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Abstract.
In this paper, the migration of European aeronautics organisations towards virtual and extended enterprises is described. This change in business processes stems from international competitive pressure as well as from new ways to co-operate over company and discipline boundaries thanks to technological developments such as the Internet. Developments in European civil aeronautics are compared to developments in the United States and elsewhere. An overview is presented of information and communications technologies and tools as enablers for extended and virtual enterprise networks. Finally, the indispensable role of the European Union and the Information Society Technology programme with respect to European developments in aeronautics and other sectors is described.

1. Introduction

The aeronautical sector provides high-quality employment across Europe and plays an important role in strengthening the position of European businesses in aerospace and other sectors. Important stakeholders are aeronautical industries, suppliers and research establishments, aircraft operators, governments and agencies concerned with transport, environment, and public health, suppliers and consumers of education and training, and last but not least European citizens undergoing positive and negative effects of various types of mobility solutions. Fulfilling current and future requirements of these groups and providing cost-effective and high-quality solutions is of primary importance to European aerospace.

Moreover, Europe's society as a whole benefits from a strong position of European aeronautics. Many of the technologies and products developed in the aeronautics sector are transitioned to other sectors through business innovation of organisations that supply products to both aerospace and non-aerospace sectors. Efforts needed by these often small- and medium-sized companies to comply with stringent aerospace requirements strengthen their position in other areas. Technology transfer and personnel movement also form important means to stimulate other sectors.

In this paper, transformations are described that take place in the aeronautics sector as an answer to the requirements and constraints posed by customers as well as by government and society. Market pressure on the one hand, and information and communications technology on the other hand, are radically transforming the way organisations operate. Aeronautics stakeholders are in the process of forming virtual and/or extended enterprises, in which people and organisations participate in dynamic, interdisciplinary co-operative efforts, spanning organisational and geographical boundaries. An overview will be given of developments within European civil aeronautics as well as in the United States and elsewhere.

Information and communications technology play a key role in future extended and virtual enterprises by providing the backbone networking infrastructure and by providing methods, techniques and tools for co-operation, knowledge conservation, learning and re-use across organisational, geographical and cultural boundaries. Based on current European projects, examples will be given of development and application of new approaches for aeronautical engineering and manufacturing spanning organisational boundaries.

Finally, the instrumental role is described of EU research, technological development and demonstration for innovation and sustainable development.

2. European aeronautics and air transport

The aeronautical sector is an important contributor to European economic and industrial competitiveness. Aircraft manufacturers, engine and equipment industries alone have a consolidated turnover of ECU 35 billion per year, of which more than 20 billion ECU results from exports strengthening the EU balance of trade. The industry directly employs 330,000 personnel. The total turnover of the European airline industry is estimated above ECU 50 billion per year. The 25 major European airlines employ more than 310,000 people [1].

European aeronautics industry, research establishments and airlines aim at continuation and extension of their global market share. Fierce competition exists on a global market with respect to customer requirements, time-to-market and profitability. Purchase/lease costs, as well as life-cycle costs, often translated in direct operator cost per seat, are major issues for aircraft operators in their strive for air traffic market increase. In parallel, innovative capabilities must be included by aircraft and engine manufacturers as well as by other partners in the total life cycle in response to requirements in the areas of safety, noise abatement and reduction of environmental effects. Industry and research establishments need to find ways to devise and incorporate new technology in fulfilment of current, emerging and future requirements and to engineer and manufacture new aircraft, subsystems and components.

To deal with market requirements and opportunities, and to spread investments and risks, European engineering and manufacturing industry, research establishments, universities and individual citizens are engaged in an increasing variety of co-operative activities. These range from education, life-long learning and employability to participation of personnel and organisations in (parts of) product life cycles. These encompass research, engineering, sustainable development, deployment, maintenance, phase-out, and reuse of knowledge and materials.

