Parametric Cost-Estimation of an Assembly using Component-Level Cost Estimates

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Abstract

There are two approaches that can be taken for estimating the manufacturing cost of a product assembly. One approach is to separately estimate the cost of each of the individual components from the work breakdown structure (WBS) and summing these component costs to determine the total cost. Another approach is to derive a parametric model that uses information about the overall assembly to produce a cost estimate.

The advantage of the former approach is accuracy, since detailed information about each component is used; the advantages of the latter approach is speed and simplicity, since only a limited number of parameters are used to generate the estimate.

This paper describes a hybrid methodology for generating a cost estimate for an assembly that combines these two approaches. The cost is estimated for each element in the WBS, but only a limited number of parameters from the assembly are used as inputs. This is accomplished by first generating detailed part-level cost-estimating relationships (CERs) that can estimate the cost for each component in the assembly. Then once these CERs have been developed, values are mapped from the assembly parameters to be used as inputs for these CERs.

This approach retains most of the accuracy of the detailed cost models while greatly simplifying the modeling process. The accuracy is maintained because the parts being modeled are part of the same assembly and share geometric relationships. Although the model appears parametric to the user, it is more accurate and robust than a parametric model because it is derived from CERs for each component.

This methodology was applied to generate cost models for aircraft engine assemblies. The accuracy of the models was almost the same as the accuracy from the detailed models, but the number of attributes required to generate the estimate was reduced by approximately 90%.

Keywords: Hybrid Cost Estimation, Parametric Cost Estimation, Bottoms-up Cost Estimation

1 INTRODUCTION

As a product is being designed, its production cost should be an important consideration. Cost estimation methods provide a means for designers to evaluate how their decisions impact the ultimate manufacturing cost of the part. There are often multiple ways of designing a part to achieve a performance objective and without the benefit of cost estimation, designers may unknowingly to choose a more expensive option.

Two contrasting approaches to cost estimation are parametric and bottoms-up. In general, parametric approaches require less data to generate a cost estimate, but they can be less accurate and are more limited in their applicability. Bottoms-up methods are more time consuming to develop and to use because of the amount of data required, but they provide a more detailed insight into the cost of a part and can more easily be adapted to new part designs.

Parametric approaches apply statistics to attempt to identify a relationship between high-level design parameters of a particular type of part (e.g., length, weight) and the cost of the part. A cost estimate is generated by entering the parameter(s) of the new design into the cost-estimating relationship (CER), a function that describes the relationship between parameters and cost. Bottoms-up approaches attempt to identify all of the features that contribute to the cost of a part and then identify a separate CER to estimate the cost of each feature. The cost estimate of the part is then generated by summing the cost estimates from the individual feature CERs.

For a given part type, greater accuracy can generally be achieved with the bottoms-up approach, since more attributes are used, which allows more of the variation in the manufacturing cost between different part designs to be explained. In addition to the improved accuracy that can be produced with the added attributes, the fact that bottoms-up CERs describe a feature cost rather than a part cost means that they can be reused for other situations where the features occur, even if the rest of the part is different. For parametric methods, new CERs need to be developed for each new part type or when manufacturing technology changes.

For the part designers, a bottoms-up approach provides more detailed information than just an estimate of the total cost to manufacture the part. Cost estimates can be provided for all of the features and/or processes that are used for a part, which can be extremely useful in optimizing the part design with respect to cost. With a parametric method, design changes are made through trial and error to examine their impact on cost. Parametric methods also often lack the ability to conduct a trade study, since the attributes on which a study is likely to be performed relate to the details on the components rather than the overall assembly.

The largest hurdle to greater usage of bottoms-up cost estimation methods is the number of attributes that are required to generate a cost estimate. This means that it is more time consuming, since more attributes need to be identified from the design. However, beyond the amount of work needed to generate the estimate, a greater difficulty is the fact that the attributes required may not be known early in the preliminary design process—and by the time they are known, design decisions may have already been made that can’t be undone.

