

Using Fourier Analysis in Evaluating Program Office Estimates



Stephen Cox, USA PEO Aviation
Matthew Latham, USA AMCOM
Angela Lemke, USA AMCOM
June 2010

Special Thanks To:
Wallace Willard, NASA
Penny Pride, USA PEO
Aviation

Distribution Statement A. Approved for public release; distribution is unlimited. This determination was made on March 31, 2010. U.S. Army PEO Aviation, Aviation Systems, SFAE-AV-AS, RSA, AL 35898.



How Do We Estimate SEPM?



- Historical data is available for analogous programs.
- We need to estimate Systems Engineering / Program Management (SEPM) for a new system.
- SEPM is not broken out in the historical data.
- We desire a good way to extract SEPM costs from the available historical data.

SEPM As A Factor

- In many cases, SEPM is estimated as a factor of another cost element.
 - 7-35% of Prime Mission Product
 - 4.6% of Recurring Production
- What if SEPM is a function and not just a factor?

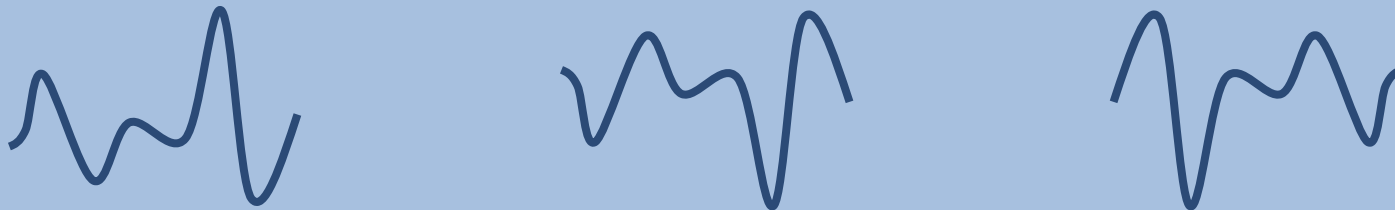
| |
|---|
| 2.0 PROCUREMENT-FUNDED ELEMENTS |
| 2.01 NONRECURRING PRODUCTION |
| 2.011 INITIAL PRODUCTION FACILITIES (IPFs)* |
| 2.012 PRODUCTION BASE SUPPORT (PBS)* |
| 2.013 OTHER NONRECURRING PRODUCTION* |
| 2.02 RECURRING PRODUCTION |
| 2.021 MANUFACTURING* |
| 2.022 RECURRING ENGINEERING* |
| 2.023 SUSTAINING TOOLING* |
| 2.024 QUALITY CONTROL* |
| 2.025 OTHER RECURRING PRODUCTION* |
| 2.03 ENGINEERING CHANGES* |
| 2.04 SYSTEM ENGINEERING/PROGRAM MANAGEMENT |
| 2.041 PROJECT MANAGEMENT ADMINISTRATION (PM CIV/MIL) |
| 2.042 OTHER |
| 2.05 SYSTEM TEST |
| 2.06 TRAINING |
| 2.07 DATA |
| 2.08 SUPPORT |
| 2.081 PECULIAR |
| 2.082 COMMON |
| 2.09 OPERATIONAL |
| 2.10 FIELDING |
| 2.101 INITIAL |
| 2.102 INITIAL |
| 2.103 INITIAL |
| 2.104 TRANSFER |
| 2.105 NEW EQUIPMENT |
| 2.106 CONTRACT |
| 2.11 TRAINING |
| 2.12 WAR RESERVE |
| 2.13 MODIFICATIONS |
| 2.14 OTHER PROCUREMENT |

The screenshot shows a 'CER Library' search window. The search criteria are: Phase: Production, Subject: Sys Engr/Prog Mngmnt, and Any Text: (empty). The search results table is as follows:

| Description | Methodology | Defn Keyword |
|---|-------------------|----------------------|
| ARMY CES (AIRCRAFT) | | |
| PROCUREMENT FUNDED ELEMENTS | | |
| SYSTEMS ENGINEERING/MGMT | [Rotocraft Model] | .0464 * REC_PROD\$ |
| Fixed & Trans Earth Stations (FATES) CERs | | |
| Test, S/PM and Other Supt Costs Factors | | |
| System Engr/Prog Management | [FATES] | .37*PMP FATES0039 |
| Production CERs - Recurring (Rec) | | |
| Program Level - Rec | [USCM7-MUPE] | 0.252*SVREC USCM7086 |
| Production CERs - Recurring (Rec) | | |
| Program Level - Rec | [USCM7-MPE] | 0.289*SVREC USCM7186 |

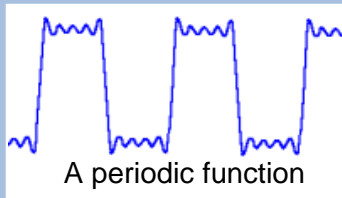
SEPM As A Function

- If a Program Office Estimate (POE) is a summation of functions, then SEPM might be a function.
- If SEPM is a function, it could be extracted from the data set using Fourier Transform (FT).
- If SEPM is a constant then it would only move the series up or down, it would not be a term identified by the transform.



What is a Fourier Series?

- The Fourier Series is used in Fourier Analysis of periodic functions (ex. current, voltage, harmonics).



- Fourier Analysis uses trigonometric functions for various waveforms and the summation of those functions.
- The sum of the trigonometric functions is the **Fourier Series**.

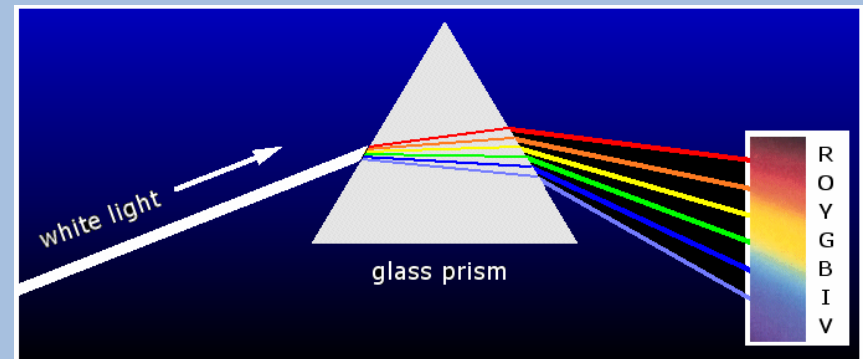
- The Fourier Series is named after Jean Baptiste Joseph Fourier (1768-1830).
- Fourier was a French mathematician as well as a friend of Napoleon and scientific adviser to Napoleon's army.



Jean Fourier


Fourier Transform Description

- In Fourier Analysis, a Fourier Transform (FT) is the process that decomposes a function into basic pieces.
- A FT is like a prism that splits white light into its constituents.
- A FT takes a function (typically of time) and transforms it into a function (typically of frequency).
- In essence, a FT describes frequencies that are present in the original function.



White light consists of all the **frequencies** of the color spectrum and the prism splits them apart and allows us to see the separate **frequencies**.

UPAS Program Office Estimate

- A short suspense cost estimate is needed for a new aircraft system, the Unmanned Paper Airplane System (UPAS).
 - Specifically, leadership is interested in procurement phase costs.
 - A cost estimate for key cost drivers of the procurement phase was created for the UPAS using cost estimating relationships (CER) for analogous systems.
- 
- CERs were used to calculate non-recurring production, recurring production, systems engineering / program management, and fielding costs.

Cost Estimating Relationships

A RAND NOTE

Aircraft Airframe Cost Estimating Relationships:
All Mission Types

R. W. Hess, H. P. Romanoff

December 1987

RAND

The screenshot shows the 'Sample CER Library - ACEIT Librarian Editor' window. The left pane shows a tree view of the library structure, including 'Sample CER Library', 'Methodology Library', and 'Sample CER Library'. The right pane displays a list of CERs for 'ARMY CBR (AIRCRAFT)'. The list includes categories like 'ADT/IE FUNDED ELEMENTS', 'PROC ENG AND PLAN (PEP)', 'DEVELOPMENT TOOLING', 'PROTOTYPE MANUFACTURING', 'SYSTEMS ENGINEERING/MGMT', 'SYSTEMS TEST AND EVAL', 'TRAINING', 'TRADEING', 'SUPPORT EQUIPMENT', 'PROCUREMENT FUNDED ELEMENTS', 'NON-RECURRING PROD', 'RECURRING PRODUCTION', 'ENGINEERING CHANGES', 'SYSTEMS ENGINEERING/MGMT', 'TRADEING', 'MODIFICATIONS', and 'SRM'. Each entry includes a 'Ratocraft Model' and a mathematical equation.

