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SKUNK WORKS LESSONS LEARNED

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THE SKUNK WORKS APPROACH

The Lockheed Skunk Works has demonstrated a unique ability to rapidly prototype, develop and produce a wide range of highly advanced aircraft for the U.S. armed forces and intelligence agencies (See Figure 1). The P–80, U–2, F–104, SR–71, F–117, YF–22 and, more recently, the Tier 3– Dark Star are widely recognized as among the most significant achievements of the aerospace industry. These and other Skunk Works aircraft have incorporated breakthrough technology to achieve new thresholds in aircraft and system performance. The common thread among these aircraft is that they were created by men and women working together employing a unique approach to aircraft development — the Skunk Works approach. This management approach, developed by the founder of the Skunk Works – C, L. "Kelly" Johnson, fosters creativity and innovation, and has enabled prototyping and development of highly complex aircraft in relatively short time spans and at relatively low cost. It has also demonstrated efficient, economical production of complex systems in small quantities and at low production rates.

The Skunk Works Operating Rules

Based on lessons learned from early Skunk Works programs, Kelly Johnson developed and wrote the Basic Operating Rules of the Skunk Works. These fourteen "rules" address program management, organization, contractor/customer relationships, documentation, customer reporting, specifications, engineering drawings, funding, cost control, subcontractor inspection, testing, security, and management compensation. Although the language does not sound as if it would be applicable in today's environment, the basic principles are relevant and are applied in present Skunk Works' operations on a regular basis. (Comments in Italics expand the reasons behind the rules.)

1. The Skunk Works' manager must be delegated practically complete control of his program in all aspects. He should report to a division president or higher. *(It is essential that the program manager have authority to make decisions quickly regarding technical, finance, schedule, or operations matters.)*

2. Strong but small project offices must be provided both by the customer and contractor. *(The*

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Figure 1. 50 Years of Skunk Works Aircraft

customer program manager must have similar authority to that of the contractor.)

3. The number of people having any connection with the project must be restricted in an almost vicious manner. Use a small number of good people (10 to 25 percent compared to the so–called normal systems). *(Bureaucracy makes unnecessary work and must be controlled brutally.)*

4. A very simple drawing and drawing release system with great flexibility for making changes must be provided. *(This permits early work by manufacturing organizations, and schedule recovery if technical risks involve failures.)*

5, There must be a minimum of reports required, but important work must be recorded thoroughly. *(Responsible management does not require massive technical and information systems.)*

6. There must be a monthly cost review covering not only what has been spent and committed, but also projected costs to the conclusion of the program. Don't have the books ninety days late and don't surprise the customer with sudden overruns. *(Responsible management does require operation within the resources available.)*

7. The contractor must be delegated and must assume more than normal responsibility to get good vendor bids for the subcontract on the project. Commercial bid procedures are very often better than Mil Spec ones. *(Essential freedom to use the best talent available and operate within the resources available.)*

8. The inspection system as currently used by the Skunk Works, which has been approved by both the Air Force and Navy, meets the intent of existing military requirements and should be used on new projects. Push more basic inspection responsibility back to subcontractors and vendors. Don't duplicate so much inspection. *(Even the commercial world recognizes that quality is in design and responsible operations not inspection.)*

9. The contractor must be delegated the authority to test his final product in flight. He can and must test it in the initial stages. If he he isn't, he rapidly loses his competency to design other vehicles. *(Critical, if new technology and the attendant risks are to be rationally accommodated.)*

10. The specification applying to the hardware must be agreed to in advance of contracting. The Skunk Works practice of having a specification section stating clearly which important military specification items; will not knowingly be complied with and reasons therefore is highly recommended. *(Standard specifications inhibit new technology and innovation, and are frequently obsolete.)*

11. Funding a program must be timely so that the contractor doesn't have to keep running to the bank to support government projects. *(Respnsible management requires knowledge of and freedom to use, the resources originally committed.)*

12. There must be mutual trust between the customer project organization and the contractor with very close cooperation and liaison on a day–to–day basis. This cuts down misunderstanding and correspondence to an absolute minimum. *(The goals of the customer and producer should be the*

same – get the job done well.)