To enable greater use of bottoms-up methods in estimating part costs, Masel and Judd [2] proposed the use of a hybrid cost estimation method that incorporates advantages of both parametric and bottoms-up cost estimation. The costs in the hybrid system are estimated by detailed, bottoms-up CERs. However, instead of requiring the user to specify the feature parameters that are inputs to these CERs, Attribute Estimating Relationships (AERs) are used to calculate the inputs for the CERs from the high-level part attributes.

With AERs, the cost estimating approach appears to the user to be parametric, but the cost estimates are actually generated using a bottoms-up approach. The initial research on the use of AERs studied their effectiveness when estimating the cost of a single part. This paper will discuss their use when estimating the cost of an assembly composed of multiple individual parts.

2 METHODOLOGY

2.1 Structure of Hybrid Cost Estimation System

The use of Attribute Estimating Relationships in developing a system for estimating the cost of an assembly has the potential to provide even greater benefits than when they are used to generate the cost of an individual part because an assembly requires physical connections between parts.

The structure of the parametric cost estimation approach is shown in Figure 1. The design data that are needed as inputs to the CER relate to the overall assembly.

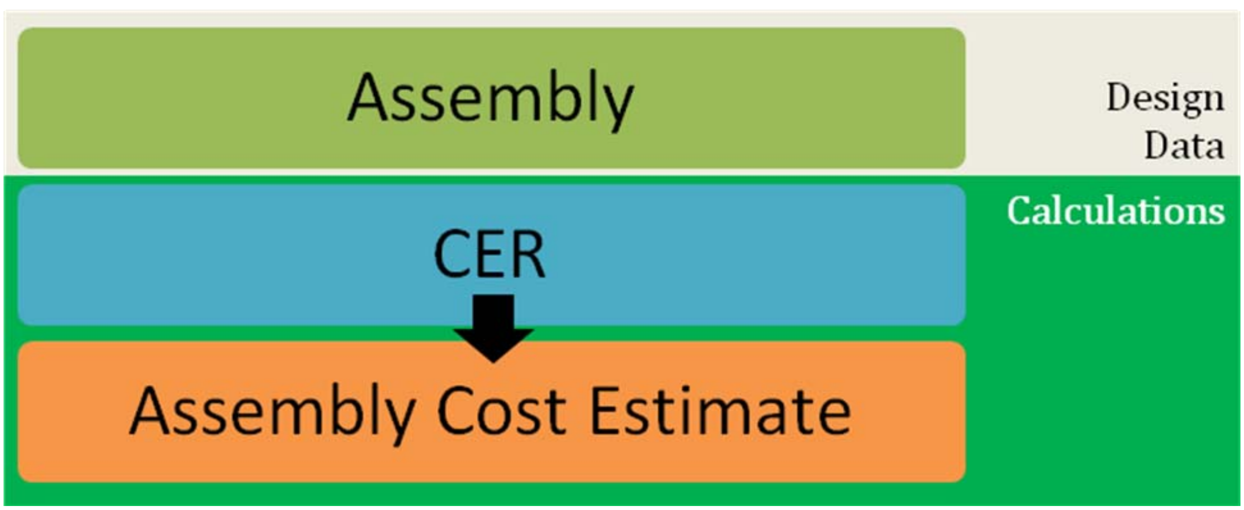

Figure 1: Hierarchy of parametric cost estimation approach

The structure of the bottoms-up cost estimation approach is shown in Figure 2. Note that much more design information—all of the features must be considered separately—is needed in order to generate a cost estimate. The attributes of each feature are the inputs to the CERs, which generate a cost estimate for each feature. The cost of the assembly is the sum of all of the feature cost estimates, plus the estimates for the cost of processes performed on the overall assembly, such as welding and inspection.