CONTENTS

PREFACE iii

SUMMARY v

FIGURES ix

TABLES xi

ABBREVIATIONS xiii

EVALUATION CRITERIA DEFINITION xv

Section I

I. INTRODUCTION 1

Approach and Principal Benefits 2

Major Objectives 4

II. DATABASE AND ANALYTICAL APPROACH 8

Estimating Sample 8

Database Verification 9

Principal Engineering Variables 9

Approach Evaluation 9

III. SELECTION OF 11

IV. ENGINEERING 11

General Data Representation 11

V. TOOLING Data Representation 11

General Data Representation 11

VI. MANUFACTURING Data Representation 11

General Data Representation 11

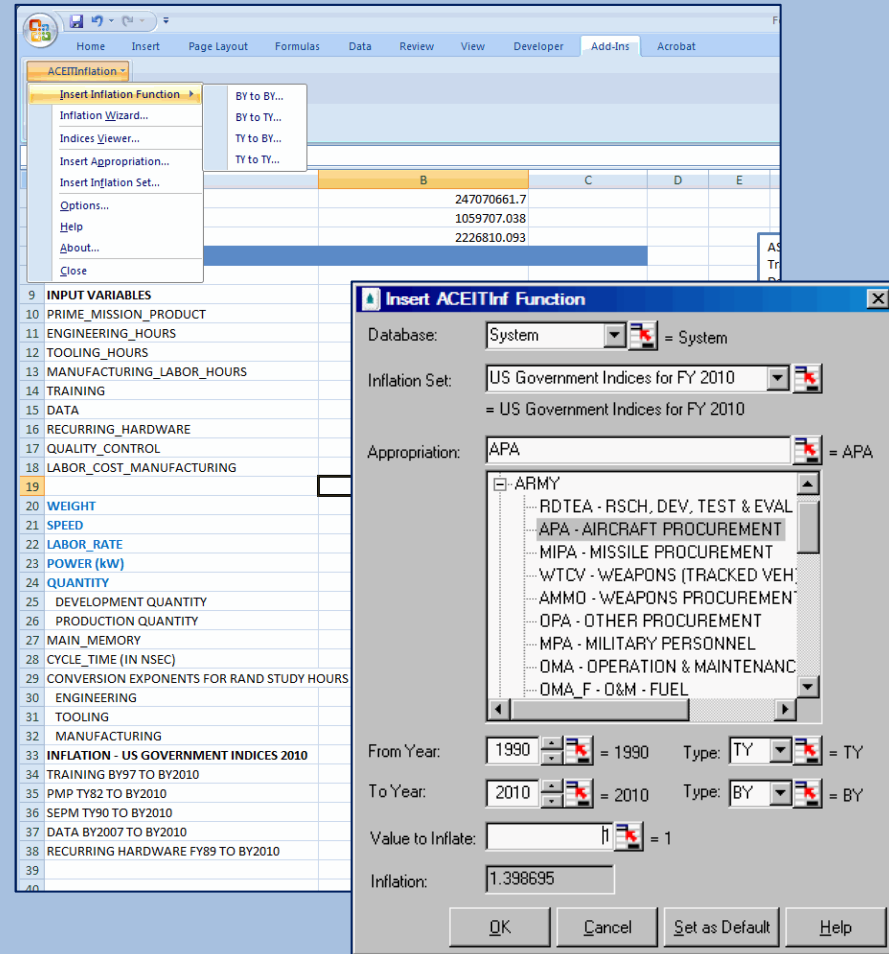
VI. MANUFACTURING Data Representation 11

General Data Representation 11

- Sources for CERs included
 - ACEIT Librarian
 - RAND study, “Aircraft Airframe Cost Estimating Relationships: All Mission Types” by R. W. Hess and H. P. Romanoff, December 1987.
- CERs were selected to be functions of system characteristics such as weight and power.

Normalizing the CERs

- CERs were normalized to Base Year 2010 (BY2010).
- OSD Inflation Indices for 2010 were applied.
- ACEIT Inflation Utility 7.2 was used to generate inflation factors.



Labor Hour Adjustment

- Engineering, tooling, and manufacturing labor hours were adjusted to reflect production only.
- The CERs included both development and production.
- A conversion equation was provided in the RAND study.

| A | B | C | E | F | G | I | J | K |
|---------------------------------|----------------|---------|-----------------------------|----------------|---------|-----------------------------|----------------|---------|
| Characteristic | Database Range | | Characteristic | Database Range | | Characteristic | Database Range | |
| Empty Weight (lb) | 9,753 | 320,085 | Empty Weight (lb) | 9,753 | 320,085 | Empty Weight (lb) | 9,753 | 320,085 |
| Maximum Speed (kn) | 389 | 1,250 | Maximum Speed (kn) | 389 | 1,250 | Maximum Speed (kn) | 389 | 1,250 |
| Number of Test AC | 10 | 33 | Number of Test AC | 10 | 33 | Number of Test AC | 10 | 33 |
| Conversion Exponents | | | Conversion Exponents | | | Conversion Exponents | | |
| Engineering | 0.163 | | Tooling | 0.263 | | Mnf. Labor Hours | 0.641 | |
| Maximum Speed (SP) | 600 | | Maximum Speed (SP) | 600 | | Maximum Speed (SP) | 600 | |
| Empty Weight (EW) | 10000 | | Empty Weight (EW) | 10000 | | Empty Weight (EW) | 10000 | |
| Production Qty | 116.1 | | Production Qty | 116.1 | | Production Qty | 116.1 | |
| Development Qty | 12.9 | | Development Qty | 12.9 | | Development Qty | 12.9 | |
| Total Qty | 129 | | Total Qty | 129 | | Total Qty | 129 | |
| Engineering | | | Engineering | | | Engineering | | |
| *Hours | | | *Hours | | | *Hours | | |
| ENGR(100) in thousands | 4022.577708 | | TOOL(100) in thousands | 2212.021418 | | LABR(100) in thousands | 5940.7916 | |
| ENGR(Cum) in thousands | 4193.055061 | | TOOL(Cum) in thousands | 2365.235678 | | LABR(Cum) in thousands | 6994.107806 | |
| ENGR(Dev) in thousands | 2880.915799 | | TOOL(Dev) in thousands | 1290.845965 | | LABR(Dev) in thousands | 1598.572443 | |
| ENGR(Prod) in thousands | 1312.139261 | | TOOL(Prod) in thousands | 1074.389714 | | LABR(Prod) in thousands | 5395.535362 | |
| *Dollars | | | *Dollars | | | *Dollars | | |
| Engineering Labor Rate (1986\$) | \$59.10 | | Tooling Labor Rate (1986\$) | \$60.70 | | Tooling Labor Rate (1986\$) | \$50.10 | |
| Engineering Cost (\$K-1986) | 77547.43034 | | Tooling Cost (\$K-1986) | \$65,215.46 | | Tooling Cost (\$K-1986) | \$270,316.32 | |

| A | B | C | E |
|---------------------------------|---------------------------------|--------|-----------------------------|
| Characteristic | Database Range | | Characteristic |
| Empty Weight (lb) | 9753 | 320085 | Empty Weight (lb) |
| Maximum Speed (kn) | 389 | 1250 | Maximum Speed (kn) |
| Number of Test AC | 10 | 33 | Number of Test AC |
| Conversion Exponents | | | Conversion Exponents |
| Engineering | 0.163 | | Tooling |
| Maximum Speed (SP) | 600 | | Maximum Speed (SP) |
| Empty Weight (EW) | 10000 | | Empty Weight (EW) |
| Production Qty | =POE!\$B\$26 | | Production Qty |
| Development Qty | =POE!\$B\$25 | | Development Qty |
| Total Qty | =POE!\$B\$24 | | Total Qty |
| Engineering | | | Engineering |
| *Hours | | | *Hours |
| ENGR(100) in thousands | =0.0103*(B13^0.777)*(B12^0.894) | | TOOL(100) in thousands |
| ENGR(Cum) in thousands | =B20*((B16/100)^B8) | | TOOL(Cum) in thousands |
| ENGR(Dev) in thousands | =B20*((B15/100)^B8) | | TOOL(Dev) in thousands |
| ENGR(Prod) in thousands | =B21-B22 | | TOOL(Prod) in thousands |
| *Dollars | | | *Dollars |
| Engineering Labor Rate (1986\$) | 59.1 | | Tooling Labor Rate (1986\$) |
| Engineering Cost (\$K-1986) | =B23*B25 | | Tooling Cost (\$K-1986) |

