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CONCURRENT DESIGN FOR PIPING SYSTEMS

by

D.Orlandi & T. Atti

Basic Systems and Engines Installation design Dept.

AGUSTA, Via Giovanni Agusta 520
21017 Cascina Costa di Samarate – Italy

ABSTRACT

To survive and excel in a market where the needs are for highly competitive products (shorter availability time, quality level constantly better at the lowest possible costs), it is mandatory to improve the industrial processes. This can be obtained by means of suitable tools and relevant methodologies and procedures, in order to concurrently operate between Engineering and Manufacturing at design level with the aim of reaching the best efficiency.
The Agusta piping system design evolution is presented, being additionally a significant subject to develop a practical application of concurrent engineering concepts.

INTRODUCTION

In this paper it is presented the evolution that Agusta has developed in the piping design discipline with the main target to practically introduce some of the "Concurrent Engineering (CE) concepts.
The aim of this work was to enhance both the design and manufacturing procedures, in order to minimize problems during the installation activities, as well as to recover, at design level, any anomaly that could, later on, occur during pipe manufacturing.
This target was pursued developing three different methodologies.

1. Pipe "3-D Design Methodology .
2. Pipe "Improved 3-D Design Methodology , by introducing dedicated computer simulations, "Pipe bending simulation and "Pipe assembly simulation , to analyze, at design level the pipe manufacturability.
3. Pipe "Reverse Engineering Methodology , by developing a dedicated software to recover, into the 3-D procedures , the pipes designed and manufactured by means of the techniques used before the extensive introduction of CATIA tools: TRADITIONAL METHOD.

PIPE DESIGN TRADITIONAL METHOD

Before the 3-D design methodology was introduced in the design activities, the design of piping systems consisted in a multiple exchange of information between Engineering and Manufacturing Departments.
This method is still used to define some configuration changes on helicopter not designed in a 3-D environment.

At first the designer gives a rough definition of the pipes in terms of Part Number (P/N), selected material (type of material, tube size, thickness) and rough length required to manufacture the pipe, without having the possibility to include the data which define the geometry and, consequently the routing of the detailed pipe. The drawing is released in a preliminary issue with the above mentioned parameters.
The geometry, and therefore the shape of the pipe is defined at a later phase of the process.
The only way to define the suitable routing of the pipe, interfacing correctly both with the rest of the systems and with the structural parts, is to define and manufacture a sample of the pipe directly on the first helicopter (usually a prototype) or, alternatively, on an helicopter full scale mock-up.
The pipe sample will then be used as the reference shape to manufacture all the pipes having the same P/N: it is the **MASTER** pipe of a given P/N.
For this reason this method is commonly identified as **"MASTERIZATION PROCESS"**.
From the master pipe the Manufacturing department derives the geometric data set of the pipe shape, that are later fed back to Engineering to be formalized, as a design document, into the pipe drawing for an updated and complete release.
A flow diagram of the discussed "Masterization process is presented in the enclosed **FIG. 1** (pag. 66.12).
Three major problems correlated to this methodology were identified:

1. Very long time schedule
2. High associated costs
3. Confusion in the responsibility sharing

The described practice, in fact, requires normally very long time (even months) to be successfully completed, and the pipe final drawing can be issued only after that the pipe has been manufactured, often generating confusion with regards to the design leadership.
Usually the pipe masterization process is realized on the first helicopter prototype, therefore delaying its final assembly.
Alternatively, the pipe masterization process could be realized on a full scale mock up, with the associated high costs of realization and configuration update.
Moreover, the master pipe shape can hardly give consideration to helicopter configurations different from the one used for masterization, requiring therefore, additional masterization also in case of minor modifications.
This usually happens as, typically, the first prototype is not fully representative either of a prototype completely equipped with all systems or of the production configuration.

The hydraulic piping systems of the EH101 helicopter, the design activities of which initiated in early 80's, suffered of the above mentioned problems and were aggravated by the high number of prototypes (9 prototypes, each with different configuration) as well as the different production configurations (6 different versions up to now).
The use of the "masterization process method , in spite of the experience gained with the prototypes, required for a large amount of work as well as a long time to freeze the hydraulic pipe configuration. This also in addition to the requirement to maintain, as far as possible, a large amount of common pipes among the different configurations.

PIPE 3-D DESIGN METHODOLOGY

The introduction of the 3-D design method in Agusta, using the CATIA software, has allowed a more efficient design activity.
More recent programs, like NH90 for example, were developed taking the advantages of the 3-D design potential. This helicopter was designed in an Electronic Mock Up (EMU) environment allowing the designer to have a complete and detailed perception, in 3-D, of how the subject of its design activity interfaces with the rest of the helicopter.
Since all the designers perform their activity within the same virtual Mock Up environment,
they can have, almost in real time, the knowledge of a possible interface problem and correct their design.
The use of PIPING module (package module of CATIA) allows the designers to define, during the design phase, the geometry of the pipe and to integrate the model of the part with many related information (i.e. material, tube-fittings compatibility, relationship with identification labels, flow direction, relationship between assembly P/N and part P/N,…) useful to produce, through specific procedures, the automatic generation of the 2-D drawing (drafting mode) of the part itself.
The use of 3-D design therefore permitted a dramatic reduction in terms of both costs and program time schedule since the full scale mock up is no longer strictly necessary to define the pipe routing and the relevant geometrical nominal data.
This new approach concentrated some more activity under the Engineering responsibility but, in the complete process flow, led to a considerable amount of time saved (compared with the traditional method).
During the development of the NH-90 five prototypes, a consistent reduction in the number of pipes to be remanufactured (due to structural/shape non compatibility), resulted additionally in a general benefit to the hydraulic system piping design program.
Since the pipe routing is defined within the Engineering activities, the use of 3-D in the piping design has, in addition, significantly contributed to the proper identification of the responsibilities.
A flow diagram of the 3-D design process is presented in the enclosed **FIG. 2** (pag. 66.13).
The three major problem areas identified using the TRADITIONAL METHOD, has been properly addressed and overcame by introducing the 3-D method in the design process.
An accurate analysis has evidenced other areas where further improvements could have been implemetted.
Actually the designer did not have a direct knowledge whether the designed pipe would have caused problems during the manufacturing process, related to the use of an Automatic Bending Machine (ABM).

PIPE IMPROVED 3-D DESIGN METHODOLOGY

Taking the advantage of the CATIA potential, an improved methodology and associated software, was developed to permit the possibility to verify, during the pipe design phase, some of the pipe manufacturing activities. This allowed to anticipate, and correct in advance, the potential problem that would raise while manufacturing the part, according to a **"DESIGN TO MANUFACTURING"** concept.
Two aspects of the manufacturing process have been considered significant to be included within the design activities before the official release of the applicable pipe drawing:

- the **"pipe bending process"** and
- the **"pipe assembly process"**

Two specific software packages were introduced allowing the systems piping designers to verify, well in advance, through a **computer simulation**, the above mentioned processes.
The representative flow diagram is shown in **FIG. 3** (pag. 66.14).

– **Pipe bending simulation**

The main goal of the pipe bending simulation is the verification, at design level, of the actual possibility to bend a pipe on an Automatic Bending Machine (ABM).
In order to guarantee that a pipe can be manufactured by the ABM it is necessary to verify that:

1. The pipe has the same bending radius for all the pipe curves.
2. The bending radius, used for a given pipe size, is compatible with the dies available as ABM tooling.
3. The straight portions of the pipe, between two consecutive bends, as well as the initial and final parts, are not shorter than an established minimum length (function of the pipe size).
4. Any collision of the pipe with the machine, or its surrounding structure, is avoided during bending operation.