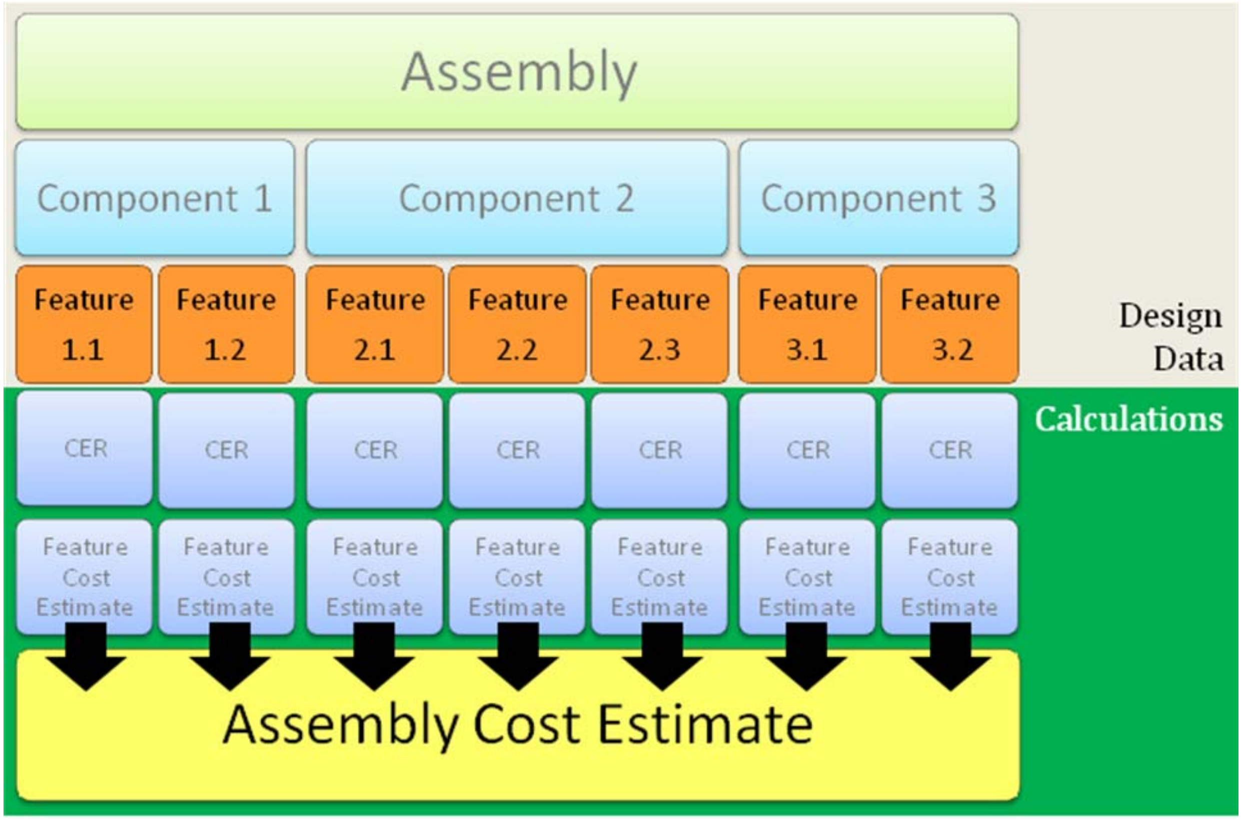

Figure 2: Hierarchy of bottoms-up cost estimation approach

Figure 3 illustrates the structure of the hybrid cost estimation approach. The same layers of part information are used as in the bottoms-up approach, but the majority of the information is calculated, rather than being specified by the user. The user provides the values for the assembly attributes at the top level of the hierarchy and these values are used to calculate values for the component and feature attributes using the AERs.

The AERs capture information about design rules for the part features; they are generated using statistical methods, similar to the methods used to generate parametric CERs. The values calculated by the AERs provide the inputs to the CERS—the same CERs that would be used in the bottoms-up methodology in Figure 2—which provide an estimate of the cost for each feature in the assembly.

An additional advantage is of hybrid approach is that the transparency of the bottoms-up method is retained, so that a cost estimate is generated for each feature, rather than only producing an estimate for the entire assembly. This approach also allows the values calculated by AERs to be updated as more design information becomes known. Unlike parametric methods, which only provide one level of an estimate (i.e., the overall part or assembly cost), cost estimates generated using the hybrid approach can be recalculated as more detailed design information becomes available.

