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# Using Bottoms-Up Cost Estimating Relationships in a Parametric Cost Estimation System

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# Presentation Overview

- Cost Estimation Background
- Project Objectives
- Phases of Project
  - Bottoms-up Cost Estimation
  - Feature Attributes
  - Part Geometry
- Results

# Application of Cost Estimation

- Use Cost Estimating Relationships (CERs) to predict the cost of producing a part
- Done during preliminary design phase
  - Many design decisions to be made
  - Multiple options for achieving desired functionality
  - One of primary decision criteria is often cost
  - Need tools to evaluate cost of design decisions

# Approaches to Cost Estimation

- Bottoms-up
  - For accuracy
- Parametric
  - For simplicity
- Other methods (Duverlie & Castelain, 1999)
  - Analogic
  - Intuitive

# Bottoms-up Cost Estimation

- Procedure
  - CERs are determined for each feature
  - Feature costs for a part are summed to get total cost
- Advantages
  - Accurate
  - Transparent
  - CERs are reusable for new part types
  - New processes and new materials can be easily integrated

# Parametric Cost Estimation

- Procedure
  - Relationships are identified between total cost and significant part parameters
- Advantages
  - Less information required from users
  - CERs for entire part can be quickly developed

# Project Objective: Original

- Objective: Develop methodology to improve accuracy of cost estimates for jet engine components
- Bottoms-up approach was used, to achieve accuracy
  - Detailed CERs were developed to estimate the cost to produce each of the features and found on a part
  - Detailed geometric model to estimate material cost
  - Prototype developed for limited number of part families
- Full implementation of this approach was declined by project sponsor
  - Too time-consuming for users to generate a cost estimate

# Project Objective: Revised

- Objective #1a: Develop methodology to improve accuracy of cost estimates for jet engine components
- Objective #1b: Minimize number of attributes required to produce a cost estimate
  - Needed to maintain accuracy of bottoms-up approach, while producing a system that appeared more parametric to the user

# Modified Project Approach

- Retain bottoms-up CERs for calculating cost of part features
- Develop Attribute Estimating Relationships (AERs)
  - Estimate values for some attributes needed as inputs for the CERs
  - Estimate values for geometric attributes related to overall part shape

# Project Phases

- Development of Bottoms-up CERs
  - By feature
- Development of Attribute Estimating Relationships (AERs) for features
  - AER outputs were inputs to Bottoms-up CERs
- Development of AERs for part geometry

# Development of Bottoms-up CERs

1. Identify the significant features on a part
2. Identify the process(es) used to create each feature
3. Develop feature CERs from standard machining formulas

   Example:

   $$time_{thread} = k \bullet dia \bullet length \bullet pitch$$

   - *k* is a constant that combines the process parameters (speed, feed, etc.)

# Using Bottoms-up CERs

- Total Cost =

  Material Cost + (Labor Hours • Labor Rate)

  - Material Cost is determined using geometric attributes to determine the part volume
    - Material Cost = Initial Volume • Density • $/pound
  - Labor hours include
    - Time to produce the features
    - Time for all-over processes (e.g., inspection, cleaning)



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# Attribute Estimating Relationships

- Purpose:
  - Reduce the number of attributes that are needed as inputs to the CERs
- Process:
  - Identify relationships between high-level attributes and attributes needed for CERs
- Examples of AER format:
  - Thread length = 0.053 • Part Length
  - Flange OD = Flange ID + 2.42



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# Calculation of AERs

- General Form
  - $y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_n x_n$
    - y = attribute being estimated
    - $x_i$ = value for given attribute
    - $\beta_i$ = scaling coefficient
- Coefficients can be determined to minimize
  - Sum of Squared Error
  - Standard Deviation of Error

# Attributes Used in AERs

- Dimensions
  - Relationships between sizes
- Boolean attributes (Yes/No)
  - Existence of a feature on a part
- List attributes
  - Type(s) of features on a part
- Quantity attributes
  - Number of features on a part

# Feature AERS

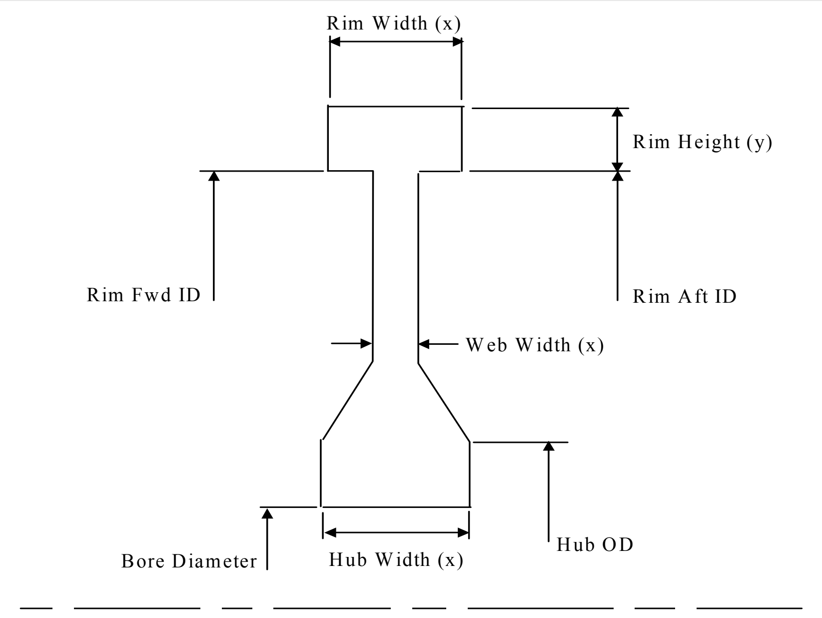
- Features were primary focus of study
  - Needed to reduce number of values from user
  - AERs determine quantity and dimensions of most features
  - User only needs to define which features a part has
- AER-calculated values are used to calculate most inputs to bottoms-up CERs
- Different AERs can be used for different part types

# Geometric AERs

- Most parts studied are axisymmetric
  - Determine cross-sectional shape of part
  - Revolve 360º around centerline to calculate volume
- Need to estimate amount of material required to create original part
- Some dimensions scale together
  - e.g., as Flange ID increases, so does Flange OD

# Testing AER Methodology

- Feature and Geometric AERs generated for jet engine disks
- Figure shows cross-section of a generic disk
  - 8 primary dimensions to describe shape
  - May also have appendages extending from both sides



# Results with Feature AERs

- AERs developed for 16 features
  - All features do not appear on all disks
  - 56 AERs developed for feature input attributes
- Accuracy compared against actual cost for estimates with and without AERs
  - Average percent error was unchanged from detailed estimates
  - Standard deviation of error increased by 3%

# Results with Geometric AERs

- Good accuracy achieved with models that use only extreme dimensions of the part
  - Accuracy measured against original volume estimate
- Disks without appendages
  - Min ID, Max OD, Hub Width, Web Geometry
  - Average Error = -3.5%
- Disks with appendages
  - Min ID, Max OD, Total Length
  - Average Error = 1.7%

# Conclusions

- Attribute Estimating Relationships can be used to simplify cost estimation process
  - Produces system with benefits of bottoms-up and parametric cost estimation
- Development process requires more effort than a bottoms-up system alone
  - Savings is in reduced time required to generate the cost estimate of a part

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