Sustainable Knowledge Growth
Inaugural Speech

Michel van Tooren

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TU Delft
Faculty of Aerospace Engineering
Delft University of Technology
SUSTAINABLE KNOWLEDGE GROWTH

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By

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Mijnheer de Rector Magnificus,
Leden van het College van Bestuur,
Geachte Collegae hoogleraren, docenten en medewerkers
van de universiteit,
Geachte dames en heren studenten,
Beste familieleden, vrienden en overige gasten,
Zeer gewaardeerde toehoorders,

Dames en heren,

In 1996 the Faculty of Aerospace Engineering reorganised
itself and adopted the matrix structure for its organisation.
The traditional vertical disciplines of the aeronautical study
(aerodynamics, performance, control and simulation, aircraft
technology based management, structures and
computational mechanics, production technology, aircraft
materials and finally astrodynamics and satellite systems),
were completed with a set of two horizontal chairs to
integrate the knowledge and crafts of these vertical chairs,
foocussing on the objects the faculty is based upon: aircraft
and spacecraft. Later addition of the vertical group enginee-
ing mechanics led to the current state of the Faculty,

Figure.1

The horizontal chair Systems Integration Aircraft and other
advanced transport systems, my chair, has responsibilities
with respect to education, research and management within the faculty, just like any vertical chair. Although all three duties are of equal importance I will focus in this inaugural speech on its research activities. But first some words on the term horizontal chair. The label 'horizontal chair' provokes a broad range of reactions. Some non-believers in the matrix structure have interpreted the name as a metaphor for the medical term DOA (dead on arrival), other people associate the name with leisure and laziness. I just follow my own interpretation and consider my assignment as 'knowledge integration based on vision'. Hopefully this lecture will convince you that this interpretation is a useful one.

vertical chairs led to very competent, but narrow science and knowledge areas. The underlying segregation of knowledge is based on historical developments of segregation and integration of aerospace related knowledge. This segregation and integration of knowledge in turn, is based on the functional segregation and integration found in aircraft and spacecraft developed over the last 100 years. The resulting aircraft architecture is illustrated in Figure 2.

Figure 2 Second S-Curve Aircraft Architecture (see for S-curves Figure 3)

Future progress will have to be based on understanding the roots of this segregation and integration, and on subsequent reinventing of the aircraft and spacecraft over and over again to implement progress in the many disciplines involved in aerospace science and technology. The latter
should lead to a constant redefinition of the segregation and integration boundaries.

The Faculty has taken the step to make this process the responsibility of the new set of horizontal chairs. This lecture tries to define the work content of the horizontal aircraft chair for the coming years as follows: to support the instantiation of the first steps towards a new aviation era. In this sense the horizontal chair is trying to cross the, at least in political Holland, currently assumed horizon for the aerospace world based on the conception of the air transport industry as a mature industry. Instead of a focus on stabilisation and efficiency the aim is to depict new horizons of technical progress and break unforeseen barriers.

This new era is still far away and needs considerable preparation before reshaping can start. This process will be long and costly, but it can reinstate the guiding role of aerospace for technological development.

THE EUROPEAN CHALLENGE IN AEROSPACE

In the strategic research agenda of ACARE, the Advisory Council for Aeronautics Research in Europe, the challenge for the aerospace world is outlined, Figure 3. Air transport is reaching the end of the second S-curve as far as improvement in performance is concerned. The demand for air transport, however, is expected to grow considerably in the coming decades. To make this growth sustainable new solutions will have to be created. It is not yet clear which technology can enable the entry into the Age of Sustainable Growth, the third S-curve.

Some aspects of the 3th S-curve aircraft systems identified by ACARE and relevant in the current context are given in Table 1. In the following sections the possible contributions of the horizontal chair to the achievement of these objectives will be highlighted.

THE PROSPECTS OF A HORIZONTAL CHAIR

The idea of a horizontal chair was and is subject of many discussions. From a scientific point of view the concept of a broad approach to the field of aerospace is contradictory to the idea of ongoing specialisation. Being part of a University at a time where scientific output of research activities is a major topic, the horizontal chairs have to give a view on their contribution to the progress in aerospace sciences. The easiest comprehensible view comes of course from the perspective of knowledge integration.
The traditional conceptual and preliminary aircraft design activities are the more accessible activities of the horizontal chair, and are therefore a constant part of its work. But there is much more that can be done. The horizontal chair should stimulate an object oriented attitude based on a multi-disciplinary interest and knowledge, with the objective to educate designers and improve design methodologies. Being the group that has to work with all the vertical disciplines it should have the better view on the rise and fall of present vertical segregation. To explain this we will now look at the history, the present and future of aeronautics.

