Integrated CAD-CAM-CAE for Complex-Shape Aircraft Gas Turbine Parts

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Abstract: - This program is aimed at developing a "trademark" program specific to research institutes that also undertake production activities, in order to manufacture prototype and limited-series components with complex shapes with a view to identifying the surface generation and process particularities by modeling and simulating the specific technological design, HSC processing and the real-time control and coordination of these operations. A particular feature of the project is the quality system integration. For this purpose, the hardware of the existing machine tools is modified to assure the active control of parameters and a report is issued on the actual parameters. The report printed on a barcode card accompanies the component throughout the technological workflow, assuring the traceability of the component history, and a quality report is issued. The complex modeling and coordination program has been developed based on quality standards that are in line with the quality requirements specific to the production of turbojet engines and assures the guarantees and confidence of our European Partners in our ability to take part in complex international projects with high levels of scientific and technological difficulty.

Key-Words: - Turbomachinery, Modeling, Design, Processing, Control.

1 Introduction

The National Research and Development Institute for Gas Turbine mainly specialize in research and development of turbojet engine products for the aeronautic industry, superchargers, etc. During the last two years, the institute has developed both local and international research programs in its field. Here are several projects in which the Institute takes part as partner: METHOD, SILENCE®, ABRANEW, VITAL, JEAN, CoJen. The purpose of the CAD-CAM-CAE integrated system is to identify and model the main factors affecting the highly complex design, processing and quality processes, increasing productivity in the mentioned sectors and significantly reducing costs mainly due to shortening the design, testing and manufacturing time. It is also worth mentioning the cost savings due to eliminating certain document management and archiving auxiliary departments.

The design process identifies the critical components of turbojet engines (complex components modeled based on flow and strength calculations performed using special software with finite elements) and models the process of passing from the "hot" element to the "cold" element that is to be processed by cutting. The project also defines a simulation / testing model for the parts and the assembly, shortening the preparation time by reducing the number of calculation iterations.

The program includes the CNC modeling and simulation of the cutting process dynamics in intensive HSC processing conditions. After integrating the design parameter modeling with the production one, the program further provides data regarding the production rates and scheduling for the CNC tools. Studies will also be conducted on the modeling and simulation of the kinematical and organologic structure of the CNC machine tools in order to determine the HSC processing specific process parameters.

2. IQMD-Integrated Quality, Manufacturing, Design- Concept

To promote the products you need to take into consideration all business influences. Due to those influences, companies are pressed by the globalization and economical factors, work force and technological pressure.

To reduce the time to delivery of the products on the market and to succeed using innovative solutions, a company needs to have the capacity to design, manufacture and certify a product (for example a gas turbine or a compressor) in time and for the right application.

The company must introduce a performing PLM system (Product Lifecycle Management). The PLM system adopted by INCD Gas Turbine –COMOTI it's a specific one, due to a large number of particularities which define the Institute activity. The IQMD philosophy for bladed parts included in turbomachinery is the developing product management, which means that the manufacturing processes are always updated with information up to date. This fact is possible using the ERP module – Connect Toolkit. In figure 1 it can be seen the information flow inside the PLM system equipped with IQMD specific module.

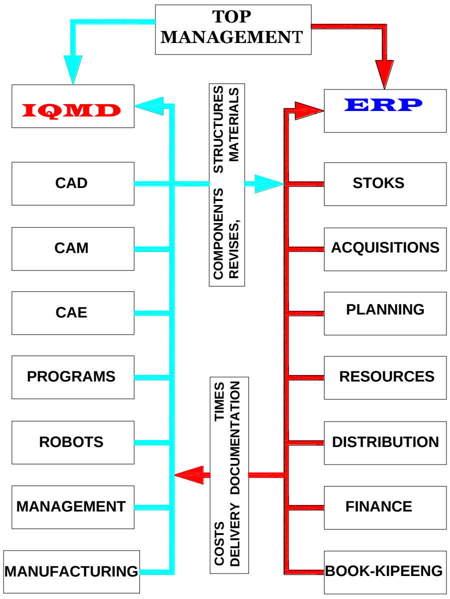

Fig.1-Flow chart-PLM's COMOTI System

Due to the high competitively between different compartments, the manufacturing process is overlapped with the last stages of the design process; practically some parts are manufactured before others are finished to be designed. This fact is possible due to the new technologies used in designing process, analyzing and validation of the new products. At CAD level of the designing process, we can mention the 3D representation of the components and of the assemblies using software like Catia, NX, SolidEdge, Solid Works, and Inventor.

