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Prototype Aircraft Sub-Assembly Fabrication using Common Stage Walking Line Assembly Model

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ABSTRACT:

This paper describes the application of Walking Line Assembly (WLA) in prototype fabrication of yoke sub-assembly and its effectiveness. The technical aspects and challenges involved in development and fabrication of engine mount yoke tube assembly for a civil aircraft are presented. Activities representing reverse engineering process and fabrication of yoke tube are detailed comprehensively. WLA model adopted for this assembly is compared with conventional methods and fixed layouts. Further, WLA model is modified with a common stage set on every process where the expected capability of the task in the shop floor is brought out in consensus with the operational demand and standards. This is achieved with very little disturbance to the existing aircraft fixed line fabrication set up. This model has given encouraging results by expediting the processes and provides an ideal option for building of prototypes in the development stage of an aircraft project.

KEYWORDS:

Engine mount assembly; Model effectiveness; Reverse engineering; Walking line assembly

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1. Introduction

Engine yoke tube sub-assembly reinforced with trusses is fabricated for the purpose of mounting the aircraft engine and its casing. Engine mount is assembled in an assembly jig that represents the pitch up and toe-in orientations of the engine in its final assembly on aircraft. Realization of this sub-assembly involving critical tolerance dimensions and assembly parameters is a technically demanding challenge [1]. This involves carrying out stringent quality checks at every process and stages involved in the route books. Such activity is generally carried out in fixed assembly units for production standard aircraft so as to achieve high degree of quality and reliability in the process [2]. Establishing an assembly procedure for a prototype aircraft where no process or reference records are available is a challenge and usually undertaken based on the design requirement. Considering that the procedures are being carried out for the first time, the additional challenges include realization of the parts as scheduled for the sub-assembly and the ability of the new process model to address the complexities in fabricating the yoke sub-assembly.

The yoke tube is mounted with suitable cup brackets at the fastening locations of the engine and holding points of the stub-wing yoke bracket attachment to the fuselage. The parts include two hollow semicircular annular tubes connected by sleeves: four double leg brackets, four single leg brackets, two planar truss attachment brackets, four gas vent brackets and four truss attachment brackets.

2. Reverse engineering & fabrication

To accommodate a change in the curvature of inner and outer contours, reverse engineering technique is applied to match the surface of the yoke tube on the brackets. Chrome-Molybdenum steel is the material used in building the yoke tube assembly. The jig as shown in Fig. 1(a) is set up for positioning of the cup brackets. Master cup brackets machined as per the nominal yoke geometry are used to capture the formed yoke surface. These are degreased, cleaned and locked onto the jig and polymerized resin is applied on to the butting region of the master cup brackets. These brackets are then carefully positioned and locked to the jig on one side and against the yoke tube surface on the other side, so that the resin shall encapsulate and create a matching pattern of the butting yoke region. The positioned master cup brackets are then carefully removed for curing without disturbing the set surface on the yoke. The realised pattern surface is shown in Fig. 1(b).

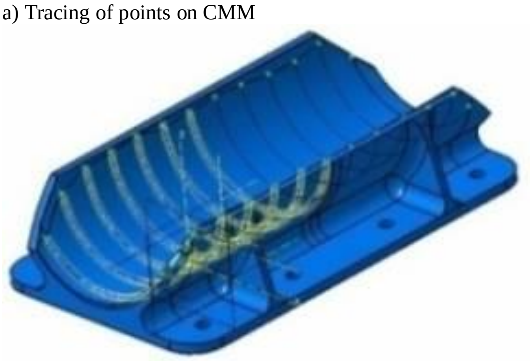
The Co-ordinate Measuring Machine (CMM) brings in ability to trace points on the pattern surface [3-4]. These master cup brackets are set with a reference, based on 3-2-1 principle and points are traced at intervals of 5mm along true length and on contours at 10mm respectively. The brackets being 150-200 mm long, about 15 to 20 contours are scanned using the CMM at pre-defined reference. The scanned point data from CMM is the input to the CAD system for construction of the model [5] and these contours are used to develop a lofted surface which represents the corresponding yoke tube surface as shown in Fig. 2(a)-(d).