A CATIA model, with a dynamic representation of the ABM moving parts, as well as the static ones, was created and integrated with dedicated software that reproduced the machine kinematics. A picture of the true machine and its CATIA model, are shown in the following **FIG. 4** and **5.**

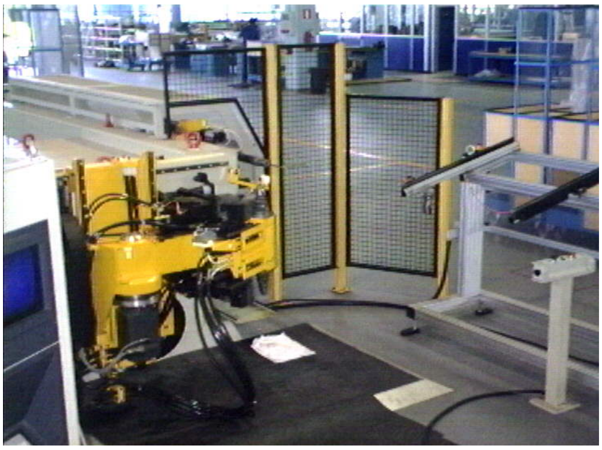

FIG. 4 Picture of the ABM

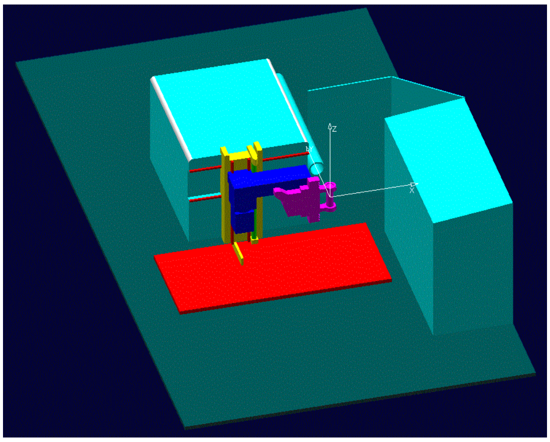

FIG. 5 CATIA model of the ABM

The software is implemented with a data base file characterizing each pipe size (mm and inches) with the corresponding die tool available, the minimum feasible bending radius and the minimum straight portion length.

According to a Concurrent Engineering to pipe manufacturing approach, the software was loaded into the CATIA Workstation environment used for pipe design.

After the designer has modeled a pipe according to the 3-D piping rules, he is requested, to simulate the pipe bending operation, by following the Bending Simulation Program Procedure.

The software will automatically check if the pipe has been modeled in accordance with the first three criteria listed above. If any of the first two checks is not verified, a video message is given to the designer, together with suggested corrective action. If everything is consistent with the database, the program will propose the most suitable die among those in the data base and the pipe default material chosen for the helicopter program. To initiate the bending simulation the designer must accept the program findings. Only at this stage can the bending simulation be initiated.

If a straight portion of the pipe model is shorter than the minimum permitted (3rd criteria above), the simulation stops and an error message is provided to the designer.

If a collision with an obstacle is detected (4th criteria above) the simulation stops and proposes to start the simulation from the other pipe end. If also in this case a collision is detected the program stops and the designer is forced to modify the pipe design and reperform the simulation.

Only when the simulation is successfully completed the designer is allowed to freeze the pipe design with an extremely high confidence level that the pipe bending in manufacturing will be a trouble-free operation and the 2-D drawing format can then be released

See **FIG. 24** (pag. 66.15) for a physical example of a 2-D drawing format.

Following **FIG. 6** through **22** give a visualization of the simulation steps of a pipe which has 4 bends in 4 different planes.

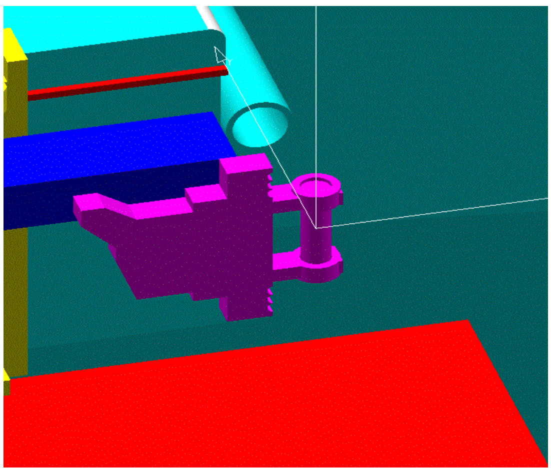

FIG. 6 Detail of the movable head of the ABM

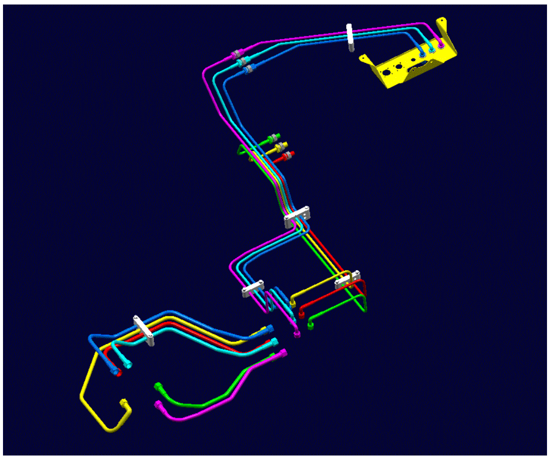

FIG. 7 Piping model with the subject pipe

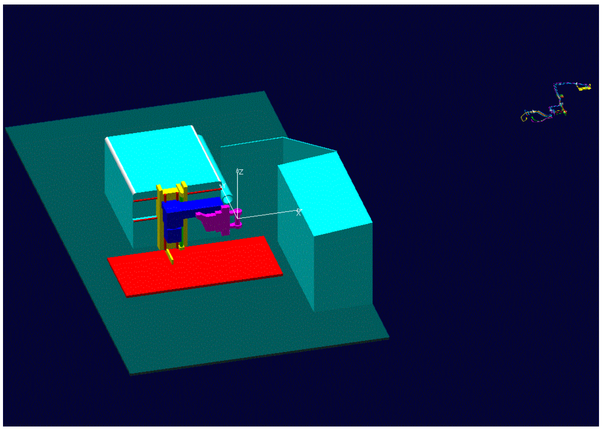

FIG. 8 The piping model is loaded with the ABM

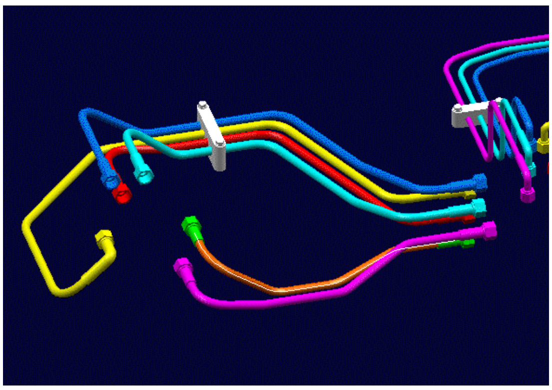

FIG. 9 The subject pipe has been identified (It changes the color into orange)