Designing, the main reason of existence of the horizontal chair, is normally associated with synthesis: finding a solution that satisfies a set of requirements. The focus on synthesis assumes a segregation of functions of a future object, which is reflected in the requirements. For an aeronautical engineer the requirements can be organised in demands on flight mechanics, stability and control, aerodynamics, propulsion, structures and materials, Figure 4. This is reflected in both the segregation of activities in our Faculty and in the aerospace industry.

This segregation has clear roots in the development of aircraft. Started with the desire to imitate birds’ ability to fly, followed by segregation of required functions of aircraft initiated by Cayley (see textbox) and others, universities and industry find themselves in an institutionalised aerospace conception that hampers progress. It is the main function of the horizontal chairs to challenge this institutionalisation and to help shape a framework for progress. The consequence of this approach should be: reinventing the Faculty over and

<table>
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<tr>
<th>REQUIRED FUTURE AIRCRAFT SYSTEM ASPECTS IDENTIFIED BY ACARE</th>
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<tr>
<td><strong>Quality and Affordability</strong></td>
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<tr>
<td>- Increasing passenger choice.</td>
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<td>- Transforming Air Freight Services.</td>
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<td>- Creating a Competitive Supply Chain able to halve time-to-market.</td>
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<tr>
<td><strong>The Environment</strong></td>
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<tr>
<td>- To reduce fuel consumption</td>
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<td>- To reduce perceived external noise by 50%.</td>
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<tr>
<td>- To make substantial progress in reducing the environmental impact of the manufacture, maintenance and disposal of aircraft and related products.</td>
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<tr>
<td><strong>Safety</strong></td>
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<tr>
<td>- Reduction of the accident rate by 80%,</td>
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<td>- Reduction of human error and its consequences</td>
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<tr>
<td><strong>The Efficiency of the Air Transport System</strong></td>
</tr>
<tr>
<td>- To enable the Air Transport System to accommodate 3 times the volume of passengers, freight and air traffic by 2020 compared with 2000.</td>
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<td>- To reduce the time spent by passengers in airports to under 15 minutes for short-haul flights and to under 30 minutes for long-haul.</td>
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<tr>
<td>- To enable 99% of flights to depart within 15 minutes of their advertised scheduled departure time, in all weather conditions</td>
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*Table 1 Future Aircraft System Aspects*
Important in the development of the science of aerodynamics and aircraft design is Sir George Cayley who 'invented' the airplane in 1799. He came up with a design in which the lift generation and power plant are separated, which proved to be an essential conceptual thought. In his mind the power plant consisted of a set of oars, making it possible to 'row' through the air, see figure. Cayley made measurements of lift using a model attached to a whirling arm invented by the mathematician Benjamin Roberts. This whirling arm was the windtunnel of the 18th century. Instead of moving air over a fixed aircraft model, Cayley made the aircraft model move in still air.

Cayley was also the first to understand the principle of stability and control. His invention showed the application of dihedral in the wing and the use of a tail. He also understood that the required power would be dictated by take-off requirements and not by cruise conditions. In addition he came with the principle of diagonal bracing as a low-weight structural design principle.

Cayley's ideas were elaborated on by William Henson, resulting in the design (on paper only) of the Aerial Steam Carriage (1843), a model that never actually worked. Cayley continued his work on gliders, which resulted in 1853 in the first manned unpiloted flight with a heavier-than-air vehicle.