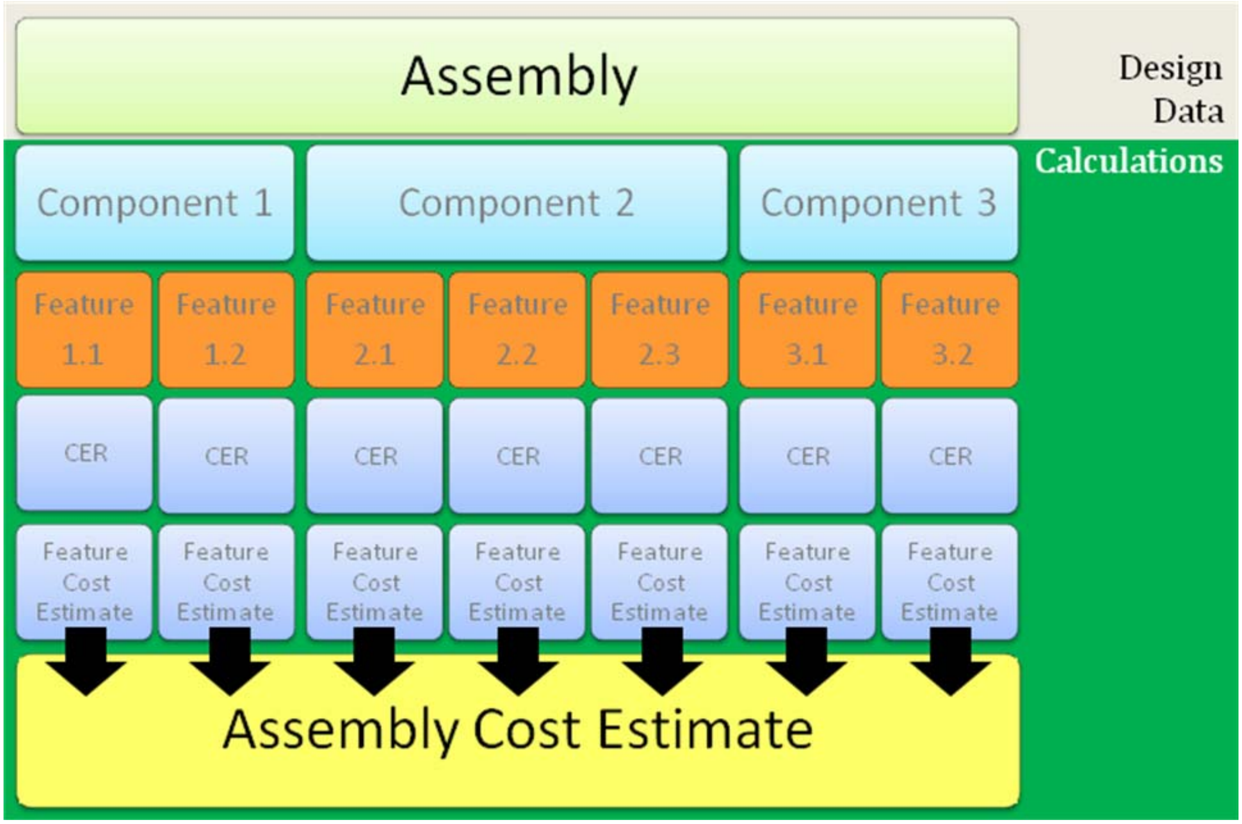

Figure 3: Hierarchy of cost estimation using hybrid cost estimation approach

2.2 Development of Hybrid Cost Estimation Methodology

Development of a hybrid cost-estimation system begins with the generation of the detailed CERs for each feature. Because the cost of the assembly is estimated by accumulating the costs of all of the features on the assembly's components, CERs are needed to be able to estimate all of the features that could exist. Once the feature CERs have been developed, they could be used directly for estimation of the assembly cost. However, as noted previously, this greatly increases the burden on the user, so assembly-level attributes are selected that can be used with AERs to calculate the values of the feature attributes.

