Joint Strike Fighter

Cost Modeling in the JSF

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Summary

This paper is about the Joint Common Cost Model, a cost model developed to meet the unique challenges of estimating the cost of the Joint Strike Fighter Program. The cost model was developed to estimate the cost of a family of aircraft with maximum design and manufacturing commonality which meets the requirements of the United States Navy, Air Force, Marine Corps as well as the United Kingdom's Royal Navy. The JCCM incorporates the effect of commonality among different Service variants, the cost of advanced material composition, the cost of low observability, the costs of a robust avionics suite, the costs of a propulsion system capable of conventional flight and short take off and landing, and the cost effects of affordability initiatives in the area of Producibilty and Manufacturing. To our knowledge a model that meets these difficult requirements had not previously been developed.

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1.0 Introduction to JSF Program

The Joint Strike Fighter (JSF) Program is an aircraft development effort to design and produce the next generation of affordable strike fighter aircraft for the U.S. Air Force, Marine Corps, Navy, and UK Royal Navy. Each Service variant will be a member of a highly common family of aircraft. Figure 1 illustrates the high degree of commonality that will allow the development and production of Service variants more inexpensively than separate programs. The U.S. Air Force variant will be a conventional take off and landing aircraft, the Navy variant will be suitable for catapult-assisted takeoffs and arrested landings aboard aircraft carriers, and the Marine Corps and Royal Navy variants will be capable of short take off and vertical landing. All variants will feature a high amount of composite material usage in the airframe, a robust integrated avionics suite, and a main engine derived from the F-22 program.

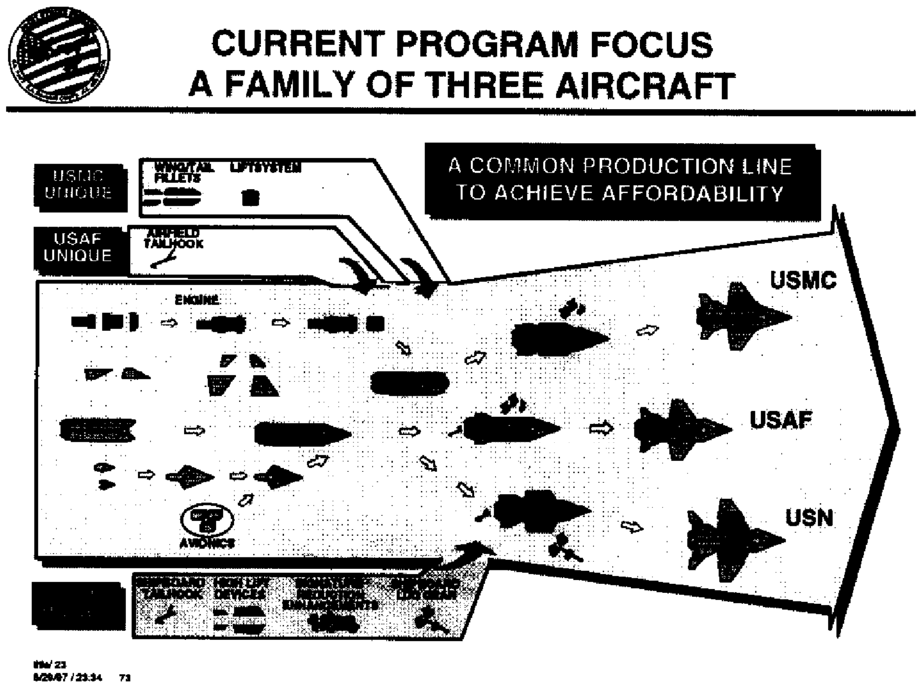


Figure 1

The program emphasizes affordability in all phases—development, production, and operating and support. The program and its contractors are implementing new business practices and the program is funding technology maturation efforts during the current concept development phase. These technology maturation efforts will reduce the risk of transition into the Engineering and Manufacturing Development (EMD) phase as well as reduce development costs. These also help the program meet the cost goals it has established for the unit recurring flyaway cost of each variant in production and reduce the operating and support cost of the aircraft.

