Development of 3D Graphics Aided Assembly Process Planning (GAPP) System for Complex Aero-Engine Assemblies using Model Based Definition

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***Abstract* - Planning assembly and manufacturing sequences, for products that involve thousands of parts and multiple sub-assemblies, needs clear-cut written and visual work instructions to aid the shop floor assemblers and to ensure a defect free assembly for first time acceptance of the final product. The integrity and perfectness of an assembly depends on the information provided in the work instructions and the clarity of visual representation of the graphics in the process plans. In this paper, a novel graphic based Process planning approach is presented and the methodology is discussed in detail.**

Keywords: Graphics aided process planning; Model Based Definition; CAPP; 3D Process planning.

I. INTRODUCTION

To maintain assembly work instructions, organizations depend on computerized process planning tools customized for their product lines. So far, most of the existing assembly process planning tools emphasized on organizing work instructions, BOM and Tools list management, graphic representation of the work instructions in 2D and version control of these process plans. A perfect assembly process plan ensures

1. First time acceptance of the assembly/minimum number of strip downs and reassembly.
2. Ease at which engineering/design changes are applied in the process plans
3. Minimum lead time to assemble the product
4. Minimum labor requirement
5. Perfectly balanced assembly line
6. Ease at which an operator uses the assembly process planning tool.

Etsuo Fukuda [1] explained various architectures of process planning systems for manufacturing using computers. Mayasuki Tanaka [2] demonstrated how online process plans are generated in sequential order. Mark A Desbiens [3] demonstrated how multi user process planning systems can be designed and managed. Kevin P Staggs [4] explained the usage of cloud computing for manufacturing. Michael J Sidner [5] explained the advances in production planning system in terms of capacity planning and balancing to meet the demand.

But the crucial features that are not covered so far and some of the drawbacks of the existing process planning systems have been

1. Poor connectivity of these systems with the engineering and design in the PLM increasing the lead time and data losses.
2. Poor clarity of the 2D graphics that helps the assemblers during assembly process.
3. Poor interactivity and ease with which an operator accesses these systems while assembling.

Software tools for simulating assembly and manufacturing layouts exists in the market and are being developed by many PLM companies. These simulations will support mostly for automated assembly lines. Moreover, the costs of these tools are high and organizations with smaller turnovers and revenues may not afford these tools.

Therefore, to address the above setbacks, a new process planning system has been developed using Digital Mock-up (DMU), Model based Definition (MBD) technique and CATIA V5 design tool. This tool can seamlessly integrate into the PLM of an organization and, at the same time, can help the assemblers and planners to create and work on the assembly process plans efficiently.

In the following passages, the concepts and structure of the 3D Graphics based Process Planning (GAPP) tool would be detailed and the work done till date to develop the tool will be demonstrated.

II. HIGH LEVEL DESIGN OF THE TOOL

Basic architecture of the tool consists of integrating a 3D modelling tool and a process planning tool. Below block diagram explains the working model of the current Process planning tool in a typical PLM system.

The three modules are

1. Product Design
2. 3D process planning
3. Manufacturing

The current focus is to develop the “3D process planning tool” module specified in the dotted lines box in the figure 1.

The main objective is to develop a tool that can seamlessly integrate 3D process planning system into design and manufacturing modules of a PLM using existing functionalities within the modelling tool.

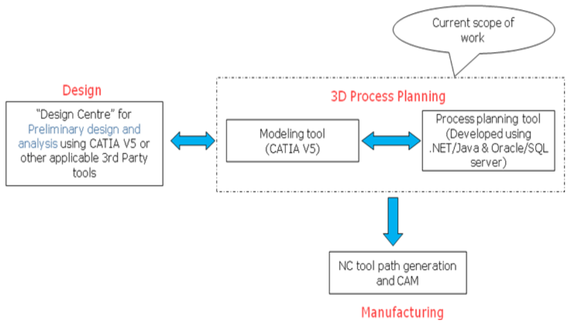

Fig 1. Block diagram of the model

As specified in the above block diagram figure.1, the process planning system needs a modelling tool and a process planning tool developed using a database and a front end environment. These two tools are integrated using automation interface and other third party applications.