Data Collection Tool

- A Visual Basic program was written in Microsoft (MS) Excel to generate a data set for Fourier Analysis.
- A random value was selected within each variable range of the UPAS POE.
- The estimate was calculated.
- Results were saved in a MS Excel worksheet.
- The process continued for a specified number of iterations.

| | PRODUCTION TOTAL | NONRECURRING | RECURRING | SEPM | FIELDING | WEIGHT | SPEED | LABOR_RATE | POWER (kW) | QUANTITY |
|--|------------------|--------------|-------------|-------------|-------------|--------|-------|------------|------------|----------|
| | 373048427.1 | 150494079 | 219303257.6 | 1047675.711 | 2203414.859 | 228707 | 848 | | 87 | |
| | 671405772.3 | 190102321.4 | 477817555.1 | 1126938.819 | 2358956.96 | 250180 | 401 | | 93 | |
| | 612412531 | 172994443 | 438475675 | 166718.8605 | 775694.1104 | 23827 | 745 | | 96 | |
| | 204583977.9 | 123670956 | 76794630.76 | 1335377.508 | 2783013.613 | 308278 | 1140 | | 69 | |
| | 334468715.5 | 129847834.4 | 201986396.3 | 833598.8767 | 1800885.932 | 172636 | 1050 | | 69 | |
| | 438165231.6 | 151927669 | 284387322.3 | 544763.1602 | 1305477.072 | 102283 | 925 | | 89 | |
| | 540724952.8 | 187071795.2 | 349980846.4 | 1189101.529 | 2483209.668 | 267267 | 1099 | | 87 | |
| | 682352142.9 | 192902484.5 | 487850026 | 446862.2633 | 1152770.185 | 80157 | 988 | | 100 | |
| | 656265351 | 176249370.6 | 478847915.9 | 268169.6088 | 899894.8999 | 42763 | 1250 | | 90 | |
| | 29653159.4 | 122795600.1 | 172594550.2 | 258131.6612 | 886877.4048 | 40802 | 477 | | 94 | |
| | 677352849.6 | 168249943.1 | 507261030.3 | 541549.2463 | 1300326.955 | 101541 | 718 | | 77 | |
| | 500096107.7 | 146447762.8 | 351439162.4 | 679765.8952 | 1529416.627 | 134312 | 628 | | 73 | |
| | 632964072.8 | 181656768.4 | 449068026.8 | 690850.6644 | 1548426.899 | 137012 | 744 | | 91 | |
| | 572393442.5 | 163000279.4 | 407861877.4 | 419523.1662 | 1111762.413 | 74166 | 549 | | 87 | |
| | 404017467.6 | 159827024 | 240261620.5 | 1273620.501 | 2655202.536 | 290830 | 614 | | 93 | |
| | 229953128.2 | 126276489 | 99701765.13 | 1288676.086 | 2686197.94 | 295066 | 933 | | 88 | |
| | 229834095.2 | 121388384.1 | 105687308.1 | 877390.8332 | 1881012.213 | 183862 | 987 | | 98 | |
| | 426956509.6 | 156288669 | 267969972.8 | 856050.9057 | 1841816.884 | 178375 | 1178 | | 82 | |
| | 344947154.8 | 133924628.7 | 208426222.8 | 820018.9376 | 1776284.396 | 169182 | 788 | | 79 | |
| | 651729132.2 | 181622352.5 | 469125931.9 | 184575.9647 | 796271.8563 | 27005 | 599 | | 100 | |
| | 327463941.2 | 122869312.4 | 202511530.7 | 632954.275 | 1450143.809 | 123023 | 811 | | 73 | |
| | 423085045.1 | 146922868.8 | 273172485.5 | 958048.6069 | 2031642.152 | 204875 | 856 | | 73 | |

| A37 | | | |
|-----|----------------|--------|---|
| | A | B | C |
| 1 | NUM_ITERATIONS | 20000 | |
| 2 | WEIGHT MAX | 320085 | |
| 3 | WEIGHT MIN | 9753 | |
| 4 | SPEED MAX | 1250 | |
| 5 | SPEED MIN | 389 | |
| 6 | LABOR_RATE MAX | 100 | |
| 7 | LABOR_RATE MIN | 68 | |
| 8 | POWER MAX | 360 | |
| 9 | POWER MIN | 3.7 | |
| 10 | QUANTITY MAX | 200 | |
| 11 | QUANTITY MIN | 10 | |
| 12 | | | |
| 13 | WEIGHT | 231943 | |
| 14 | SPEED | 1228 | |
| 15 | LABOR_RATE | 81 | |
| 16 | POWER (kW) | 242 | |
| 17 | QUANTITY | 129 | |

Fourier Series - Definition

$$f(x) = \frac{1}{2} a_0 + \sum_{n=1}^{\infty} a_n \cos(nx) + \sum_{n=1}^{\infty} b_n \sin(nx)$$

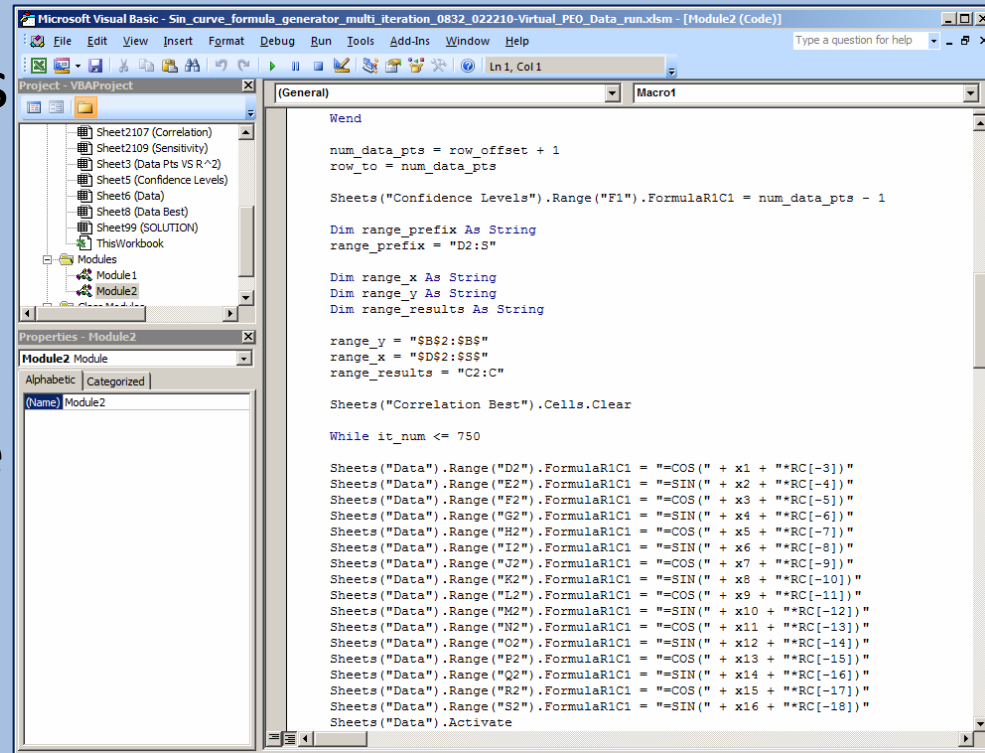
- General definition of a Fourier Series
- Using sine and cosine functions accounts for phase shift

$$\begin{aligned} a_0 &= \frac{1}{\pi} \int_{-\pi}^{\pi} f(x) dx \\ a_n &= \frac{1}{\pi} \int_{-\pi}^{\pi} f(x) \cos(nx) dx \\ b_n &= \frac{1}{\pi} \int_{-\pi}^{\pi} f(x) \sin(nx) dx \end{aligned}$$