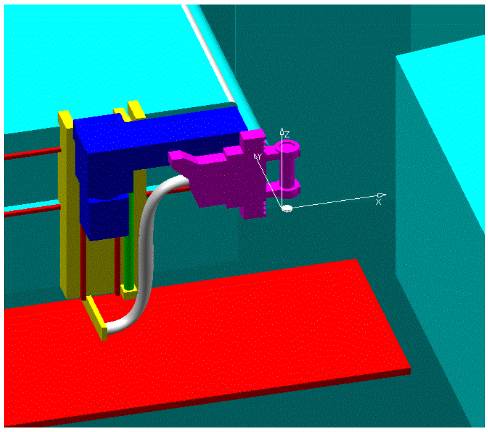

FIG. 10 The ABM has compared the pipe data with the database parameters

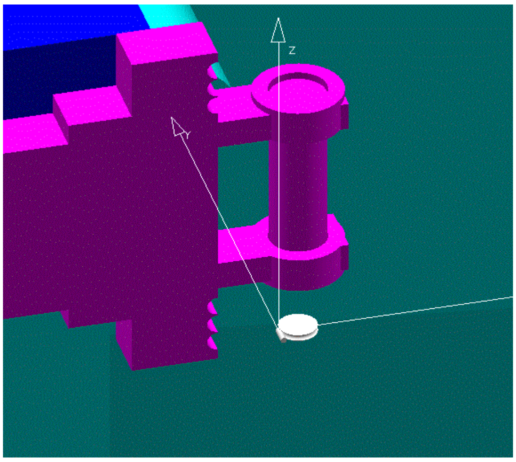

FIG. 11 Simulation initiates- 1^ step

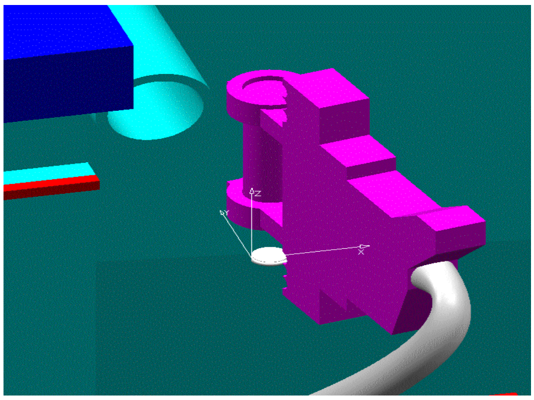

FIG. 12 2^ step (first bending)

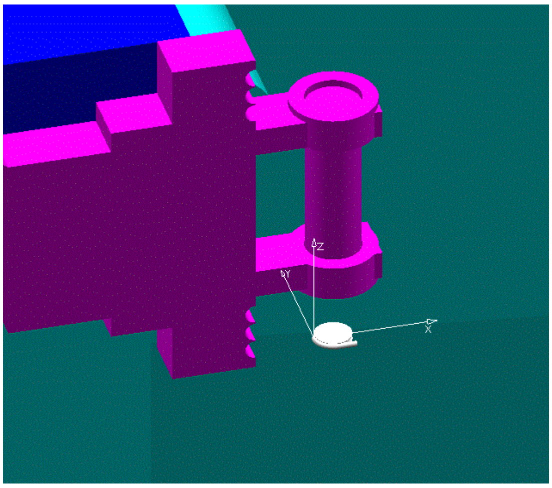

FIG. 13 3^ step (first bend completed)

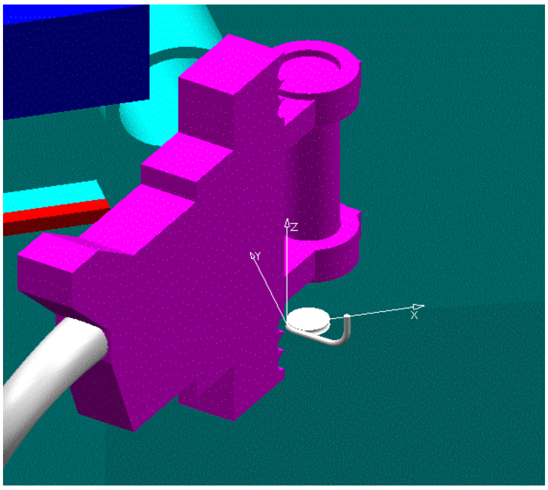

FIG. 16 6^ step (second bending)

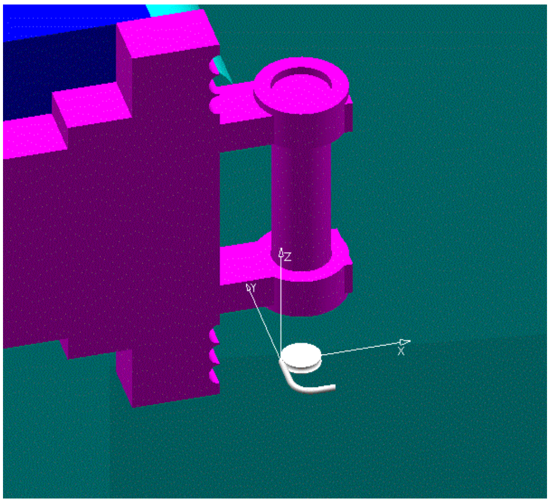

FIG. 14 4^ step (second straight segment)

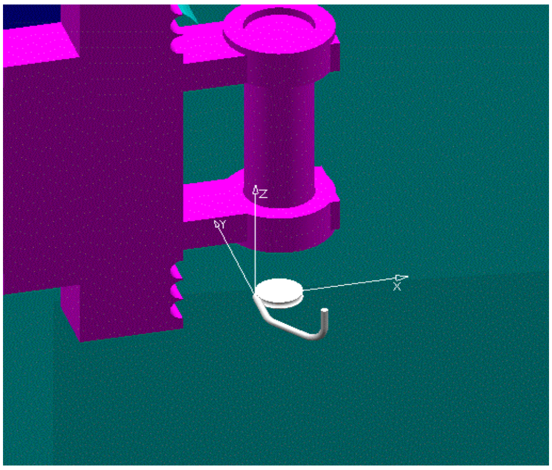

FIG. 17 7^ step (third straight segment)

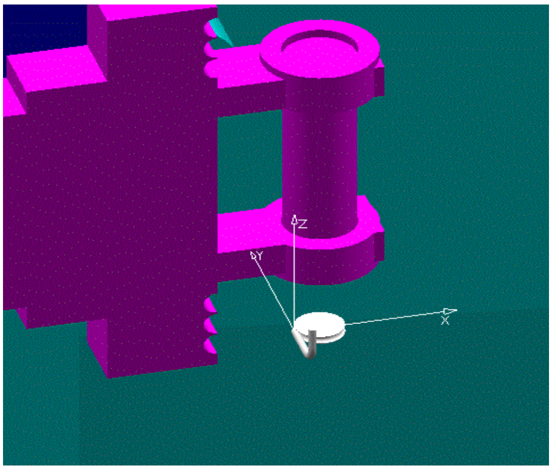

FIG. 15 5^ step (second bending plane)

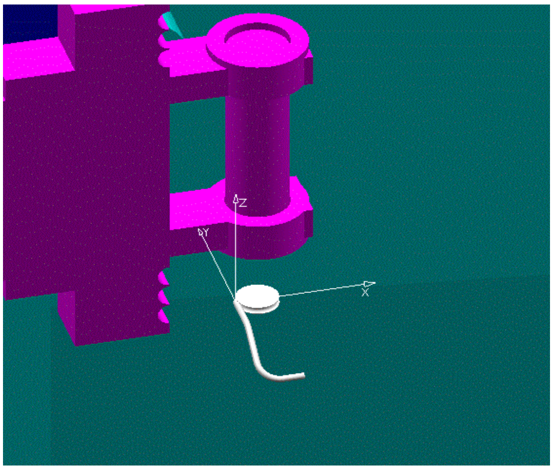

FIG. 18 8^ step (third bending plane)

