INTER-REGIONAL IMS PROGRAM
INTELLIGENT MANUFACTURING SYSTEMS

FINAL PROJECT SUMMARY

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November 2004

EXECUTIVE SUMMARY

Composite based Manufacturing has been until now supported mostly by large military, aerospace and material enterprises, traditionally involved in engineering and manufacturing of high performance products, which could afford the time consuming trial-and-error experiments and certification processes for high-volume production of long-life products. Recently, however, projects on composites applications can be increasingly found in the civil-commercial business, characterized by customized solutions, faster time-to-market, short-term turnaround, and stiffer competition. This business is in itself well suited to Small and Medium Enterprises (SME). This requires, however, that SME relinquish the traditional role of supplier to major industries and start to co-operate, to form networks and participate to the chain of added value as *co-designer* and *co-maker*, thanks to improved capabilities for design - an ongoing trend.

These are the questions addressed by the project INCOMPRO. *INCOMPRO activities focused on design*, seen as a key process to minimize the time lag from product conception to cash and as a continuous aspect of the whole production process. INCOMPRO deals with *Composites* as the essential building materials of a new group of products, defined as *intelligent*. They are called so because of their inherent physical and morphological properties, thanks to which they adapt themselves to working conditions. Among the products that have inspired this project, and which seem well suited to it, the following can be mentioned: marine propellers, liquid ring compressors, booms for sailboats, structural panels for trains and planes.

This project basic aim was to realize an Intelligent Engineering Framework, called *Virtual Engineering Environment (VEE)*, for the design and prototyping of new applications based on composites. It was considered beyond the scope of this project to develop new numerical models for the simulation of specific manufacturing techniques (e.g. Liquid Composite Moulding, Resin Transfer Moulding, and Vacuum Resin Injection).

The VEE system is a computer simulation framework that allows design, development and testing of a product before it is actually built, thus eliminating many of the intermediate and costly experimental tests. Realized with a concurrent *bottom-up* and *top-down* approach, it integrates, among others existing components, *a data base* of material properties - selected types of resin and fibers -, a *knowledge base* of rules generated from parameters and constraints of actual manufacturing processes, *feature based Product Data models*, *improved modeling algorithms* based on FEA codes, and a new design method, called *Design-of-Deformation, that provide the optimal product shape*. Thanks to the integrated VEE approach the relation between the design and analysis phases of a new product and its development process are strengthened and linked in a cost-effective and efficient way.

Today industrial state-of-the-art confirms INCOMPRO original vision of high degree of Innovation project goals. Indeed, no competitor offers today SME-affordable VEE-Platforms for “intelligent” products and the first experiments to penetrate the market with such kind of products is led today by INCOMPRO end user partners. This innovation was manifested through the creation a Knowledge Base System (KBS) with associated, expandable material database, a specialized optimization tool for the design of deformations, called DoD, and all the associated algorithmic improvements within the existing finite element code SYSPLY. These innovations were the founding software blocks of the VEE and were supported by the creation of suitable data converters, enabling integration of proprietary software blocks, and CORBA-based communication software, ensuring open VEE extensibility and integration of future R&D results.

Furthermore, intelligent product demonstrators, such as booms, propellers and panels, were designed and produced, providing a concrete test-bed for the VEE validation. The validation of these real prototypes was however partial due to the late availability of the VEE for effective usage within INCOMPRO at end user site and due to extra improvements and constructive features that were necessary to be performed and implemented in order to allow its usage on “real” and testable type of structures and prototypes.

A novel RME manufacturing concept for intelligent marine propeller blades has been proposed, mainly aiming at the use of a wide range of stiffening fibers having levels of modulus of elasticity in flexure totally different when impregnated of epoxy resin and hardened as laminates. As stiffness is basically directly proportional to the product of the modulus of elasticity and to the surface moment of inertia, it has been considered more efficient to change the elasticity parameter, instead of restricting the simple inertia parameter which only depends on the variable blade thickness.

This RME concept increases the laminate versatility, above all in the environment in which this deformation is to be managed, depending on the applied load, versatility which allows to induce a deformation in flexure combined to a deformation in torsion.

The INCOMPRO real manufacturing procedure rely on an innovative *Fiber Placement Robot* which will lay the continuous stiffening fibers (prepreg roving or tape) pre-impregnated using an epoxy resin. This laying or uncoiling of the filament shall result in the generation of the whole propeller that is both central hub and blade profile.

In order to simplify the tools used in the first phase, a two-blade propeller has been considered, having a geometrical shape suitable to the uncoiling or laying procedure. The guide ring of the robot is fed by various coils of *prepreg rovings,* such as carbon, glass, aramide and polyethylene, whose combination will be preset specifically depending on their modulus of elasticity in flexure and torsion. The equipment, actually at development stage, will use two types of uncoiling, the circular uncoiling to generate the propeller centre (hub) alternate to the helicoidal uncoiling to generate the blades.

During the designs and construction of the above mentioned demonstrators, a large amount of material characterizations was performed through the systematic laboratory examination of coupons, probes and then the demonstrators themselves. A great degree of know-how was accumulated in this process, some of which will feed directly to the KBS database in the near future, and specific design skills in composite technology, which have been already exploited in less demanding R&D project achievements, such as a new full-composite two sets aircraft and a new design of pedestrian gateways.

