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Crewed and Space Transportation Systems Cost Model *CAST*

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OUTLINE



- **CAST - What it is**
 - Relationship to NAFCOM
 - Relationship to Project Cost Estimating Capability (PCEC)
- **Development Approach**
 - Overall goals - Philosophical framework
 - What we are estimating
 - Work and Functional Breakdown Structures (WBS & FBS)
 - How we are estimating
 - Basis of estimate – historical database
 - Cost Estimating Relationship (CER) development
- **End Product**
 - Model and data
 - Depth and breadth





CAST – What It Is

- **What it is**
 - New, unique cost model for use in estimating space transportation systems, including crewed systems, and earth-to-orbit and in-space transportation systems.
- **Relationship to NAFCOM**
 - CAST includes, but offers a more tailored estimating capability than NAFCOM
 - NAFCOM CER historical database is point-of-departure for many of the CAST CERs
 - CAST CERs draw on NAFCOM experience, but are not necessarily the same
 - Researching/updating/documenting NAFCOM historical database to be sure we understand it
 - As applicable, segregating out spacecraft datapoints
 - Adding additional datapoints as appropriate
 - Other changes/enhancements
 - NAFCOM 12 CERs will remain accessible as-is through PCEC
- **Relationship to Project Cost Estimating Capability (PCEC)**
 - CAST will be part of/accessible through PCEC
 - Model and data/documentation (through ONCE and REDSTAR)





Crewed and Space Transportation Systems Cost Model Development Approach



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- **Overall goals - Philosophical framework**
 - **Definition of a model: Mathematical relationships based on known historical data for use in estimating the cost of future systems**
 - **Focus: The data and arithmetic; Not the “bits and bytes”**
 - We are feeding math and data to PCEC developers for incorporation in the overall PCEC
 - **Emphasis: Basis of Estimate = Traceability and transparency of estimate to database**
 - Development and documentation of the database and analytical processes behind the CERs incorporated in the model
 - Provides flexibility to use CAST data/model as point-of-departure for tailored/customized estimates





- **What do we want to model? - Primary Assumptions/Considerations**

- There will be a set of CERs or equivalent estimating capability available to PCEC users for each WBS line item
- The WBS/CERs should be set up to utilize/reflect as much historical source data as possible
- The WBS/CERs should be set up to provide users with as much useful information as possible to cover a wide range of potential uses
- Results in need to consider multiple dimensions

- **Breakdown Structure Dimensions:**

- 1. End Items (Products & Services) = WBS**

- Point of Departure = NAFCOM (Launch Vehicle and Crew Vehicle Templates), MIL HDBK 881, Others
 - Will feed NPR 1720 (1.8) and CADRE; but estimates will be done at lower levels
 - Initially hardware only, but add launch and flight ops (and NREC facilities) to provide full LCC estimating capability

- 2. Time = Non Recurring and Recurring CERs for each WBS element**





- **Breakdown Structure Dimensions (continued):**
- 3. Functions (Engineering, Touch, Mfg Support, QA, etc.) = Functional Breakdown Structure (FBS)**
 - A lot of the historical data is in this format, not by end item
 - Many (most?) cost reduction/affordability approaches relate most directly to functions, not end items
 - E.g. Touch labor vs. automated welding; SR&QA vs. reduction in Gov't Mandated Inspection Points (GMIPS); Facility O&M vs. shared facilities
 - Separate from, but equal to WBS CER results: \sum WBS elements = \sum FBS elements
 - CAST includes estimating relationships between WBS and FBS elements – ratio analysis
- 4. Elements of Cost = Labor hours, Labor \$'s, Overhead \$'s, ODC's, Materials, Subcontracts**
 - Included (explicitly or implicitly) in WBS and FBS results
 - Primary inputs on (for instance) 533 data
- **Wraps**
 - Review/define terms
 - Contractor, Non-Prime Support, Civil Service
 - Program Management & Support, SE&I, S&MA, Vehicle Integration, etc.
 - Cost-to-cost non-linear CER's (not just a %)
 - Based on historical data: R&PM, Cx, SLS, etc.
 - Non-Recurring vs. Recurring; Program Approach (e.g. Cx vs. SLS vs. Shuttle)





