CASI 2002 AY PROGRAM
PHASE I FINAL PROJECT REPORT

FIXTURE DESIGN CRITERIA: PHASE I

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July 25, 2003

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Contract Number F00001-01-D-0001

Security Classification, if required

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Project Summary

The objective of this project was to research technologies to improve and speed fixture designs within Tinker AFB. Envisioned is a Roadmap for Fixture design. One current deliverable is an electronic Fixture Design Manual. This manual is complete with detailed descriptions of theoretical fixture design principles (a power point presentation), a detailed text, a summary of available hydraulic fixtures (as per the request of the sponsor), and animation of 7 fixtures (including 3 designed and employed currently at Tinker) in a CAD software ProEngineer™. A final report and a full cost/benefits analysis is also presented. Projected benefits of this project include improved repair processes, reduced costs, and higher reaction speeds. A Phase II is currently underway to research and analyze fixtures currently employed at Tinker in various shops and to capture and document the design Engineers' perspective.

Introduction

Basic fixture design for manufacturing applications envelopes two main aspects: location and clamping. Between these two functions, the 6 (3 translation and 3 rotation) degrees of freedom are constrained, while effectively positioning and orienting the part during processing. The location of box-type parts is usually achieved using the 3-2-1 principle. This principle locates the primary plane by three non-collinear points, typically widely spaced; the second plane is located by two points and the third plane by one point. Cylindrical part axes are usually located using V-blocks while concentric locators are used to locate priorly drilled holes. The cutting wrenches (forces) are supported by effectively holding the workpiece, to minimize distortion or deformation of the object. Chip clearance, ease of part loading and removal, use in multiple applications (versatility) is often additional considerations in designing fixtures. Jigs also provide tool guidance in addition to the location and clamping provided by fixtures. Usually sheet metal fabrication and assembly often requires other types of fixtures than machining fixtures. In any case, fixture design is most cost-justified for batch or mass production runs. Considering this, the fixture designs for single-piece parts are better accomplished by modular fixtures. Fixture design is typically a setup cost function, making it very valuable in flow time and indirect cost calculations. Due to the rapid response required in many applications, the fixture design principles must be integrated and properly detailed so as to facilitate the fast design development of a fixture. Flexible, palletized and modular fixtures are quite common in today's industry to maintain rapid tooling in the agile environment.

This project researched standard principles involved in jig and fixture design, employed for machining operations. An electronic manual is designed to serve as a roadmap for fixture design. In a Phase II, it is proposed to research the parts manufactured in each production area and develop part taxonomy. Similar parts will be grouped using Group Technology concepts and part family classification. Based on the geometries of the parts and their features, the machines typically applied for creating features on these parts, and the type of processes employed, complete part complexity taxonomy will be developed. The types of fixtures currently developed and employed for each application will again be recorded. The principles and limitations of each fixture will then be analyzed. Correlation between theoretical fixture design principles and

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actual practical development at Tinker will be drawn. Using this, a formal generalization of the concepts and methodologies of fixture design for Tinker will be developed. Specific constraints for each shop will again be identified. Hence, a step-by-step procedure for jig and fixture design will be developed. In addition to a hard-copy fixture design manual, a procedural CD-ROM/Web-page for fixture design principles for manufacturing of different part geometries will be developed. The links with conventional CAD and CAE systems will be explored to automatically integrate part design concepts and engineering (stress, deflection, etc.) analysis. In summary, a roadmap to fixture design and/or existing fixture modification will be developed.

Acknowledgements

We express our sincere gratitude to the Tinker Air Force base, and particularly to Mr. Gary Stroud for providing this wonderful opportunity to study Fixture Design at Tinker and for creating a wonderful work environment. This project has allowed us to learn much about Fixtures as well as the facilities afforded by Tinker in manufacturing processing. We extend our sincere appreciation to Mr. Steve Moore and Mr. Pat Grissom of CSD, Mr. Bob Ochs and Mr. Robert Winters of Design, and Ms. Dalia Lopez and Mr. Hank Schank of Engine Augmenters for spending several hours of their time to assist us with this project. We also thank Mr. Bill Crane of Altec for all his efforts in expediting this project. Last but not least, we acknowledge the support of Carl Hatlelid, Tom Landers and John Nazemetz of CASI and Wayne Jones of the Tinker AFB in facilitating this project.