Over again, just like the aircraft itself is reinvented. To make this approach operational, both proper boundary conditions for the work as such and a shift of the work content are of importance. The former will be discussed first.
NEW ROOM FOR CREATIVITY

Some important boundary conditions for the work of the horizontal chair can be derived from the work of Drucker, ref.1. In his book he described some major challenges that we will face in the 21st century. A summary of these challenges and strategies to approach them are shown in Figure 5. Translating this to the Dutch situation we can identify four major threats and three major strategies to face them, Figure 6; one of the main issues in many countries, and certainly in the Netherlands, is the threat of politics. The dream of flying inspired Leonardo da Vinci to many of his inventions. His view and talent of observation is expressed in many of his drawings. The position of the modern aerospace scientist and the aerospace industry is illustrated by a parody of his most famous drawing, Figure 7; scientist and industry pictured as the ‘soon to be sitting duck’, this time with fear on its face and its back against the wall with only a shadow of the aerospace dream surrounding it, waiting for its final judgement. This position results from the immense success of the aerospace industry. Never before have so many people been able to travel so inexpensively all over the globe. This leads to the misinterpretation of politics and the public that aerospace has fully matured and can put all its efforts into optimising its efficiency within its current technological boundaries instead of stretching these boundaries. Getting aerospace back on the agenda as a technological challenge and rich source of innovation instead of a sustainability problem is a major challenge, especially in the Netherlands. This struggle for attention is keeping too much of our true intellectual property occupied with finance instead of technology.

In addition, many governments couple their investment decisions to the presence of related industrial activity within their geographic borders. The Netherlands is one of the countries that are extremely vulnerable in this respect. Without a self-creating aerospace industry, the willingness to invest in aerospace related research and education is very limited. It is easily forgotten that one’s research agenda should follow the agenda of European politics and industry. The Dutch contribution to the European research fund can only be beneficial for the Dutch society if we co-develop knowledge within the European context. Investing through Brussels in combination with direct support within the Netherlands is the only way forward. Cutting resources and eliminating knowledge centres in the Netherlands is far from creating a Dutch knowledge based society in a European context.
A second major threat is the reluctance of young people to add to the progress of science and technology. Fortunately aerospace is still a technical area that attracts young people to a technical study. However, its responsibility for the future of many other fields of non-object centred technology is growing disproportionally. Object oriented education is therefore the only way forward to ensure a western society that can fulfil its own need for trained brains. For the aerospace industry however, this means that it has to share its future resources with more and more technical areas. It is the responsibility of both politics and the Faculty to use and exploit this ability in a proper way. Progress is made by people, and in our case well-educated people. Education must be regarded as an investment, never as cost. Proper education in technology requires well-equipped laboratories.
and facilities in combination with a well-balanced compilation of historically based explanations, industry focussed training and future oriented mind shaping. The increasing complexity of technology should lead to more intensive education instead of minimisation of education.

A third threat is the increasing complexity of products and processes in aerospace. Aircraft are a very complex means of transportation in which development, production and maintenance are very costly and, as a consequence, very risky. Progress requires proper focus and constant re-invention of rules and regulations to remove unnecessary roadblocks. In this context a major role should be reserved for the certification authorities. Their role should be enabling and stimulating instead of repressing and blocking. It is a challenge for the government to reshape its organisation in order to make it a tool for policy making and policy implementation. Feasibility of technical progress is often just the result of political willingness and decisions.

A fourth, and in the context of this lecture last major threat is the dawning scarcity of engineers. For aerospace engineering this problem is worsened by the reduction of experience of each individual engineer, Figure 8, due to the combination of the reduction in number of aircraft development programs and the increase in complexity and duration of each new program. As a consequence and as a challenge less people will have to do more in the future. In combination with the third threat this leads to the conclusion that our future engineers should be much more productive. Drucker has expressed this need in many of his more recent publications. The increase of productivity of labourers through mechanisation and automation has lead to extremely affordable and accessible technology in sectors of mass production. This success, however, is not transferable to low volume production sectors. There, the cost of the design and engineering effort is the major determining factor for accessibility and also a major limiter of progress because of the irreversible effects of project shutdown on the sustainability of companies.

Figure 8 Reduction of available experience, ref.2.

It is a major challenge to the engineering world to find a way to improve its productivity considerably. One should think about a required twofold increase in this respect as a first step.
product development should take this aspect into account. Working in the virtual enterprise and bringing together many different disciplines from over the globe to work together in one huge project must be taken as the perspective for the future of the aerospace industry.

Engineering has always been considered as an exact science where decisions were based on clear, measurable criteria. This is not in accordance with aerospace practice. Many decisions, which should be based on technical criteria, are instead taken on political bases. This leads to divisions - segregation - in systems based on production volumes over different countries instead of divisions based on system efficiency criteria. This will, however, not change in the near future so it has to be regarded as a given constraint for further discussions.