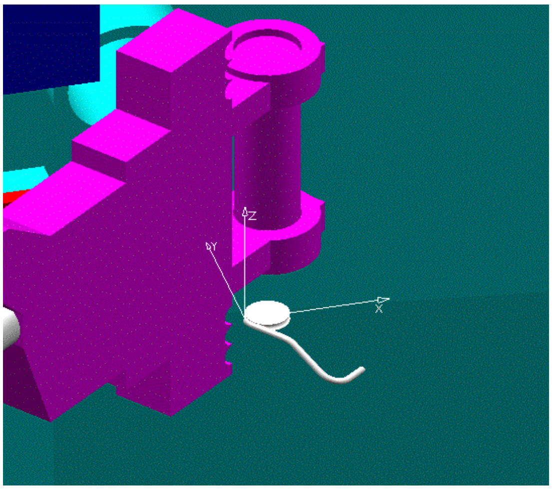

FIG. 19 9^ step (third bending)

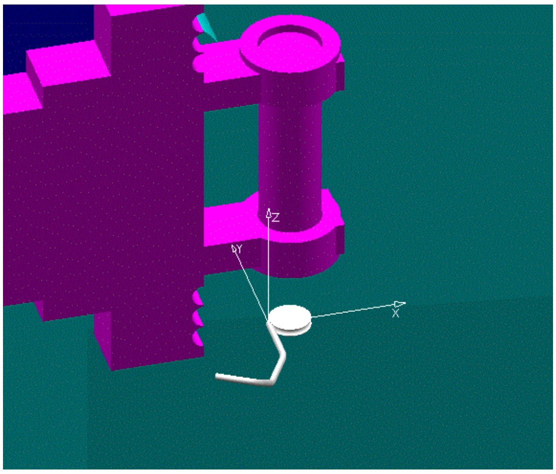

FIG. 20 10^ step (fourth bending plane)

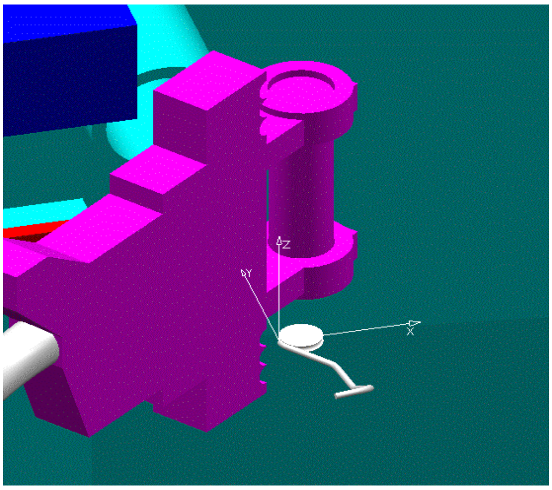

FIG. 21 11^ step (fourth bending)

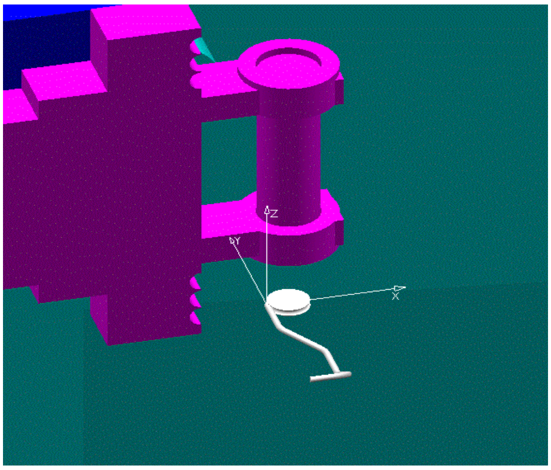

FIG. 22 12^ step (pipe simulation completed)

Upon specific request, the program can generate the bending file in a format suitable for the direct use of the ABM. See **FIG. 23** for the bending file of the simulated pipe

```
||                   3G3230A01351A
9R30@                        8X
0.00Y   -0.00Z    0.00X   -0.00Y
59.55Z   -0.00R 5X   90.58Y
59.55Z   -0.00R 5X  146.35Y
59.55Z  -39.05R 5X  208.78Y
15.55Z  -82.77R 5X  263.70Y
15.55Z -121.22R 5
```

FIG. 23 Bending file produced by bending simulation

- **Pipe assembly simulation**

Besides the bending of a pipe, when using connectors with the “swaging technology , another critical operation in the manufacturing of a pipe or of a loom assembly, is the swaging of end or intermediate permanent connectors.

These kinds of connectors are nowadays usually utilized in high or medium pressure systems, as they give superior reliability characteristics with regards to the avoidance of fluid leakage.

Such good performance is compensated by a relatively high costs of the connectors that, if not properly swaged, have to be discarded. To avoid this the swaging of the connectors, is performed by means of dedicated small jigs that permit the proper position and fix in the space of the pipe/s and the permanent fittings.

The use of a universal tool for pipe positioning, can significantly reduce the cost and the time required for the operation thanks to the simple and fast operation of setting-up the universal jig.

In terms of reducing the “non recurring costs it permits to avoid the building-up of a lot of different small pipe/loom dedicated jigs.
Its increased flexibility allows the reduction of the pipe assembly time permitting the production of small lots of similar pipe/looms assemblies.
The **Universal Crimping Jig (UCJ)** includes five towers that can move longitudinally along its structural base. Each tower has an arm, that can move vertically along the tower and laterally. The head on the arm has two rotational degrees of freedom.
With a high level of flexibility, it is therefore possible to fix in the space different pipes with different geometries.
Nevertheless, there is a limitation due to the possible physical interference between the pipe/s and towers/arms.
Also in this case, a simulation of the operation can anticipate eventual manufacturing criticalities that would require a modification at design level.
Following the same approach defined for the “pipe bending simulation , the “pipe assembly software can be implemented to require that the designer intervente if anomalies in the crimping operation are detected.
A 3-D model of the universal tool was created as well as a dedicated simulation software.
With such software the designer has the possibility to simulate the positioning of the pipe on the UCJ, its correct catching by the relevant heads on the arms and to check for any interference with the jig structure.
He can also verify the possibility of restraining (through the movable UCJ arms and heads) the pipe and the required fittings for the swaging activity in order to guarantee the pipe assembling (tube plus fittings) operation during manufacturing.
As an additional output from this software, it is possible to generate a file with the Numerical Control Data for the automatic positioning of the heads of the UCJ for the real crimping operation.
The use of this software is not included yet in the operative process of the pipe manufacturing:
it is one of the future targets to be pursued.
In the **FIG. 25** to **29** it is given the visualization of the pictures of the UCJ, together with its 3-D model, and an example of the crimping simulation process.