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CONSOLIDATED REPORT OF THE PROJECT

BACKGROUND

This report presents a preview of the information compiled for designing work holding devices under different operating situations. The nature of operation, the principle of design, the essential supporting elements required and the different type of the available devices are discussed in detail. The work holding devices that are elaborately discussed in the report are chucks of different types, and jigs and fixtures used for various operations.

In the majority of machining operations, the design of the machine tool is such that it provides a rotary or linear movement to the cutting tool. Drilling, Grinding, Milling, Broaching, Turning and Planing are some of the examples of cutting operations. In a Lathe, rotary movement is given to the work instead of the tool and the tool is translated to remove material. In a milling machine, the cutting tool is rotated and translated on a stationary workpiece to remove material. The workpiece must be suitably located to permit cutting action, by restraining the necessary degrees of freedom. Clamping or holding is applied to support the work against cutting forces and torques. In cases where the work piece is rotating, the holding force required for the holding device increases with increasing RPM. The importance of the work holder is briefly detailed in the manual with regards to its design and construction.

One objective of this project is to collect information about different types of work holding devices, for various machining applications. This information is complied and organized in the form of a reference guide to assist design and manufacturing staff in tooling design. As information is continuously updated and added for different types of products and for different working conditions, this guide will ease the work of design engineers by providing a suitable starting point.

DIFFERENT MODULES OF MANUAL

The work has been broken up into phases. This report documents the activities in a phase I. Phase I is a compilation of theoretical principles of fixturing and standard textbook reference, although some practical fixture designs are also included. The second phase will research several fixtures used at Tinker and group them using part family concepts to serve as ready reference for future designers. Some validation/verification of principles in real-time will also be implemented at that time. Together these phases will attempt to design a ‘Roadmap for Fixture Design’. The work to date is divided in five modules and it has been compiled as such within an electronic CD-ROM manual.

- **Details about Hydraulic chucks:** The different types of chucks with their physical dimensions and characteristics are explained. Different types of chucks are compared.

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- **Details about Jigs and fixtures:** Difference between a jig and a fixture, key decision points to be considered on tooling design, aiding parts in efficient functioning of the device and different types of jigs and fixtures with their drawings are detailed.

- **Basic principles in designing:** Simple and easy tips which explain the basic principles of design and operation with Do's and Don'ts sketches.

- **Animations on practical devices:** Animations are shown for different types of jigs and fixtures used for various operations such as drilling, milling, lapping and turning, showing the locator positions and clamping positions so that the principles could easily be understood. All animations are developed in a commercial CAD software in 3-D.

- **The detailed design manual on Jigs and fixtures:** A synopsis, gives textual details to include initial considerations, materials to be used, types of supporting parts, type of mechanism to be used, concept of standardization, and types of jigs and fixtures.

HYDRAULIC CHUCKS:

In general, chuck is a device that holds a part on its outer or inner surface. Typically, wherever the part has to be rotated in a lathe, the holding device is a chuck. The chuck may also be a tool holding chuck in other situations. In this section information regarding basic features of chucks, different types of chucks, improvements in the design of chucks, various applications of chucks and different manufacturers of chucks are collected and compiled for ready reference. This module was principally developed at the request of the sponsor.

Tool holding chucks:

Concentricity, holding force, presetting, vibrations and rigidity are the basic selection criteria when going for a new tool holding device. The different types of chucks – collet chuck, hydraulic chuck, shrunk fit chuck, hydro mechanical chuck - are described in this section with their relative accuracies, advantages and disadvantages. The advantages of using a hydraulic chuck over collet-type chuck is that it does not have as many moving parts to hold the tool, and the pressure is applied uniformly throughout the gripping area. Hydraulic chucks provide,

- Lesser vibration
- Easy pre-setting
- Uniform pressure throughout the tool shank
- Access to use different sleeves to accommodate tools of different sizes.

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In the shrunk-fit chuck, the tool is inserted in the tool holder when it is hot and the tool is made integral with the tool holder. In the hydro-mechanical chuck the gripping force is generated by an external hydraulic pump on a self-locking mechanical chuck. The gripping force is twice that of a shrunk-fit chuck and thrice that of a hydraulic chuck. Choosing the type of chuck among the four types depends upon the number of parts to be produced, holding force required and the accuracy required. Such information is compiled in this section and presented sequentially with comparative statements between the types of chucks.