The methodology and detailed procedure for developing the tool shall be discussed in the following passages.

III. 3D PROCESS PLANNING

A. *Implementation*

The implementation of this tool would be in different phases. A common standard methodology to organize the assembly information in the modelling tool (CATIA V5) has been developed according to the assembly flow. Through this methodology, the 3D models generated for the engineering and design requirements will be used to simulate the assemblies and sub-assemblies in CATIA V5. This includes simulating the assembly sequences, BOM information, Assembly operation titles and the hierarchy related to the assembly sequences.

Subsequently, using VBA/CAA in CATIA knowledge ware, an interface to extract the 3D models required for the process planning is also in development.

The extracted 3D models from the main/sub-assemblies will then be converted into light weight 3D files such as 3Dpdf or 3D XML. These files will then be used for final process planning purposes. The advantage of converting the 3D CATIA files into 3D pdf or 3D XML files is that these files do not require an expensive CATIA license for viewing. Moreover, a shop floor assembler does not need all the design or engineering information for assembly purposes. Therefore, only information required for the assembly, manufacturing will be captured into these 3D xml or pdf files and transferred to the process plans. This information contains Annotations, Dimensions, and Stackups etc.

A dedicated process planning system will then collect all the information from CATIA V5 and generates the header information required to develop process plans for that particular assembly. Then the relevant xml files will directly be linked to these automatically generated process plans. The information contains, Assembly operations, BOM data from CATIA V5 and 3D xml files.

Then, the planner uses the information generated by the process planning tool to write the detailed work instructions and will publish this to the shop floor.

As per the basic architecture of the tool, the implementation would be in 4 modules.

1. Development of assembly methodology in CATIA V5.
2. Development of Process planning tool.
3. Development of VBA/CAA to integrate the CATIA V5 and Process planning tool (2)
4. Development of Database to maintain Graphics and Process plans.

The below block diagram details the architecture with which the process planning tool would be developed.

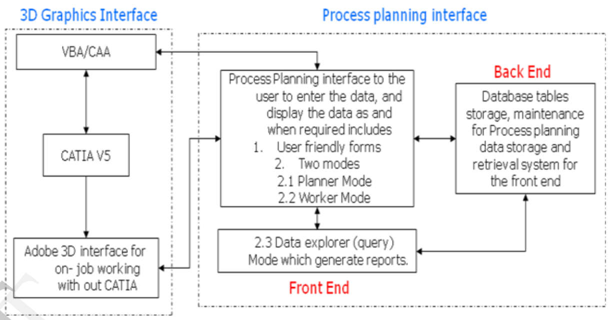

Fig 2. Architecture of the tool

B. *Methodology and simulation*

The methodology is developed considering a sample dummy aero engine turbofan assembly. The assembly is developed in CATIA part modelling and assembly modules. The turbofan assembly is considered because of its complexity and number of sub-assemblies that will aid in simulating the current requirements. Therefore the above Digital Mock-up (DMU) will ensure enough reference information to simulate the subassemblies and process plans.

The complete assembly is divided into 7 subassemblies and the flow chart is developed as shown in the figure 3.

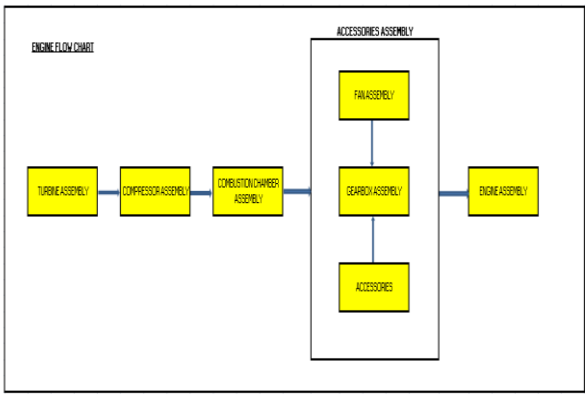

Fig 3. Flowchart of an engine assembly

To simulate serialized and parallel subassembly configurations, the flowchart is designed in such a way that the modules are arranged in serial and parallel sub-assemblies.