FIG. 25 Pictures of the UCJ

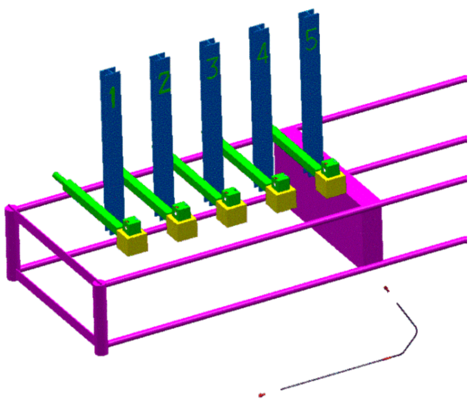

FIG. 26 CATIA model of the UCJ with pipe to be assembled

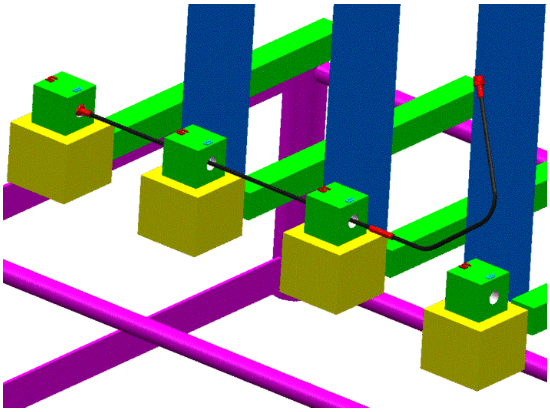

FIG. 27 Pipe on three towers

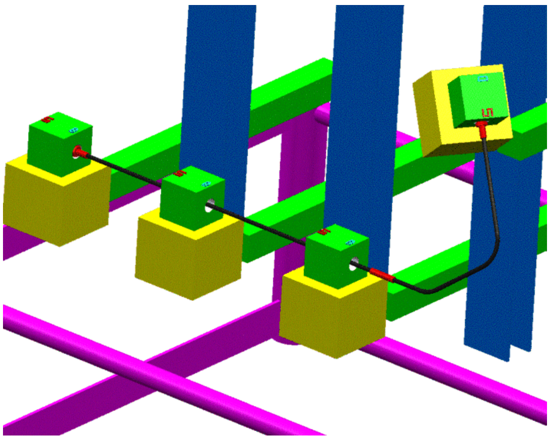

FIG. 28 Pipe completely restrained to the UCJ

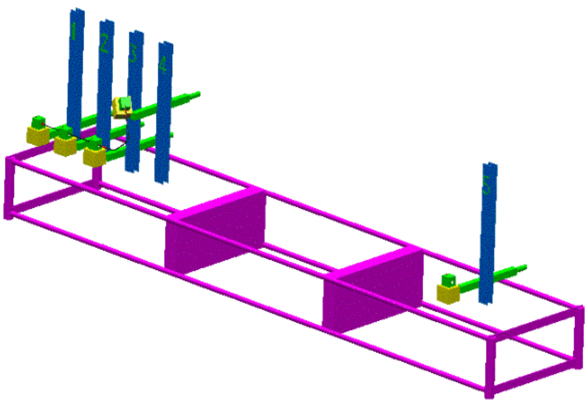

FIG. 29 General view of the model of the UCJ with the pipe in position

PIPE "REVERSE ENGINEERING" METHODOLOGY

To enhance the whole benefit obtained with the described methods, a further task was performed to properly manage, and recover in a 3-D environment, the pipes defined by the traditional "masterization method. This could be the case for helicopters not originally designed in a 3-D environment (like EH 101, A109, A129) or the few cases of pipes for which practical problems, like on site (on helicopter) modifications, would better require for the use of the masterization process.
A third specific software program was therefore set up in order to have, as a final output, the CATIA model (PIPING module) of a masterized pipe.
This software is interfaced with three databases from which it collects the information necessary to generate the CATIA model of the pipe.
The logic flow diagram is presented in the **FIG. 30** (pag. 66.16).
The geometric data file is obtained by measuring (by means of a dedicated laser measuring tool) the masterized pipe.
The output of the measuring activity is a file organized in the same format as produced by the "pipe bending simulation software, thus containing the Cartesians coordinates (X, Y, Z) of the pipe assembly, the identification code of the tool used to bend it and the pipe P/N. In the following **FIG. 31** it is reported an example of such a file.

```
||
EA2910Z505043A143B+A
16R48@                   8X
792.70Y -594.24Z  213.83X
794.63Y -470.70Z  210.09R 0X
780.54Y -405.60Z  242.30R 0X
775.07Y  157.55Z  212.79R 0X
504.52Y  171.38Z  210.92R 0X
504.20Y  336.26Z  186.15R 0X
579.25Y  336.05Z  188.66R 0
```

FIG. 31 Data file of geometric definition of the pipe P/N EA2910Z505-043

The file name is in a code form in order to provide for indications with regards to the fittings used on the pipe in object and their relative position.
The defined software operates according to the following operations.
Through the Cartesians coordinates the pipe is first reproduced in a "linearized form as a series of

connected lines which vertices have the coordinates “as measured . The line initiates in the first measured point and terminates in the last one

The second operation is a translation/rotation (as a rigid body) of the linearized pipe, changing the reference coordinates in order to have the first point in the origin of the new reference system (0, 0, 0), the first line along X axis and the first bend in the X-Y plane. The vertices will have, consequently, the coordinates in the new reference system. See **FIG. 32** as an example of such linearisation.

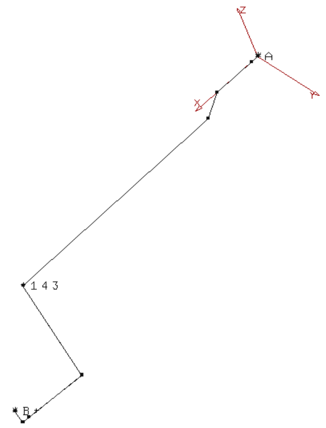

FIG. 32 Linearisation of pipe P/N EA2910Z505-043

The third operation is to complete the pipe model by properly placing the fittings (captured from a dedicated library) at the two end points of the linearized pipe. Then, the pipe with the size and bending radius consistent with the die used for bending is created. See the following **FIG. 33** for final result.

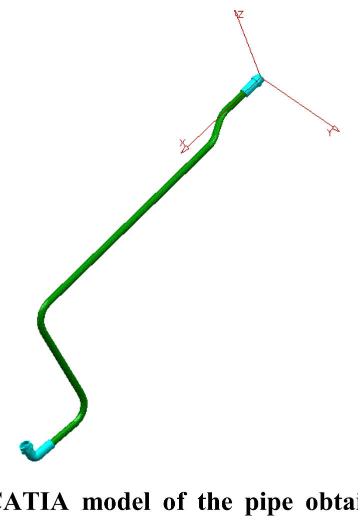

FIG. 33 CATIA model of the pipe obtained automatically from the REVERSE ENGINEERING software

A specific procedure permits the use of this program in “batch mode , allowing a fast analysis of pipes having a common part of P/N.

An additional output of the software is the possibility to print the geometric data of the created CATIA model, in a format consistent with the applicable helicopter program.

This software allows a **Reverse Engineering** process to close the loop between the Engineering and Manufacturing relationship.

BENEFITS GAINED WITH THE PRESENTED IMPLEMENTATIONS

The logical introduction of the presented implementation started from the beginning of the NH90 program. This is a multinational program designed in a 3-D environment.

The available data on the first prototype confirm that approximately 10% of the pipes (designed using the 3-D methodology) were rebuilt because of installation problems. The reason for this is to be attributed to the initial difficulties with the use of a new methodology applied among different companies sprayed out all around Europe. The problems were mainly related to the process of exchanging and updating the models of the different parts (structure, hydraulics, electrics, …) among the different partners.