Work holding chucks:

Work-holding chucks are usually used in Lathes. Chucks are either manual or power actuated. Air and oil is used to transfer power in pneumatic and hydraulic chucks respectively. The numbers of jaws differ according to the usage. Two-jaw, three-jaw, four-jaw and six-jaw chucks are available and they are chosen depending upon the shape of the product and the type of operation required. Working principle of all the types of chucks is explained in this section. The information of different manufacturers of chucks along with their product varieties is also provided for ready reference.

DESIGN OF JIGS AND FIXTURES:

This section explains the designing of Jigs and fixtures and a visual presentation is prepared to explain the details. The basic difference between jig and fixture is that the former locates and holds the work piece while also guiding the cutting tool, whereas the latter just locates and clamps the work piece. The jig may or may not be fastened to the machine table whereas the fixture should be fastened to the machine table precisely.

The points to be considered before deciding to go for jigs and fixtures, as well as the theoretical principles for designing of jigs and fixtures are explained next. As the initial cost involved in any new process or change of process is an added expense it should be justified by its returns. As far as jigs and fixtures are concerned, the cumulative output in terms of production units, manufacturing time, labor required and ease of operation is more important.

During the design stage, technical points such as principle and method of location, cutter action on the work, locators and clamps to be used, body design, provision for chip clearance should each be adequately considered. The suitable off-set blocks and gauges will bring the cutter to the cutting point very closely within a short time which will reduce the total manufacturing time during mass or batch production.

Utilizing the concept of standardization, fool proofing will reduce the manufacturing cost of jigs and fixtures. Similarly, suitable choice of operating mechanism of the jigs and fixtures according to the working environment will also help reduce the manufacturing cost. All these are explained in this section through visual presentation. Different types of jigs used for drilling, boring, and welding are shown in the presentation. Similarly various types of fixtures used for milling, drilling, boring, grinding, assembly and inspection are also shown.

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Complete procedural drawings for designing a jig and a fixture are shown which helps the reader to understand the type of locators and clamps to be used and the their proper placement. Additional jigs and fixtures for different operations are also shown for the facilitating the user to gain familiarity with the design of jigs and fixtures. The view of clamping more than one work piece in the same set-up and different contoured parts along with their fixture arrangement are also shown.

DO'S AND DON'T'S

Decision making and the evaluation of multiple options pose challenges, even for experienced designers. On a similar note, lesser experience may lead to design blocks. The need for completing the work in a short lead-time, and fatigue may also contribute to incorrect application of design principles.

Drawbacks of such kinds could be minimized through the development of a ready reference guide of Do's and Don'ts. The nature of jigs and fixtures is such that they have to be produced for every individual type of product. So, designs are often quite unique and situational. All the same, the basic principles, for positioning of locators, supports, clamps, cutter action and clearance, are standard for most products. The individual locators, clamps and surface contact points may each differ in size, shape and other parameters, but the fixture design based on similar principles. Hence, documenting the related information will help in designing a jig or a fixture in the following manner:

- It could be used a starting point for developing fool-proof designs.
- It could be followed by semi-skilled laborers and first time designers.
- It ensures correctness even when the work is done in haste
- It makes supervision and inspection simpler
- It minimizes lead-times

The information about the basic principles to be followed and the positioning of the work piece and the cutting tool are collected in this section. The correct usage and provision of locators, clamps, supports, hinges and cutter action, and proper alignment contact surfaces, cutting forces are specified with examples in this section. Verification of the information available in this section when a jig or fixture is designed will reduce the deviations from the principles to be followed. The information provided in this section shows both the correct and incorrect arrangement so that the incorrect one can be avoided.

Sample Fixtures (Animations)

In this module of the manual, animations of the arrangement of several jigs and fixtures are shown. The seven animations prepared explain the arrangement of the work holding devices for different types of operation. This will facilitate the designer to observe the arrangement and effect corrections in the existing design.

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The animations are developed in ProEngineer™ for fixtures in,

- radial drilling in a cylindrical work piece,
- drilling multi holes in a leaf jig,
- milling a key way,
- straddle milling of a engine component (connecting rod),
- lapping operations on two different contoured work pieces and
- Turning operation in a lathe.

The last two bullets are 3 actual fixtures developed by CSD engineers, Steve Moore and Pat Grissom.