- Formal definition of coefficients

Fourier Analysis Program (FAP)

- The objective is to produce a Fourier series that will describe cost data.
 - Amplitude becomes cost
 - Time becomes a variable based on a system specification
- The code to perform the Fourier Analysis was written in Visual Basic.



```
Microsoft Visual Basic - Sin_curve_formula_generator_multi_iteration_0832_022210-Virtual_PEO_Data_run.xlsm - [Module2 (Code)]
File Edit View Insert Format Debug Run Tools Add-Ins Window Help
Project - VBAProject
  Sheet2107 (Correlation)
  Sheet2109 (Sensitivity)
  Sheet3 (Data Pts VS R^2)
  Sheet5 (Confidence Levels)
  Sheet6 (Data)
  Sheet8 (Data Best)
  Sheet99 (SOLUTION)
  ThisWorkbook
  Modules
    Module1
    Module2
Properties - Module2
Module2 Module
Alphabetic | Categorized |
(Name) Module2
(General) Macro1
Wend
num_data_pts = row_offset + 1
row_to = num_data_pts

Sheets("Confidence Levels").Range("F1").FormulaR1C1 = num_data_pts - 1

Dim range_prefix As String
range_prefix = "D2:S"

Dim range_x As String
Dim range_y As String
Dim range_results As String

range_y = "$B$2:$B$8"
range_x = "$D$2:$D$8"
range_results = "C2:C"

Sheets("Correlation Best").Cells.Clear

While it_num <= 750

  Sheets("Data").Range("D2").FormulaR1C1 = "=COS(" + x1 + "**RC[-3])"
  Sheets("Data").Range("E2").FormulaR1C1 = "=SIN(" + x2 + "**RC[-4])"
  Sheets("Data").Range("F2").FormulaR1C1 = "=COS(" + x3 + "**RC[-5])"
  Sheets("Data").Range("G2").FormulaR1C1 = "=SIN(" + x4 + "**RC[-6])"
  Sheets("Data").Range("H2").FormulaR1C1 = "=COS(" + x5 + "**RC[-7])"
  Sheets("Data").Range("I2").FormulaR1C1 = "=SIN(" + x6 + "**RC[-8])"
  Sheets("Data").Range("J2").FormulaR1C1 = "=COS(" + x7 + "**RC[-9])"
  Sheets("Data").Range("K2").FormulaR1C1 = "=SIN(" + x8 + "**RC[-10])"
  Sheets("Data").Range("L2").FormulaR1C1 = "=COS(" + x9 + "**RC[-11])"
  Sheets("Data").Range("M2").FormulaR1C1 = "=SIN(" + x10 + "**RC[-12])"
  Sheets("Data").Range("N2").FormulaR1C1 = "=COS(" + x11 + "**RC[-13])"
  Sheets("Data").Range("O2").FormulaR1C1 = "=SIN(" + x12 + "**RC[-14])"
  Sheets("Data").Range("P2").FormulaR1C1 = "=COS(" + x13 + "**RC[-15])"
  Sheets("Data").Range("Q2").FormulaR1C1 = "=SIN(" + x14 + "**RC[-16])"
  Sheets("Data").Range("R2").FormulaR1C1 = "=COS(" + x15 + "**RC[-17])"
  Sheets("Data").Range("S2").FormulaR1C1 = "=SIN(" + x16 + "**RC[-18])"
  Sheets("Data").Activate
```

Regression Analysis

- A table was created containing
 - User defined system variable
 - Cost
 - 8 sine functions
 - 8 cosine functions
- Regression analysis was performed on the virtual POE data to determine the coefficients in the Fourier Series.

| | A | B | C | D | E | F | G |
|---|----------------|---|---|---|---|---|---|
| 1 | SUMMARY OUTPUT | | | | | | |
| 2 | | | | | | | |

| =Regression!\$B\$17+Regression!\$B\$18*COS(0.8*Data!A2)+Regression!\$B\$19*SIN(0.3*Data!A2)+Regression!\$B\$20*COS(1.9*Data!A2)+Regression!\$B\$25*SIN(5.9*Data!A2)+Regression!\$B\$26*COS(0.7*Data!A2)+Regression!\$B\$27*SIN(6*Data!A2)+Regression!\$B\$32*COS(1.7*Data!A2)+Regression!\$B\$33*SIN(0.5*Data!A2) | | | | | | | | | | |
|---|------------------|-------------|----------|----------|----------|----------|----------|----------|----------|----------|
| A | B | C | D | E | F | G | H | I | J | K |
| variables / (10T) | PRODUCTION TOTAL | Results | Coef 1 | Coef 2 | Coef 3 | Coef 4 | Coef 5 | Coef 6 | Coef 7 | Coef 8 |
| 0.059870625 | 193338350.6 | 313634293.2 | 0.999122 | 0.219714 | 0.972864 | 0.208017 | 0.986963 | 0.260394 | 0.986963 | 0.260394 |
| 0.339695895 | 651728884.5 | 375053862.4 | 0.971862 | 0.951113 | 0.243509 | 0.927973 | 0.608062 | 0.997103 | 0.608062 | 0.997103 |
| 0.345771734 | 296535035.7 | 377615350.7 | 0.970851 | 0.957831 | 0.220461 | 0.935687 | 0.594957 | 0.99878 | 0.594957 | 0.99878 |
| 0.515240696 | 656265159 | 445395180.7 | 0.935661 | 0.944215 | -0.42471 | 0.973083 | 0.178682 | 0.767244 | 0.178682 | 0.767244 |
| 0.732664472 | 371010044.7 | 477261681.7 | 0.871342 | 0.417538 | -0.95989 | 0.545736 | -0.39622 | -0.08204 | -0.39622 | -0.08204 |
| 0.928700055 | 308313536.4 | 449191618.3 | 0.796029 | -0.29035 | -0.88684 | -0.10864 | -0.8056 | -0.81031 | -0.8056 | -0.81031 |
| 1.043905572 | 356510172.8 | 431080778.9 | 0.744685 | -0.66003 | -0.59812 | -0.48999 | -0.94827 | -0.9929 | -0.94827 | -0.9929 |
| 1.09955806 | 572393111.6 | 427160737 | 0.718126 | -0.79969 | -0.41151 | -0.64945 | -0.98511 | -0.99211 | -0.98511 | -0.99211 |
| 1.337802486 | 317125508.6 | 462439068.3 | 0.592642 | -0.97193 | 0.483843 | -0.99955 | -0.89135 | -0.38652 | -0.89135 | -0.38652 |

| | Coef | Standard Err | t Stat | P-value | Lower 95% | Upper 95% | |
|----|-----------|--------------|----------|----------|-----------|-----------|----------|
| 16 | Intercept | 4.66E+08 | 29944399 | 15.57663 | 4.82E-17 | 4.06E+08 | 5.27E+08 |
| 17 | Coef 1 | 42874586 | 36298687 | 1.181161 | 0.245735 | -3.1E+07 | 1.17E+08 |
| 18 | Coef 2 | -6E+07 | 46567934 | -1.29046 | 0.2056 | -1.5E+08 | 34543590 |
| 19 | Coef 3 | -1E+08 | 37015884 | -2.71476 | 0.010343 | -1.8E+08 | -2.5E+07 |
| 20 | Coef 4 | -1E+08 | 39849586 | -2.54411 | 0.015668 | -1.8E+08 | -2E+07 |
| 21 | Coef 5 | -3272399 | 37615936 | -0.087 | 0.931186 | -8E+07 | 73172380 |
| 22 | Coef 6 | -1.5E+07 | 37123650 | -0.40838 | 0.685554 | -9.1E+07 | 60283704 |
| 23 | Coef 7 | -8.1E+07 | 40166435 | -2.0262 | 0.050648 | -1.6E+08 | 242956.6 |
| 24 | Coef 8 | 78740447 | 47506594 | 1.657464 | 0.106626 | -1.8E+07 | 1.75E+08 |
| 25 | Coef 9 | 24952405 | 35937392 | 0.69433 | 0.492193 | -4.8E+07 | 97985972 |
| 26 | Coef 10 | 28932133 | 45414756 | 0.637065 | 0.528349 | -6.3E+07 | 1.21E+08 |
| 27 | Coef 11 | 0 | 0 | 65535 | #NUM! | 0 | 0 |
| 28 | Coef 12 | -3E+07 | 40096083 | -0.75322 | 0.4565 | -1.1E+08 | 51283728 |
| 29 | Coef 13 | 34618769 | 43863315 | 0.789242 | 0.43544 | -5.5E+07 | 1.24E+08 |
| 30 | Coef 14 | -6.8E+07 | 44676459 | -1.53214 | 0.134742 | -1.6E+08 | 22343045 |
| 31 | Coef 15 | -6E+07 | 47756510 | -1.26275 | 0.215272 | -1.6E+08 | 36748472 |
| 32 | Coef 16 | -1.5E+07 | 44216926 | -0.34242 | 0.734144 | -1.1E+08 | 74718910 |