The aerospace sector has to compete with many other sectors for financial resources. This is valid for both governmental financial support as for investments by the financial markets. Therefore progress has to be made in a sequence of steps, each one of them leading to a measurable return on investment. For governmental support this return must be seen in a broader sense. Growth in the amount of graduated engineers should be regarded as a return on investment.

FORWARD THROUGH RENEWED INTEGRATION

There is a major interest in multi-disciplinary design and optimisation, both in the industry as in the research community. The current design approach, however, is based on the traditional division of disciplines in the aerospace
world. Integration is, therefore, a partial sum of the traditional disciplines without a proper and critical review of the underlying segregation and resulting integration.

This approach is doomed to get extinct although the underlying idea is right and important. A re-segregation of functions of aircraft and spacecraft as objects should be the first step to take. This is one of the areas where systems engineering could have a positive contribution. Its methods of requirement analysis and functional requirement compilation are of substantial interest here. This in contrast to the heavily overrated use of the systems engineering approach in the more creative parts of product development processes. Here the methods and theory used in industrial design and architecture are much more applicable.

Through the requirements analysis approach, a refined segregation of functional requirements must be the basis of the subsequent synthesis. The segregation should be reinvented on a regular basis to follow new market needs, to follow new technological solutions to old problems and to implement new technologies for un-precedented possibilities.

Subsequent integration is, therefore, also a continuous process of reinvention. New needs and technologies have to be synthesised to fulfil the requirements in an effective way. Proper integration borders are a function of product scale, production volume and state of technology readiness. Continuous improvement and re-segregation and integration must be the mind-set of each designer and, therefore, of each horizontal engineer. This clearly illustrates the need for re-segregation and re-integration of education and of the industry and the need for continuous learning of industrial organisations and their resources. Venture theories such as resource based views are a first step in this direction although still very much based on traditional and steady state divisions of resource knowledge boundaries.

Propositions for integrated solutions to multi-disciplinary requirements can only be judged through proper validation. For complex products the size of progress steps is considerably limited by the cost of validation. In the early days of aircraft development, simply building a prototype and trying it out was an affordable approach to design improvement. Nowadays the necessary steps to create real progress in performance are so complicated that validation has to be done on reduced models of the real object as much as possible. This means that mostly computer-based simulations, validated with small scale models are to be used. However, the validation of the models is no longer close to validation of the real object. Therefore, big steps are becoming more risky. Development of proper tools, therefore, becomes of the utmost importance. In order to create co-operative tools that allow the designers to explore new passages into the future in an effective way, close co-operation between tool builders and object designers is crucial.

This future can be based on a very rich past. Many aircraft configurations have been invented of which only a few have been elaborated for practical use. An overview of this past in the form of a 'Darwinian tree' is shown in figure 10. To judge these concepts on their potential contribution to the 3rd S-curve and taking into account the developments in all aerospace disciplines we need the aforementioned tools to provide us with cost-effective predictions of the properties of new combinations of functions, technology and configurations, Figure 11.
PRODUCTIVITY ENHANCEMENT

The productivity of engineers in the aerospace world will have to increase substantially to keep development costs for increasingly complex objects within affordable limits and also to fulfill the total demand on resources for future developments. The reduced interest of young people in technical studies and the decreased birth rate in the western world will demand an increase in productivity in order to be able to face future needs of skills.

It was long believed that the information technology would automatically increase our productivity. For sure, IT has increased productivity when measured in the amount of generated information per person. However, the possibilities to generate information with the IT tools led to an increase in demand of information e.g. from airworthiness authorities. This effectively led to a decrease in productivity when measured in number of engineering hours required per aircraft program.

IT does allow us to create more and more data on our proposed designs and create different views on our activities in an early stage of the development. However, IT has not been able to significantly cut cost or development time. Drucker, ref.1, claims that the real increase will only come if we shift our attention from the technology part of IT towards the information part of IT. We should use IT to clearly record, manage and re-use existing knowledge and to support knowledge enhancement. Current IT systems have mainly created knowledge requirements to keep the IT system running and to manage all our new analysis tools without delivering a real contribution to the afore mentioned areas.
It is my strong feeling that proper use of existing IT tools and development of proper IT tools for recording, managing and re-using existing knowledge and to support knowledge enhancement is the first step to enable real progress in the field of aircraft and spacecraft design.