a) Master brackets clamped on jig with resin

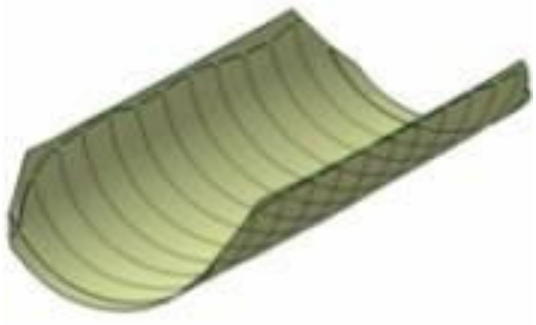
b) Resin surface pattern

Fig. 1: Reverse engineering: Pattern development

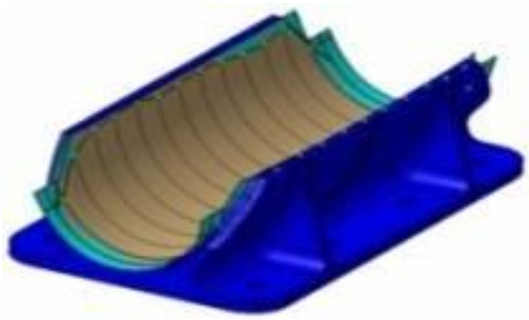
a) Tracing of points on CMM



b) Point import & contour generation



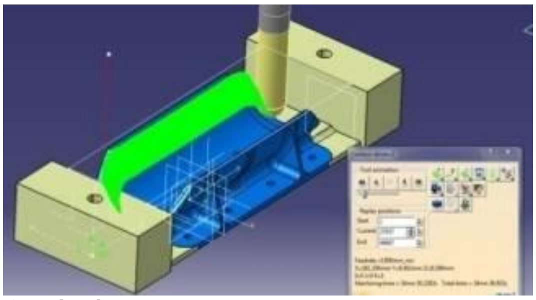
c) Surface building & extrapolation



d) Volume building on the model

Fig. 2: Generation of CAD surface

The model of the cup bracket representing the mapped yoke surface is input to Computer Aided Machining (CAM) system for manufacturing. This involves establishing lugs and fixtures to the existing model and develop a CNC program to fabricate the part as in Fig. 3(a) and (b). Depending upon the complexity of the surface, sequence of set ups are organized for the completion of the designed brackets [6]. Thus the surface pattern extracted on the master cup bracket is mapped on to the bracket suitable for its integration with yoke tube. The fabricated cup brackets are subjected to inspection for validating the mapping surface butting the yoke tube. The end region and edge distances are given utmost importance as these regions undergo TIG welding. Suitable machining strategies, tools, clamping, process parameters are chosen to complete the machining of all the cup brackets [7-8].



a) Tool path generation: CAM in CATIA V5

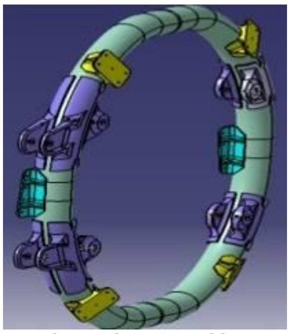
b) Exporting of NC programs on CNC machine

Fig. 3: Generation of tool path and NC program using CAM

Fabrication of 18 brackets, yoke tubes and the sub-assembly fabrication demands facilities like CNC machining, CMM, pipe bending, TIG welding, NDT viz., dye penetrant testing, radiography testing, Heat treatment, Bush pressing, Cadmium plating, Horizontal milling, Jig boring, Painting and Tagging. These processes are generally sequential and output of first process forms the input for the second process. Due to this dependency, every step towards realization of the sub-assembly becomes stringent and critical from the inspection and schedule point of view. The sub-assembly in an aircraft development programme is built with the aid of the jigs. Weld jig sets the yoke tube assembly in position during the welding process. The complexities involved in welding are handled systematically to minimize warpage. Heat treatment jig for the process of heat treatment where in the residual stresses are removed by mounting the yoke assembly on this jig with calculative reinforcements.

