connection with an objective function it is ready for the use with an optimization algorithm. This tool is used for the SCT project work on the global level design with good results and will be improved for other areas concerning aircraft design and assessment.

An aircraft is generally described as a set of parameters, momentarily more then 200 on the global level. They are representing the different domains of aircraft design in one way and in a matrix form they are constraints, free and fixed parameters when the analysis tool is used in combination with optimization tools (a few examples are shown in table 1.).

Fixed parameters are description parameters for the aircraft. They are just inputs (e.g. number of pax, friction coefficients, technology level, ...)

Free parameters are values which may be recalculated during the design process (e.g. weights, ...)

Design parameters are the most important parameters during the design loops with optimizers. If a design engineer is working on a project with an aircraft design program and he wants to change the wing area, he will open the data set on the computer, change the wing area, run the program and "analyses" the result. In an optimization process the design parameters are "responsible" for this work. The design engineer is defining the design space (minimum, maximum, step of the design parameters). The optimizing algorithm is doing the aircraft analysis with respect to the constraints (or borders), the objective function and gives back the best possible result.

Constraints are reflecting the market requirements (e.g. range ,take off field length, ...) and the engineering influenced borders (e.g. maximum main landing gear track, minimum fuselage length and diameter, ...)

SCT exmple parameters Table 1.	Fixed	Free	Design	Const
Number of passengers	x			
Cruise Mach number	x			
Cruise altitude			x	
Diversion Mach number			x	
Bypass ratio of the engine			x	
Turbine entry temperature			x	
Wing area			x	
Design range				x
Take off field length				x
Approachspeed				x
Noise				x
Structure weight		x		
Technology level	x			

Objective function or design target is currently the guide of the design process to the final aircraft design. For subsonic airplanes it is the aim of the design engineer to reduce the direct or total operating costs (DOC/TOC). For special aircraft like short take–off and landing vehicles (STOL) the objective function could be the minimum take–off run, which is normally used as a constraint (see table 1).
The following figure 2 shows the special problem for the future SCT when the designer is just looking on the TOC.

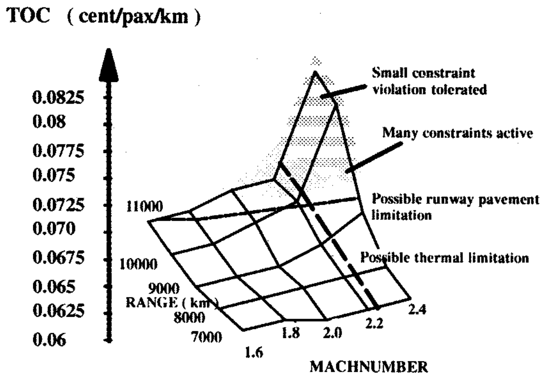

Figure 2 TOC versus range and Mach number

It is obvious that the design engineer will opt for a reduced cruise Mach number below 1,0. If we are looking for the next generation SCT, it will be necessary to correct the TOC by adding an extra value for the reduction of travel time for the passengers.
Figure 3 shows the TOC – Δ Revenue as an objective function. A minimum appears at approx. Mach 2 in the constraint unviolated area.

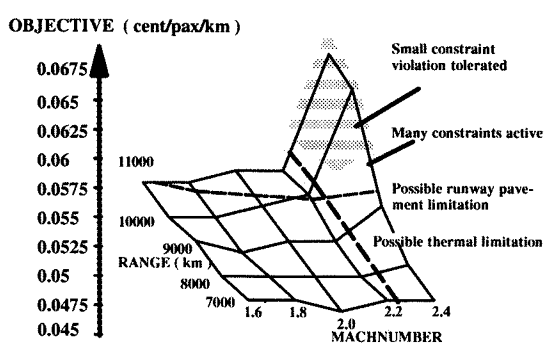

Figure 3 TOC – Δ revenue verus range and Mach number

The next step will be the introduction of the possible return of investment (ROI) as the objective function for a new project.

4. How important is technology for the next generation supersonic aircraft ?

Figure 4 shows the level of structure weight reduction versus maximum take–off weight (MTOW) for a supersonic and a subsonic commercial aircraft with the same set of design requirement.