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What We Are Estimating – WBS/FBS



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- Current CAST WBS

| 1 2 3 | 1 2 3 | 1 2 3 |
|--------------------------------|------------------------------------|---------------------------|
| SYSTEM | SYSTEM | SYSTEM |
| Program Segment | Vehicle Segment (continued) | Ground Segment |
| Program Mgt & Support | Propulsion | Production Facilities |
| Systems Engr & Integ | Liquid Engines | Facility |
| Safety & Mission Assur | Solid Motors | Tooling |
| Vehicle Segment | Reaction Control Sys | Launch Facilities |
| Integration, Ass'y, Checkout | Orbit Maneuvering | Pad |
| Structures | Avionics & Power | Vertical Processing |
| Wing | Guidance, Nav, & Control | Horizontal Processing |
| Tail | Communication & Tracking | Launch Control |
| Fuselage/Body | Data Processing | Payload Processing |
| Thrust Structure | Instrumentation | Mobile Launch Platform |
| Adapters | Telemetry | Landing |
| Holddown Structures | Thermal Control | Infrastructure |
| Secondary/Support Structs | Elec Power Generation | Test Facilities |
| Tanks | Elec Pwr Distribution & Control | Integrated Vehicle |
| Fuel | Flight Termination System | Propulsion |
| Oxidizer | Shroud/Fairing | Structures |
| Intertank | Structures | Operations Segment |
| Thermal Protect | Payload Accomodations | Launch Operations |
| Mechanisms | Utilities | Flight Operations |
| Flight Controls | Separation | |
| Separation | Crew Systems | |
| Recovery | Environ Ctl & Life Support | |
| Umbilicals | Crew Accomodations | |
| Main Propulsion Systems | Displays & Controls | |
| Feed | Software Segment | |
| Fill & Drain | Flight Software | |
| Purge & Vent | Ground Software | |
| Pressurization | Test Segment | |
| Thermal Protection | Ground Test Operations | |
| Passive | Special Test Equipment | |
| Active | Flight Test Operations | |





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What We Are Estimating – WBS/FBS



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- FBS Examples: Program & Propulsion Segments
- Works with WBS as two-dimensional matrix
 - Not every matrix “box” is relevant/has data
 - Nature of input/source data dictates which direction calculation goes

FBS Elements

| 1 2 3 | | | LABOR | | | | | Engineering | | | | | |
|------------------------|--|--|-----------------------|---------|-----------|-----------|------------------------|-----------------|--------------|--------------------|------------------|---------------|--|
| LAUNCH SYSTEM | | | Program Mgt & Support | | | | | Sys Integ | | Design & Sys Analy | | Special | |
| | | | PM&S | Bus Ops | Logistics | Supt Svcs | ODC | | | Analy | Sustain | Studies | |
| Program Segment | | | | | | | | | | | | | |
| Program Mgt & Support | | | X | X | X | X | X | | | | | | |
| Systems Engr & Integ | | | | | | | | X | X | NREC | REC | X | |
| Safety & Mission Assur | | | | | | | | | | | | | |
| Vehicle Segment | | | | | | | | | | | | | |
| Propulsion | | | | | | | | | | | | | |
| Liquid Engines | | | X | X | X | X | X | X | X | NREC | REC | X | |
| Solid Motors | | | | | X | X | X | X | X | NREC | REC | X | |
| Reaction Control Sys | | | | | | | | | | | | | |
| Orbit Maneuvering | | | | | | | | | | | | | |
| 1 2 3 | | | Manufacturing | | | | MATERIAL & SUBCONTRACT | | | | | | |
| LAUNCH SYSTEM | | | Touch | | Mfg Supt | SR&QA | Facility | Flight Hardware | | | Support Hardware | | |
| | | | | | | O&M | Flight Hdw 1 | Flight Hdw 2 | Flight Hdw N | Support Hdw 1 | Support Hdw 2 | Support Hdw N | |
| Program Segment | | | | | | | | | | | | | |
| Program Mgt & Support | | | | | | | | | | | | | |
| Systems Engr & Integ | | | | | | | | | | | | | |
| Safety & Mission Assur | | | | | | | | | | | | | |
| Vehicle Segment | | | | | | | | | | | | | |
| Propulsion | | | | | | | | | | | | | |
| Liquid Engines | | | X | X | X | X | Pumps | Nozzle | Controller | | | | |
| Solid Motors | | | X | X | X | X | Case | Propellant | Nozzle | | | | |
| Reaction Control Sys | | | | | | | | | | | | | |
| Orbit Maneuvering | | | | | | | | | | | | | |