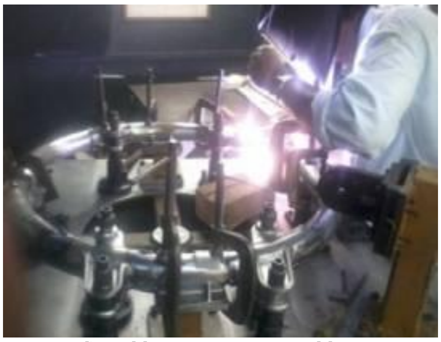
The primary step of truing for flatness of the semicircular yoke tubes with sleeves welded together results in the complete yoke ring. The fabricated parts are installed on the weld jig and the pre-assembly dimensional check up is done on CMM to ensure the suitability of brackets on the yoke ring. All legged brackets are positioned at these critical regions to suit the Interchangeability (ICY) along Y-axis after welding and heat treatment. Sufficient allowance is provided at the fork gap and holes for accommodating any warpage. The fork end attachment holes undergo final machining operations to suite the assembly jig. This assembled unit is subsequently taken for testing, degreasing, cadmium plating, linseed oil treatment, painting, bush pressing and finally to the sub-assembly jig for further operations as shown in Fig. 4 (a)-(i).

a) Yoke tube flatness assessment



b) Mock up assembly

c) Pre-set dimensional testing on CMM



d) Welding process on a weld jig

e) Welded brackets on yoke tube

f) View of completed assembly

g) Suitability with next assembly

h) Inspection on nacelle jig

i) Yoke assembly with truss & frames

Fig. 4: Engine mount yoke tube assembly fabrication

3. Methods and planning

This section details the planning and execution of operations in realization of the complete sub-assembly addressing all the fabricated parts, jigs, process operations, inspection and work centers. Generally, there are no dedicated assembly lines created for a prototype sub-assembly. Instead, facilities available in process and product layouts that are used to support the fixed assembly configuration of other production aircraft are tapped and utilized [9]. The sequential steps addressed in the route book are described in Table 1 with time taken for every process following WLA and Common Stage WLA (CSWLA) models.

Table 1: Scheme of work

Process	Activity	Time (days)	
		WLA	CSWLA
1	Preparation	14	10
2	Welding of yoke with sleeves	30	7
3	Welding of brackets – 8 Nos.	11	5
4	Welding of brackets – 4 Nos.	7	4
5	Welding of angular brackets – 4 Nos.	7	2
6	Jig boring and horizontal milling	8	5
7	Bush fitting and welding	8	3
8	Heat treatment	8	9
9	Horizontal milling and jig boring	18	8
10	Cleaning	2	2
11	Pre-final set operation	12	10
12	Preservation and tagging	9	2
	Total	**134**	**67**

Assessment of material requirement and availability shall be the preparatory phase of the assembly requirement. The sequence of operations mentioned in Table.1 is elaborated by the planning and methods group after thorough discussions with the designer and the manufacturing group. It is observed that there are 12 processes segregated on the basis of inspection, methodology and clearance at the end of each process. In an aircraft production facility, similar activity and processes are grouped under each shop floor with a process incharge responsible for that activity [10-11]. These shops are governed by shop floor managers, inspectors and group head etc. The sub-assembly event is supported by the route book that describes the processes and process shop responsibilities in a sequence. No process is overlooked or superseded at any point of time. The process is allotted in the flow of production line according to shift, incharge availability etc. The resources for each activity are arranged by the process shift incharge as shown in Fig. 5. An aircraft assembly process shop is so organized that every type of process activity is done with utmost excellence to achieve the maximum efficiency which determines the credential of the process shop.

