8 Discussion

8.1 Introduction

This chapter presents a discussion of the results of the use of the methodology to design for jigless assembly, the assembly feature selection process to enable jigless assembly and the Feature Library for Jigless Assembly, developed from this research study.

Although, the aims and objectives of the research have been the development of the methodology, selection process and Feature Library, the success of the research cannot simply be judged on the fact that they have been developed in some form or another. The quality and efficacy of the results obtained, as a direct consequence of using these tools and techniques need to be considered.

This will be done in two ways. The first is to state whether the methodology, selection process and Feature Library have in fact delivered a jigless assembly solution, in absolute terms, as illustrated in Chapter 5.

Second, the Costings Analysis portrayed in Chapter 6 offers a good measure as to whether the financial benefits accruing from the use of the methodology, selection process and Feature Library are large enough to warrant the adoption of such tools and techniques.

After the quality and efficacy of the results obtained have been reviewed, the relationship between the developed methodology, selection process and Feature Library and the catalogue of previous research on Design and Assembly Processes' Methods and Methodologies, Feature Based Methods and Tolerance Representation and Analysis can be evaluated.

This comprises an examination of the shortfall between the tools and techniques developed in this research study and the already existing tools and techniques, to specifically achieve designs for jigless assembly.

Finally, the weaknesses and limitations of the tools and techniques developed in this research study will be analysed.

8.2 Delivery of a Jigless Assembly Solution by the Methodology, Selection Process and Feature Library Developed from the Research Study

The Case Study demonstrator structure is currently assembled manually and relies heavily on the use of jigs for assembly. The application of the methodology to design for jigless assembly, the assembly feature selection process to enable jigless assembly and the Feature Library for Jigless Assembly, has resulted in a re-engineered design that enables jigless assembly.

Firstly, on a 'macro scale', the methodology to design for jigless assembly has provided the means to analyse and compare alternative assembly concepts based on a reduction in product-specific jigs, fixtures and tooling. The generation of alternative assembly concepts was still left to the users, although this was intentional as the methodology was intended to give a framework to support designing for jigless assembly rather than automatically generating jigless assembly concepts.

The assembly concept selection of the alternative assembly concepts was in the first instance based on engineering judgments and practicalities; after the choice had been narrowed to three, Error Budgeting was used to select the preferred assembly concept, whilst retaining an element of engineering judgment and practicality that ruled out one of the remaining two concepts.

The preferred assembly concept managed to only use one form of tooling, i.e. the Build Tool, which served as the jig for the Spar; no other product-specific tooling was used including the reconfigurable robotic drilling and fastening system. As there were

no jigs to realise location then the parts effectively located themselves with the use of location features selected by the assembly feature selection process.

On a 'micro scale', the assembly feature selection process to enable jigless assembly worked effectively to aid the designers in selecting appropriate assembly features. However, the 'Re-engineering Ground Rules' restricted the choice of assembly features that were available for selection and hence, it could be argued, that the selection process was not fully tested.

Even so, the greatest benefit to arise from the application of the assembly feature selection process to enable jigless assembly was its simplicity in use and the way in which it forced the designer to adopt a structured, repeatable and logical approach. This simplicity is key since if the selection process is to be used as early as possible in the product's development then there will be very little quantifiable information available, such as geometry, until the product development matures. The selection process does not require this amount of detailed information as long as the configuration and shape of the parts (rather than definitive geometry), has been determined.

Instead, the selection process of location features is based upon basic kinematic principles and four fundamental areas of selection criteria – design, manufacturing, cost and accuracy. It is true, though, that more work needs to be done on each one of these selection criteria and the inter-relationships they possess. However, the identification of these selection criteria is an important step forwards in the pursuit of an assembly feature selection process to enable jigless assembly.

In addition, the broadening and expansion of the definition of an assembly feature has helped to encompass the whole range of major activities involved in assembly. This has assisted in apportioning the correct area of functionalities, in terms of location, support, clamping and fastening within an assembly, which would make the process of determining and resolving errors at assembly easier.

Lastly, the development of a Feature Library to facilitate jigless assembly has given a vehicle by which the assembly feature selection process can be directly applied. As the Feature Library follows exactly the same structure as the assembly feature selection process then assembly features can be selected from the Feature Library at appropriate points and places throughout the application of the selection process.