It has anyway to be considered a successful approach since for the first time, in Agusta experience, the first prototype was assembled outside and faraway from the Company final assembly line or experimental shop. The NH90 prototype was assembled in Eurocopter France while the hydraulic piping was designed and manufactured in Italy, inside the Company.

Once the 3-D design methodology became more familiar and the models more accurate, the piping design was significantly improved and on the third NH90 prototype (still assembled in France) only the 4% of pipes was rebuilt.

The same 3-D design methodology has been used on the recent AB139 program. This helicopter was assembled in the Agusta production line while the main structure was designed and manufactured in PZL in Polland. The experience accumulated on the NH90 program brought excellent results in the piping design effectiveness, such that practically 100% of the designed pipes have been installed without requiring modifications.

It has additionally to be noted that, for the AB139 helicopter program, the pipe design and production process took advantage of the use of the Bending Simulation, part of the “improved 3-D pipe design methodology .

On a six month basis of application, approximately 12% of pipes with potential manufacturing problems were discovered and properly corrected during the design phase, thus significantly increasing the efficiency of the total process.
Thanks to the confidence gained in the process, in order to optimize the pipe production process and to minimize the time duration of the assembly of the first two AB139 aircraft, it was decided to launch the manufacturing of two complete sets of hydraulic pipes, well in advance of the assembly of the first helicopter structure.

Regarding the Reverse Engineering Method, it has been implemented during the final industrialization of the EH101 Hydraulic system piping (originally designed with CADAM tool and manufactured through the traditional masterization process).
The Reverse Engineering Method was used to produce the final release of the drawings of each of the about 300 different pipes (covering the various EH101 configurations), in which the bending data were included.
Starting from the files of the bending data, generated by the production shop with the use of the pipe Laser Measuring Tool, it was possible to automatically generate the 2-D CADAM drawings of the pipes in the final issue (see **FIG. 34** at pag. 66.17).
This resulted in a dramatic time reduction of the drawing release: few man hours for all the pipes, compared to an estimate of one man hour per each pipe, with the additional advantage to avoid the possible typing errors of an operator that would manually insert the bending data into the 2-D drawing.
An additional side advantage of the work was to generate CATIA 3-D models of each pipe, establishing the basis for a possible future migration of the EH101 piping system from 2-D to 3-D design.

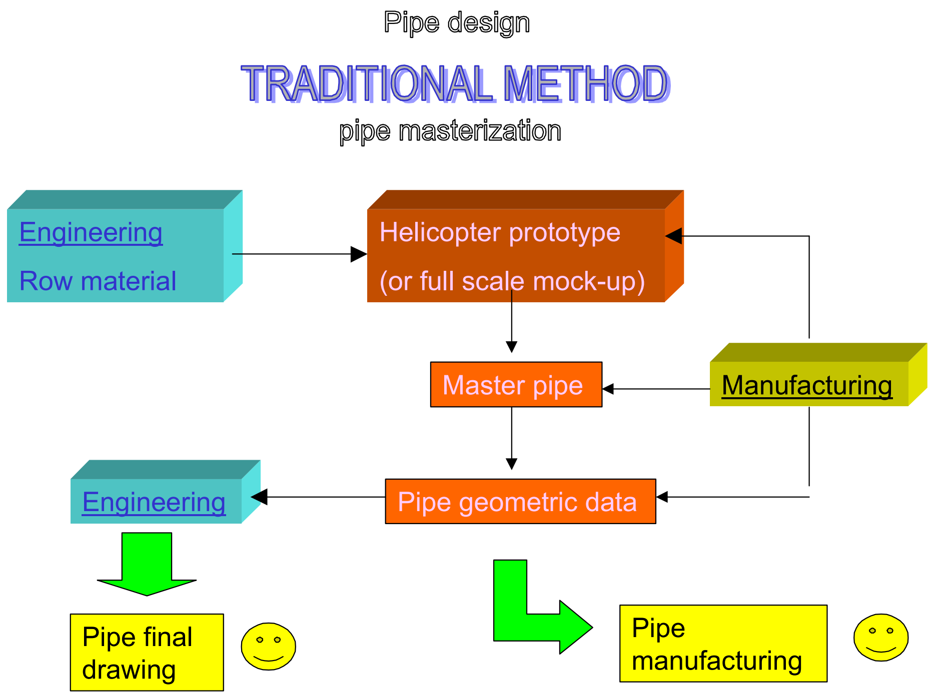
Pipe design
TRADITIONAL METHOD
pipe masterization
Engineering
Row material
Helicopter prototype
(or full scale mock-up)
Master pipe
Manufacturing
Engineering
Pipe geometric data
Pipe final drawing
Pipe manufacturing

FIG. 1

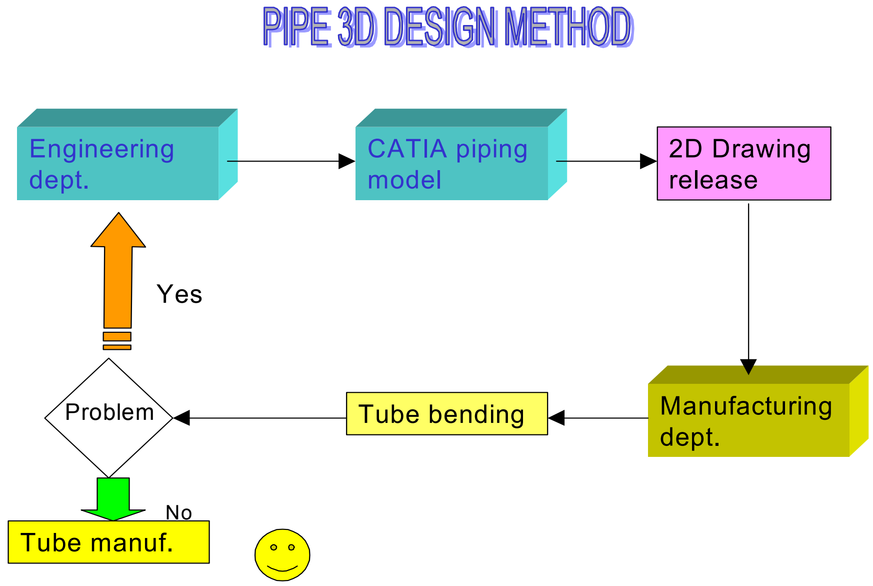
PIPE 3D DESIGN METHOD
Engineering dept.
CATIA piping model
2D Drawing release
Manufacturing dept.
Tube bending
Problem
Yes
No
Tube manuf.