The fabricated part is assigned to the inspector for quality approval and proceeds to the next process shop. Dimensional imperfections and property degradations if any take an additional route for snag rectifications from the designer and defect analysis by the shop floor managers. Once the sub-assembly of interest is completed, it is taken to the fixed assembly floor of the aircraft where it is inspected by mounting on a jig and then transferred to the aircraft assembly. It is noted that the actual time of work at the process shop is the product of process duration and worker efficiency but the time over-run generally occurs in the preparatory and disposition phase of the process. When the demand exceeds supply, challenge sprouts up in catching a time slot in the facility to be utilized. The challenge boils out to be a problem when the planned activity is held up by a disturbance due to process interruptions and shortages.

Similar is the case for prototype development and fabrication of yoke ring sub-assembly. The time taken by the first prototype with the existing WLA model was 134 working days. Since it is a development, testing and prototype category, an exclusive assembly line is redundant and would be expensive.

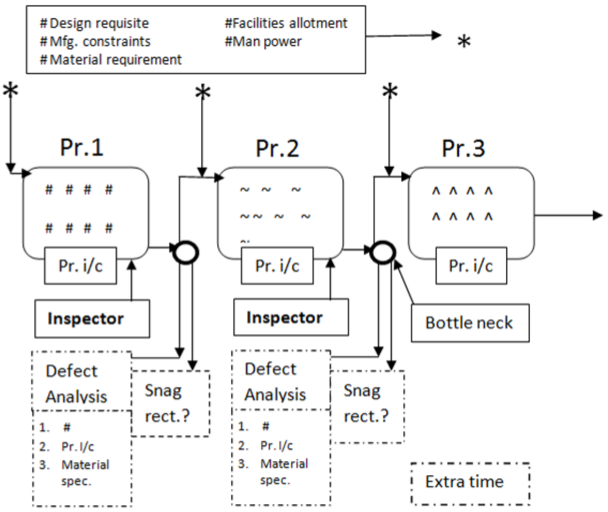


Fig. 5: Process flow in an assembly unit

The process and product run shop floor are exclusively set up for production series aircraft to meet the fixed assembly requirements. The prototype development programme introduces disturbance to the existing production sequence as it is to be done for one off quantity, say for a testing or research purposes. The study shows that such sub-assembly activity is possible with support from facilities and would demand adequate time for completion of task. This time frame is long by inserting the fabrication process in the route book at the time slot available at the end of part production in the process or product assembly lines [12]. Waiting time is also observed in such process due to facility allotment, resource non-availability and decision disposition as shown in Fig. 5. A dedicated team is formed for this prototype activity consisting of an engineer, welder and two fitters with a logistics person supervised by the head of manufacturing. The engineer handling sub-assembly responsibility is termed as "*WLA incharge*" who is an 'on- demand' resource allocated to facilitate the process completion.

4. Activities in WLA

Every activity involving application of heat energy manufacturing techniques on the yoke sub-assembly necessitates carrying out the dye penetrant test and radiography examination. These two tests are monitored by the respective inspectors. The inspector's clearance in radiography calls for shop floor records to judge and approve the process parameters. This understanding of the inspector's quality requirement is crucial and becomes a bottleneck if the clarity on quality needs is found deficient. So the part goes for a referral to the designer for disposition and decision, examining the reason for defects and monitoring the process capabilities. This involves retrieval of information on process and services and leads to expending additional time for resolving the query. If it is understood initially, much of this time can be gained by resolving them during the supervising process itself. The practices where in the process is executed by the technicians, supervised by the engineer and tested by inspector at separate locations and time, as shown in Fig. 6, lead to such delay [13]. The lack of understanding in the areas of quality and inspection requirements shall become bottle necks, questioning the efficacy of the process parameters, handling and process checks. The designer requirements are on dimensional and material property compliances. The shop floor-manufacturing aim shall be in bringing productivity in the process and inspector's perspective will be to meet to the standards. These three verticals become distinct with each one seeking to improve their productivity and efficiency.