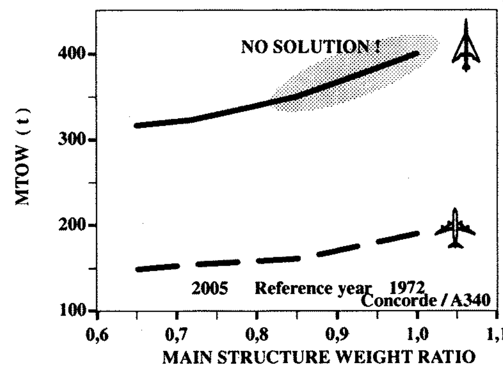

Figure 4

Weight reduction is a major factor to make the next generation supersonic transport competitive to subsonic aircraft. The target of approx. 30 % (year 2005 technology) is a very ambitious, but necessary. There is on one side a constraint for a "minimum" technology and on the other side, more than 30 % structure weight reduction will not lead to significant MTOW reductions. The reasons are :

- Main structure are less than 25 % of the MTOW
- Minimum thickness due to installations or connections
- Minimum thickness due to foreign object damage

Table 2 gives an imagination about the effects of actual and the year 2005 structure technology.

1996		2005	
A340	SCT	A340 Type	SCT
MTOW 271 t	440 t	190 t	340 t
M0.82/7200nm 250 Pax	M2.0/5200nm 250 Pax		

Table 2 MTOW–Structure Technology Comparison

It can be seen that an SCT with todays technology will not be feasible due to the high maximum take–off weight (MTOW). If it is acceptable to have an aircraft classification number (ACN) not higher than the Boeing

747. It is obvious that a today technology SCT needs a landing gear somewhat larger as the B 747 and it has to be integrated into a fuselage with a diameter less than an Airbus A320. This is too much for talking about an engineering challenge. The next generation supersonic aircraft needs a higher level of technology to be competitive with subsonic aircraft.

5. Critical issues for SCT the technology

During the conventional subsonic design process, the project department does freeze the design in a very early stage and the necessary technology was defined by experience. Meanwhile the specialists departments are working towards the certification with the expected achievements of the technology program. Finally the aircraft will be certified with performance shortfalls and expensive performance improvement programs are introduced during the delivery schedule of the aircraft. This process only works, if the aircraft is not at the design limits.

For the next generation SCT the choice of technology is more important than for subsonic aircraft.
Firstly, because there will be no chance to act against performance shortfalls (especially range shortfalls). It will be a spiral with a steep slope to regain the design range by increasing the MTOW after nearly 100 % design readiness.

The best example is the Concorde, where seven years of flight test and major modifications were requiered to regain the transatlantic range with a reduced number of passengers and a nearly doubled MTOW (not to mention the amount of expenses).

Secondly, especially for the structure case there is an important time problem. For the current subsonic aircraft it is mandatory to finish the first life simulation before the first flight. Actually this full scale test is accelerated by shorter, higher loaded cycles. For the next generation SCT, the test cycles have to include the thermal effects of the high cruise Mach number. The complete aircraft structure has to be heated up to 100 °C, with peak temperatures up to 125 °C (a Mach 2.4 aircraft to 150 °C with peaks up to 190 °C). It was a problem for the Concorde and it will be a larger problem for the next generation SCT, with an expected wide use of reinforced plastic (more than 60 % of the structure), its thermal behavior and a design life four times longer than for the Concorde (subsonic aircraft standard) . If we do not solve this problem, it will be necessary to start the material testing now for a first flight in ten years, but on the other hand we are expecting a frozen design around the year 2000. Hence, the major task for the SCT design process must be to identify the areas and the amount of technology required in a very early project phase, with the result to introduce the technology when the aircraft detail design starts towards the certification.

6. What about the choice of technology ?

Figure 4 has shown the influence of structure weight reduction on the maximum take–off weight. But the knowledge of lightweight design philosophies or materials is not for free. Money has to be spent in the form of funding (technology program) or during the predevelopement of the project.