This focus on knowledge as the basis of our engineering activities is better known as Knowledge Based Engineering (KBE). This will be the main subject of the remaining part of this lecture. It will be shown how KBE can help us face the aforementioned threats, while meeting the related constraints. The KBE technology helps to structure and record knowledge in such a way that (engineering) knowledge becomes reusable, transferable and expandable. The reuse and ease of extending of knowledge will help to meet the increasing knowledge demand. In effect it will enable the required productivity enhancement and will bring a new challenge to young people. It will also help to initiate the so-called knowledge society that will make it easier for western countries to compete with low wages countries.

**KNOWLEDGE BASED ENGINEERING**

At many stages design tools are supporting the design process. To make a categorisation of these tools possible in the context of this lecture, it is first important to define the basic steps of the design process, Figure 12.

For each of these steps tools are being developed and used. The tools can have different appearances; they can be methods and data presented in sheets or handbooks; they can be software for recording and analysis like CAD programs and CFD software; they can also be humans being consulted.

![Figure 12 The Basic Design Cycle](image-url)

Each tool is a kind of substantiation of design supporting knowledge. All tools together, added to the knowledge and craftsmanship of the designer, complete the knowledge base for the design work. In this context designer should be read as design team. What in a modern context is called a multidisciplinary or integrated design team can be as small as one person but also as large as thousands of people. Especially the larger teams can benefit enormously from improved tools.

Knowledge based engineering is a modern approach to the compilation of knowledge required in a product development process. Before discussing the possibilities of this approach as a means to really introduce concurrent engineering in the
early phases of the design process, freeing the mind and time of the designer for creativity, i.e. creating knowledge, we first discuss what KBE is and how it is applied today.

Knowledge based engineering is the science of identifying, recording and re-using engineering knowledge. By combining proper methodologies and IT tools, engineering knowledge can be recorded in re-usable rules in addition to data. These rules can be applied to different sets of data in order to generate new instantiations of the knowledge in new products. A comparison between the traditional design process and the knowledge based engineering design process can be made with the help of Figures 13 and 14.

In this way families of products can be defined in rules, and family members can be generated automatically based on an input data set. Many examples of this way of working are available now for more or less complicated products. In the aerospace industry the KBE applications are generated inside the integrator companies and used by these companies and their subcontractors for detail engineering purposes. This way of working has already proven to be cost-effective and to result in considerable lead time reduction. However, this way of working does not yet help the freeing of intellectual resources for improved creativity. It mainly automates repetitive activities in the detail-engineering phase by very useful cost reduction, which eliminates the need for the western world to search for low cost engineering capability in low-cost countries.

The potential of KBE, however, is much larger. It can help us to approach the challenges mentioned earlier. A proper application of KBE in the conceptual and preliminary aircraft design stage can free intellectual resources for knowledge creation instead of just knowledge application. We will now discuss an initial application of this concept: parametric modelling of complex products.
PARAMETRIC MODELLING

The CAD system is the most widely applied tool in the synthesis phase of the design process. CAD systems are generic tools that can be used to create a geometric model of the design and to perform some basic engineering analysis on it.

Current generations of CAD systems are mainly feature based, which means that they have a standard set of parameterised primitives that can be tuned and combined to represent a design, Figure 15. The knowledge recording capability and related learning capability of these systems are very limited. Their simple primitives are the main limitation in that respect. Feature based modelling is a nice technique in the detail design phase that can be coupled very successfully to earlier discussed KBE principles. However, on a higher level of abstraction the feature based approach is too primitive to capture the knowledge behind complex products. For a CAD program an aircraft wing will always be a set of surfaces and solids, never, for instance, a lift generating object compiled from different wing sections with leading and trailing edge devices and an internal structural concept. However, if one looks at the work of the conceptual aircraft designer, it is this global modelling approach that he is looking for, not a primitive feature based approach. When the conceptual designer wants a geometric representation of his ideas he would like his knowledge based engineering design environment to create this geometric model and generate the corresponding CAD drawings.

The conceptual designer wants to be able to compare different solutions of a design problem in a fair trade-off. He can do this by integrating high level elementary solutions with global solutions and have their properties evaluated in a flexible way. Progress in aerospace will be based on new
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concepts and new configurations. These new concepts and configurations can only be applied if properties can be predicted in a cost-effective way in order to reduce the risk of failure. Development costs are so high that a single project failure can be disastrous for the company sustainability. To facilitate the conceptual designer, a KBE system should supply high level primitives, like wing trunks, fuselage sections, power plant sections and landing gear sections, Figures 16 and 17. In addition, it should be easy to train the system or a system operator to add knowledge, in this case new high level primitives that represent the newly created knowledge in the design process.

