Source: https://commons.wikimedia.org/wiki/File:X-planes_group_photo.jpg

Estimating Future Air Dominance

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NOTE: The views expressed are those of the author and do not necessarily reflect the official policy or position of the Department of the Air Force or the US Government.

Problem Description

- How do you estimate the cost of a future aircraft?
- What can we learn from recent experiences?
- How can we reduce life cycle costs while still in the conceptual design?

- This briefing will attempt to explain:
  - Difficulties of aircraft cost estimating
  - Methods for estimating life cycle cost of aircraft programs
  - Affordability considerations for life cycle costs

Military Aircraft Cutting Edge Keeps Changing

Timeframe	Dominant Performance Goals	Technology Drivers
1940s-1950s (1stst and 2ndnd Generation)	Speed Ceiling Rate of climb	Aerodynamics Propulsion Materials
1960s-1970s (3rdrd and 4thth Generation	Maneuverability Agility Flexibility Multi-role	Mission systems Systems integration Propulsion
1970s-1990s (5thth Generation)	Stealth	Airframe shaping Materials Mission systems
2000s-Beyond	Affordable stealth Data fusion Connectivity Persistence	Optimized airframe design Open mission systems Networked operations Unmanned operations

Difficulties in Cost Estimating

- Typically, aircraft programs are attempting to do new things (hence the need for a new platform) that stretch the state of the art
- Cost data is constrained by experience on a few programs; due to high cost and long schedule, only so many can be undertaken
- All programs have specific requirements and issues meeting those requirements that challenge achieving cost/schedule performance
  - Recent military aircraft have experienced major redesign in the middle of development phase—when peak staffing is reached
  - Continued follow-on development has occurred to finish original design work and refresh/update capabilities
- Early production estimates are based on legacy programs and early actuals on specific program which may not be complete and learning curve variations can greatly affect out-year projections
- Operating & Support (O&S) costs are large out-year costs that are affected by decisions made early on (on average 63% of life cycle costs)

APPROACHES & METHODS TO ESTIMATE LCC COSTS

Steps to a High Quality Cost Estimate

The Twelve Steps of High-Quality Cost Estimating

1. **Define the estimate's purpose**
2. **Develop the estimating plan**
3. **Define the program characteristics, the technical baseline**
4. **Determine the estimating structure, the WBS**
5. **Identify ground rules and assumptions**
6. **Obtain the data**
7. **Develop the point estimate and compare it to an independent cost estimate**
8. **Conduct sensitivity analysis**
9. **Conduct a risk and uncertainty analysis**
10. **Document the estimate**
11. **Present the estimate to management for approval**
12. **Update the estimate to reflect actual costs and changes**