2.0 Introduction to JCCM

The Joint Common Cost Model, or JCCM, was developed by the JSF Program Office and the Service cost estimating communities. Figure 2 illustrates the architecture of the JCCM. The JCCM is a parametric cost model which estimates the Engineering and Manufacturing Development (EMD) and Production phases of the JSF program. This model uses Cost Estimating Relationships (CER) statistically driven from U.S. Navy, Air Force, and Marine Corps Fighter/Tactical aircraft cost database. The JCCM was developed and is being improved periodically to estimate the unique aspects of the JSF program. The JCCM incorporates the cost effects of commonality among Service variants, estimates separately the cost of each Service variant, is sensitive to the material composition of the airframe, incorporates the cost savings due to affordability initiatives, and is sensitive to the design and rate and overhead differences between the two competing weapon system contractors. The inputs of the model is based on Weapon System Contractor's (WSC) Preferred Weapon System Concepts (PWSC).

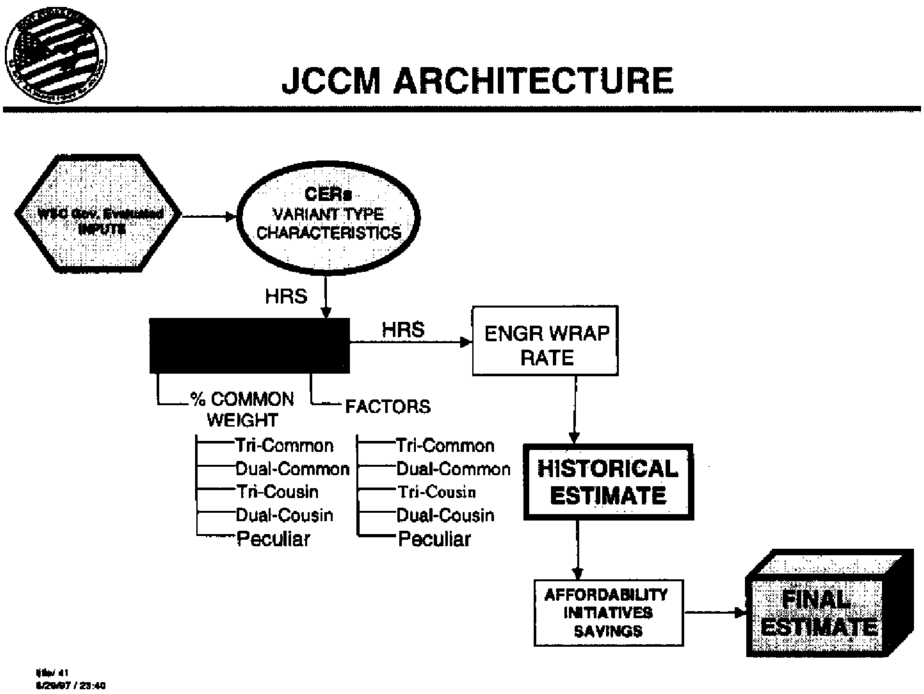


Figure 2

2.1 EMD

The JCCM estimates all EMD costs. Major Work Breakdown Structure (WBS) elements include the Air Vehicle, including Airframe, Propulsion, Avionics, and Armament; System Test and Evaluation; Systems Engineering and Program Management; Data;

Training; Peculiar Support Equipment; Government In-House; and Engineering Change Orders.