DESIGN MANUAL

This module of the project is textual and is a more detailed write-up of the second module. It helps designing from concept to prototype. In the case of jigs and fixtures, the initial stage is one of planning while the finishing stage is the practical workholder proof-of-concept.

Before designing a fixture the practical applicability of the fixture should be considered. It is not meaningful to design a fixture which cannot be manufactured with the available machines or which cannot be used for the practical working environment. The material to be used, rigidity of the fixture, upkeep of fixture, 'salvageability' and the safety of the operator in using the fixture has to be each considered before designing the fixture. Information regarding all these points is explained in detail.

Material behavior is important in the sense that the working conditions must be fulfilled by the chosen materials. Mechanical stresses, cycling and heat are some of the dynamics under which the fixture operates. The material has to be chosen depending upon the requirement. The manufacturing processes by which the fixtures are made also differ depending upon the working conditions. The three broad classifications are welding structure, built-up structure and cast structure, out of which the welding structure is the most material saving process while the built-up structure is the most modular and flexible. Similarly, the operating mechanism should also be determined by the working conditions and the resources being utilized.

Locators, supports, clamps, cutter action on the work, set blocks and chip clearance are some of the key concepts in the design of jigs and fixtures. Standardization is the economical factor to be considered while designing which helps to re-use the standard parts even after the device becomes obsolete. The information regarding all the above factors is detailed in the design manual that could be used as a ready reference to follow. The various types of Jigs, jig bushes and fixtures are also described in this part.

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COST ANALYSIS

Fixture design is an indirect cost entry and directly affects the setup cost. While the benefits of fixtures and minimization of the total time to design a fixture is never in debate, a simple analysis of costs is provided here. This analysis is by no means comprehensive and must be viewed more as a guideline for justifying the development of a roadmap as presented in this work.

Fixtures as per their application can be broadly classified as:

1.) Manufacturing Fixtures
2.) Repair fixtures
3.) Inspection Fixtures

Although they often appear similar each category is unique. Manufacturing fixtures may require heavy clamping forces and highly accurate location of work piece. Repair fixtures may require highly accurate location over its inbuilt features which need to be preserved, whereas inspection fixture may just require location and clamping during measurement. Also inspection fixtures have to be built rapidly to reduce lead-times. Accordingly, the application and utility decides the time and eventually the money spent on each fixture.

Manufacturing fixture design can be considered to consist of the following stages.

1.) Part analysis
2.) Fixture Design
3.) Design Analysis
4.) Manufacturing
5.) Measurement and Prototype testing with and without part
6.) Putting fixture to use

Certain things to be remembered while designing a fixture:

1.) Application of the fixture (manufacturing/repair/inspection)
2.) Number of parts for which the fixture will be used
3.) Level of accuracy required
4.) The criticality of the part with respect to the aircraft?
5.) Replaceability, reusability and discardability of the fixture
6.) Standardization of fixtures and fixturing principles

The time and money spent on a fixture should justify its use. The entire procedure can be captured by the flow chart illustrated below. It can be seen from the subsequent pie-chart that the time and effort is maximum for design, which is eventually reflected in its cost.