Serialized sub-assemblies require their previous subassemblies (predecessors) to complete, whereas, Parallel sub-assemblies can be done independently all at the same time.

In the figure 3 flow chart serialized assemblies are

1. Turbine assembly
2. Compressor assembly
3. Combustion chamber
4. Accessories
5. Engine assembly

Parallel assemblies consists of

1. Fan assembly
2. Gearbox assembly
3. Accessories

These parallel sub-assemblies can be assembled simultaneously to the engine without any interruption.

Using the above flow chart, the parts required to simulate each sub assembly are modelled. Below given is a snapshot of the complete engine assembled using the finalized methodology. The dimensions of all the parts in the assembly are considered approximate and are modelled just to simulate the assembly and are not for real assembly and manufacturing purposes.

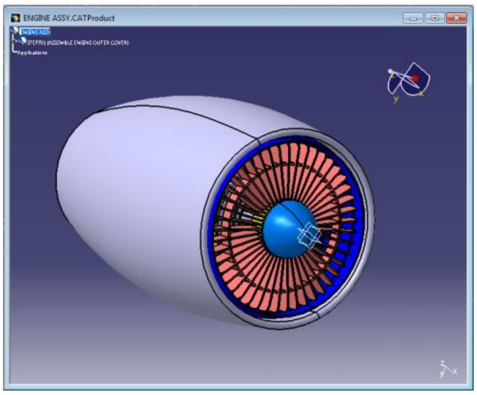

Fig 4. Turbofan assembly

C. Development of assembly sequences

To simulate the assembly processes in CATIA, assembly sequences are developed for each subassembly as per the flow chart. This is done in MS excel considering each part and the way it is assembled in CATIA.

These assembly processes consists of

1. Steps, major assembly titles for a sub-assembly
2. Sequences- detailed assembly instructions of each step
3. BOM, required for each step
4. Tools, Required to assembly each sequence/step

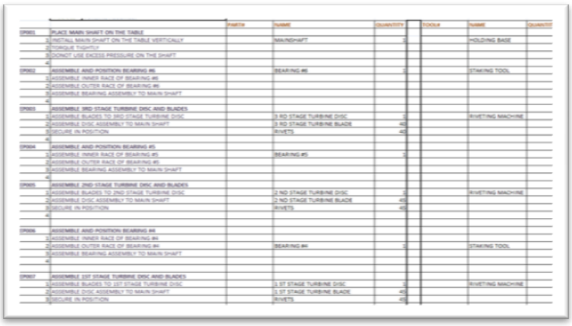

Fig 5. Development of assembly process plans in MS excel

The above assembly sequences are simulated in CATIA using a customized methodology for assembly.

D. CATIA Tree structure

Now, "Turbine disc assembly" in the engine flowchart has been chosen to simulate the subassembly.

Fig 6. Simulation of assembly steps in CATIA model tree

E. Procedure

1. Each subassembly is a CATIA assembly file (CAT product)
2. Each STEP is developed as a CAT product which also contains the STEP numbers and STEP title of the subassembly.
3. Each part in that particular STEP is a CAT part which will be in that subassembly CAT product
4. All these STEPS (CAT Products) related to a subassembly are assembled one step over the other in descending order.
5. All the Steps are assembled as per the hierarchy followed.
6. That means STEP001 is a child of STEP002 and STEP002 is assembled to STEP003 and soon.
7. To ensure as much assembly process planning information in the model tree, STEP titles are added to each STEP's assembly file as its INSTANCE NAME in properties option.
8. Also, part numbers to various parts, tools list and time required to assemble the step can be given at this point to automate the assembly process plan generation.
9. The above point will reduce the planner's work in creating automatic process plan generation and ensures minimal manual entry at the time of plan generation.