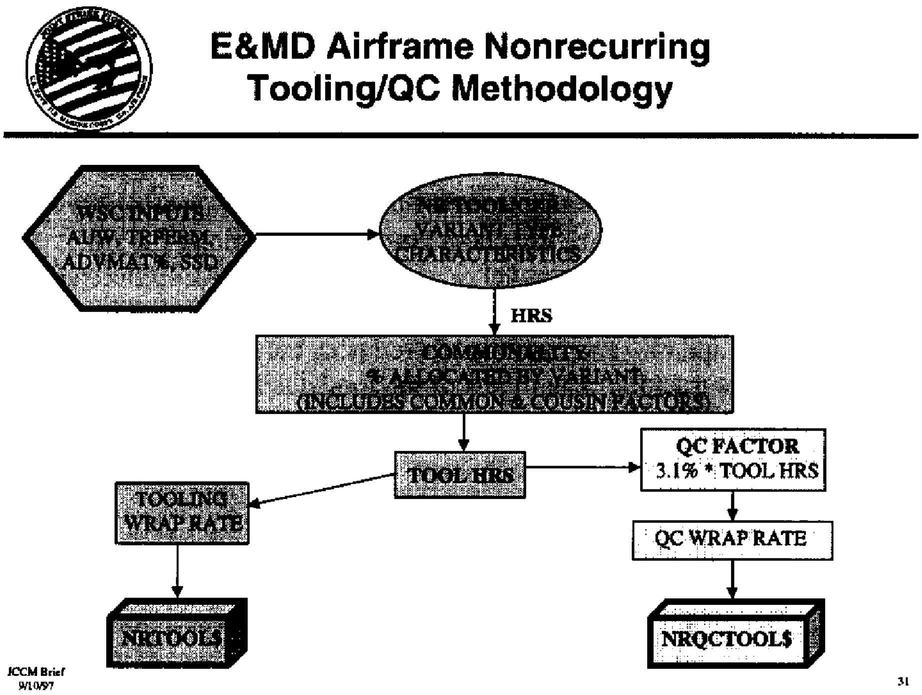


Figure 3

2.1.1 EMD Air Vehicle

The methodology for Airframe EMD labor costs uses parametric cost estimating relationships based on historical military aircraft development programs. The Airframe labor costs are estimated using the traditional functional areas of recurring and non-recurring engineering, tooling, quality assurance, and manufacturing. The costs of labor in these functional areas are aggregated to total airframe costs. For example, the largest labor area in the EMD phase of the program is airframe non-recurring engineering. The non-recurring engineering CER has independent variables for weight empty, first flight date, carrier suitability, supersonic capability, stealth, and material composition. The weight empty is the most significant variable. The carrier suitability, supersonic capability, and stealth are dummy variables. The CER estimates engineering labor hours which are converted to dollars by using each contractor's labor and overhead rates.

Airframe raw material, purchased parts, and purchased equipment costs are estimated using CERs from recent military aircraft programs. The methodologies are sensitive to the material mix and equipment of each variant.

The Propulsion EMD estimate is done at the engine component level such as combustor, fan, turbine, etc. The methodology for the main engine is an analogy to the F-119 engine used on the F-22. The baseline F-119 analogy is adjusted for technical complexity in the areas of performance, technical risk, and manufacturing by engineers familiar with the program to derive JSF engine component development costs.

The methodology for Avionics is an analogy to the F-22 avionics suite. The avionics estimate is built up from avionics elements such as control, navigation, and instrumentation; radar; sensors; controls and displays; core processor; electronic warfare; vehicle management system; etc. Again, the baseline analogy is adjusted for performance, design, and other differences by engineers and analysts familiar with both programs.

2.1.2 Other EMD Elements

System Test and Evaluation is estimated by its separate WBS elements of Contractor Flight Test, Ground Test, Avionics Test and Evaluation, Subsystem Test and Evaluation, and Other Test and Evaluation.

The methodology for Contractor Flight Test is based primarily on a labor hours per flight analogy to a recent fighter aircraft contractor flight test program.

The methodologies for the remaining System Test and Evaluation elements of Ground Test, Avionics Test and Evaluation, Subsystem Test and Evaluation, and Other Test and Evaluation are based on average hours per pound from two historical fighter development programs.

System Engineering and Program Management and Data costs are estimated as part of the same CER as is used to estimate the Airframe non-test non-recurring engineering hours. Twenty two percent of those hours are allocated to Systems Engineering and Program Management, two percent to Data, and the remaining 76% are allocated to airframe non-recurring engineering.

Training and Peculiar Support Equipment are estimated as factors of Air Vehicle plus non-ILS Systems Engineering and Program Management less Engine costs.

Government In-House costs are composed of Ground Test Facilities, Flight Test Facilities, Program Office, and Small Business Innovative Research. Government Ground Test Facility wind tunnel costs are estimated as a rate from the facility per occupancy hour. Sled test costs are estimated by cost per test.

Government Flight Test Facilities are estimated as a rate per hour from the flight test location.

Program Office costs are estimated as rate per person using current program office staffing levels.