Figure 5 shows the curve from figure 4 in a larger scale for the SCT in combination with a "cost of technology" curve (gray shaded). The slope of the MTOW–Curve had been discussed in chapter 4. On the cost side, it is a fact that the amount of spending, for achieving the necessary technology, will become larger if the targets are more ambitious.

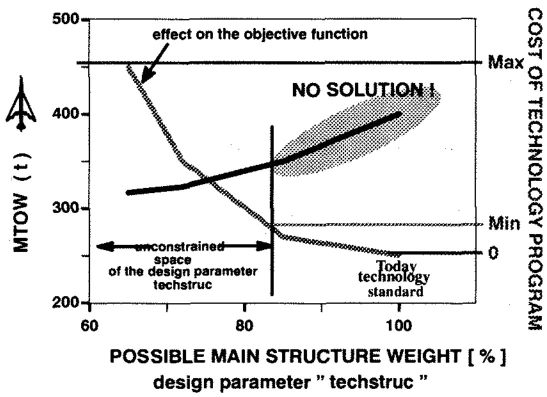

Figure 5

It is also obvious that especially for the SCT, a minimum of structure technology and a minimum of funding is essential for the realization of the project with respect to the design requirement and constraints. But the most interesting point, is to find the area where the SCT is competitive with subsonic aircraft in combination with the assumed 20% ticket surcharge.

7. Technology assessment with optimization tools

If we summarize the mentioned facts, it has to be solved how the cost of technology can be combined with the current SCT objective function "TOC – Δ Revenue"?

The technology level is currently (see table 1) a fixed parameter. The idea is to set this parameter to the design level and add a value on the objective function regarding the use of the now design parameter "technology level ".

Current objective function :

OBJ = TOC – Δ Revenue

A general multi–criterion objective function is a combination of standalone objectives put together with weight factors :

$$\text{Objective function} = wf_1 * obj_1 + \ldots\ldots\ldots\ldots + wf_i * obj_i$$

(wf: weight factor)

With the new objective function for the next generation SCT, an optimization algorithm should find a possible minimum for a combination of minimum TOC and the expenses for technology :

$$OBJ = wf_1 * (TOC - \Delta\ Revenue) + wf_2 * cost_{struc} + wf_3 * cost_{prop} + wf_4 * cost_{aero}$$

8. Variation of the weight factors

One point of interest is to look how stable the design program runs with a variation of the weight factors, how reliable and how explainable the results are. For these calculations the objective function is reduced to :

$$OBJ = wf_1 * (TOC - \Delta\ Revenue) + wf_2 * cost_{struc}$$

and the parameter "structure technology" has been set to the design level. A function

" technology cost (techstruc)"

as seen in figure 5 has been introduced.

In simple words , it means that the reduction of the now design parameter "techstruc" will lead to a reduction of the aircraft structure weight (due to the multidisciplinary connection including all snowball effects), but also an increase of the technology program cost and a different objective function. It is a trade–off between aircraft performance and program cost. Figure 6 shows the results of the variation with the weight factor, which gives one side of the objective function an advantage or a disadvantage.

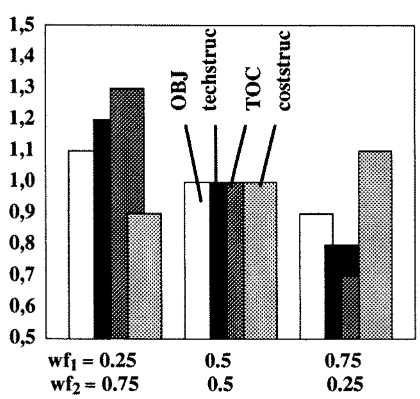

Figure 6

9. Choosing technology

The main item of this paper is to propose a method for predicting the optimum mix of technology and hence the best possible aircraft design in combination with low or best invested expenses for a technology program. To get a different result for a pure market driven aircraft design and an aircraft design reflecting additional cost requirements, will the results be explainable and is the multidisciplinary program approach stable enough to work will be the next study item.