F. Simulation of a sub assembly (TURBINE DISC ASSY)

1. STEP001-PLACE MAIN SHAFT ON THE TABLE

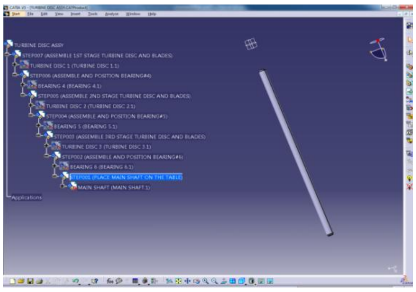

Fig. 7

2. STEP-002-ASSEMBLE AND POSITION BEARING #6

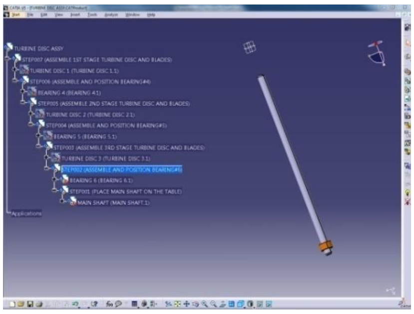

Fig. 8

3. STEP-003-ASSEMBLE 3RD STAGE TURBINE DISC AND BLADES

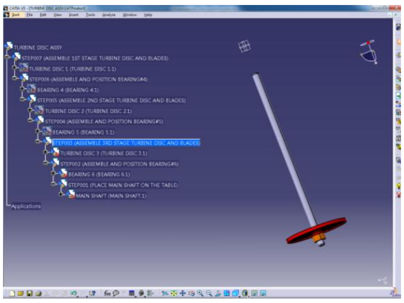

Fig. 9

4. STEP-004 - ASSEMBLE AND POSITION BEARING #5

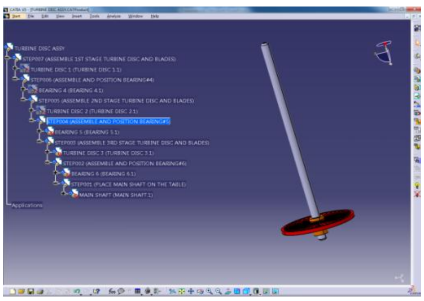

Fig. 10

5. STEP-005-ASSEMBLE 2ND STAGE TURBINE DISC AND BLADES

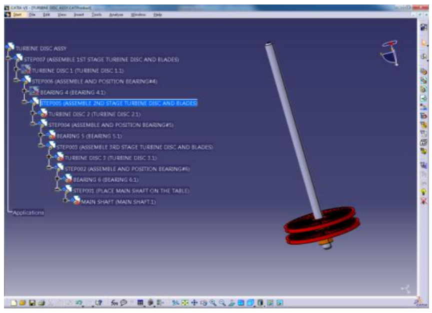

Fig. 11

6. STEP-006-ASSEMBLE AND POSITION BEARING #4

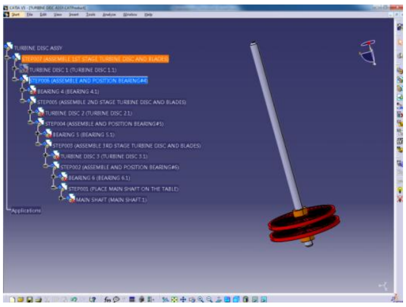

Fig. 12

7. STEP-007-ASSEMBLE 1ST STAGE TURBINE DISC AND BLADES

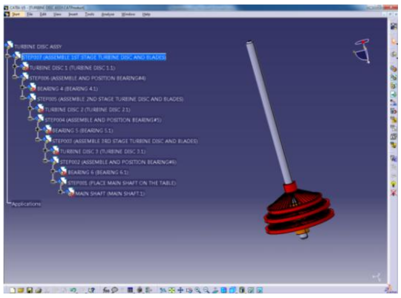

Fig. 13

This completes the simulation of one (Turbine disc assy) sub module in the flowchart.