FIG. 2

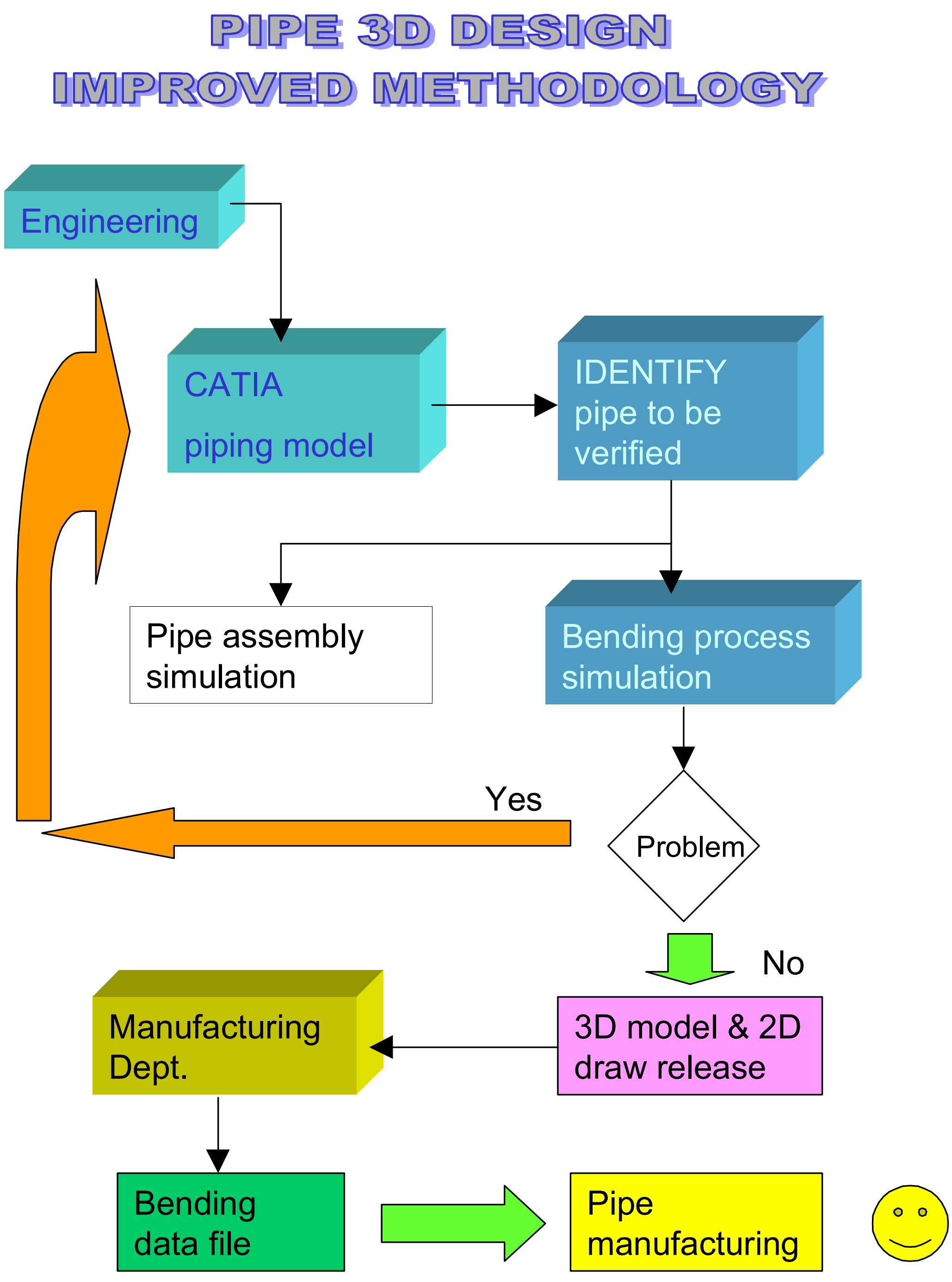
PIPE 3D DESIGN
IMPROVED METHODOLOGY
Engineering
CATIA
piping model
IDENTIFY
pipe to be
verified
Pipe assembly
simulation
Bending process
simulation
Yes
Problem
No
Manufacturing
Dept.
3D model & 2D
draw release
Bending
data file
Pipe
manufacturing