High level primitives can be combined to represent the solution proposed by the designer. Combined primitives can be analysed to find the properties of a proposed solution. These properties can be compared to the requirements and, if necessary, the instantiation of the high level primitives can be adjusted to follow the designer’s thoughts about improvements.

![Diagram](image_url)

**Figure 18 Design and Engineering Engine**

In this way a design support tool is created that can free the mind and time of creative designers to work on new paradigms. This design tool can be referred to as a Computational Design Engine (Morris, ref.2) or as a Design and Engineering Engine, (DEE). Their basic skeleton is shown in figure 18. It should be clearly noted that DEE’s are used to support the designer in manipulating his ideas by modelling and analysis, not to take over the creative function of the designer.
The concept of the DEE's is based on different developments in the field of management and IT. The management world provided the idea of family thinking as a concept to re-use production knowledge and equipment for larger product volumes. By identifying family similarities in different products and using flexible production units, the scale effect can be used for production cost reduction. IT is creating tools and programming environments based on artificial intelligence principles that allow for the recording of the engineering intent behind a product design in rules. The rules, combined with a proper set of data, can generate a family of products. Using the principle of object oriented thinking and programming (ref.3), high-level primitives can be created in a generic programming environment to produce a specialised design support environment.

The DEE itself can be seen as a high level object itself. It defines different methods (e.g. analysis tools) that can be applied to a specific class of objects. The class we want to work on the conceptual aircraft design level is the aircraft. An instantiation of this class is built up of different high level primitives. This compilation of primitives results in a product tree, the basic knowledge carrier of the design. The methods to be applied on the class of products can be internal and external methods. The currently available IT tools allow for programming of different tools inside the product tree. However, most users on this level would like to use the commercial tools available on the market like FEPackages, costs analysis tools and CFD tools. The DEE should supply transparent bi-directional interfaces to these tools. In this way external methods are created to complete the class under consideration. These interfaces form one of the key issues for future development of DEE's.

DEE's can be created for different scales, Figure 19. After the aircraft conceptual design phase one wants to proceed with the preliminary design and the detail design. The detail design itself can be divided in the conceptual, preliminary and detail design phase for many of the aircraft subsystems. In the future the DEE's should allow for coupling of knowledge on different scales of the design. Starting from a certain design phase one would like to use the results of that phase as starting knowledge for the next one. Through proper coupling one could start at the conceptual phase and end at the detail definition. On each level the relevant methods, i.e. analysis tools, are included in the related DEE to incorporate multi-disciplinary, concurrent engineering.
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The parametric modelling part is the current main problem when creating DEE’s, i.e. the creation of robust high level primitives that are easy to extend. If we want to perform aircraft multi-disciplinary design, analysis and optimisation, we need parametric models for these aircraft. Some initial research in this field was done by the horizontal aircraft chair, the Systems Integration Aircraft group of the Faculty (SIA). Some of the results will be discussed here.

To show the position of the parametric modelling phase in the design process, Figure 20 is used. The top part of the figure shows the diverging character of the synthesis phase. Many potential solutions are generated for the design problem. In a subsequent converging process the different potential solutions should be analysed and trade-off studies should be made to proceed to the next design level. To facilitate a proper trade-off, the design status of the different solutions should be at an equal level. This is normally done through a first analysis and optimisation step. For this we need models of the different solutions to feed the different analysis tools. These models have to be updated several times during the optimisation, to incorporate improvements suggested by a designer or optimiser. This process is lengthy and costly due to a considerable amount of handwork required. Normally, a pre-selection of the potential solutions is used to limit this effort. In many cases time and financial constraints lead to the elimination of promising ideas. It is in this phase that parametric modelling would help to broaden the exploratory solution domain.

Figure 20 Different aspects of the design process and the position of parametric modelling

If we look at the current literature on multi-disciplinary design and optimisation, it becomes clear that true parametric modelling of complex products is not applied. Optimisation of very simple design solutions is performed by very complex optimisation tools, which often leads to very well known parameter values. KBE allows the creation of parametric models of complex products through the implementation of full parametric high level primitives and a set of operations (addition, subtraction etc.) applicable to these primitives.
the proper connection of the external contours and the internal structure. Finally the generative model can create input for several tools for subsequent analysis. With this primitive, a building block has been created with which a large range of aircraft wings, tails and movables can be built or even a blended wing body aircraft. This potential is shown in Figure 17 and 22. By adding a second primitive, the fuselage, a large range of aircraft can be modelled in a parametric way. This is also illustrated in Figure 17.