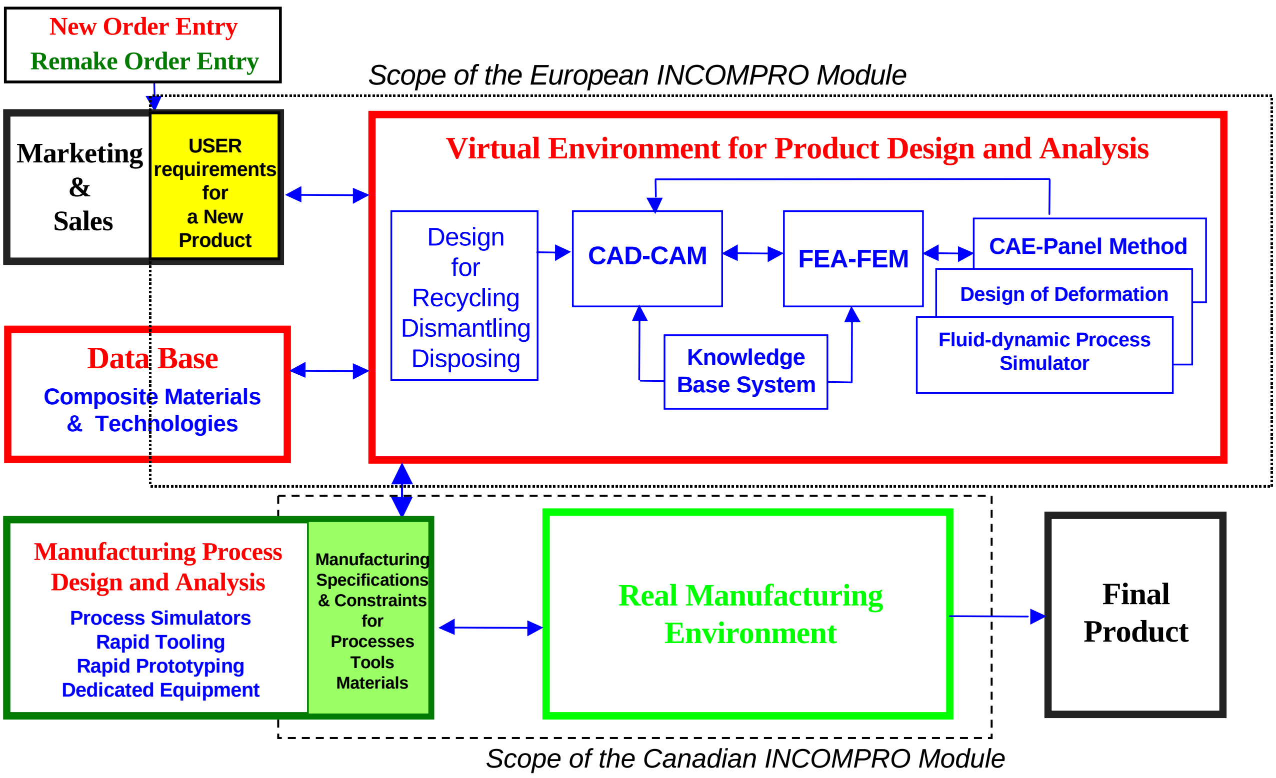

Fig. 1: INCOMPRO Integrated Design & Manufacturing Environment

The effectiveness of the VEE Framework is restricted by more general constraints of today composite and optimization landscape, in particular:

- Uncertainties on material properties values and correlation between measurements and computation values. There is an evident need for novel and systematic methods to design experiments test and characterize composite materials for intelligent products
- Lack of methods for global analysis of expected solutions versus computed ones in large-scale, complex optimization problems. There is a need for additional, heuristic search algorithms to explore "at large" the highly nonlinear optimization space and evaluate effectiveness and manufacturability of provided solutions.

Further R&D activities are already planned at regional and national levels to continue the innovation stream launched by INCOMPRO in composite technology, in particular on the following R&D topics:

- Develop a light, low-cost version of the VEE, based on a simplified integration of the two basic and most innovative components, the KBS and DoD, and supported by a stand-alone, if necessary multiprocessor PC platform
- Speed-up the search and improve designer visibility of the objective function minima, thanks of code optimization, "intelligent" search strategies and parallelization of the search algorithms for HPC (High Performance Cluster) computing platforms
- Customize GUI interactions and improve visualization to fulfill the needs of specific application domains and end-users requirements, such as designers of propellers, booms, etc.
- Continuous enrichment of the KBS contents, capturing new composites characteristics and best practice manufacturing rules, learned in past and future realizations of real prototypes, for most promising composite materials and manufacturing technologies, such as RTM, LCM, VRI, etc.
- Improve KBS usability for "smart" designers, increase designer's freedom and options to "choose, combine and teach" to the KBS new materials and fiber architectures, which make the KBS evolve toward a "learning" Knowledge-based Expert System
- Extend VEE Extranet capabilities with emerging XML and .NET technologies
- Extend KBS and DoD data exchange interface and protocols to comply with the emerging standard STEP
- Further development of Innovative equipment for the automation of high quality, complex lay-up processes in composite manufacturing.

In conclusion, the overall performed research and development work constituted an original and valuable contribution to the following areas: *Computer Integrated Engineering and Manufacturing*, *Optimization of the process to determine fiber reinforcement structures*, *FEA code and lay-up procedures, Virtual Prototyping*, *Automation of the lay-up process for precise manufacturing of composite based components.*

Information on further exploitations of technologies developed in the INCOMPRO framework available on the following websites: www.icimsi.ch, www.aeriks.com, www.aceair.ch.

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