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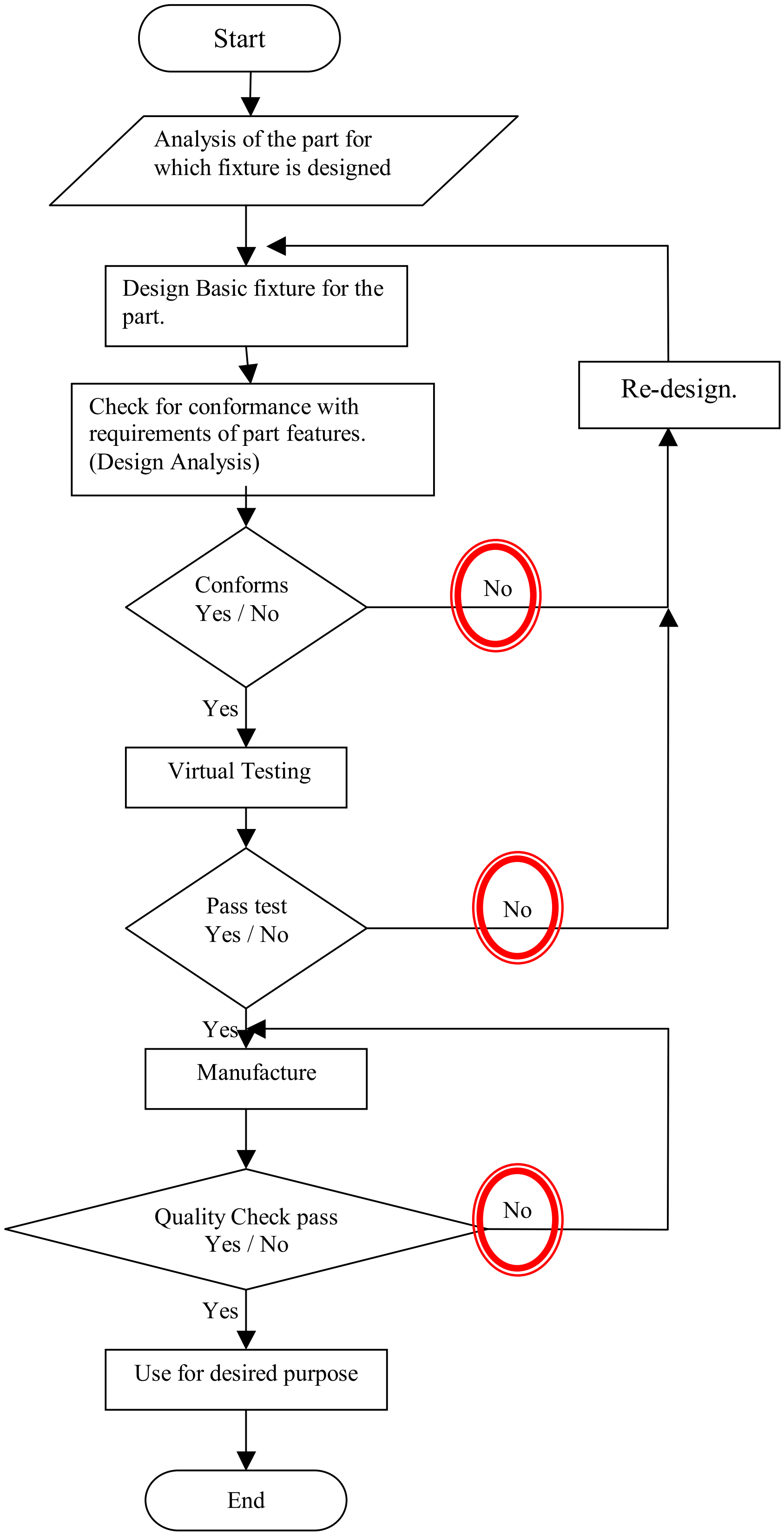