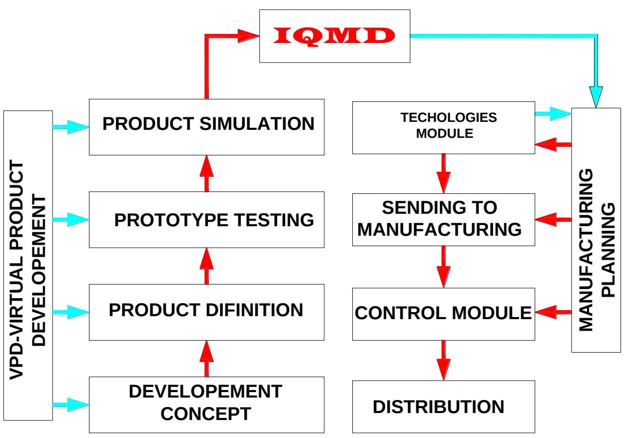

Fig.2-Flow chart-IQMD integrated system

For CFD (Computational Fluid Dynamics) analysis, we can mention software like. Fluent, Ansys CFX, StarCD and for dynamical structural simulation we can mention software like, Abaqus, Ansys Structural. Figure 2 presents the main modules developed for the specific activities of COMOTI [1].

2.1 The product defining module

Designing components for gas turbines like fans is a complex process which imply the fulfill of different stages (see figure 3).

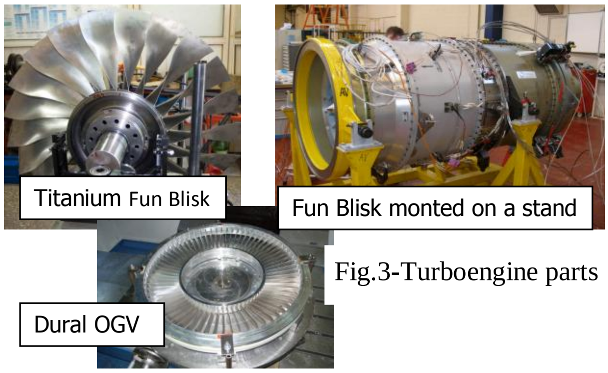

Fig.3-Turboengine parts

In first stage it's made the optimal geometrical calculation during the gas turbines operating, named "hot" geometry. Then it has to be passed to the manufacturing process, so called "cold" geometry, used for fabrication. This transformation imply management and utilization of the necessary recursive processes used by different commercial software like "Nastran" or in-house software. Practically, the structural loads coming during the operating time of the gas turbines are applied on the "hot" geometry and a recursive process is done until the deformed geometry is overlapping with a specific tolerance onto the initial geometry, resulting in this way the "cold" geometry.

To reduce the technical documentation elaboration time, it was developed a parameterized profile design.

It was created libraries with "master" models for the relevant parts. The calculation and design for the critical parts in gas turbines like bladed parts it's done by optimizing so called "master" parts. The time and the quality of the designing process is reduced and those also the costs. All big companies in the gas turbines field of activity developed in house software to design blade geometry to obtain in useful time the best profile, based on design and testing process. INCD Gas turbines – COMOTI developed own software to define blade profiles. This software allow to represent blade profiles parametrical, allow optimization process and establish a bidirectional link, exactly, without errors with standard CAD systems, based on spline curves, surfaces and solid models. The recursive calculation of the "cold" geometry starting from "hot" geometry is a iterative process which take into account the operating parameters who modify the blade profile geometry [2].

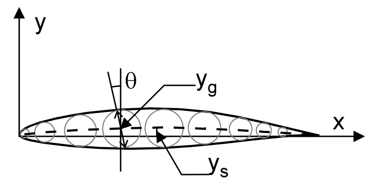

Fig.4 -An airfoil description a local coordinates system

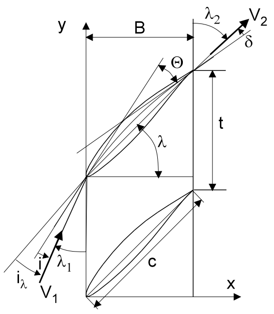

Fig 5 – Positioning the profile inside a blade network

The most influent parameters are centrifugal force in rotors and thermal field. The surface parameterization is done taking into consideration the possibility of an inverse transformation from the meshing nodes to the parameters used for surface generation. Knowing the meshing nodes position we can generate automatically parameters, which are describing the airfoils and finally the automatic generation of the CAD surfaces for parts manufacturing (CAM).