Steps 3–5: Need to work content that drives cost estimate

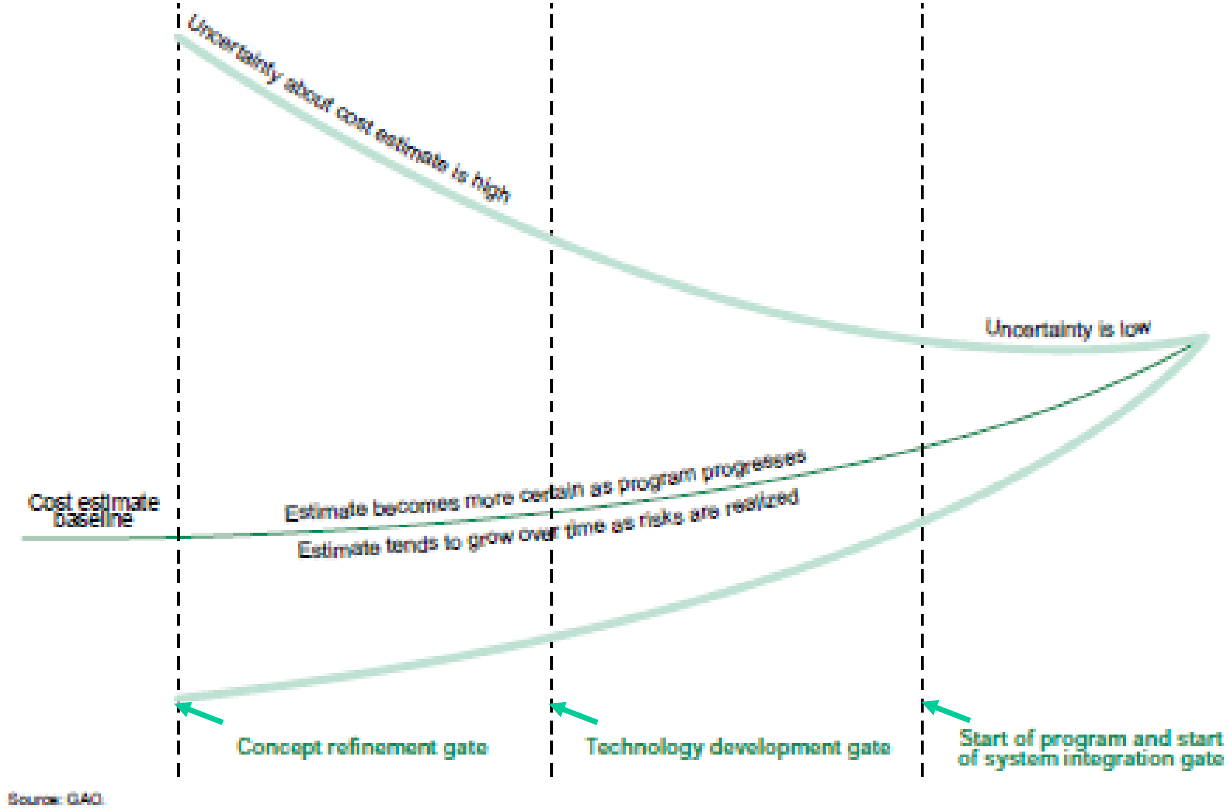
Steps 6–7: Need to understand history and what is different

Steps 8–9: Need to understand range of possible outcomes

Source: ***GAO Cost Estimating and Assessment Guide: Best Practices for Developing and Managing Capital Program Costs***

Cost Estimate Uncertainty

All estimates have a range that changes as the program matures
****This fact needs to be constantly pointed out to decision makers****



Cone of Uncertainty: *GAO Cost Estimating and Assessment Guide: Best Practices for Developing and Managing Capital Program Costs*, page 38

Cost Estimating Methods have Advantages and Disadvantages

Cost Estimate Method	Advantages	Disadvantages
Parametric - method uses statistical analysis to relate cost to one or more independent variables	* Easy to perform and quickly adjust * Can be done early when little tech definition * Uses actual history from several programs	* Relationships may be associative but not causual * May not be able to predict radical change * Typically higher level in nature
Analogy - method uses historical data from analogous system or subsystem that is similar to one being estimated and uses adjustments to account for differences using factors based on quantitative measure or expert judgement	* Easy to associate cause and effect * Easier to get judgement based on experience from prior known program * Not as much detail knowledge required as engineering estimate method	* Must have similar baseline program data * Requires more technical insight than in the case of parametric method * Expert opinion can be constrained and may not have greater context
Engineering Estimate - method uses low-level component breakout each of which is estimated by the functions (direct labor, direct material, o/h, other) using drawings and industry standards	* Easy to associate cause and effect * Very detailed with ability to drill down to specific work packages (EVM) * Can be used with schedule analysis	* Difficult and time consuming to implement * Need detail knowledge of work scope and resources * May not account for unanticipated work that may be included in overall data used for analogy/parametric
Actual Costs - method uses actual costs from early units or production units to estimate future costs of the same system (note: contract price may not reflect actual cost)	* Eliminates uncertainty from using data from other programs or contractors * Can be detailed enough to have high confidence in low-level adjustments	* Data not available early in the program life * May still require projections to account for new approaches and make vs buy changes