The Feature Library also includes the much broader and expanded range of assembly features, particularly to facilitate jigless assembly, than conventional forms of Feature Libraries that can be found in typical Feature Based Methods.

8.3 Appraisal of the Financial Benefits Accruing from the Use of the Methodology, Selection Process and Feature Library

The results of the Costings Analysis calculated in chapter 6 indicates that there would be a 6% Recurring Cost saving for each Case Study demonstrator structure produced and that it would take around two years to pay back the initial investment of the project at the current production rates. This would give an Internal Rate of Return of 9.4%, using six workstations for a minimum project time of six years.

A predicted 6% Recurring Cost saving would be an appealing figure as a minimum value of 5% is generally required for cost-reduction, capital expenditure projects of this type to be even contemplated. In addition, the Internal Rate of Return of 9.4% is acceptable; with Finance Departments generally looking for a 10% Return on Investment for projects of this type.

It must also be stressed that these figures do not take into account the Non-Recurring Costs of the product-specific tooling that is used for the current method of assembly.

If jigless assembly were to be introduced as a re-engineering exercise, as in the situation of the Case Study, then the Recurring Cost savings would have to compete against the Recurring Cost savings of the current assembly.

If jigless assembly were to be adopted for a new product or a new production line for the same product, then there would be the substantial Non-Recurring Cost savings due to the minimisation in product-specific jigs, fixtures and tooling compared with the current methods of assembly based around the use of jigs.

However, it proved extremely difficult, if not impossible, to ascertain how much exactly was the cost of the current assembly tooling for the Case Study demonstrator structure. This was because of a number of reasons, including:

- Commercial sensitivities regarding the cost of tooling
- The cost of the current assembly tooling has long since been amortised into the Recurring Costs of the assembly operations
- The original costs of the current assembly tooling have been lost
- There was not the time and commitment available from industrial personnel for the arduous task of estimating the current assembly tooling costs

Nonetheless, to give an idea of how much assembly tooling does cost the following information is provided.

The total tooling costs for the Airbus A340-500/600 aircraft were reported to be approximately £10 million (Naing, 1999).

The tooling is divided into Assembly and Operational Tooling, where Operational Tooling are small support tools such as drills, drilling templates, reamers, etc. Table 8.1, below, shows some approximate numerical values for the A340-500/600 tooling.

Trailing Edge	**Leading Edge**	**Main Assembly Jig at Broughton**
£ 5.3 million of tooling – of which,	£ 2 million of tooling – of which,	1700 Operational Tools – resulting in,
• £ 3 million Assembly Tooling • £ 2.3 million Operational Tooling, ~ 40 %	• £ 1 million Assembly Tooling • £ 1 million Operational Tooling, ~ 50 %	• Costs • Logistics of Storage, Maintenance, Accessibility • Set-up Time

Table 8.1 Some numerical values for the Airbus A340-500/600 aircraft's tooling

It can be seen that the Non-Recurring costs of tooling are substantial. Any reduction in the use of assembly or operational tooling would represent a significant saving in the development costs of aircrafts.

The evidence of this section has shown that the use of the methodology to design for jigless assembly, the assembly feature selection process to enable jigless assembly and the Feature Library to facilitate jigless assembly could have a large and considerable impact on both the Non-Recurring and Recurring costs associated with the design, manufacture and assembly of aircraft.

8.4 Evaluation of the Relationship Between the Techniques and Tools Developed in this Research Study Compared to Previous Research

The relationship between the techniques and tools developed in this research, namely:

- The design for jigless assembly methodology
- The assembly feature selection process to enable jigless assembly
- The Feature Library to facilitate jigless assembly

and the tools and techniques developed from previous research, grouped into the three, broad areas of:

- Design and assembly processes' methods and methodologies
- Feature Based Methods
- Tolerance representation and analysis

is a very close one as the tools and techniques developed in this research deliberately built upon the previous research of others, in order to not have to 're-invent the wheel'.

There is a direct association between the corresponding first two tools and techniques developed in this research and the first two tools and techniques developed from previous research.