Figure 21 Wing trunk high level primitive

The parametric modeller for aircraft on a conceptual design level consists of segregated knowledge carriers. Here, one of the knowledge carriers, the so-called wing trunk, will be discussed a bit further to illustrate its potential, Figure 21. The primitive under discussion, the wing trunk, is a building block that allows designers to build a parametric model of every part of the design that can be seen as a member of the family of aircraft parts with the function of creating aerodynamic forces. The external contour of all these parts is the basis for their appearance. The wing trunk parametric model allows for the specification of any number of definition curves as a starting point. The generative model, a name used in KBE to depict a model that can generate itself based on a set of input data, creates the external surfaces and the internal structure of the wing trunk based on all the input data given by the designer.

The generative model can add an instantiation of a wing trunk to other instantiations of the wing trunk, taking care of

Figure 22 Movables based on the wing trunk and an end cap high level primitive

These simple examples show that the KBE tools are extremely powerful and allow for the creation of DEE's. The results can be seen as proof of feasibility and give some assurance that any effort in further development of the DEE concept is useful and is likely to contribute to a solution for future scarcity of intellectual resources and virtual enterprises.
NEXT STEPS TOWARDS DEE’S

To create DEE’s not only parametric modelling is required but also solutions for the other blocks shown in Figure 18.

A proper initiator tool, the tool that creates a first set of parameter values for the primitives in the parametric model, is needed to further support the designer. A first initiator tool for the aircraft conceptual design level has been created by SIA. It is a software tool in which a large amount of conceptual design knowledge, both data and methods, was recorded. It helps to create an educated, knowledge based, first estimate for the parameter values of a specific solution.

To support the designer in the exploration of his ideas, a proper link to different analysis tools is required, Figure 23. Some connections were realised for the parametric models discussed before. These connections are basically tools that contain knowledge extraction and transfer capability, and that combine this capability with knowledge for the control of the analysis tools. Creating robustness and generality to make sure that they work for a wide range of instantiations is the major challenge for further development of these connections or interfaces.

The multi-disciplinarity of a DEE is reflected in the number and range of analysis tools that are included. Current experiments are limited to structural and aerodynamic analysis, Figure 24. Future versions should include many other fields of interest. Cost analysis is one of the first tools to be added.

In order to make the DEE fast and easy to use, it would be worthwhile to design and implement an interface to the combinatorial phase of the generative model creation. A graphical or even voice operated tool to select, instantiate and combine high level primitives, could create a high level support tool for a product development team.

Besides implementation of ideas in an actual set of DEE’s, it is even more important to get a better understanding of the underlying principles that will make the DEE robust and effective. The first scientific steps to be taken are the development of theoretical models that define more accurately the relation between DEE’s and e.g. the theory of object oriented programming (OOP), rule based reasoning and intelligent agents, ref.4. The examples shown in this
booklet were made with the KBE software package ICAD. The product model in this case includes all the design activity steps applied to the objects. Future design packages will probably separate the product models from the design process steps. OOP and intelligent agents will play a major role in these developments. This should ultimately lead to a practice of parametric modelling and subsequent DEE instantiation for many design problems. In this way the required intellectual resources for major steps in the development of aircraft and other complex systems can be facilitated. An example for a simple DEE supporting the design of smart panels is shown in Figure 25.

This DEE supports the design and implementation of smart materials for active noise reduction. This technology demands considerable analysis and several optimisation steps to create feasible instantiations. When applying this technology, the use of trial and error is prohibitive. A DEE gives the required cost reduction.
TO CONCLUDE

I hope that this lecture has shown the challenges that lay ahead of us in relation to cost-effective and innovative aircraft design. It will be an interesting task for SIA to contribute to the integration of knowledge management and engineering, aerospace sciences and information technology to achieve truly sustainable knowledge growth.

At the end of this lecture I would like to thank Theo de Jong and Adriaan Beukers of my Faculty for their continuous trust and most of all my wife Valeria Antonelli for all her support over the past years.

REFERENCES