Some overlap with WBS line items and elements of cost

FBS elements can vary by WBS line item





Crewed and Space Transportation Systems Cost Model

What We Are Estimating – WBS/FBS



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FBS CER Application Example

Question:

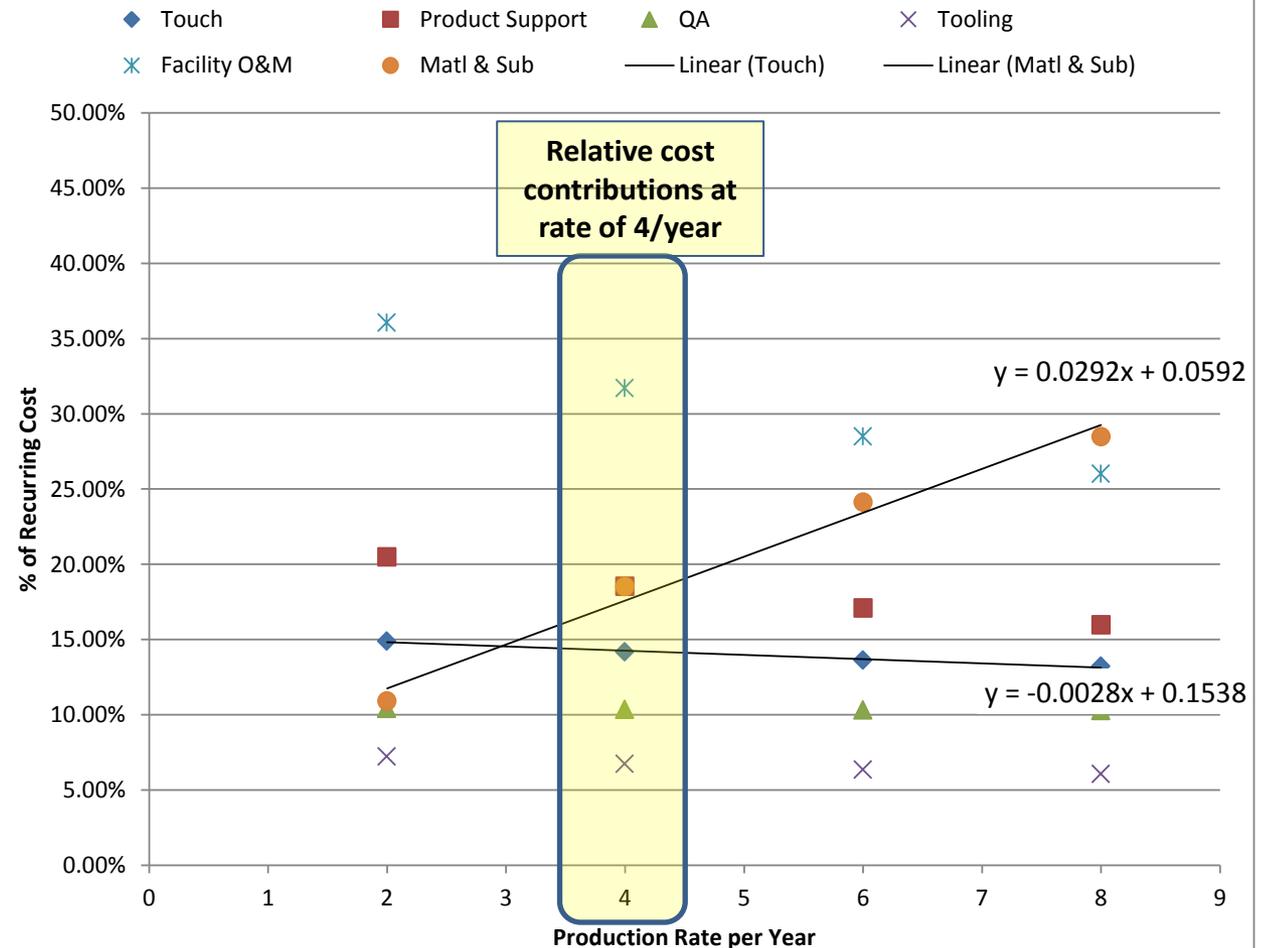
- At production rate of 4 per year, what is savings if introduce automated welding equipment for propellant tank manufacturing?