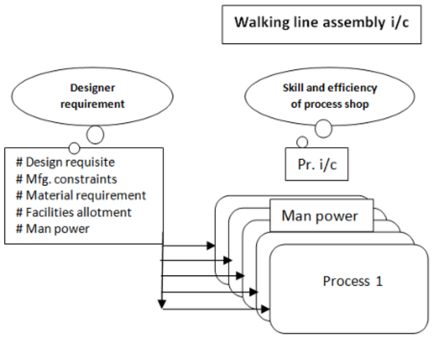


Fig. 6: Tasks involved in a process of WLA

The WLA model favours the sub-assembly realization but inspection clarifications and waiting time on completion of process lead to bottlenecks and time delays. While the tendency of the human resources viz., designer, process incharge (shop floor) and inspectors aim to present the efficiencies independently, only when a problem is encountered these independent resources showcase a disjoint phenomenon probing for clarifications and approvals to proceed to the next process causing considerable interruption in workflow. The process-incharge becomes a liaison responsible to achieve progress in work and implement the quality as per the inspector's perspective to progress the job. This responsibility has transmission losses on judging the importance of end target, tolerance and sometime leading to overworking of the technicians and time in understanding the process and product clearances by the inspectors. Schedules indicated for completion in a prototype development activity thus is dependent on the following points:

- A feedback loop necessary to reassess or raise and resolve a query with the designer.
- Possibility of the working executives to over/under estimate the quantum of work involved in a prototype activity.
- Delay in inspection and clearing of the job to next stage considering its crucial nature.
- Delay in decision making from the designer's perspective considering the Class-1 status of the components/assembly and non-availability of any legacy information about any performance reduction as it is being done for the first time.

To overcome these issues, proactive discussion with inspector before the initiation of the process and sharing of the importance of the process on the sub-assembly product and in-turn obtaining a word of caution from the inspectors, to be exercised during the process implementation would greatly reduce rework, rejections and delays. The implementation of this model and practice helped in setting an achievable target and eliminate unnecessary operations. This meeting has an impact in disseminating information across verticals and resolving bottlenecks involved in the sub-assembly directly with an understanding of the end result. The WLA supervising incharge thus in this model enables the implementation of the above parameters [14-15].

5. Common Stage WLA model

In a prototype development, there are situations where results are expected at the earliest, so as to take up a decision to progress the manufacturing process. This may involve a new pattern of handling the existing process. This new pattern is considered as a disturbing point in a full-fledged production process schedule. The rise of this disturbing point is because of the discontinuity in the flow that happens due to the need for educating the technicians, setting of the facilities, educating the task force and analyzing the process. As prototype development is essential for any technical progress, implementing the R&D team's requirement for prototype can be effectively carried out by implementing CSWLA. The standards expected by the inspectors, efficiency in the shop floor, proper technical description by the designers are brought to forefront on a common stage-WLA with an incharge attending every process as shown in Fig.7. Progress of the product during walking line pattern is delegated to WLA incharge who monitors the progress associated with the sub-assembly. The immediate idle time in the process shop is identified and the resources are assigned. The resources are so co-ordinated that the workers associated for the process are identified to execute the operation during the idle time of the facilities in the process shops. This ensures no disturbance and buffering of facilities, on the shop floor and need for any exclusive set of manpower and resources in a prototype fabrication.