FIG. 3

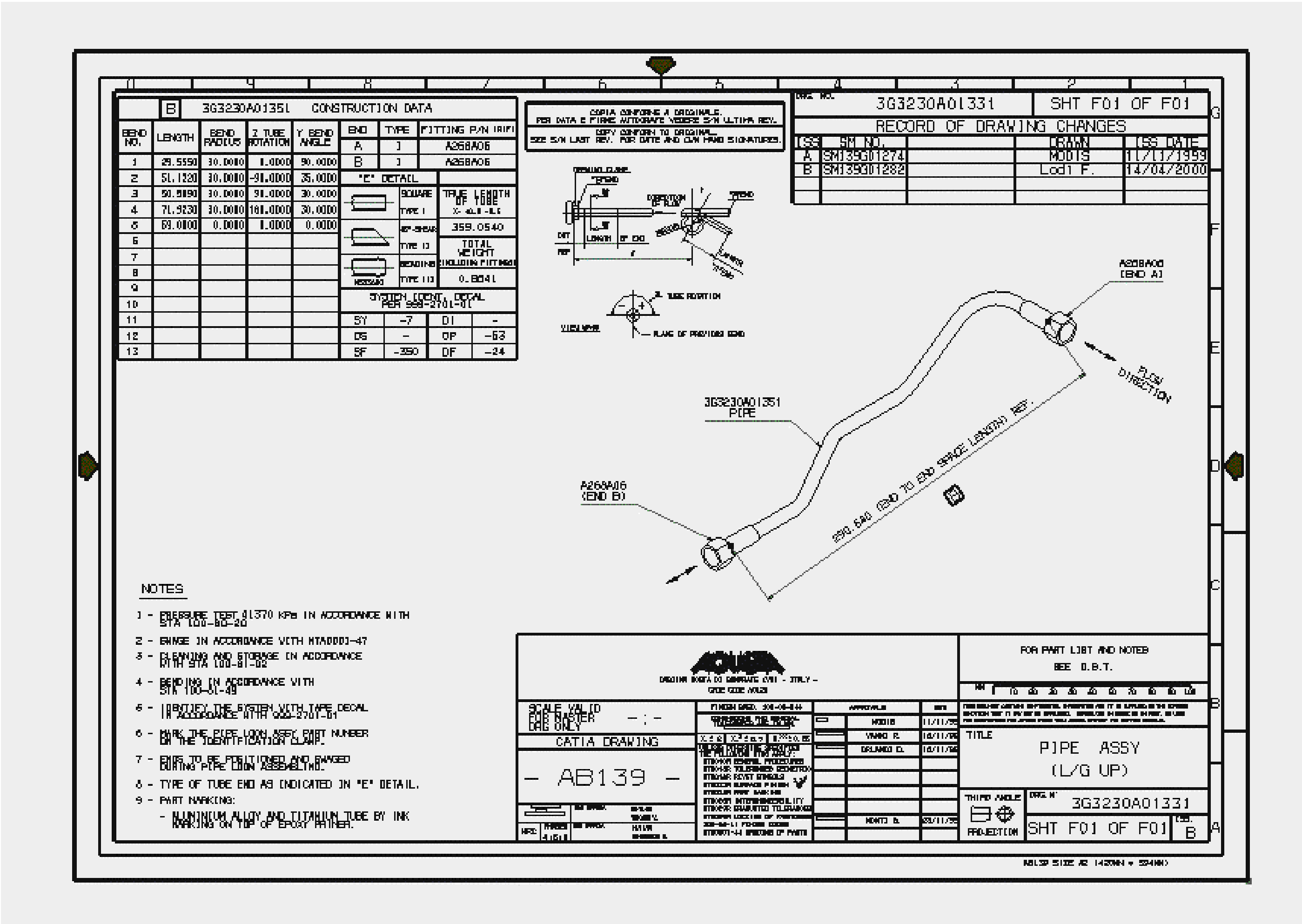

FIG. 24 2D drawing format

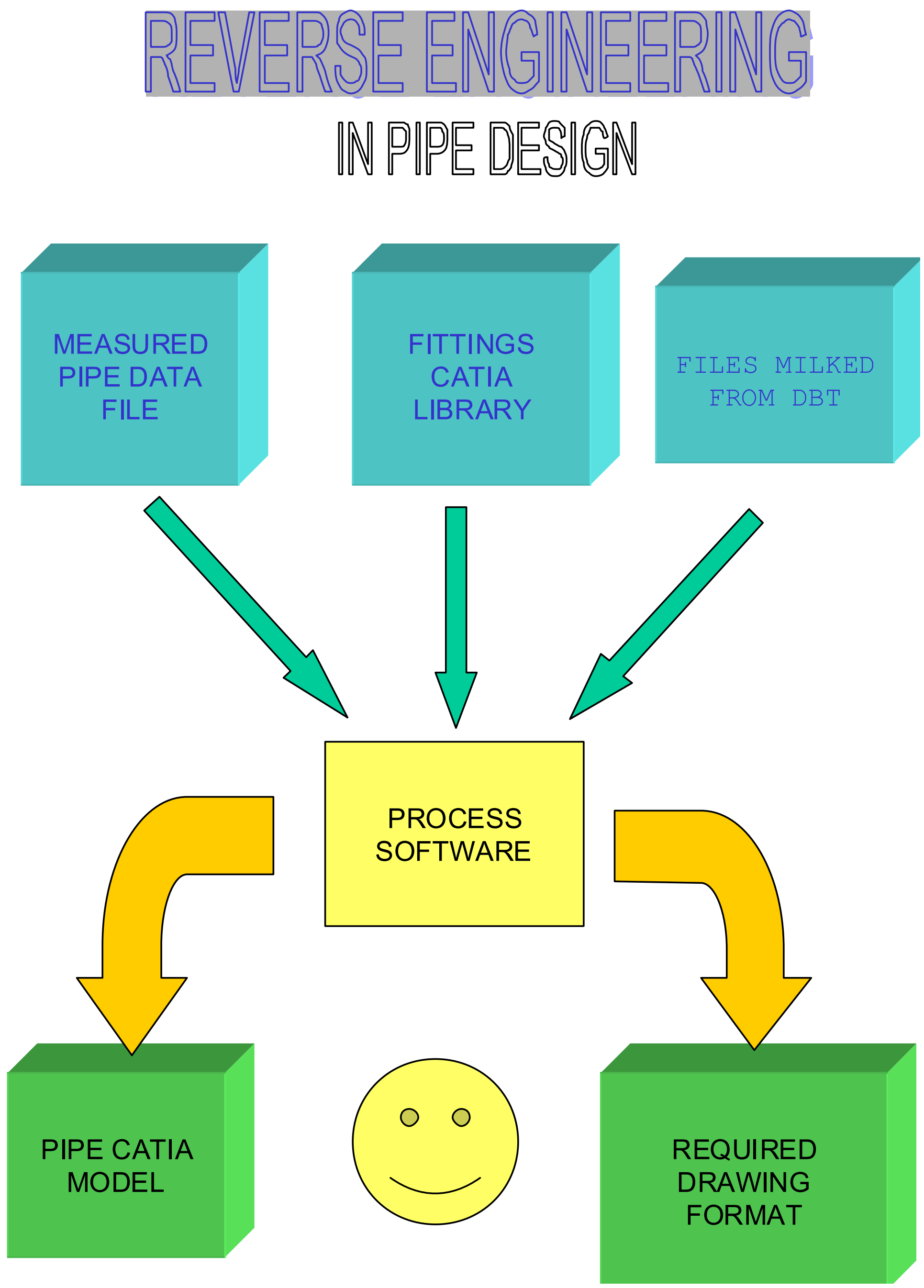

FIG: 30 Reverse Engineering flow diagram

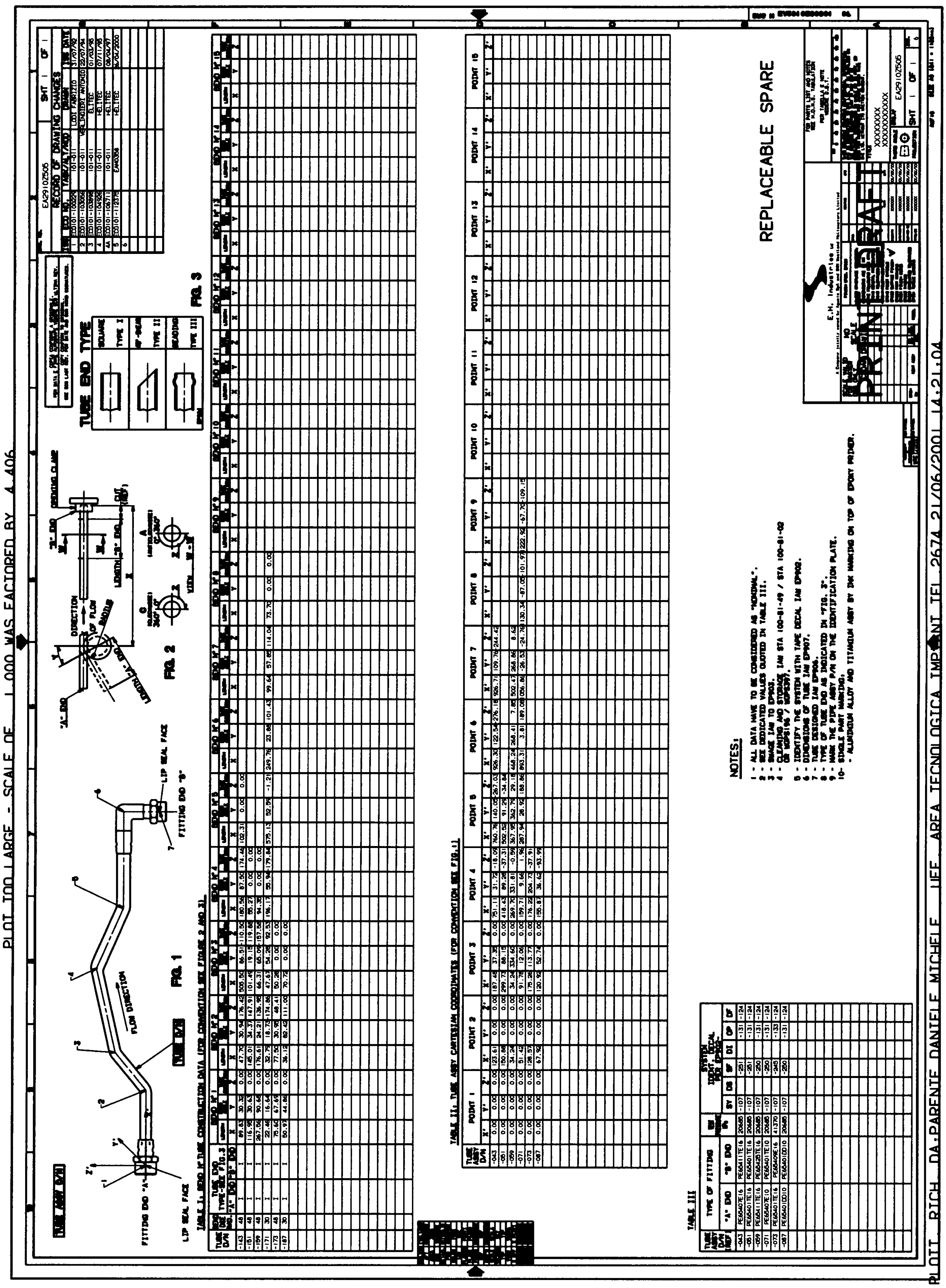

FIG. 34 Drawing P/N EA2910Z505 (EH101 program) updated by means of the Reverse Engineering software