To realise the envisaged air traffic market increase, not only safe, environmentally friendly and cost-effective aircraft must be developed. Better transport of passengers and freight must also be achieved, through harmonised air traffic throughout Europe, and through a passenger-attractive infrastructure at airports integrated with other transport modalities. Safety and environmental effects need to be maintained under growing traffic volumes. This complex of factors warrants an integrated approach as already exemplified by the European Air Traffic Control Harmonisation and Integration Programme EATCHIP and by co-operative research and technological development by industry, research establishments and aviation authorities on air traffic and airport systems as part of the EU fourth framework programmes.

As a consequence, there is a strong increase in co-operation between different aerospace stakeholders.

3. Towards aeronautics virtual and extended enterprise networks

Market pressure on the one hand, and information and communications technology on the other hand, are radically transforming the way aerospace organisations operate. Aeronautics stakeholders are in the process of forming virtual and/or extended enterprise networks, in which people and organisations participate in dynamic, interdisciplinary co-operative efforts spanning organisational and geographical boundaries. Through better, cost-effective collaboration, competitive products and services can be provided.

US best practice in aircraft research, development, and manufacturing, has demonstrated dramatic results in development time and cost reduction. Excellent example in a civil context is the dramatic reduction of development time and cost Boeing and its suppliers have achieved through the adoption of concurrent engineering and supply-chain management practices for the Boeing 777. In a military context, similar examples can be found in on-going work in integrated product teams and extended enterprises for modern military aircraft such as the F-22 and the Joint Strike Fighter. US organisations, in close co-operation with US Government, are actively

developing, promoting and supporting standards, technologies and tools that will enable manufacturers and their suppliers to effectively inter-operate. Two influential examples include the Continuous Acquisition and Lifecycle Support (CALS) initiative [2], and the $60 million National Industrial Information Infrastructure Protocols (NIIIP) project, which is seen by the US Advanced Research Projects Agency as one of the fundamental building blocks of the (US) National Information Infrastructure.

The goal of the CALS initiative is to enable integration of enterprises on a world-wide basis. CALS began primarily as a US Government and US defence industry effort to integrate systems development, production and support. In the early 1990s, the US Department of Defense set a goal to integrate enterprises on a world-wide basis, to enable parties working on defence systems to be able to work from a common digital database, in real time, on the design, development manufacturing, distribution and servicing of products. Originally named Computer-aided Logistics Support, first focus and initial results were in logistics. Current efforts focus on common data bases using AECMA 2000M (international Specification for Material Management Integrated Data Processing) and AECMA 1000D (International Specification for Technical Data Publications, utilising a Common Source Database), on process improvement, on concurrent engineering, on technical information exchange using STEP (Standard for the Exchange of Product Model Data, ISO 10303) and SGML (Standard Generalized Markup Language), on information infrastructure (enabler for the virtual enterprise), and EDI/EDIFACT for exchange of messages, including electronic purchasing.

Although CALS began as primarily a US defence effort, it has become recognized as an important activity by the US Department of Commerce, by other governments, by NATO, and by large industries such as Boeing, Lockheed Martin, DAEWOO, NEC, Aerospatiale, British Aerospace, FIAR and many others to achieve enterprise integration throughout the world. All efforts aim at the central CALS paradigm: "Create once, use many". In addition to these activities, harmonisation of standards (US Defense, US civil standards, European aircraft industry standards (AECMA), international) is an on-going process. As a consequence of changes in military directions in the US and because of the internationalisation, current direction is towards international standards [3.

The NIIIP vision is to make US industrial companies more globally competitive and efficient through a new form of collaborative computing that will support the formation of Virtual Enterprises [4], [5]. The US Government contributes about 50% of the funding, to enhance the US information infrastructure, to improve competitiveness of US industry, and to stimulate job growth.