Aircraft Development Cost Estimating - Background

- **Often, we look at the major “chunks”**
  - **Design – nonrecurring effort to translate requirements to a solution (design engineering, systems engineering, program management) – both hardware and software required**
  - **Build – effort to make multiple engineering units to be used in testing solution against requirements**
  - **Test – effort to verify and validate the solution will meet requirements**
  - **Logistics – development effort to support the system once it is fielded (e.g. F-35 Autonomic Logistics Information System)**

Design Estimating Methods

- Hardware design
  - Cost Estimating Relationship – Relates non-recurring engineering effort to performance/technical parameters (weight, speed, RCS, carrier, first flight, material type usage)
  - Headcount approach – assumes a staffing level based on historical programs and a planned schedule for work
  - Propulsion – historical analogies using complexities for adjusting effort (at module level) and for schedule or CER using relationship to design parameters (thrust, air flow, overall pressure ratio, afterburner, etc.)
- Software design
  - Source Lines of Code (SLOC) with growth projections and historical productivity (hrs/SLOC)
  - Parametric methods using calibrated commercially available models

Build Estimating Methods

- Development cost from historically analogous programs
  - Labor: hours per pound
  - Material: raw materials using $/lb approach, subcontracted items using priced bill of materials with adjustments
- Production cost from historically analogous programs
  - Adjustments for material type usage
  - Use production cost data and historical cost improvement curves to “backwards project” for the build cost of test units
- Prototype data from prior demonstration on program
  - Not typically useful due to major design differences between a prototype used for limited demonstration vs aircraft used for fleet use to be supportable to fly many missions over many years