Assume

- WBS Tank CER output = \$10M/tank
- Estimated savings = 60% reduction in touch labor

Application

- Touch Labor % of Total \$ = $-.0028 \times (\text{rate}) + .1538$
- Touch Labor % @ 4/year = $-.0028(4) + .1538 = 14.3\%$
- $14.3\% \times (\$10\text{M} \times 4) = \5.7M touch labor cost per year
- $\$5.7\text{M} \times 60\% = \$3.4\text{M}/\text{year}$ savings
- $\$3.4\text{M} / \$0.150\text{M}/\text{MYE} = 22$ EP reduction in touch labor headcount





How We Are Estimating



- **Basis of estimate – historical database**
 - Evaluate the existing historical database : relevance, validity, content, assumptions
 - E.g. Centaur G' (i.e. Shuttle Centaur) – 80's, derivative and incomplete, CISS included?, allocations?
 - Add new historical datapoints
 - Pretty sparse, mostly mods, many not completed:
 - Shuttle upgrades: Super Lightweight ET, ASRM, MEDS (glass cockpit)
 - New programs: ARES, Orion, J2X
 - Limited knowledge: RS68, EELV
 - Publicly available: supplemental (?), anecdotal vs. verifiable
- **Cost Estimating Relationship (CER) development**
 - Scarcity and age/applicability of data relative to utilization methods in CER development
 - The choice, measurement, and quantification of qualitative and/or binary independent variables
 - Dummy variables vs. “complexity” factors
 - Manned/unmanned, upper stage/booster, expendable/reusable, etc.
 - Program Approach (“Platform”), Funding Certainty, Insight/Oversight (Wraps)
 - Relative to a baseline system vs. “pure” judgment - documentation
 - Sanity checks
 - Best-fit regression results must make sense
 - E.g. negative slope for New Design variable
 - Add fixed/variable cost estimating capability: learning and rate curves