The process of determining the assembly attributes that will serve as the parametric inputs to the AERs is iterative: candidates are selected and tested to evaluate how accurately they can estimate the values of the feature attributes. If some of the AERs are not effective at calculating feature attributes, the assembly-level attributes can be added or changed until satisfactory accuracy is produced by the AERs. In selecting candidates for assembly-level attributes, there are four types of attributes that can be chosen:

- Dimensional
- Boolean attributes (Yes/No)
- List attributes
- Quantity attributes

Some dimensional information is necessary to describe the size of the assembly. As noted in [2], a good estimate of the volume of a part can be made by knowing only the outer dimensions of a part. Therefore, the dimensions chosen from the assembly should define the outer dimensions of the main components; it is not necessary to describe the overall dimensions of the assembly, since the cost of the assembly is not being estimated directly.

The number of dimensions used should be limited—an extensive list of required dimensions defeats the purpose of the AERs. Instead, list attributes, Boolean attributes, and quantity attributes can be used to describe the features and configuration of the assembly. Using list attributes is an important way of identifying which features are present in an assembly. Although AERs can be used to predict the size of these features, it can be difficult to predict which features will be chosen for a given design.

Design engineers should be involved in selecting the appropriate list attributes to be used for an assembly. The purpose of AERs is to represent typical design rules and the insight of design engineers can help to identify relationships between the overall part configuration and the detailed component features.

3 IMPLEMENTATION OF HYBRID COST ESTIMATION METHODOLOGY

The hybrid cost estimation methodology was implemented for estimating the cost of combustors in an aircraft engine. The FIPER cost estimation tool (described by Koonce, et al. [1]) was used to implement the methodology. Using this tool provided the advantage of easy reuse of feature CERs when those features are found on multiple parts. The tool also provides transparency into the cost estimates at the feature level rather than showing only the cost estimate for the assembly.

The general structure of the combustor cost estimate is shown in Figure 4. The typical components are listed in the second row, although the actual components that will be found in a given assembly can be described more specifically when necessary.

Generating a cost estimate of the combustor assembly when modeling each of the components separately required the user to specify values for up to 233 attributes. The attributes described the dimensions of each component separately as well as the types of features that were found on each component. When the combustor was considered as an assembly, the majority of the component attributes were calculated by AERs so that only 20 attributes needed to be specified by the user. Of these attributes, only 6 of them were dimensional; the remainder described the materials used for the components and the features or configurations of the combustor components.

The same CERs were used in estimating the cost of each feature as were used in estimating the cost of the detailed models of each component separately. The only difference is that the input values to these CERs were calculated as a function of the assembly attributes rather than being entered by the user.