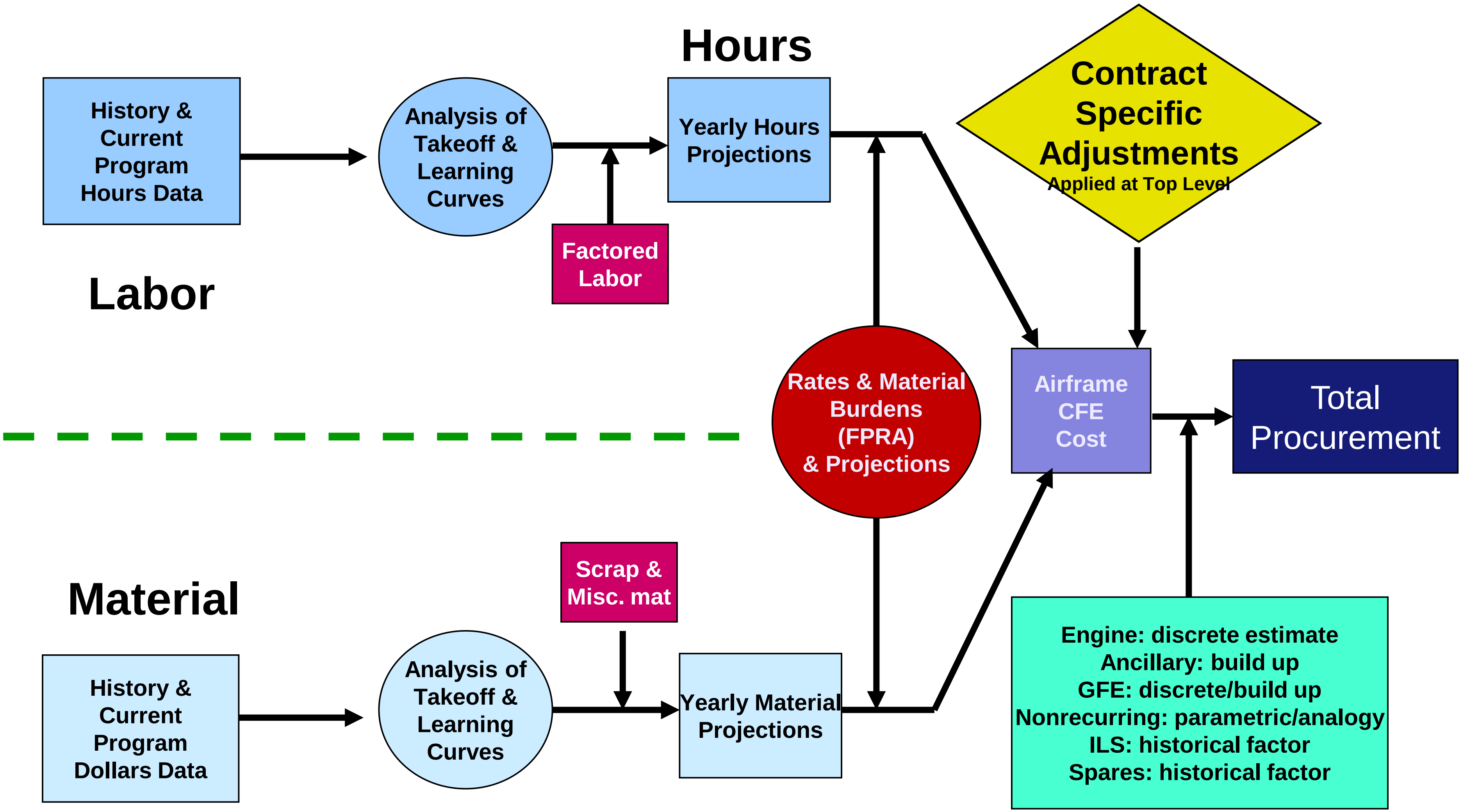
Test Estimating Methods

- **Historical comparisons often used to determine scope and the cost for the program**
- **Ground test – use of analogies to estimate the cost of specific elements: SILs, test articles, wind tunnel testing, etc.**
- **Flight test – use historical analogies to determine total test hours required (based on lower level categories) and the expected productivity (flight test hours/aircraft/month); analogous headcounts used to determine the support staff (prime and subcontractor) required to complete the total test hours**
- **Government support to test – typically based on test program plan with input from the test centers**
- **Software releases (drops) to determine achievable schedule**

Production Estimating Approaches

- Use functional categories of labor and material using historical data from analogous programs
- Use learning/rate (or cost improvement) curves for each cost element to project unit cost savings for cumulative and yearly savings
- Use labor rates and material factors based on current pricing
- Adjustments made for weight, material complexity (use of higher priced metals and composites), accounting
- Propulsion costs based on historical analogies and CERs
- Discrete estimates used for GFE, ancillary equipment, tooling
- Historical factors used for support equipment, spares
- Contract adjustments for specific program acquisition approach – e.g. multiyear, block buy, advanced procurement, etc.