This automatically link is important because the cold geometry calculation is done inside the finite element software and is good that all other transformations which will come to be done without errors. In case there is a divergence of the solution, it is imposed to reconcile the hot geometry together with the aerodynamic department to ensure the necessary stability. The programming platform to define the blade profile was Visual C# Express and SQL Server Express in order to implement the shown algorithm [3].

This suppose to be easier to program and gives the possibility to solve complex programming problems. Working with a database is dictated by the big amount of data necessary to be used. To use the database, the software will have a “data adapter” module. The “data adapter” module is using from the database the information, which the software will use to do the corresponding operations. Another role of this module is to update the information with the recent data calculations. The mechanical analysis of the bladed parts geometry is done in house software and MSC NASTRAN DYTRAN. Flutter verification is done, dynamic analysis, impact analysis, how it interacts with other parts and an optimization. The aerodynamic control is done with Ansys CFX. Finally, the geometry obtained is “frozen” The publication [4] shows the parameterization method and iterative process of the “cold” profile of the bladed parts.

2.2 Stress calculation module and dynamic virtual simulation of bladed part.

The software is linking directly with the CFD modules. At this stage of the software, the hexahedral model of the analyzed geometry is created automatically, including the smallest details like chamfers, fillets, balancing rings and variable radius fillets. In addition there are put it also the limits conditions and loads in such a way that if a model which was build in few days, now is created in 10 minutes.

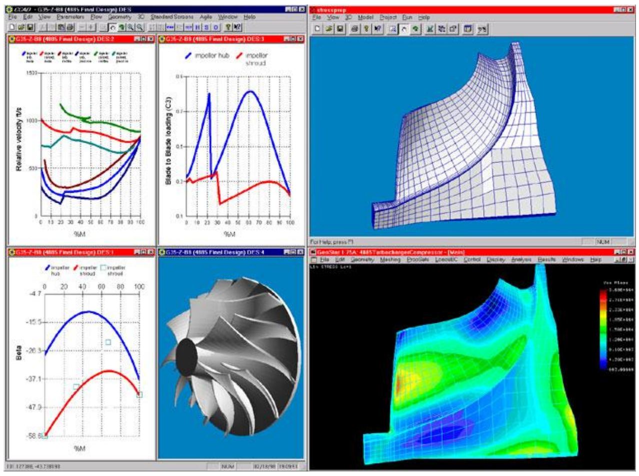

Fig.6 – Automatically acquiring of a node network and stress calculation.

The finite element method has the advantage that allows calculation of different solutions with more rotary assemblies which improve the precision in estimation of the own frequencies of the whole assembly, of the excited vibration, and finally of the stability of the rotor. The dynamical analysis module of the rotor assembly is done from 3 sub modules: one for lateral vibrations, one for torsion vibrations and one for axial vibrations with applicability to more rotors. This module offers also solutions in real time which allows engineers to work interactively and to observe how rotor balance is influencing the rotor assembly vibrations, sealing wear, change of bearings and problems due to low frequency excitation. The lateral vibration module has following abilities: analysis with more rotors and materials, modelling of the static arrow of the rotors and reactions in bearings, diagrams for critical speeds, reaction forces due to shaft curvature and rotor inclination, modelling of the linear and nonlinear bearings with amortization liquids, transitory regime analysis. The axial and torsion vibration module has following advantages: outstanding own frequency vibrations, excited vibration in the stationary regime, transitory regime analysis. In addition, the bearings modelling supports advanced options like bearings with balls and roles, simple bearing, fluid film absorbers, gap bearings, properties which depend on temperature of the lubrication liquid and others.

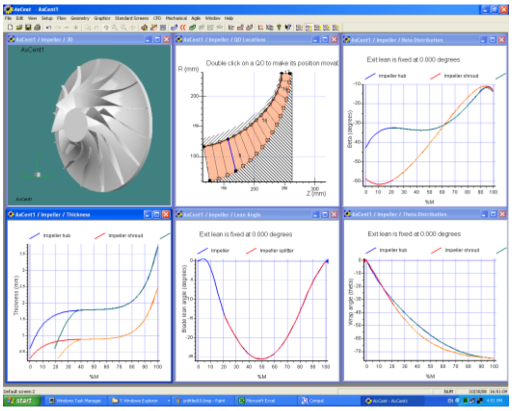

Fig 7- Definition of the bladed part and different analizes of the dinamic operational functioning.