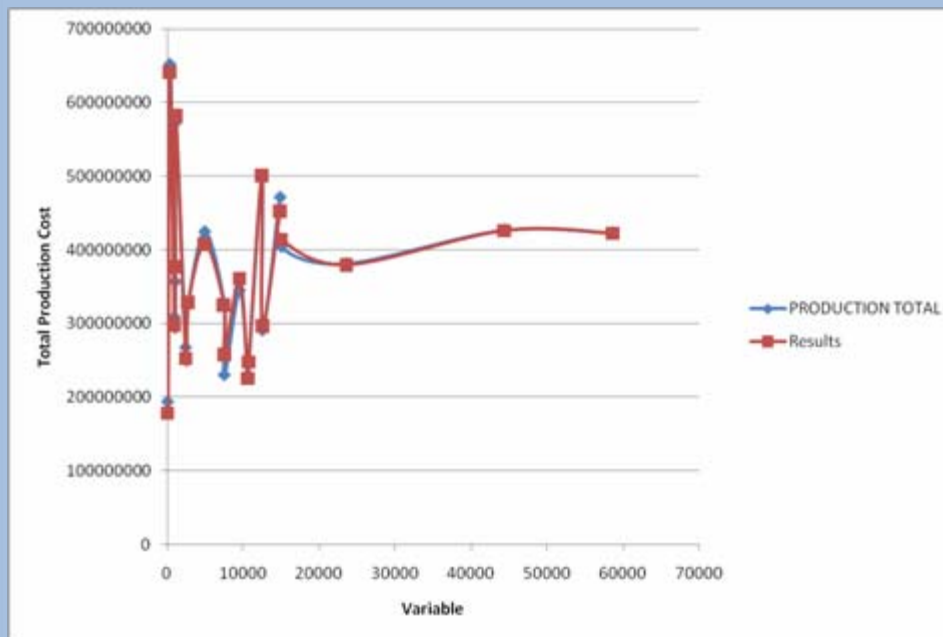
FAP – Correlation

- The Regression tool outputs y-intercept and a coefficient for each of the 16 terms
- Combining these yields a Fourier series of the form: $y = \text{Int} + \text{coefficient1} * \cos(\text{constant1} * \text{var}) + \dots + \text{coefficient16} * \sin(\text{constant16} * \text{var})$
- This Fourier series is applied to each variable in the data set
- The Correlation tool in the Data Analysis add-on is used to find the R^2 value between the Fourier series and the data set

| | A | B | C |
|---|----------|----------|----------|
| 1 | | Column 1 | Column 2 |
| 2 | Column 1 | 1 | |
| 3 | Column 2 | 0.800627 | 1 |

FAP – Iteration

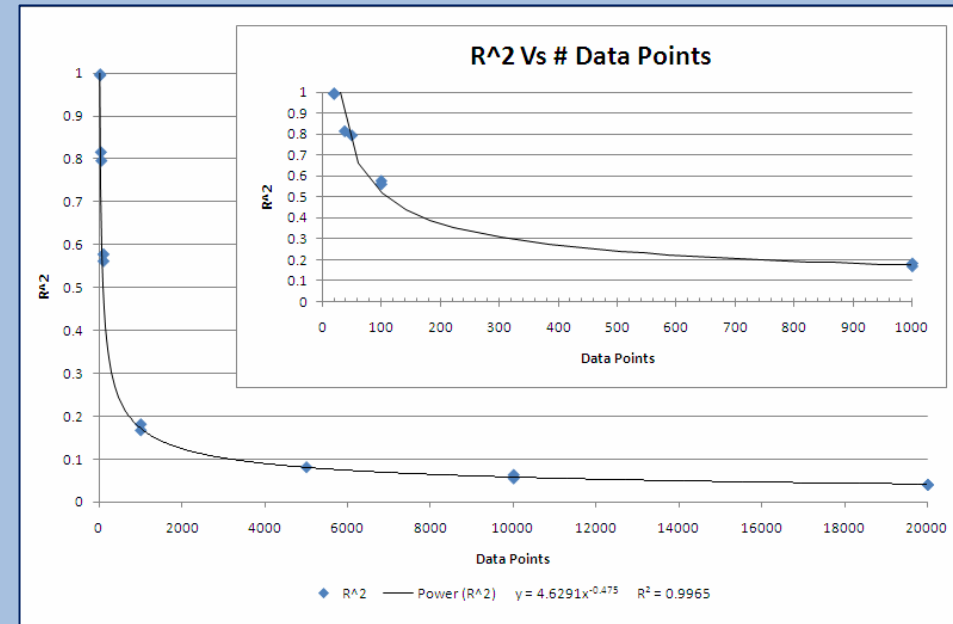
- The previous steps are run for a number of iterations.



- With each iteration
 - The constants of each sine and cosine term are randomly varied
 - Regression and correlation are evaluated
 - When the R-squared value is better than the previous best, the data table and regression results are saved.
- The best Fourier series produced can be used to predict the desired cost using the user designated variable.

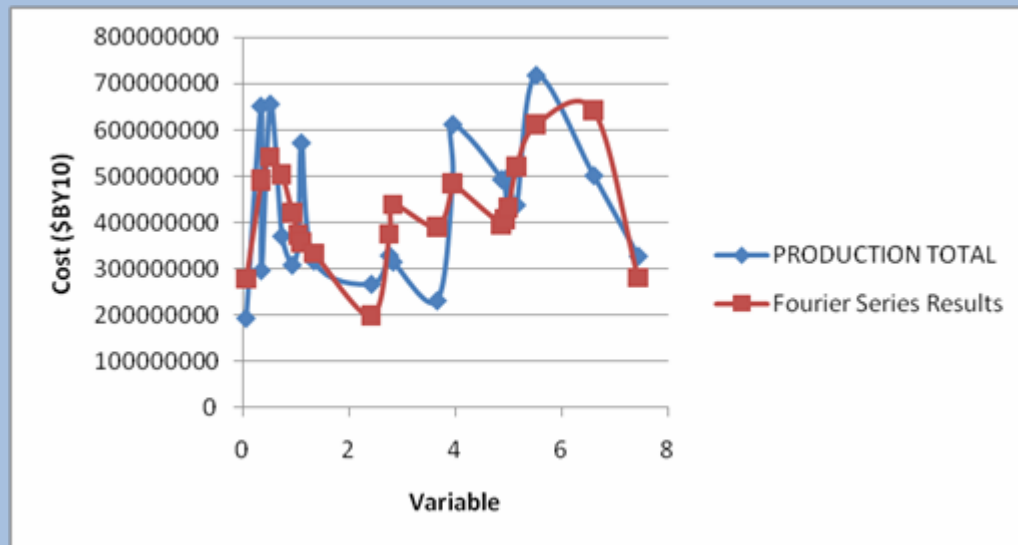
PM UPAS Production Cost Run

- The data collection tool was used to produce two seeds of 20,000 data points.
- The FAP was run on various numbers of data points to test the quality of the Fourier series that can be produced for different size data sets.
- Results show that smaller data sets, which are typically available in estimating the cost of aircraft, produce better R-squared values.



PM UPAS Run - Statistics

- A Fourier analysis was performed on a set of 50 data points from the first seed of the PM UPAS data.
- The correlation between the Fourier series and the data set generated an R-squared value of 0.801.
- The second seed of 20,000 data points was tested using the Fourier series .
- The percent difference between the Fourier series results and the actual cost was recorded.