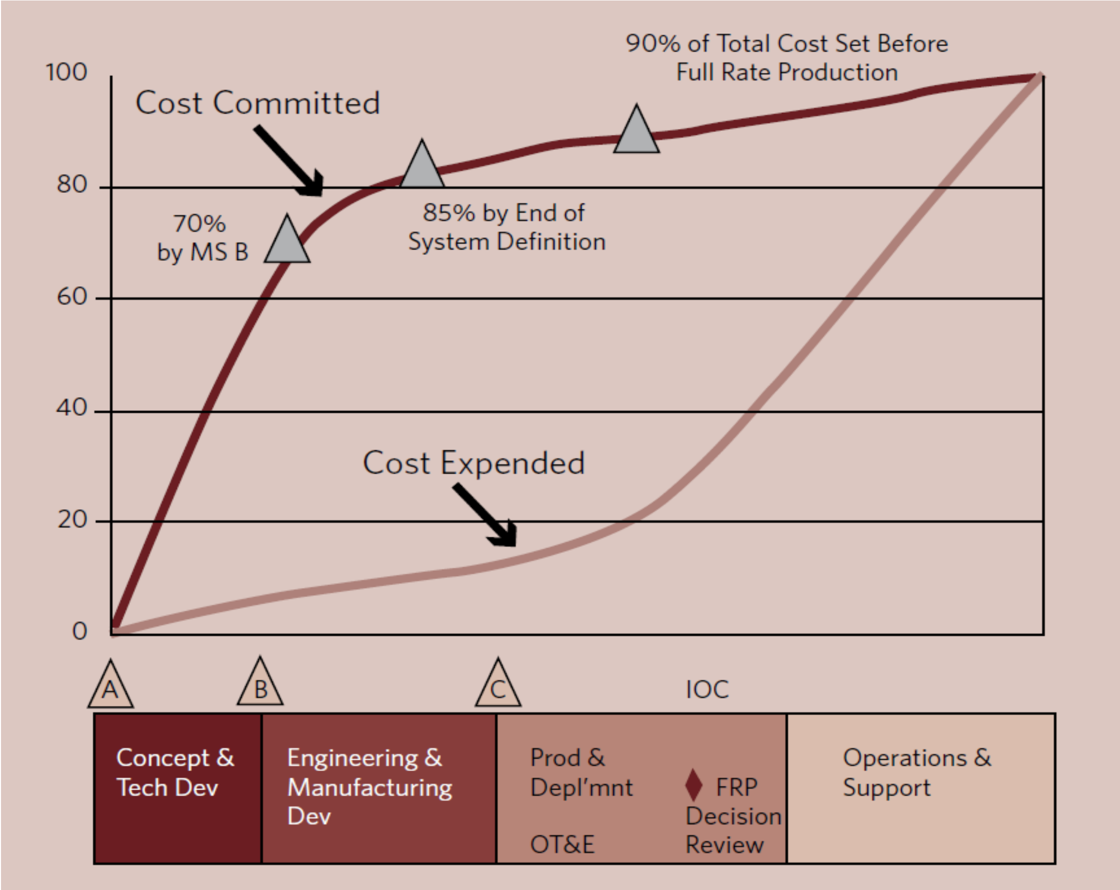
Production Cost Estimating Methods Flowchart



O&S Estimating Approaches uses OSD CAPE categories

- **Unit-level Manpower – operator, maintenance, and other support using manning and rates**
- **Unit Operations – consumable items such as fuel, electricity, training devices, software leases, etc. using usage data from analogous programs**
- **Maintenance – cost of labor and materials to support primary system, simulators, training devices, and support equipment**
- **Sustaining Support – cost of system specific training, support equipment replacement, sustaining engineering support, information systems, technical data, other sustaining support**
- **Continuing System Improvement – hardware and software modifications based on anticipated mods and software size**
- **Indirect support – installation, personnel, and training based on historical analogies**

Decisions made early will affect O&S costs



Source: *Designing for Supportability: Driving Reliability, Availability, and Maintainability In While Driving Costs Out* by Dallosta & Simcik, published in Defense AT&L, Mar-Apr 2012, Figure 4, page 37.

- MS A decisions
  - CONOPS / Mission Requirements
  - Manned / Unmanned; fixed / rotary winged; etc
- MS B decisions
  - Engine – fuel consumption rate
  - Platform and sub-system selected; limited manpower flexibility
  - Software complexity
- MS C and Beyond decisions
  - Quantity and flight hour adjustments

Recent aircraft development programs - cost contributors

- **B-2**: **experienced major redesign - changed from high to low altitude requirement; delay in development, affected subsystems design; all-aspect LO design difficulty; nearly all software was new; small percentage of drawings release at CDR; new materials and processes; concurrency with production**

- **F-22**: **YF-22 prototype did not reflect F-22 EMD design; sought major advances in airframe, engine, and avionics all at once; equal workshare teaming arrangement -- artificial work distribution; prototype design team moved from CA to GA – only 10% of staff stayed; initial weight estimates were much higher and still increased after PDR and CDR; integrated avionics -- a significant challenge; large amount of software required; engine required new core design**