In the above 7 steps, each assembly sequence is added as one CAT Product file and the step titles are added in the description field of that relevant product.

Each subassembly consists of parts contained in its subassembly. All these steps are assembled in a specified hierarchy in ascending order. This gives a clear picture of how a subassembly can be simulated using a modelling tool such as CATIA V5.

G. Simulation of a complete assembly

1. Turbine disc assembly

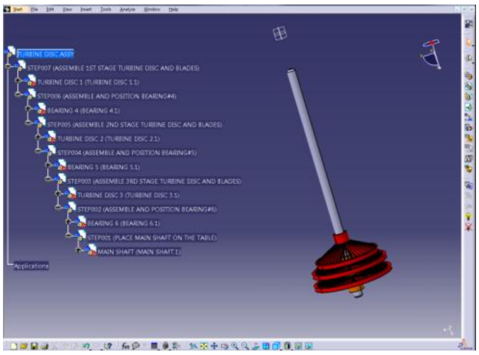

Fig. 14

2. Compressor Disc assembly

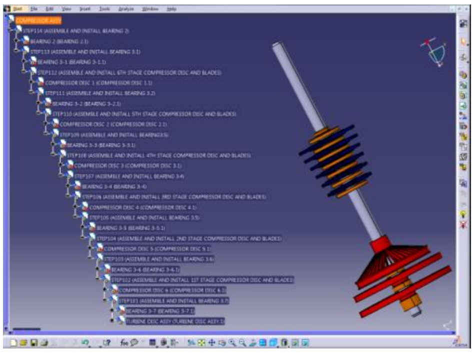

Fig. 15

3. Combustion chamber assembly

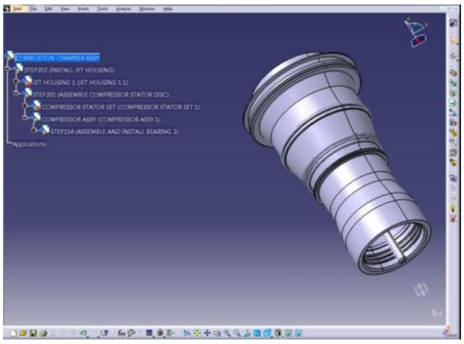

Fig. 16

4. Fan assembly

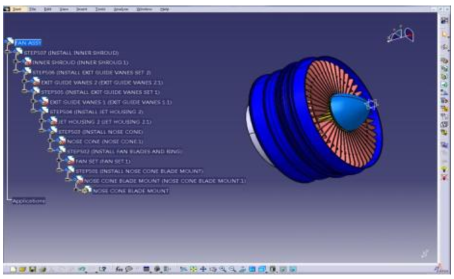

Fig. 17

5. Gearbox assembly

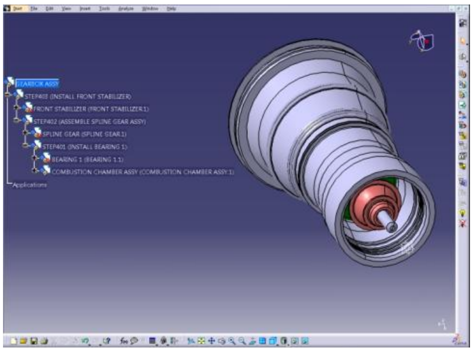

Fig. 18

6. Accessories Assembly

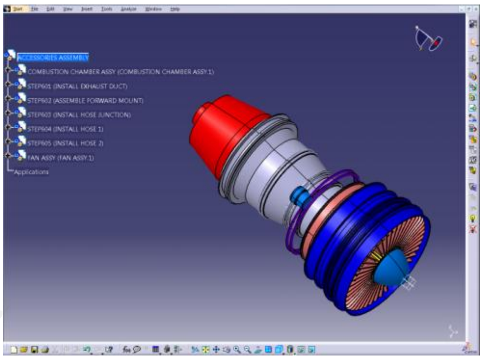

Fig. 19

7. Complete Engine assembly

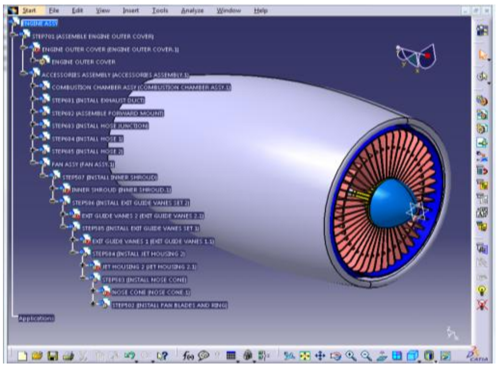

Fig. 20

Figure 20 depicts a complete engine assembly. This assembly consists of all the subassemblies involved in the engine flowchart shown in the figure 3. These sub-assemblies are also assembled considering the flowchart structure i.e. as a serial sub assembly or as a parallel sub assembly. The definitions of a serialized and parallel subassembly are given in the previous chapters.

H. Simulating Serial, Parallel operations and Sub-assemblies.

Arranging Serial and parallel assembly operations:

1. As discussed in the previous section, a serialized operation requires its previous operations to complete. To simulate this scenario, the below tree structure has been followed.