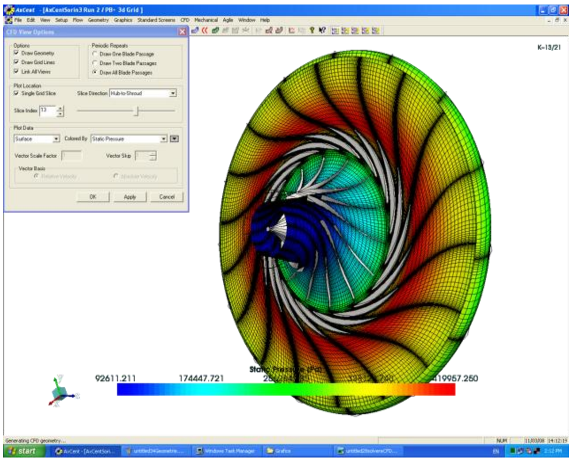

Fig 8- Example of finite volume analysis. Static distribution of the pressures in rotor.

In publication [5] the data coming from the solver „Blade to blade „

2.3 Module of administration of databases

For administration of CAD files, management of specific activities of manufacturing department and collaboration among the members of product development team, COMOTI was adopted the utilization of Siemens-Teamcenter. This module was configured for achievement of the following functions: stocking, realization of complex archives, personalized access, control of elaborated versions, protection of data integrity and restricted access for modifications, control of circuit of technical documentation, classification of components, multi CAD support. Module of administration of databases for technical documentation of product is correlated to database elaborated by manufacturing department in order to decrease the period for launching and monitoring of manufacture process. The link among these database platforms is given by BOOM files are elaborated by Design Department and they are found in Teamcenter database.

2.4. Manufacturing module

The project proposes several solutions for the real-time modeling of the design, production and control activities specific to research and development, as well as to the prototype and small-scale production in the gas turbine production industry, for components of high theoretical and technological complexity and requiring high levels of reliability. The outcome of this project will be the development of a new, specialized product for the modeling and real-time coordination of processes. The project develops an interface to define the technological process sequence and the operation plan based on the tree (history) in the modeling program;

The following specific objectives are proposed for integrating the production activity with the system:

- identifying the factors and modeling the technological parameters for optimizing the intensive processing (HSC) of complex bladed components with thin walls, made of titanium, steel alloys and aluminum alloys;
- developing an interface with the CNC processing machines allowing the processing of the modeled solid without any additional data processing

The following specific objectives are proposed for integrating the control activity with the system:

-developing an interface with the CNC processing machines to acquire data for the final dimensions and to issue dimensions acceptability reports;

-modifying the hardware of machine tools in order to implement the integrated system proposed;

-developing a program for launching production based on the documents and reports generated by the procedures created as part of the project. The components of manufacturing module are shown in Fig. 9.

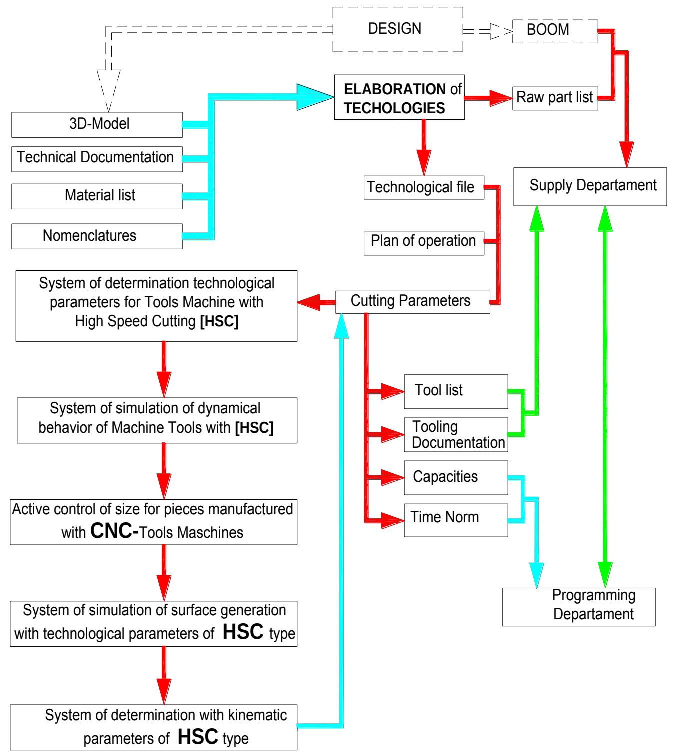

Fig. 9 Manufacturing module.