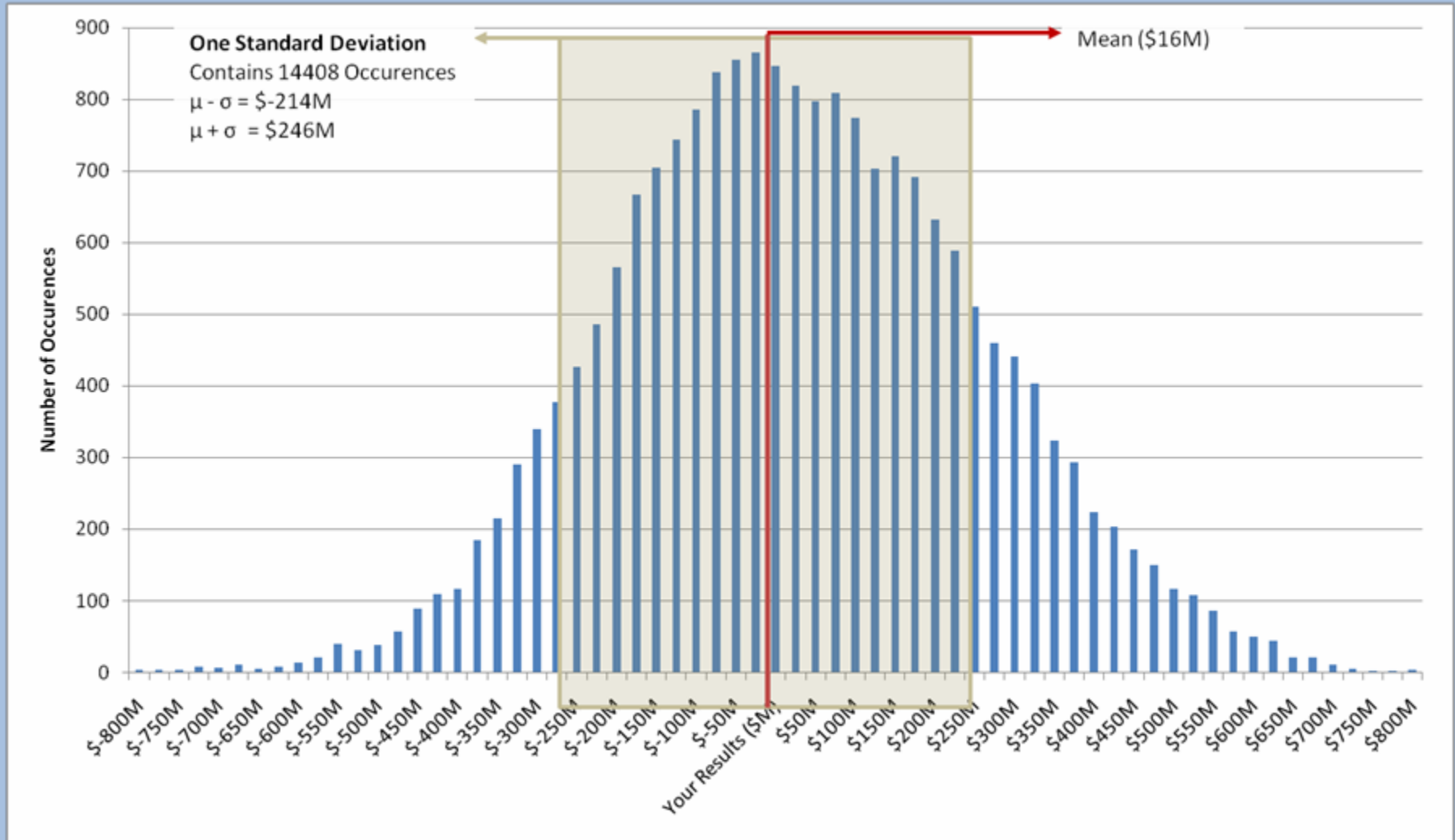


Fourier Analysis – Statistics

- A statistical analysis was performed on the 20,000 data points to determine the quality of the costs predicted by the Fourier analysis.
- The distribution of the differences between the actual and predicted costs is normal.

| | A | B |
|----|-------------------------------|------------------------|
| 1 | <i>Virtual POE Statistics</i> | |
| 2 | | |
| 3 | Mean | 16,052,339 |
| 4 | Standard Error | 1,625,793 |
| 5 | Median | 8,366,544 |
| 6 | Mode | #N/A |
| 7 | Standard Deviation | 229,921,886 |
| 8 | Sample Variance | 52,864,073,472,204,200 |
| 9 | Kurtosis | -0.087 |
| 10 | Skewness | 0.082 |
| 11 | Range | 1,692,729,663 |
| 12 | Minimum | -893,370,769 |
| 13 | Maximum | 799,358,894 |
| 14 | Sum | 321,046,787,008 |
| 15 | Count | 20,000 |

Fourier Analysis – Statistics



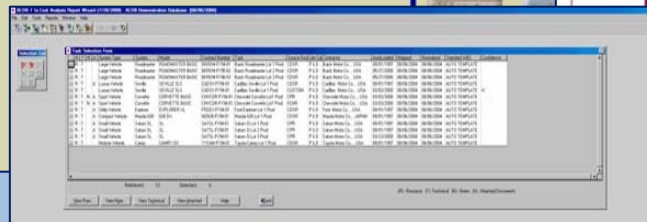
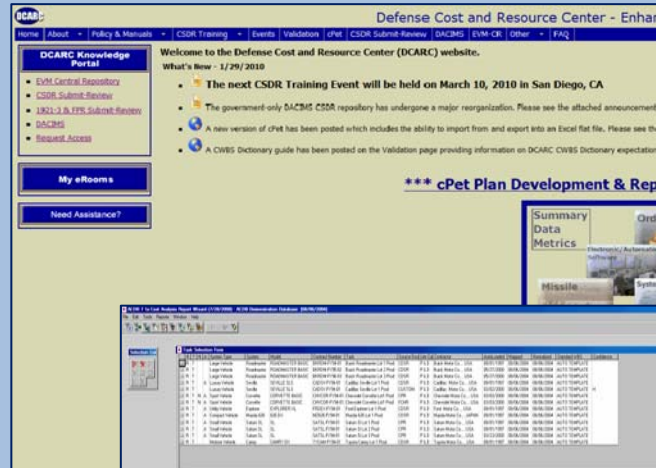
Testing the Method - Actual Data

- Fourier Analysis produced good results from the UPAS Virtual POE data.
- Will the results be similar with actual data?
- The Fourier Analysis Method was tested on actual aircraft data.



Data Sources for Actual Data

- Data for the actual cost of aircraft systems was gathered.
 - ACEIT Automated Cost Database (ACDB) Report Wizard
 - Defense Automated Cost Information Management System (DACIMS) Library located on the Defense Cost and Resource Center (DCARC) website



ACDB Overview

Automating the Estimating Environment

Relevant and Accurate Data is the Lifeblood for Cost Analysis

ACDB is a comprehensive and flexible database solution to allow easy access to relevant cost, technical and programmatic information.

- Allow access to relevant data points
- Develop specific methodologies, learning curves and cost factors
- Integrate with statistical software packages
- Enhances the quality of estimating methodologies

BUILD

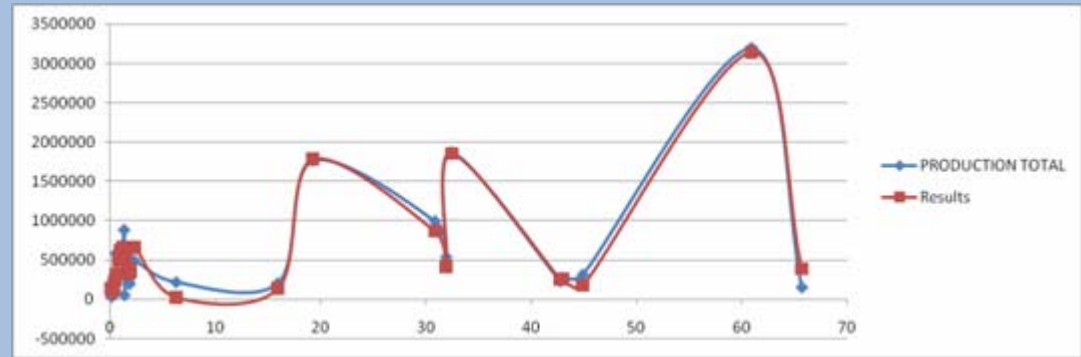
| Database Development Kit (DDK) | Report Wizard |
|--|--|
| <ul style="list-style-type: none"> Used by a database developer or administrator (DBA) to structure and populate database Easy map and normalize data to a standard WBS and consistent Base year Allows cost analyst to build a cost/schedule/technical/programmatic database to support cost research Includes built-in support for most of the standard DoD cost reporting formats, e.g. CPL, CDSR, FICR, COSR and CRST. Includes templates for custom data formats and contract pricing documents Automatic data loading through Excel Stores a wide range of information including attached documents, notes, technical data, re/normalized cost data | <ul style="list-style-type: none"> Used by estimators and analysts to access/extract data to use for analysis, factor, CER, or learning curve Easy conduct advanced sorts and filters Review historical studies, cost reports, program information, and technical data Search and retrieve: <ul style="list-style-type: none"> • Raw costs • Mapped and normalized data by WBS • Mapped and normalized data by CES • Technical data |
| <p>Cost Report Wizard</p> <p>Same features as Report Wizard with additional capabilities:</p> <ul style="list-style-type: none"> • Centralized data access over LAN/WAN or internet • Built-in multi-level security | |