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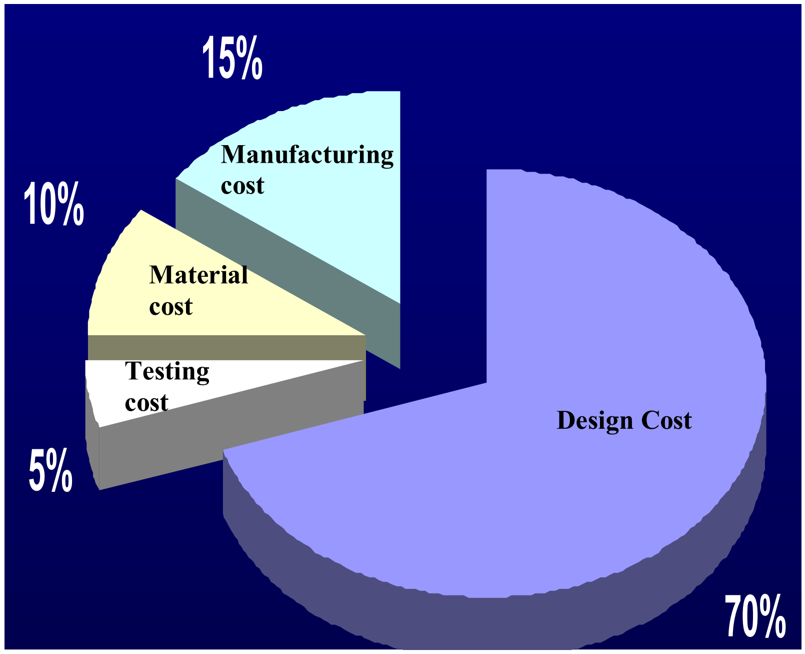
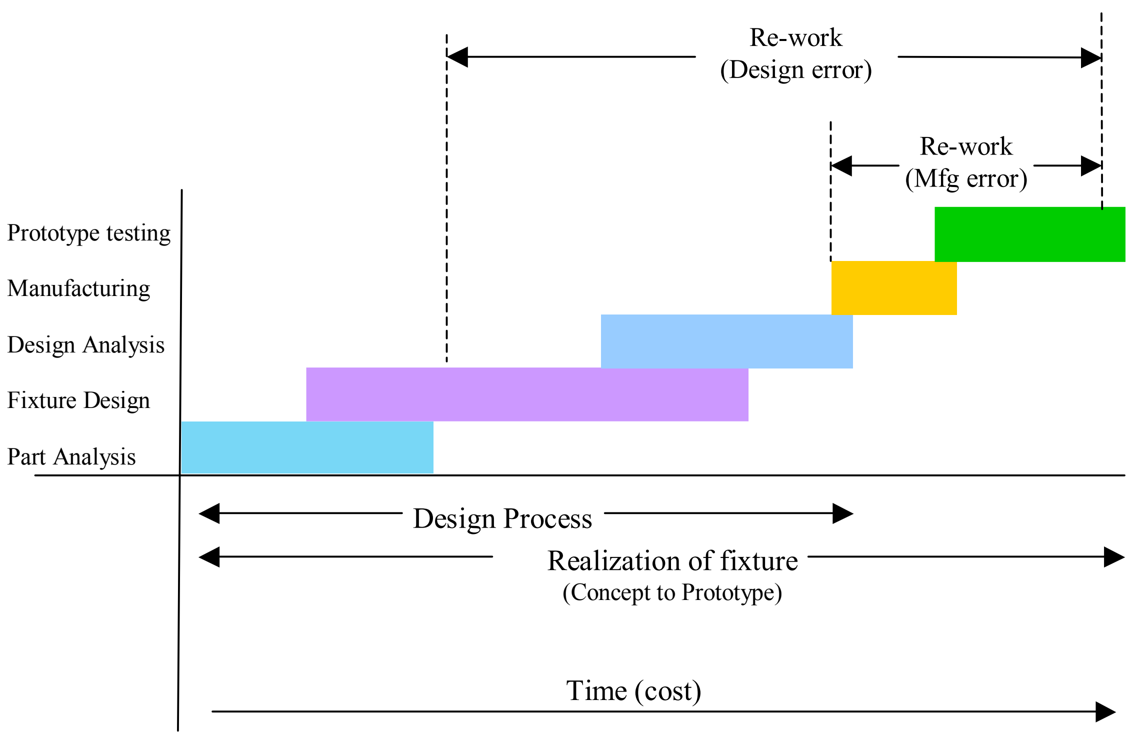


Consider the production of a fixture from its concept to prototype. The following Gantt chart shows the time spent on different steps in fixture design.



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At every non-conformance point, (marked with red circles in the flow chart) the design cost shoots up non-linearly. The non-conformance cost in most cases is 100 % of what has been already encumbered or spent. The Gantt chart also shows the rework time spent due to design and manufacturing errors.

Considering that a fixture is realized over a span of 60 days, nearly 40 days are spent on designing the fixture. In extreme cases, it should be kept in mind that for that period of time a few aircrafts costing in the excess of 15 million dollars each are sitting idle.

Estimate for cost of fixturing (100 fixtures for 50 aircrafts)

Assume 50 design engineers are working over them for 2 months at a rate of $50 per hour.

Total man hours for 45 days for 50 design engineers = 18000

Cost for design engineers	= $900,000.00	+
Cost of planes idle for 60 days Of the fleet of 84 let us consider 25 are under routine or breakdown maintenance) (25 aircrafts of average 30 million per craft at rate of (1% annually) 0.000028% per day)	= $1,235,000.00	
Total design cost over span of 2 months	**= $2,135,000.00**	

Consider there is 30 % non-conformance of fixtures. The production lines get overloaded by at least 40%. And the increase in lead-time increases the cost (due to idle aircrafts) by 30 %.