Small Business Innovative Research is a factor of the previously estimated program development cost.

2.1.3 Commonality

The JCCM explicitly estimates the effects of commonality for Air Vehicle costs. The treatment of commonality is a rigorous process which begins with a government team that assesses commonality by individual part. The team looks at the size, shape, material composition, and function of each part. The degree of commonality of each part is assessed at a basic level as common, cousin, or unique. Common parts are defined as physically identical. Cousin parts are defined as having the same material, function, and interfaces, and similar internal geometry. For example, cousin bulkheads are made of the same material, serve the same function, and have the same external dimensions, but have similar web thicknesses and number of penetrations. Cousin parts share common fabrication or assembly tooling. Unique parts are defined as having application to a single variant.

Within these three basic definitions of commonality there are additional levels of commonality according to the number of variants that have that level of commonality. For example, common parts can be tri-common among all variants, dual-common between the Air Force and Marine Corps variants, dual-common between the Air Force and Navy variants, or dual-common between the Marine Corps and Navy variants. There are the same additional levels for cousin parts.

Every part in the airframe is assessed for commonality. The weights of the parts are summed for each level of commonality. The commonality levels for an airframe can then be expressed as a percentage of total airframe weight. For example, 50% tri-common means that half the weight of the airframe consists of parts that are common among all three variants.

The next step in determining the cost effects of commonality is determining the amount of non-recurring and recurring effort saved for each level of commonality. For the non-recurring costs of design, tooling, and quality control, a government and industry team studied each functional process to determine how much effort would be saved for each level of commonality relative to performing the effort separately for each variant.
The non-recurring cost effect of commonality is expressed as a factor relative to the cost of performing the effort separately for each variant, or uniquely. Unique effort has a commonality factor of one, meaning that no effort is saved. Effort assessed as common

or cousin has a factor of less than one. The factor is multiplied times the effort estimated for a unique aircraft.

Consider the example of the design process for unique versus common parts. No design effort is saved for unique parts because each unique part must be designed separately for each variant. So the commonality factor is 1 for the Air Force variant plus 1 for the Marine Corps variant plus 1 for the Navy variant, or 3, divided by the number of variants, which is 3. So the commonality factor for design of a unique part is 1, and the non-recurring design cost of unique weight in each variant gets multiplied by 1.

At the other extreme of commonality is tri-common parts, those that can be used for all variants. The part must be designed initially for the first variant. Then additional trade studies in stiffness, loads, stress, etc., as well as finite element modeling must be done to ensure the part's use in each of the other two variants. The government and industry commonality team determined that this additional effort is a factor of .2 (two tenths) of the cost of designing a unique part. So the non-recurring design cost of a tri-common part is 1 for the Air Force variant plus .2 for the Marine Corps variant plus .2 for the Navy variant, divided by the number of variants, which is 3. This fraction gives a commonality factor for design of tri-common parts of .47, and the non-recurring design cost of tri-common weight in each variant gets multiplied by .47.

The commonality methodology for recurring costs is similar to the methodology for non-recurring costs. The same commonality weights and percentages are used as in the non-recurring methodology. The cost effects of commonality are estimated using learning curves. Tri-common parts are run down a learning curve for the total quantity of aircraft produced. Unique parts are run down separate learning curves for the quantity of each variant. The weights of cousin parts are split into either the common or unique category using factors determined by the commonality team and then run down the appropriate learning curve. For example, parts that are dual cousin between the Air Force and Navy variants have 84 percent of their effort run down a common Air Force and Navy learning curve and 16 percent of their effort run down unique Air Force and Navy curves.

To summarize the treatment of commonality, commonality is part of the estimate for all the functional labor areas of the airframe as well as for the raw material and purchased equipment. Commonality is also applied to avionics and propulsion.

2.1.4 Stealth

The JCCM estimates the cost of stealth by using CERs and factors. The Program Office is conducting cost research to quantify the costs of specific stealth measures in an effort to estimate those items discretely.

2.1.5 Affordability Initiatives

The JCCM estimates the savings from affordability initiatives separately to maintain visibility and because of the difficulty in estimating these initiatives. The initiatives are identified and the cost savings are quantified in a separate database. The Program Office is conducting cost research to assess the cost and technical feasibility of the initiatives and will continue to update its estimates of them.