In Europe, aeronautics organisations have recognised the benefits of multi-national collaboration for decades, as can be seen from the grouping of companies developing the Airbus family of aircraft, and from a variety of research and technologies programmes. European companies are investing in the re-engineering of their processes, and have started to streamline and define best practices through the whole supply chain when developing and producing new aircraft. A major new programme in this direction is the ENHANCE applied research and technology programme, aimed at defining the fundamental kernel of common ways of working needed to efficiently promote the establishment of extended and virtual aerospace enterprise activities in European aeronautics. Main objectives of ENHANCE are:

- to define the new common way of working in Europe for aeronautical product development, throughout the entire aircraft lifecycle, and throughout the whole aeronautics supply chain,
- to document the associated engineering methods and organisation guidelines,
- to propose a set of demonstrating tools for aeronautical concurrent engineering future implementation,
- to assess and test innovative information technology for concurrent engineering,

- to validate the new approach through a wide range of industrial experiments, called business case studies, based on large-scale realistic industrial scenarios,
- to disseminate the outputs to the whole aeronautics supply chain through a dedicated organisation specifically set up for this purpose,
- to influence the emergence and adoption of standards in the concurrent engineering field.

Currently, too much time is spent in exchanging information, in build-up of mutual understanding, in translating data and in understanding working processes between different companies. Therefore, the main purpose of ENHANCE is to create a set of common references in aeronautical industry to drastically improve understanding and collaboration between people in the following engineering domains: Product Engineering, Life Cycle Model and Business Management, Technology and Methodology for the Extended Enterprise. Within these domains, a number of topics have been identified (see figure 1) that together will enable developers to achieve a common way of working without necessarily imposing a homogeneous computing infrastructure over all participants. The focus is on creating a team transgressing company boundaries that will satisfy customer requirements by easily and rapidly creating innovative and cost-effective solutions.