Each operation is linked to its next operation using union in descending order as shown in the below snapshot of (FAN assembly).

Fig. 21. Hierarchy to define serial operations/Sub assemblies

2. A parallel operation is one that can be assembled parallel to other operations. Accessories assembly is an example of a parallel assembly. It includes Exhaust duct, Forward mount, hoses, Fan assembly assembled parallel at the same time to the main engine.

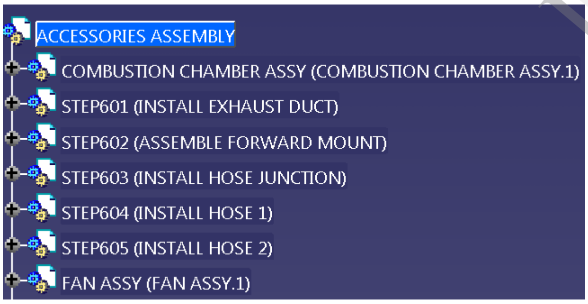

Fig. 22. Hierarchy to define Parallel operations/Sub assemblies

IV. DEVELOPMENT OF GAPP PROCESS PLANNING TOOL

A. Integration

After the development of assembly processes in CATIA V5, integrating these processes to the Process planning database is done using VBA/CAA interface.

A process planning interface is developed using VBA for CATIA that can extract all the information related to the process planning where in all this information extracted from the CATIA model tree will be automatically transferred to the Process Planning tool.

This information includes

1. 3D sub assembly models
2. Sub assembly header information
3. Operations involved in each subassembly
4. BOM information.
5. Tools list.
6. Time required for each step.

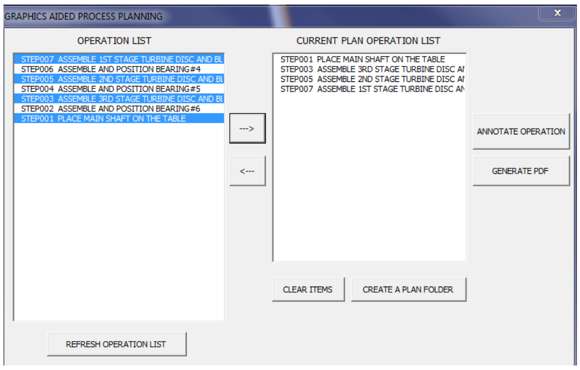

Fig. 23. VBA Interface to Extract Process planning information from CATIA models

The above tool helps as an interface to extract the required information from the CATIA V5 Assembly module.

This tool performs the following functions

1. Selects the required sub-assemblies to write a process plans.
2. Converts the sub-assemblies to 3D pdf files.
3. Helps the planner to add annotations to 3D pdf files.