The project makes relationships among all components of manufacturing module but it also has remarkable contributions in soft realization for submodules presented in this paper.

2.4.1- Module of determination of cutting parameters

In order to obtain a high productivity at manufacturing of aircraft bladed pieces, one recommends the utilization of HSC (High Speed Cutting) technology. This technology uses special machine tools with high speeds, devices for intensive cooling and high cutting feeds.

The establishment of optimal cutting parameters for bladed pieces with thin walls is based on a technological research made by COMOTI in own production facilities. The project paid a special attention to cutting parameters for surfaces of complex pieces with thin walls. This manufacturing phase is critical in a technological process due to bigger cutting period. Starting from basic relation that defines the cutting force and feed force:

$$F_r = K_r \cdot F_t ;\ F_a = K_a \cdot F_t \qquad (1)$$

The cutting moment:

$$M_{i\max} = (K_r \cdot d_1 + K_a \cdot d_2) F_t \qquad (2)$$

$$M_{i\max\, t} = k_3 \cdot B^{u_p} \cdot t^{x_p} \cdot w^{y_p} \cdot n^{1-y_p} \qquad (3)$$

one built the optimization matrix of cutting process of surfaces of bladed pieces with thin walls.

$$\begin{cases} w_{\min} \le w \le w_{\max} \\ n_{\min} \le n \le n_{\max} \\ t \le t_{\max} \\ P_{\max} \le C_1 \cdot w^{y_p} \cdot t^{x_p} \cdot n^{1-y_p} \\ M_{t\max} \ge C_2 \cdot w^{-y_p} \cdot t^{x_p} \cdot n^{y_p} \\ M_{i\max} \ge C_3 \cdot w^{y_p} \cdot n \cdot t^{x_p} \\ s_{d\min} \le s_d \le s_{d\max} \end{cases} \qquad (4)$$

We determined the correction coefficients from the above equations, on base of determinations made on COMOTI's CNC machine tools with HSC technology. The studies made on machine tools and the computational soft for optimal cutting parameters for bladed piece manufacture with HSC technology are presented in work [6-7].

2.4.2. Module for simulation of dynamical behavior of machine tools in cutting process.

Due to intensive cutting process of piece surfaces, the machine tool is very stressed. For this reason, it is necessary to simulate the machine tool behavior in dynamic regime and to determine its limits in order to obtain the wanted precision and quality of surface. The dynamical analysis was made on base of cutting process feedback according to the below relation:

$$\hat{M} = \frac{D}{2} a_p \cdot f_z^{1-m_c} \cdot (\sin^{-m_c} \kappa) \cdot k_{c1,1} \cdot V_e ; \qquad (5)$$

Details regarding the solving of failure matrix are given in work [6]. In this mode, the program realizes a loop for determination of optimal cutting parameters for bladed pieces, in limits of maximal working of machine tools [8-9].

2.4.3. Control mode of surfaces of gas turbine bladed pieces.

This module is a component of integrated IQMD system and it was conceived to decrease the intermediary times in manufacture cycle due to intermediary control phase. Usually, after a manufacturing phase, the piece is moved on a three-dimensional control machine and it is measured blade by blade. In the past, after measurements, with special codes, one built the envelope of surfaces and one calculated the deviations with respect to reference surface. After measurements, the piece is put on positioned machine tool and the surface working is continued with other machining allowance. These stages leaded to time and precision loss due to successive reposition of piece.

COMOTI has opted for connection of an ATOS-viewer control device at milling machine. This device allows the measurement of an array of points located on surfaces of bladed piece with no direct contact with the piece and visualization of enveloped surface for measured dimensions. Furthermore, the device soft allows the analysis of deviations in points with respect to corresponding design dimensions. An example for a bladed impeller that is in manufacturing process is given in fig. 10.

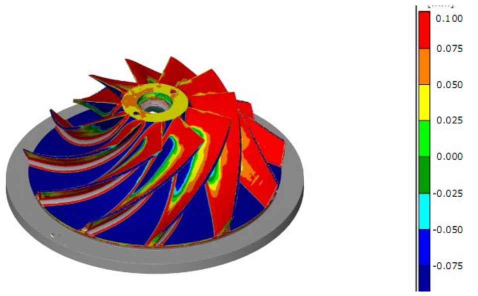

Fig. 10 Dimensional analysis of an impeller with no detachment of piece from machine tool.

The realization of this module in the framework of integrated system of production management of bladed pieces leads to the dramatic increase of labor productivity, dimensional precision of pieces and reject elimination.