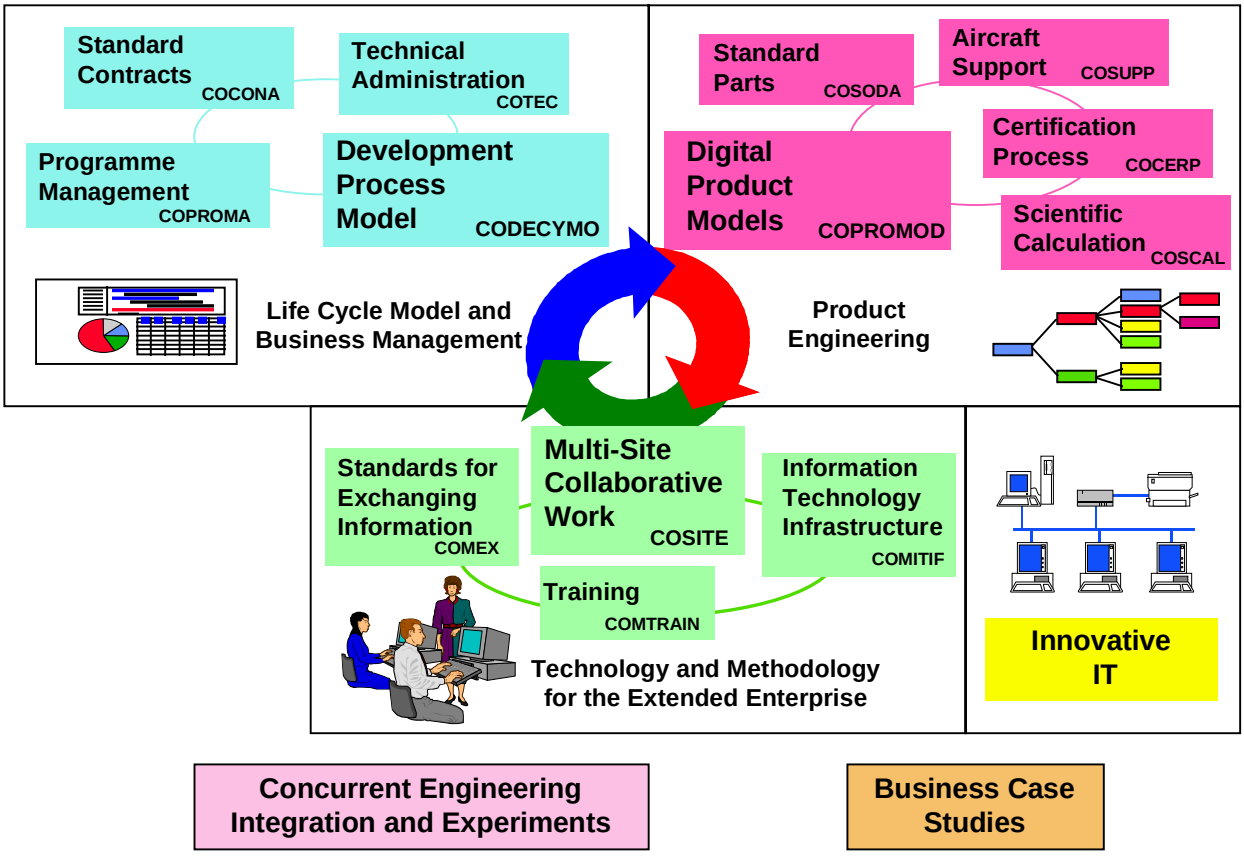

Figure 1. The engineering domains and sub-domains where ENHANCE intends to create common ways of working.

The ENHANCE consortium has been built around major aeronautics stakeholders in 10 European countries (air frame manufacturers of large and small aircraft, engines, equipment, helicopters, research centres, SME suppliers and airlines). Over the next three years, these companies will be co-operating to define the kernel for extended and virtual enterprises without which Europe will not be able to continue to succeed in the world wide aerospace market.

4. Telecommunications, media and information technologies and tools

To be able to provide timely, effective and affordable solutions in a growing market while satisfying demands on safety and environmental issues, it is necessary to integrate and harmonise computing infrastructures, standards and procedures throughout Europe in a way that every stakeholder has access to relevant parts of the infrastructure. Both existing organisations as well as virtual and extended enterprises are facing challenges in setting up teams of participants from different disciplines and backgrounds in such a way that mutual understanding as well as generation, exchange, presentation, conservation and re-use of data, information and knowledge are quickly established and exploited.

Telecommunications, media and information technology are providing building blocks upon which an environment can be built that supports a co-operative infrastructure for information processing and knowledge management. For aeronautics co-operation in extended and virtual enterprises and for dissemination of results within the aerospace sector and to other sectors, the following topics are of major importance:

- Affordable, reliable and secure high-performance networks throughout Europe: Without proper high-speed connections over country borders, efficient large-scale collaboration, including visualisation, is not possible in a data- and information-intensive environment.
- Low-cost wired and wireless access to the information infrastructure throughout Europe: Not necessarily of the same capacity, access to information shall be available to all stakeholders in the aerospace information society. Access via e-mail and world wide web services based on open international standards, under proper safeguarding of privacy and security, are essential for a true Information Society.
- Education and training: A well-educated work force is a strong point of European society. To arrive at a work force that is educated optimally for the tasks at hand, a seamless integration of working and learning environments needs to be achieved. Access from educational institutions to working environments and vice versa should be stimulated.
- Standards for information exchange: As companies move towards the adoption of extended enterprises, the need to be able to exchange information becomes increasingly important. Integration of network and information infrastructures can only efficiently be carried out if these rest on open standards which continuously comply with the speed of change in technology and which are supported by state-of-the-art tools. For aerospace, further development of international standards and application protocols in the areas of Digital Product Modelling, Computer-Aided Engineering/Computer-Aided Manufacturing and virtual reality remain of major importance. These need to be easy-to learn and use and affordable for all participants. Public availability of information about standards of exchange of information, and dissemination via the excellent EU Open Information Interchange site [6] needs to be maintained.
- Multi-site collaborative work: Since the 1980s, various types of systems supporting co-operative work have emerged. These vary from simple e-mail and computer conference systems to more elaborate forms of groupware, in which the focus is on information sharing in addition to information exchange [7]. Current developments are in the areas of management of processes, teams, data and tools (digital product modelling, workflow management, know-how management, multi-modal interaction) in distributed heterogeneous environments [7], [8], [9], [10]. Organisational modelling in such a way that entities, roles and capabilities can be modelled quickly and dynamically, e.g. through the use of ontologies [11] and agent technologies [12], is becoming more important. Heterogeneous distributed networked environments that support instantaneous collaboration across organisational and geographical boundaries, while protecting information and other assets that shall be guarded against unauthorised use, are a key enabling technology in the set-up and maintenance of collaborative environments. These need to be supported by hardware and software architectures [13], frameworks [14], [15], methods, techniques and tools to create working