The design for jigless assembly methodology was derived from the research at MIT and the theory that has developed over several years for 'designing assemblies'. However, the focus of this theory was a better understanding and representation of assembly modelling; whereas the focus of the research described in this thesis was the minimisation of product-specific jigs, fixtures and tooling. Consequently, the design for jigless assembly methodology was developed to specifically go about achieving a design for jigless assembly. The theory developed at MIT may deliver a reduction in jigs, fixtures and tooling but only as a 'by-product' of following the methodology, rather than being the goal.

Many of the processes within the design for jigless assembly methodology can be found in a number of the Formal Design Methods described in the Literature Review of chapter 2. In fact, studies have suggested that some of these methods can complement each other (DeVries, 1992; Atkinson, 1992 and Brown, 1992). It is not surprising then some processes of the design for jigless assembly methodology and the Formal Design Methods overlap, even though the individual processes may not share the same name.

Clearly, the assembly feature selection process to enable jigless assembly is closely related to the previous research on Feature Based Methods, particularly with Feature Based Design for Assembly. The current research has broadened and expanded upon the principles and concepts of traditional Feature Based Methods by *(i) tailoring the assembly feature selection process specifically to designing for jigless assembly through its integration into the design for jigless assembly methodology* and *(ii) as a result of aiming for the goal of jigless assembly from the outset, the definition and taxonomy of assembly features has been extended to include unconventional assembly features within the Feature Library*.

It is from this position that the third tool and technique of this research, the Feature Library to facilitate jigless assembly was developed, in order to explicitly support the assembly feature selection process.

Finally a review of the third tool and technique from the previously developed research comprising the area of Tolerance Representation and Analysis has been

presented. The observations of this area of research are similar to the findings obtained by Gouvinhas (Gouvinhas, 1998) into the implementation of Formal Design Methods within industry; the general view is that these methods are too complex and not mature enough to be used in a commercial environment. The same judgement can be made for the Tolerance Representation and Analysis tools and techniques reviewed in chapter 2, as most of the examples were still in development in academia.

Nevertheless, there is commercially available Tolerance Analysis software, such as Valisys (now called eM-Tolmate), VSA, etc., that are mature enough to be used by a number of companies, as illustrated in chapter 2. However, this software is also complex and difficult to use based on the experience gained from using Valisys within the JAM project; it was appreciated that software of this type needed to be used by dedicated and skilled personnel.

For these reasons, the Error Budgeting tool was developed to be of use in assemblies, as well as precision machine tools. Error Budgeting proved to be a simple tool that could be used very early in the product's development to calculate and compare the errors of alternative assembly concepts. Applied in this novel manner, Error Budgeting became a major enabling tool integrated into the design for jigless assembly methodology, working with the assembly feature selection process.

8.5 Weaknesses and Limitations of the Tools and Techniques Developed in this Research Study

The weaknesses and limitations of each of the three tools and techniques developed in this research study will be analysed individually, beginning with:

- **The design for jigless assembly methodology**

  The main weakness of the design for jigless assembly methodology is the deficiency of information regarding the manufacturing element. No

methodology has yet been developed and incorporated to take into account factors such as Process Capabilities.

One of the limitations of the methodology could be that because it has been specifically developed to design for jigless assembly, then its scope could be very narrow. The requirements for jigless assembly have to be balanced with other possibly conflicting requirements from different sources, such as design or manufacturing.

- **The assembly feature selection process to enable jigless assembly**

The main weakness of the assembly feature selection process to enable jigless assembly is the current lack of clarity and method in the Location Feature Pairs selection process. Presently, it is left up to the designer to weigh-up and trade-off the different selection criteria used. A more rigorous process is required for the selection of the Location Feature Pairs, as well as, for the selection of the other Assembly Features: Support, Clamping and Fastening features.

The limitations of the selection process are that there may not be enough information at the early stages of product development to be able to select the Location Feature Pairs and that any databases storing generic information about assembly features may be too general to use.

- **The Feature Library to facilitate jigless assembly**

The main weakness of the Feature Library to facilitate jigless assembly is that although the assembly features have been classified into their generic, attribute-driven feature types, no further quantitative or qualitative data has been collected about each of the feature types to support the assembly feature selection process.

The limitations of the Feature Library are that although the assembly features are organised to follow the structure of the assembly feature selection process, the organisation does not proceed any deeper yet into the detailed taxonomy of the features. For example, within the metrological Location Features there is an order and specification for different types of Location Feature.