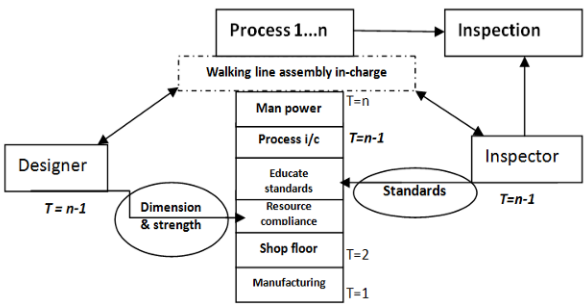


Fig. 7: Common stage WLA model

The WLA-incharge is called during the introduction of sub-assembly into the process shop. He emphasizes the inspection requirements to the process shop managers and process shop inspectors, who ensure the smooth process flow with a focus on the resource availability for the WLA without disturbing the ongoing production sequence. The records required for the sub-assembly is monitored and assured by the sub-assembly WLA incharge who ensures the standards defined by process inspectors and the design requirement are implemented. The WLA incharge bears the responsibility of educating and converting the standards from the inspectors to the skill set, efficiency and tolerance to the technicians. Care is taken to alert the manpower in the shop floor, inspectors and designer for a discussion with the WLA incharge at time T = n–1. Very early dissemination of instructions in a prototype sub-assembly is not useful as it would drain their time from regular activities and should be carried out on a 'need to know basis'. Delayed and isolated discussions shall only consume time that has been allotted for current activities in the shop floor. Thus in WLA, the process inspectors has set standards initially itself to match the designer's requirement with the technicians having set the capabilities of the facilities accordingly. This is an activity pattern at every process [16]. By this the inspector's clarification time on every parameter in the process is reduced considerably with the tasks and expected outcome being in total consensus with the intents of the designer, manufacturer and inspector in every process.

This model worked effectively across various processes such as at special machining centers, heat treatment, cadmium plating, jig boring operations etc. This enabled us to achieve the sub-assembly of yoke tube engine mount in 67 working days and the time for every process is as shown in Fig. 8. The CSWLA model was adopted in every process distributed across the fabrication set-up and resulted in the engine yoke mount tube sub-assembly being delivered for the structural testing activity in the time frame of 67 working days. It is observed that the WLA favours the prototype development without disturbing the shop floor set up. For an effective realization of the CSWLA, the following practices may be adhered to:

- The hiring of the facilities, skilled personnel etc., should be foreseen and implemented without any delays.
- The flow of process shall be seen even smoother when the materials requirements are foreseen and pre-determined.

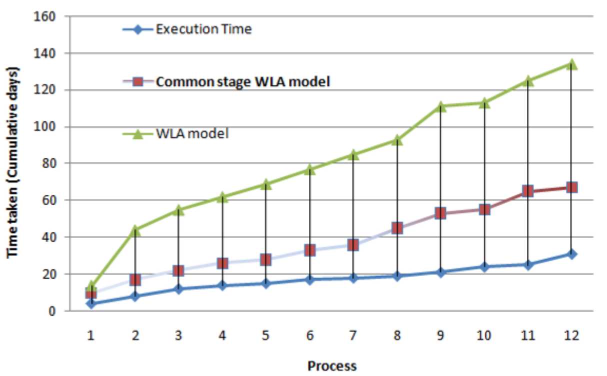


Fig. 8: Effectiveness of CSWLA model: Time vs. Process

With a dedicated layout for the sub-assembly development, the total execution activity hypothetically would be 38 working days. The WLA model has taken 134 working days for completion of all the processes involved in the sub-assembly fabrication, while CSWLA model as proposed in this work has brought down the time spent to 67 working days thereby reducing the process time by 50% as shown in Fig.8, thus clearly showing the efficacy of the model in a practical environment.

6. Conclusions

The fabrication schedule implemented in this work using the CSWLA model highlights the importance of utilizing available man power and machining resources without any intervention to ongoing shop floor activities. Application of reverse engineering methods in the fabrication of four critical brackets has presented the use of latest technologies leading towards better product output. This model has proven advantageous of:

- Utilizing the production line resources and facilitating product fabrication for prototype development and research activities.
- Ensuring a common stage platform for technical information dissemination in the areas of design, process standards and tolerances verticals.

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