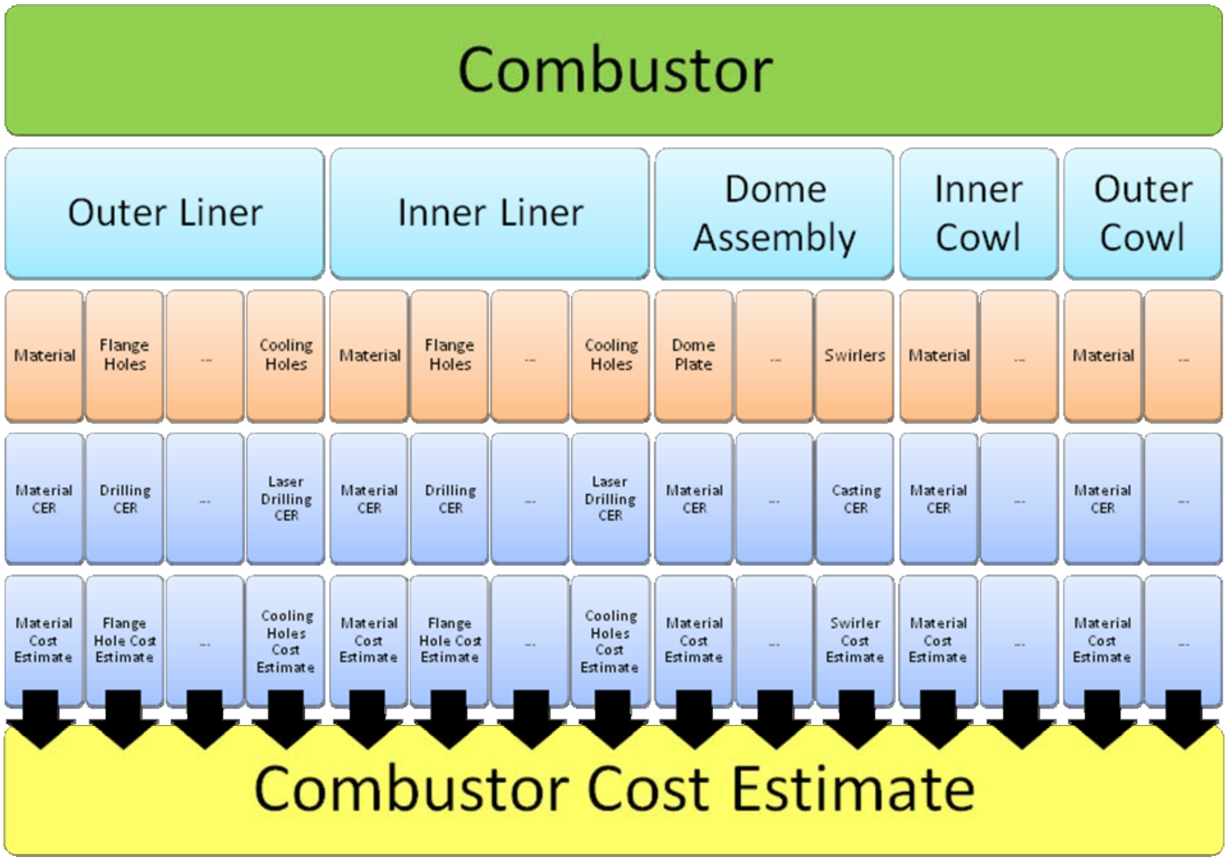

Figure 4: Hierarchy of combustor cost estimate

In spite of the significant reduction in the number of attributes being used, there was no change in the accuracy of the estimate of the cost of the entire combustor assembly. The accuracy of the cost estimates of the individual components (and features) decreased somewhat, but because there are component estimates that increase and estimates that decrease, they tend to balance each other out, lessening the impact on the cost estimate of the overall assembly.

A screen shot of the entire combustor assembly is shown in Figure 5.

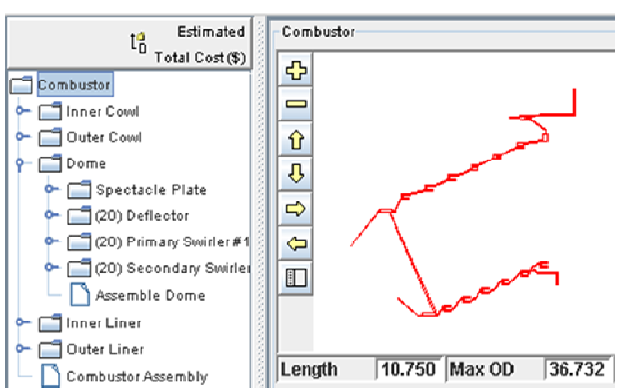

Figure 5: Screen shot of combustor assembly in cost estimator

As was shown in the hierarchy in Figure 4, the assembly consists of five components, each of which is listed separately in the breakdown on the left of Figure 5. In the figure, the dome assembly component is expanded in the tree to show a further breakdown of this assembly; the other components can also be expanded multiple times until the breakdown reaches the features on the component, which is where the cost is calculated. All of the parameter values required for the levels beyond the top level are calculated from assembly attributes using AERs.