Notes: See www.aceit.com for a list of available ACDB Government databases

© 2009 Teacote Research, Inc. All rights reserved.

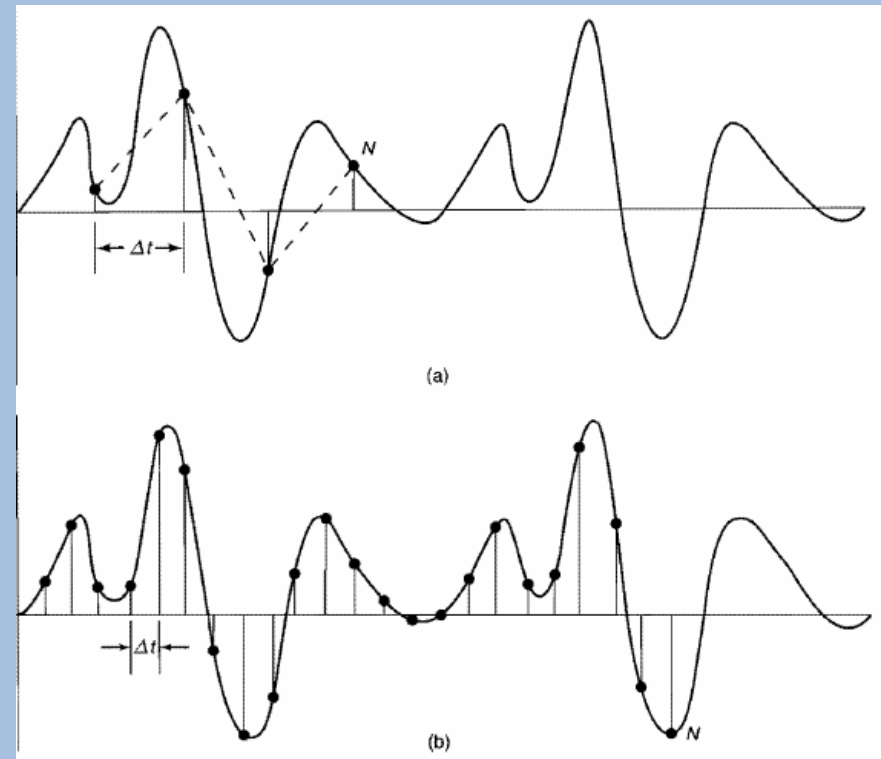
Fourier Analysis - Actual Data

- Data was gathered for 20 rotary wing aircraft and 17 fixed wing aircraft.
 - Total Production Cost
 - Maximum Takeoff Weight
 - Maximum Cruise Speed
 - Range
 - Service Ceiling
 - Lot Quantity
- Additionally, data on 3 rotary wing aircraft and 3 fixed wing aircraft was gathered to test the Fourier Series.
- All costs were normalized to BY2010 dollars using OSD Inflation Indices and the ACEIT 7.2 Inflation Utility.
- The Fourier Series produces negative costs in regions with large spacing between the data points.



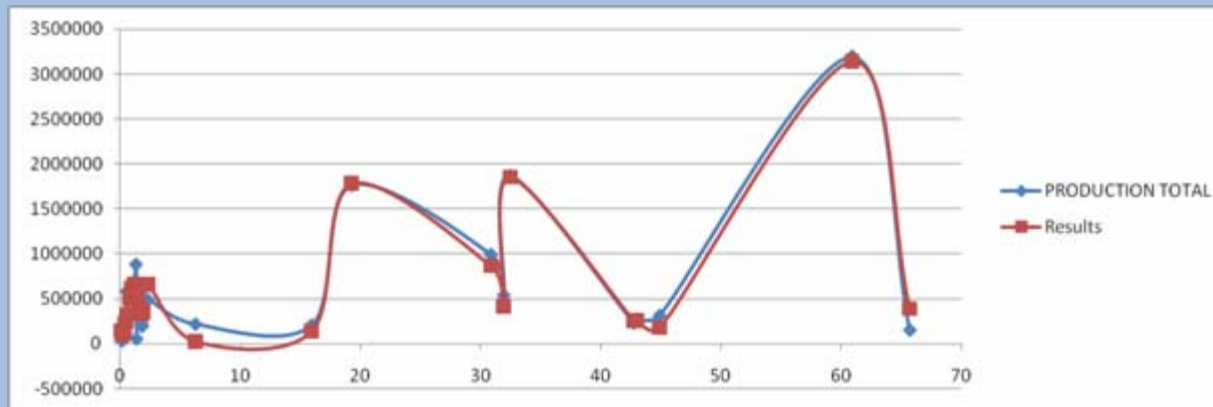
Sampling Rate

- The function behaves freely in regions with low resolution.
- Low resolution is equivalent to a low sampling rate in signal analysis.
- Sampling below the minimum sampling rate does not reveal the true behavior of the function.



Results - Actual Data

- The Fourier series produced from the actual data gave a realistic estimate of the production cost for
 - Systems similar to the systems in the data set
 - Systems with characteristics within the range of the data set (Ex. System weight must be between the lowest and highest weights in the data set).