2.4.4. Production Management Module

The turbomachinery bladed pieces are complex pieces with a long manufacturing cycle. For this reason, their manufacturing is considerate critically in realization of every gas turbine and it requires a precise programming of production. The project of soft IQMD developed by COMOTI takes into account the feature of uniqueness of production of COMOTI bladed pieces and the diversity of other complex components that are manufactured in COMOTI facilities.

The production programming takes into account the links among activities of production departments and it includes some phases. The programming stage contains the following activities:

-time programming of production

-repartition of production tasks on manufacturing departments and human and material resources

The fabrication launching stage contains the following activities:

-elaboration of launching documentation;

-documentation repartition with respect to operative programs;

The stage of tracking, control, and update of production programs contains the following activities:

-tracking and control of realization of operative programs in allocated time

-update of programs

For programming and tracking of small series and individual production, the period of manufacturing cycle represents an echeloning element of complex piece manufacturing, in space and time, specific on orders (beneficiaries). The manufacturing period of critical component, in cutting process is computed with the relation:

$$Tj = \left[L \sum_{i=1}^{n} \frac{t_{ij}}{M_i * K * n} + \overline{t_{i0}} * (n-1)\right] \frac{1}{Ds * Ns} \qquad (6)$$

where:

T_j- manufacturing period in cutting process;

L- number of the same pieces;

t_{ij}- normal period of operation (i) in phase j;

M- number of machines that execute the operation;

$\overline{t_{i0}}$- average repose time among operations;

Ns- number of work shifts;

$n-$ number of operation.

For programming of small series production, we have chosen the programming variant on base of priority indexes. We considered that this is a simple and efficient method of programming, control, and guidance of orders. This method is based on calculation of priority indexes. The method starts from the following priority rules:

-the orders with rigid terms have to be planned the first

-for orders with small time reserve, it is not recommended to accept the extension of manufacture period. It is recommended to be included in manufacturing program from the beginning of cycle.

The initial launching priority is established on base of delivery terms demanded by beneficiaries.

One uses the priority index calculated with the following relation:

$$P_{ij}(t) = T_t - T_c - [1 + k(N - n)]D_{cf} \qquad (7)$$

where:

$P_{ij}(t)$- is the priority index of piece (i) at machine tool (j) at moment (t), expressed in days;

T_t- delivery time;

T_c- current time;

$k -$ increase coefficient for a manufacturing phase;

n- number of finished manufacturing phases;

N- total number of operations / piece;

D_{cf} - period of manufacturing cycle.

The finalization time of piece (i), inclusively the manufacturing at machine (j) considered from moment T_c, is calculated with the following relation:

$$T_{ij}^{t} = T_0 + Q \sum_{j=1}^{n} t_{ij} + n.\overline{t_p} \qquad (8)$$

where:

T_{ij}^{t}- finalization term of piece;

T_0- reference moment;

Q- ordered quantity (number of pieces)

t_p - average time for a manufacturing operation.

The realized soft makes links with files of programming platform and production tracking "Project manager" that allows the very different and explicit relationships.

This module is very useful to technological services, in evaluation of manufacturing periods, material resources, and costs.

4 Conclusion

The integrated system, IQMD, for the design and cutting processing of critical turbojet engine components is a product that can be effectively implemented in any research and production company, but it can be also used by companies undertaking only one of these activities, by the limited use of only certain integrated modules. The project developed by INCD Gas turbines-COMOTI has a big economical impact by:

- creating competence in the production of advanced technologies for critical components in high-technology industries, aerospace industry and turbojet engine construction in particular;
- creating scientific competence in approaching the design of complex profiles with thin walls (considering the requirements of low jet engine noise, high resistance to dynamic and heat stress, etc.), simulation and testing in a single system integrated with HSC processing and active control;
- creating the information infrastructure for cooperation with European companies in the industry – providing the guarantee of scientific, technical and organizational competence for complex cooperation in international programs.;
- a reduction in the time of transfer of the solid models from the design workshop to production, a reduction in the time required to prepare the production, scheduling, planning, launching and follow-up documents, which we expect to increase productivity by 25-40%;
- the integration of active control and automatic acceptance reports with the system will eliminate a subjective element from the quality system and will allow for the production files to be prepared in a short time and by limited personnel; we estimate a 30-40% increase in productivity;
- improving the working and stress conditions due to the software that helps in eliminating human errors from design, processing and control.
- developing confidence in the own performance of the personnel, in the ability to compete in the market of complex products in the field of turbojet engine.

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