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How We Are Estimating



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- CER/Database Issues**

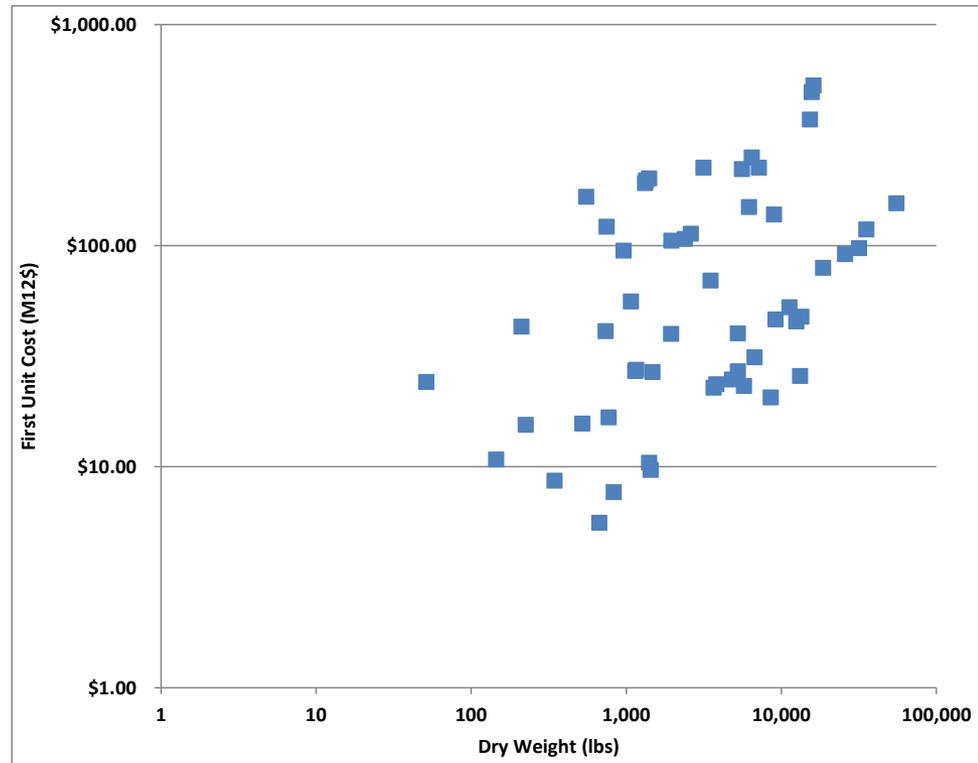
- Scarcity and age/applicability of data relative to utilization methods in CER development
- Example: Structures & Mechanisms

- 54 datapoints
- 15 subsystem/component CERs
- 5 one-point "CERs"

- 11 (10) Vehicle Systems
- Latest "initial launch year" = 1986

| Subsystem | # Points |
|-----------------------------|----------|
| 1 Mech.- Actuators | 1 |
| 2 Mech. -Separation | 2 |
| 3 Leading Edge | 1 |
| 4 Interface Hardware | 1 |
| 5 General | 17 |
| 6 Mech. - Payload Bay Doors | 1 |
| 7 Wing | 4 |
| 8 Skirt | 4 |
| 9 Base Heat Shield | 2 |
| 10 Mech. - Hydraulics | 1 |
| 11 Tank | 10 |
| 12 Intertank | 2 |
| 13 Thrust Structure | 4 |
| 14 Re-Entry Heat Shield | 2 |
| 15 Interstage | 2 |

| Vehicle | Initial Launch Year |
|-------------------|---------------------|
| 1 Apollo CSM | 1968 |
| 2 Apollo LM | 1968 |
| 3 Centaur-D | 1966 |
| 4 Centaur-G' | 1986 |
| 5 External Tank | 1981 |
| 6 Gemini | 1965 |
| 7 Shuttle Orbiter | 1981 |
| 8 S-IC | 1968 |
| 9 S-II | 1968 |
| 10 S-IVB | 1968 |
| 11 Spacelab | 1983 |





CAST: End Product



- **Model and data: Traceability and transparency**
 - CAST will provide the end item estimating capability currently available in NAFCOM
 - CAST will add:
 - Functional estimates
 - Fixed/variable production & operations estimates
 - Other expanded capabilities
 - Updated/expanded documentation of CER analyses and historical database
- **Estimating capability: Depth and breadth**
 - Both WBS and FBS dimensions
 - Time dimension - Full life cycle cost estimating capability: “sand charts”
 - Spread vs. non-spread cost
 - Cost as function of flight/production rates over time
 - (Eventually) Nonrecurring facilities, mission and launch ops