As described previously, the cost of each component is estimated separately; adding each of these component costs along with the cost of assembling the components produces the estimate of the total cost of the combustor. The assembly shown in Figure 5 is actually created from cost models of each of the individual components, which are shown separately in Figure 6.

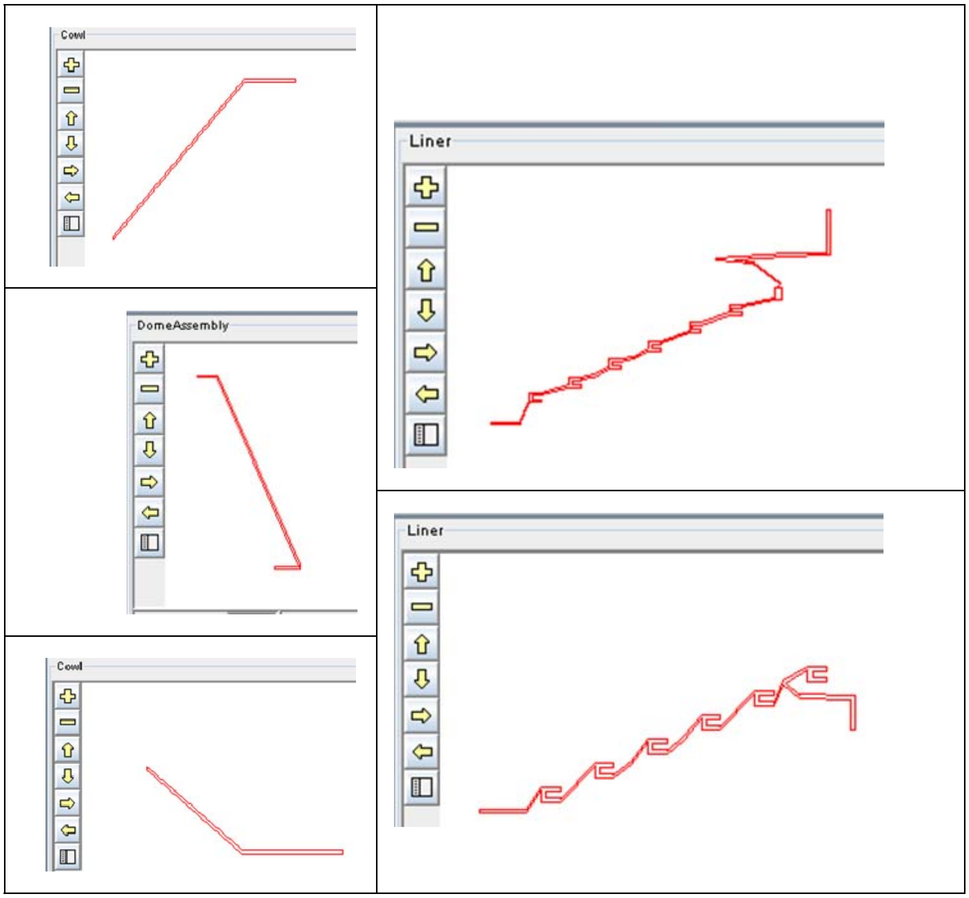

Figure 6: Screen shots of individual combustor components

All of the values used to create the geometry and features shown in Figure 6 are calculated using AERs that capture the design principles used in creating these parts. This allows the use of the bottoms-up CERs that provide greater accuracy and transparency in the estimates.

4 CONCLUSIONS

Attribute estimating relationships can be used to create a hybrid cost estimation system for an assembly or system of components. This paper discusses the process of selecting assembly-level attributes that can be used as inputs to the AERs. Using AERs limits the amount of information that users must provide to generate a cost estimate, which still providing the accuracy and transparency of a bottoms-up cost estimating approach.

The methodology described in the paper was used to develop cost models for a jet engine combustor assembly. The hybrid system produced a significant reduction in the number of attributes need to generate a cost estimate while retaining the accuracy of a detailed model. Future work will examine the application of the hybrid cost estimating approach to other modules of a jet engine.

REFERENCES

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