B. Process planning module

The process planning module consists of a

1. Assembly process planning header information
2. Graphics interface
3. Fields to write detailed instructions.

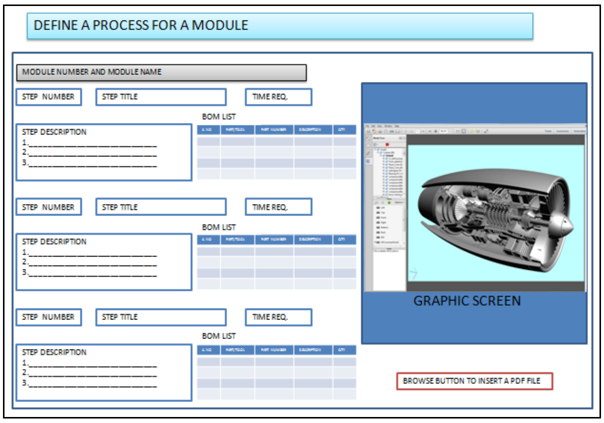

Fig. 24. Process planning interface to be developed in Visual studio

Once an assembly is simulated in CATIA V5 and its related 3D pdf files are generated and kept in the database, a process plan is automatically generated in the Process planning tool.

The Planner then logs into the process planning tool and initiates writing the detailed instructions of that particular process plan.

As the BOM (Parts list), Step Information and 3D graphics (PDF files) are already created in the process planning tool, the planner just need to write the detailed instructions for each sequence and publish it to the shop floor after validating the plan.

C. *Assembler and tool interface*

The affectivity of this tool can be enhanced by providing the assembler a hand held tool to manipulate with the 3D model while assembling at the assembly line and without reaching the computer screen. This tool is a trackball and will be held with the assembler.

Using the trackball, the assembler can remotely

1. Move across various steps in the process plan
2. Manipulate the 3D models for clarity
3. Signoff the process steps from the place where the assembler is actually assembling.

Fig. 25. A trackball [9] to aid the shopfloor assembler

D. *Tools/Software required*

1. CATIA V5
2. VBA
3. MS VISUAL STUDIO for development and ASP.net for web development.
4. MS SQL/ Oracle DB
5. Tetra 4D / Adobe X Pro (3D PDF converter)/3D Via Composer

CATIA V5 and Tetra 4D/Adobe X pro licenses are required for Planners only to develop assembly methodology, whereas MS Visual studio, VBA support is required for development and maintenance of the process planning software.

V. ADVANTAGES OF THE TOOL

1. This tool can seamlessly bridge the gap between engineering design and manufacturing databases as the primary inputs for the process plans are 3D models and the development tool used is CATIA V5, which is a design and analysis tool.
2. This tool is both planner and assembler centric. Most of the process planning tools are developed that will be interactive either to the planner who writes the process plans or to the assembler who will assemble using the written process plans. But the current tool will be interactive to both the assembler and planner.
3. This methodology eliminates 2D drawings because the concept is based on Model based Definition (MBD) and Digital Mockup (DMU) which gives complete information about the assembly processes at the first look.
4. This tool helps semi-automatic process plan generation and helps the planner reduce unnecessary work related to planning.
5. This tool enables a paperless office.
6. This tool can be successfully implemented to small scale industries and large scale industries alike because the methodology can be applied both to complex and simple assemblies.
7. The same concept can be applied to manufacturing process planning with minor changes.
8. Using a trackball device will reduce the operator movement in the shop floor to and fro the system to the place of assembly and hence reduces the lead time.

VI. FUTURE SCOPE

1. The tool can be extended to add Product design, analysis and manufacturing process planning features as it uses CATIA V5 which can support the above functionalities.
2. The tool can be implemented using Cloud computing technology which can save expensive licensing costs and can be provided on a need basis as and when the users require.
3. Animation of the 3D graphics can also be done to improve the interface and efficiency of the tool.

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[9] Figures: from Fig.1 to 24 are proprietary of Infotech Enterprises Ltd and does not contain any customer technical information. All the dimensions are for representation purposes only. Figure 25: Courtesy - Trackball, I ball-corporation.