30% crafts stay idle for 30 more days	= $600,000.00	+
Cost of non-conformance (man power)	= $270,000.00	+
Cost of overload on other machinery (40% of total cost)	= $854,000.00	
Total Cost of non conformance	= $ 1,724,000.00	
Total cost incurred for batch in 2 months	**= $3,859,000.00**	

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<u>Money saved by proper design guidelines</u>

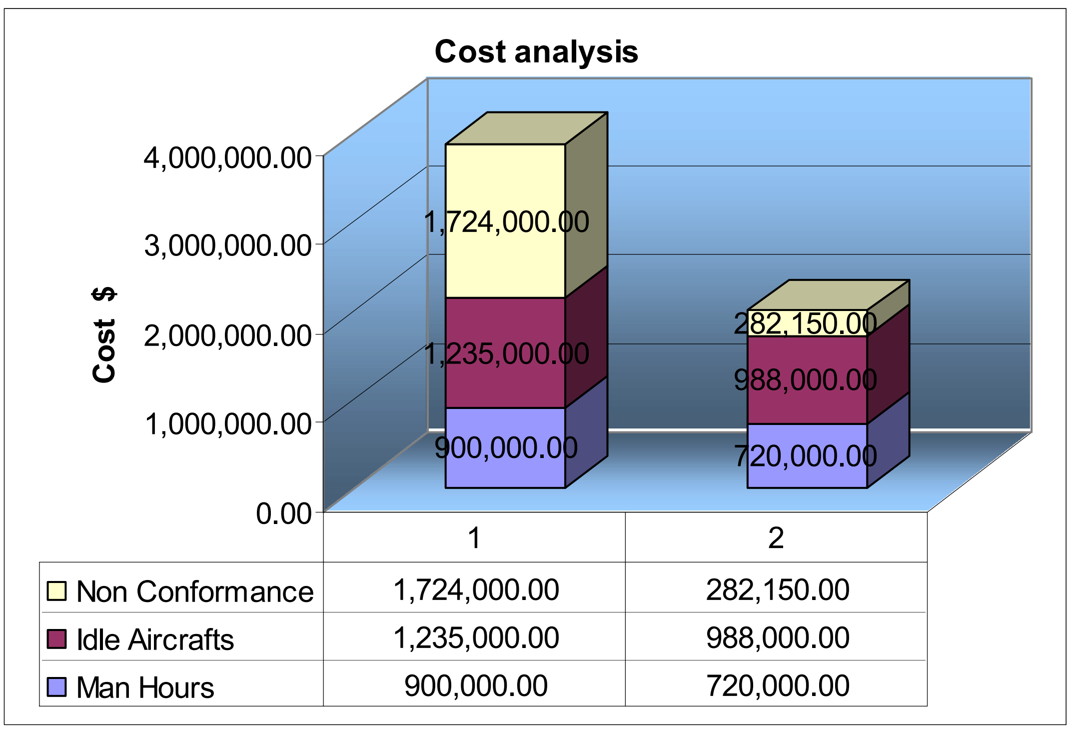
If at least 20% time is saved by proper
Design guidelines, the initial design cost reduces to = $720,000.00
Cost of idle aircrafts reduces to = $988,000.00

The cost of non-conformance, if not completely eliminated, is reduced to 1-5%.

Cost of idle Aircrafts (due to reduced lead time)	= $90,000.00	+
Reduced cost of non conformance (Man Power)	= $85,400.00	+
Reduced overload on machinery	= $106,750.00	

Cost of non conformance reduces to **= $282,150.00**
(Increased time for aircrafts, non conformance cost,
Cost of overloading the system)

Thus, new fixture design **= $1,990,150.00**



Thus total saving = $3,859,000.00 - $1,990,150.00
(Over span of 2 months) = **$1,868,850.00**

Annual saving = $11,213,100.00
This illustrates the potential savings that a proper set of guidelines can provide.

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CONCLUSION

Design data handbooks detail mechanical component design analysis with sufficient information provided regarding material specification, properties, requirements for design, etc. This facilitates designers to apply their exact requirements and choose from available resources. Also, verification with the design data books allows one to confirm that correct procedures are being followed. Similarly, the idea behind the preparation of a guide for fixturing as undertaken in this project is to develop a guide that could be used as a ready reference while designing jigs and fixtures. This project represents the first phase of designing a comprehensive roadmap for fixture design, to assist Tinker Engineers, designers and shop supervisors alike, as well as sub-contractors.