2.1.6 EMD Summary

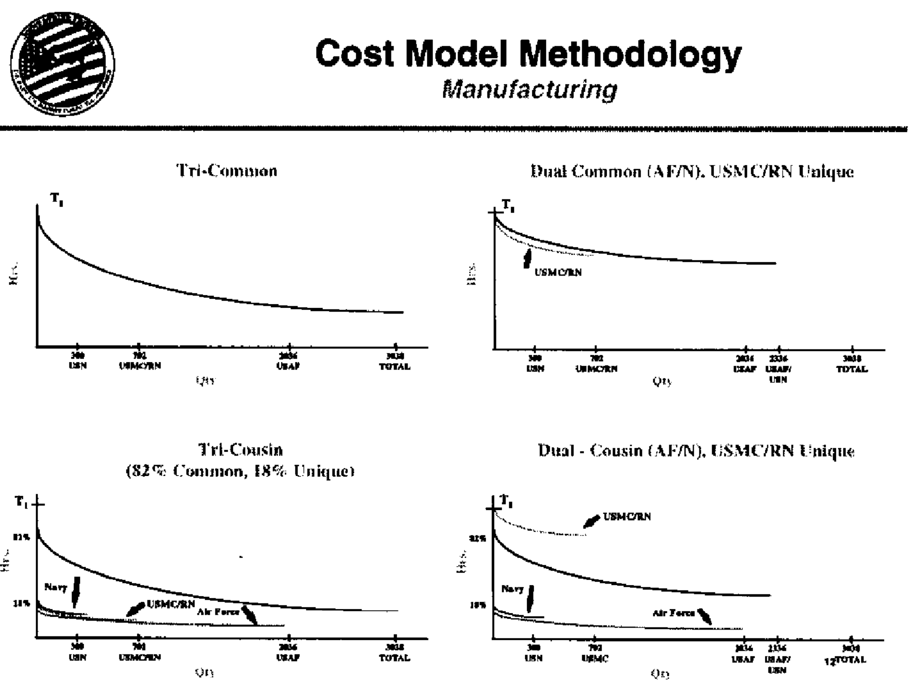
The EMD phase is scheduled to begin in FY2001. The total EMD estimate is in the range of $15 to $17 billion in FY 95 dollars. *(Steidle in Johns Hopkins APL Digest)*. This is roughly half of what it would cost to develop each variant as an individual program.

2.2 Production

The Production phase is estimated using the same CERs as are used to estimate the EMD phase. A step function adjusts from EMD Manufacturing to Production Manufacturing, but the learning curve and commonality methodologies are the same. The JSF program has a notional production profile which is used to estimate production costs. The quantities for planning purposes are 2036 Air Force units, 642 Marine Corps units, 300 Navy units, and 60 Royal Navy units. The commonality effects of the production profiles are illustrated in Figure 4.

The production estimate includes costs for Engineering Change Orders. Change Orders are estimated as a declining percentage of Airframe costs over the production run. The percentage is an analogy to a similar fighter aircraft program.

Figure 4



3.0 Summary

The JCCM was developed specifically to estimate the EMD and Production phases of the Joint Strike Fighter Program. The model provides visibility into the Program's areas of special interest such as commonality, material composition, and affordability initiatives. The model supports cost and operational performance trades and thus supports the Program's vision of developing and producing an affordable strike fighter. The model produces estimates in support of budget and planning exercises.

Reference

Steidle, C. E., The Joint Strike Fighter Program, TECHNICAL DIGEST, Johns Hopkins APL, Jan – Mar 1997, Vol 18, No. 1

List of Acronyms

JSF	Joint Strike Fighter
JCCM	Joint Common Cost Model
USN	United States Navy
USMC	United States Marine Corps
USAF	United States Air Force
EMD	Engineering & Manufacturing Development
CER	Cost Estimating Relationships
WSC	Weapon System Contractor
NR	Non-recurring
QC	Quality Control
AUW	Airframe Unit Weight
TRPERM	Total Rate per Month
WBS	Work Breakdown Structure