- **F-35**: **X-35 prototype did not reflect F-35 EMD design, desire for commonality for savings but experienced significant weight growth--led to redesign at all levels (x3 variants); large software (air & ground) for highly integrated avionics; engine issues required some redesign; thousands of heads (at the prime) plus subcontractors were charging during the redesign effort; "traveled work" for configuration changes continued during build and delayed test readiness/flights**

Largest driver in development is time

AFFORDABILITY CONSIDERATIONS

Innovative Approaches to Reduce Aircraft Cost - Development

- Incremental development—focus on one major item (e.g. airframe) and incrementally add other system upgrades – F/A-18E/F and F-117 examples
- Build off a prototype design that is production representative – F-16 example
- Use open/federated avionics system design - may require more initial effort, but saves in future upgrade programs (allows for competition)
- Plan in sufficient management reserve to fund unknown issues
- Use teaming approaches based on prior experience and clear lines of responsibility
- Relax RCS requirement - drives many design trades (internal avionics, internal weapons, internal fuel) that make it hard to accommodate changes
  - Potential use of podded systems for specific missions which can be updated over time (ATFLIR vs EOTS) and allow for competition
- Instead of family of semi-common designs, force design of most difficult mission and accommodate easier missions within that design – F-35 CV and E-2 examples
- Pursue a stable design – don't change mission and take time to perform strict PDR/CDR (B-2 bad example) and quickly realize if off track (F-35 bad example)
- Challenge contractor to use less software or use of modular capability that doesn't rely on tight integration

Innovative Approaches to Reduce Aircraft Cost - Production

Customer Choices:

- Consider innovative ways to accomplish mission using fewer units
- Use contracting approaches that contain cost (FFP options from development contract – KC-46) and align the contractor incentives to the government incentives (F/A-18E/F multiyear procurement); use economic order quantities to buy out requirement in bulk
- Use missionized avionics to allow for decreased total number produced and use of off-board systems with data links
- Reduce development/production concurrency to make sure design is production ready

Contractor Choices:

- Use of more standard materials and processes (Aluminum vs Titanium or composites);
- Use manufacturing processes to save steps in the build – quick mate joints can save assembly cost and tooling costs
- Challenge contractor to use best methods and lowest rates - allow make vs buy decisions based on best value not partner workshare agreements
- Reduce parts count to decrease assembly time
- Use commercially available engines or modified military engines vs new engine designs

Innovative Approaches to Reduce Aircraft Cost – O&S

Customer Choices:

- Early trades on CONOPs and material solution selection – e.g. unmanned vs manned comparison
- Quantity of aircraft and amount of usage (flying hours)
- Trade of today's technology vs future technology – e.g. stealth repairs
- Effect of sustainment strategy chosen

Contractor Choices:

- Reliability of subsystems and cost/subsystem to gain maximum availability at best cost
- Software attributes need to be considered – e.g. size and language
- Engine selection and fuel usage

Note: it may be difficult to understand and incentivize design considerations to minimize O&S costs early in the program life cycle

Summary

- Cost estimating new aircraft is a challenge with uncertainty
- Multiple methods are used depending on cost element, phase of the life cycle (e.g development, production, or O&S) and level of maturity of program and data available
- Use historical cost data (contractor cost data, O&S historical data) as the basis for whatever method is chosen – roots the analysis in a defendable basis
- Historical programs have various reasons for cost growth
- Innovative approaches for saving costs can affect the eventual outcome of the program costs for all life cycle phases
- Each program will have its own challenges but it is important to remember the past successes and failures

Prototype vs Production Differences – YF-22 vs F-22

Source: *F-22 Design Evolution Part II,* Code One, October 1998, page 40.


Prototype and Reality: Differences Between the YF-22 and F-22

Prototype vs Production Differences – X-35 vs F-35

Source: *X to F: F-35 Lightening II and Its Predecessors,* Code One, Second Quarter 2008, page 19.