For this purpose, we use the objective function from chapter 7 with fixed weight factors in the calculation program. This means three cost functions are defined in the cost subroutine (see following figure 7).

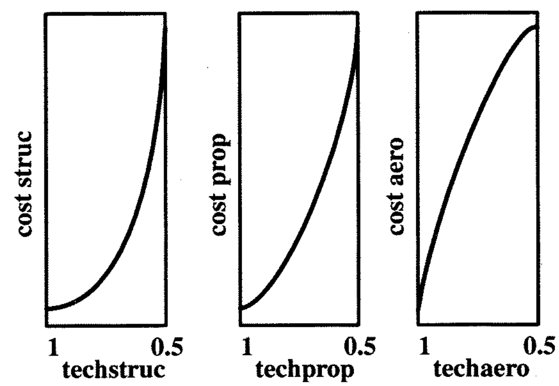

Figure 7 Three possible cost functions

And three parameters are declared to be design parameters :

Structure : A factor on the calculated main structure weight is used as a simple simulation of the influence of the technology level. The snowball effects, and this is valid for all calculations, are taken into account through the multidisciplinary optimization/iteration loop.

Propulsion : Performance improvements for the aircraft engines are possible on two areas. Firstly the engine weight, which is is handled in the same manner as the structure factor and secondly on the thermodynamic cycle. Overall Pressure Ratio (OPR) and Turbine Entry Temperature (TET4) are used to simulate improvements. The Bypass–ratio is already an important design parameter for the SCT and responsible for the trade off between take off noise and supersonic performance. The component efficiencies (μ) are not usable, currently all single efficiencies are between 90 –97 %.

Aerodynamic : This is is the most complex area for this simple technology assessment approach. Currently there are various different technology programs running, which do have a detailed description and fixed tasks (e.g. : engine integration / variable camber). The most promising step forward for the next generation SCT is the introduction of supersonic laminar flow, but this is a step, from zero to full. To simplify matters, a factor on the calculated aircraft drag or better C_D is used to simulate the technology level.

Two expected results are shown in the following figure.

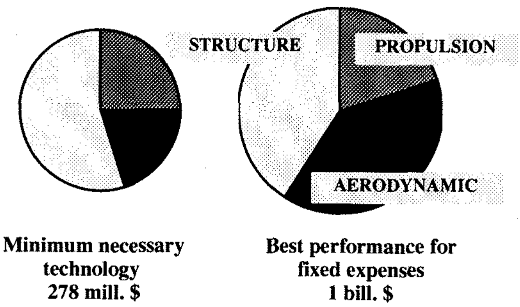

Figure 8 Technology distribution

These results are reflecting two different approaches for the next generation SCT.
The left pie shows a distribution for a minimum necessary technology. The weight factors are chosen for minimum technology program expenses, but all design requirements (e.g range/TOFL) are fulfilled.
The right one shows the distribution for a minimum TOC or best performance when there will be an additional constraint for a maximum budget.

This two distributions of the three used technology areas are different. This is the effect of the three different cost functions seen in figure 7 . The optimization algorithm is always choosing the technology factors with the largest benefits and the lowest cost penalties. So far the complete program is working stable with this additional functions and factors, but the results are depending on the cost functions and it may be the most problematic area to prognosticate these functions reliably.

10. Conclusion

The presented aircraft design method MIDAS has been used at DA during the last years working on the next generation SCT with very good results. The DA project team has made a lot of progress working on the next generation SCT using this approach. Which gives the author of this paper the opinion that multidisciplinary aircraft design by teams will be a major key for the success of any future project.

Critical issues for the realization of the next generation SCT have been discussed and how they are introduced into the design process. It was further mentioned, that especially for this project, there is a strong dependency for achieving the necessary design targets and hence the challenge to make the right decision for the necessary technology in a very early design stage, on a project which is in various areas different to subsonic aircraft.

The proposed introduction of technology factors as main design parameters together with cost functions into a multidisciplinary aircraft design program and the use of optimization algorithms may help to define the right targets for the different technology areas. Whenever an European supersonic research program will become reality, this proposed assessment tool should be taken into account, developed and used in early stages of such a program.

11. References

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