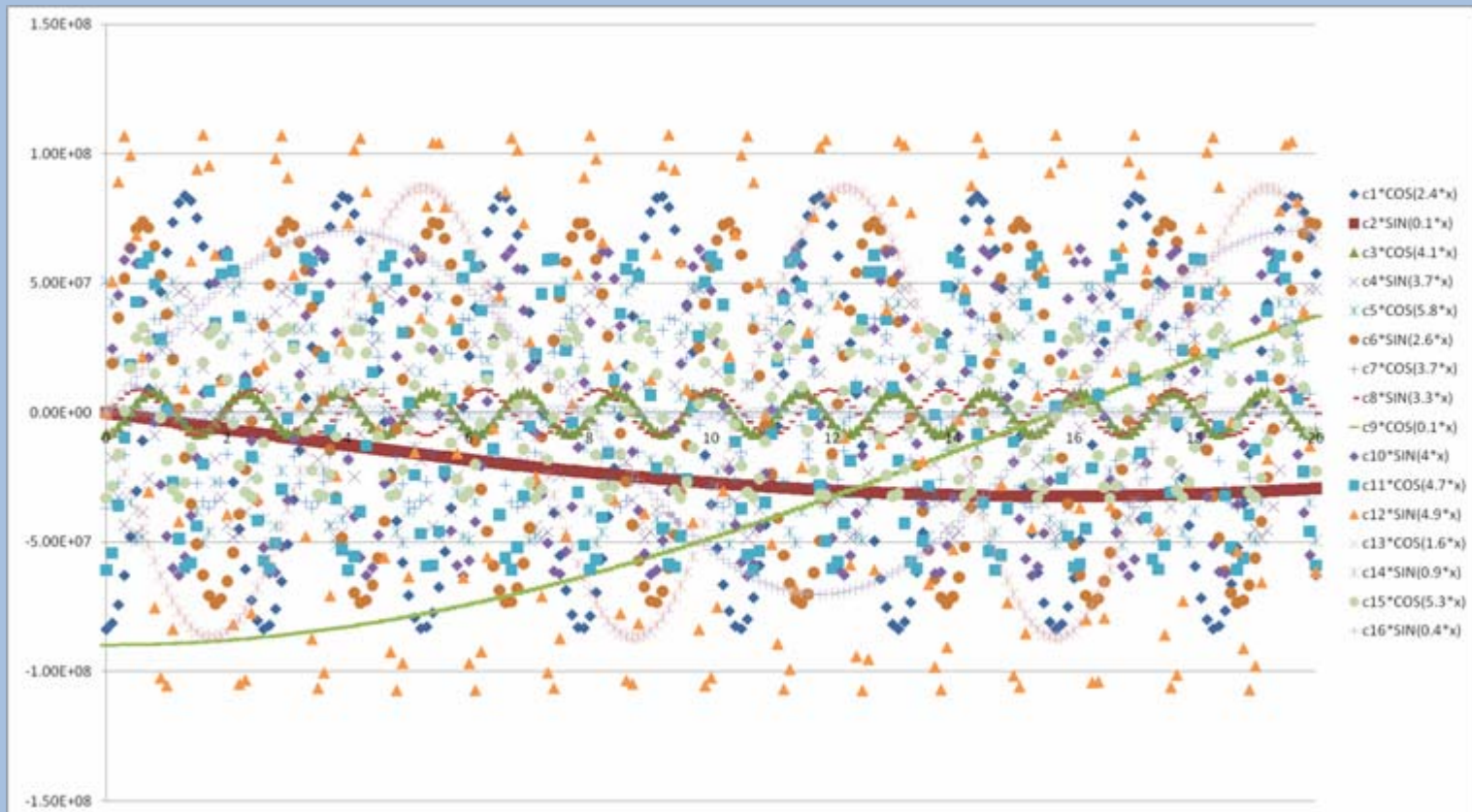
Conclusions

- Fourier analysis is a viable method for estimating a total cost when historical data is available.
- The analysis tool is useful to cost analysts because
 - It makes use of a common environment (MS Excel)
 - Produces quick and realistic results.
- This method is bound by the traditional rules for developing CERs from a data set.
- The Fourier series produced poor estimates for
 - Unlike systems
 - Systems whose characteristics were not in the range of the data set.



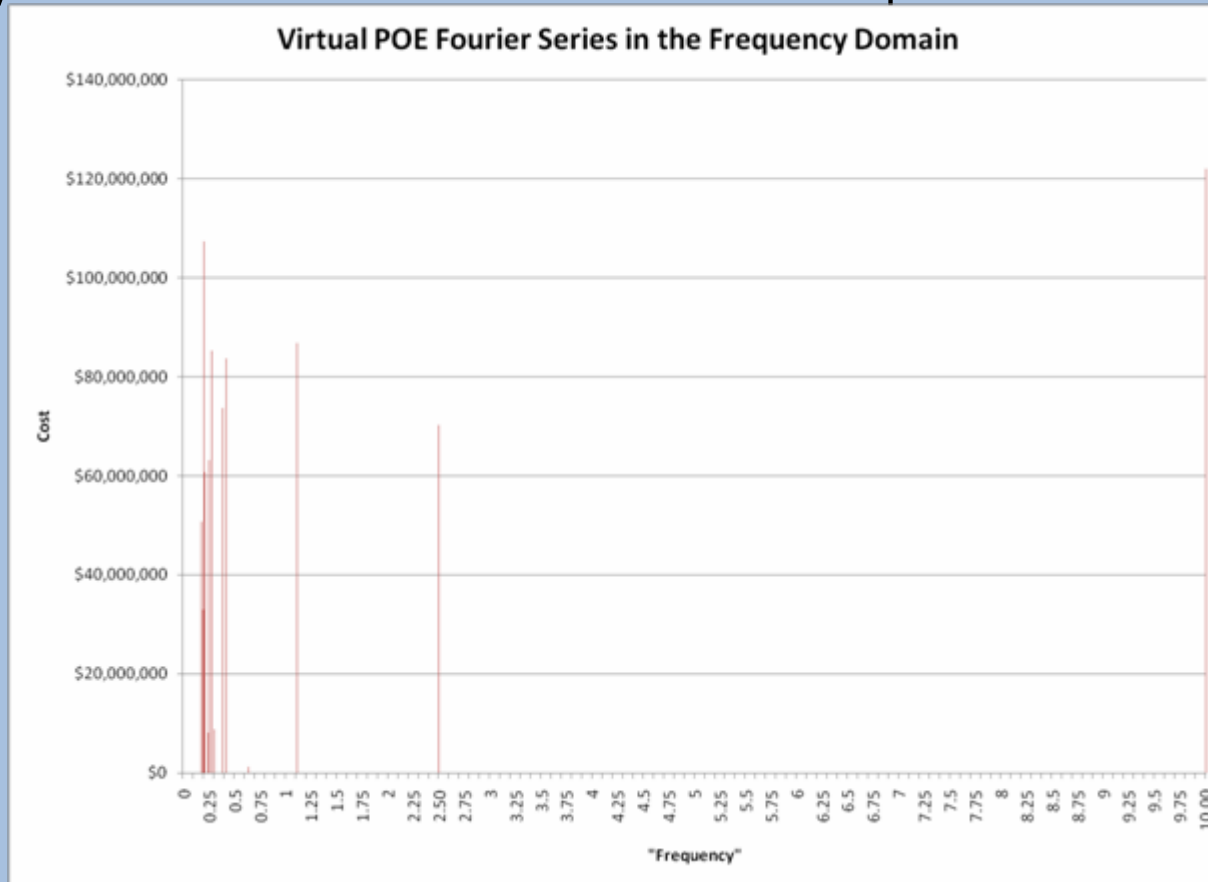
Where to next

- Extract the cost elements that make up the total cost as predicted by the Fourier series (Ex. SEPM from total production cost)

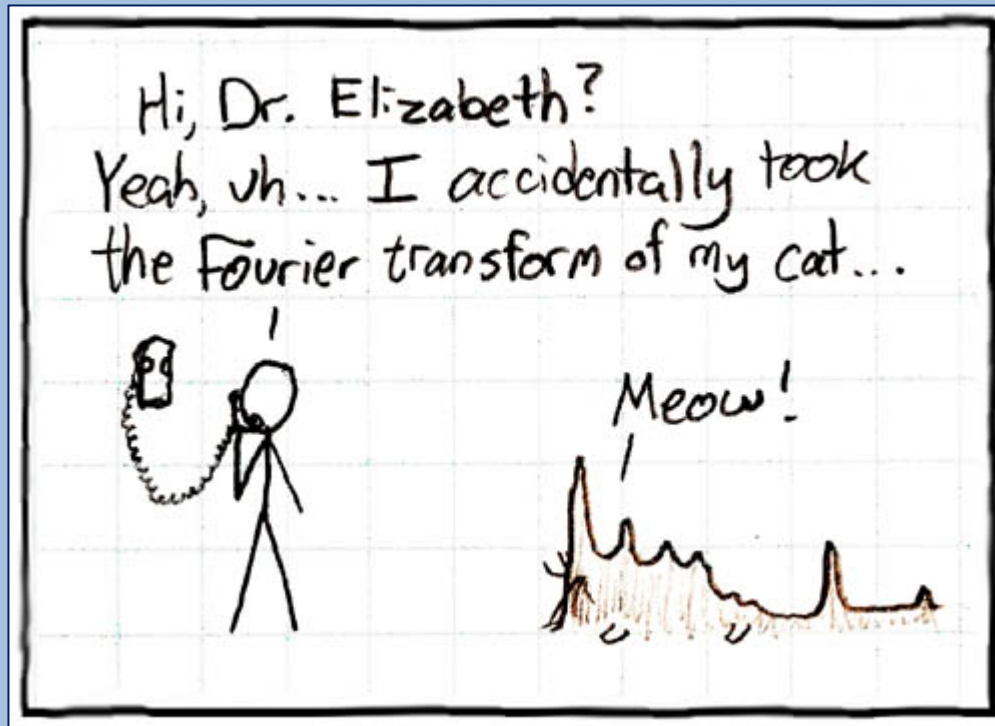


Where to next

- Transform the function from the “time” to the “frequency” domain and analyze the “frequencies”
- Do they relate to the cost elements that make up the total cost?



QUESTIONS?



xkcd comics – www.xkcd.com/26/