and learning environments that can easily be tailored to specific project needs [16]. Collaborative working environments based on inter-, intra- and extra-nets promise ease of collaboration and of individual learning. For a growing number of aerospace applications, synthetic, virtual reality, telepresence and/or immersive environments are being developed [17], [18].

- Software-intensive systems form an important part of the aerospace infrastructure. Besides the topics mentioned above, current developments in software architectures, based on frameworks, e.g. with objects, agents or components connected via a software bus, promise ease of integration of heterogeneous computing environments. Further advantages include re-use of investments in company- or industry-specific knowledge and products [14], as well as ease of (re)configuration.
- Finally, system and software dependability and certifiability is a very important topic. Both on-board and ground-based systems contain large quantities of software upon which we have come to depend. This is a topic that deserves much more consideration and stimulation than is currently the case (with the notable exception of the UK).

The aerospace and automotive sectors are already very active in these areas. Examples are the definition and adoption of the STEP standard and its application protocols [19], [20], the definition and construction of a virtual multi-discipline design, analysis and optimisation of aerospace vehicles environment [10], management of processes, teams, data and tools in computer-aided control engineering [8], [21], and enterprise enhanced operation through network middle-ware [16], [22], [23]. To keep up with developments in the United States and elsewhere, continued stimulation by the European Commission is indispensable.

5. European Commission programmes as a key factor for European aeronautics

The objectives of the European Union can broadly be described as creating and stimulating economic, political and social cohesion and the harmonious development among the member states. The European Union focuses on a number of policy areas such as [1], [24], [25]:

- strengthening the European Industrial base, in which the aeronautical sector plays an important role,
- creating a harmonised European transport policy, emphasising the need for free flow of people and goods, the increase of safety and the reduction of environmental impact related to transport,
- creating a strong European technology base, through European co-operation, the optimal use of human resources and facilities as well as dissemination of knowledge throughout Europe.

In order to support these activities the European Union implemented multi-annual framework programmes for research and technology development. The participation of the aeronautical sector in these programmes has not only resulted in realising the European objectives, but also created closer links between organisations and people that otherwise would not have been established, thus having a substantial impact on closer European co-operation and coherence [1]

The future of European aeronautics offers tremendous opportunities. Apart from short term development of deriviatives of highly successful European aircraft, new visions have been developed for new products: from very high capacity aircraft, regional and high speed aircraft to flying wing concepts and hypersonic planes. Moreover, harmonisation and integration of European air space and measures to increase airspace and airport capacity while maintaining safety and reducing environmental effects, are of major importance in the transport area. Co-operation over organisational and country borders will be imperative to successfully compete in a global market place.

As can be seen from needs and options for future research in the area of Information Society applications of general interest [27], many of the topics identified above as being of major

importance are contained in key research items in the Information Society Technologies Programme. Therefore, the aeronautical sector will maintain its role as forward-looking element in the private sector and contribute actively in the programme. From the European Union, an active approach is expected towards affordable access to public networks services, and towards removal of existing and potential barriers as identified in the Green Paper on Convergence [26].

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