13. Access by outsiders to the project and its personnel must be strictly controlled by appropriate security measures. *(This is a program manager's responsibility even if no program security demands are made – a cost avoidance measure.)*

14. Because only a few people will be used in engineering and most other areas, ways must be provided to reward good performance by pay not based on the number of personnel supervised. *(Responsible management and technical/operational personnel must be rewarded. Responsible management does not permit the growth of bureaucracies.)*

Since its inception in 1943, the Skunk Works has completed a significant number of projects that have resulted in development and/or production hardware. These programs vary significantly in terms of type of product, technologies, customer, contracts, specifications, support requirements, and other parameters. However, there are some general characteristics that emerge:·

- Need to rapidly field a new capability ·
- Requirement for new technology breakthroughs ·
- Willingness to accept risk – contractor and customer ·
- Use of prototyping to reduce development risk ·
- Low rate and low quantity production ·
- Specialized management methods required and accepted·
- Need and/or desire to maintain tight security

The Have Blue stealth technology demonstrator and F–117 stealth fighter are two recent highly successful Skunk Works programs that have these general characteristics.

More than ever, the current environment demands that each acquisition dollar be spent wisely and efficiently. The Skunk Works management approach offers a proven, quick, efficient way to: develop new technology through prototyping; execute engineering and manufacturing development (EMD) programs; procure limited production systems at low rates; and upgrade current systems with new technology.

Program Management

A Skunk Works program is organized around a program manager who is given total control of all program aspects including engineering, test, manufacturing, quality assurance, security,.plans and schedules, budget control, etc. Thus, the program manager has the ability to control his costs and meet rational program milestones and objectives.

Other functional organizations within the Skunk Works (Lockheed Advanced Development Company) such as human resources, information services, facilities, environmental health and safety, and legal provide "on demand" support to the program managers. Furthermore, staff support in any specialty area of the corporation is available to the program manager if needed. As a program grows and transitions into development and production, additional functions are added such as product support, training, and assistant program managers for specific program end items as needed,

Skunk Works program offices are small. For example, at the height of F–117 development and production, the Skunk Works management team was 20 to 30 people total, and the Air Force's System Program Office (SPO) was similar in size. The objective is to establish a "one–on–one" relationship between the Skunk Works and customer procurement teams, with clear lines of responsibility and full authority for all managers, both contractor and customer,

The Skunk Works approach also demands the use of a small number of high quality individuals staffing each function. Individuals are given broad responsibility and have a substantial workload. Our experience has shown that under these circumstances individual achievement is most often much higher than management's expectations. The F–117 is a program that achieved excellent results while using a relatively small number of people. The maximum number of direct Skunk Works employees during each phase follows :

Have Blue Demonstrator 340
Full–Scale Development 2500
Production..... 4000
Sustaining Support 1200

The benefits of keeping both management and total personnel at a minimum are: greater individual responsibility and satisfaction; better communications; high productivity; and reduced costs .

The key to success is a cohesive team working closely together to achieve well–defined objectives. Tasks, responsibilities and progress are measured and tracked in a series of integrated plans and schedules developed by the contractor and customer to meet the program/system requirements.

Individual managers have access to all plans and schedules and understand how their part contributes to the total program. Progress is measured in formal weekly program reviews with the total program directorate. Other smaller or individual meetings are used to iron out differences of opinion or improve operating procedures.

When expanding technical capability, failures are inevitable and changes must be incorporated. In specific situations, special task teams are formed to develop solutions to critical problems. Progress is reviewed frequently by management, and decisions are made on a weekly or even daily basis for critical problem areas. In summary, individual commitment and performance is at its peak when the team believes in the objectives, recognizes his or her individual responsibility, and shares in the progress towards meeting those objectives.

Contractor~ Customer Relationship

Successful implementation of a Skunk Works management approach requires that the program customer be strongly committed to operating in a similar manner. This should not be a unique management approach: it is a rational way to develop new products containing advanced technology components. The starting point is a small, high quality, highly responsive customer pro-

gram office, and a small supporting organization only as needed. The customer program manager must be given singular authority and broad responsibilities. The program manager should report directly to a senior decision–capable management level free of external "staff" direction.

During the F–117 development, a small Air Force System Program Office (SPO) at WPAFB was augmented by small supporting organizations at Hq. USAF, Hq. TAG, Air Force Flight Test Center – Edward's AFB, Sacramento ALC, and Nellis AFB. This SPO director reported directly to the Commander, Aeronautical Systems Division, who was a Lieutenant General .

Successful development, production and fleet operations were achieved by building mutual trust over time among the contractor, Air Force, and supporting subcontractors. The Air Force and Lockheed program team maintained daily, open communications on program issues which resulted in teamwork, rapid joint problem solving, and mutual trust, rather than adversarial relationships.

Frequent technical and program reviews were conducted, but only important work and decisions were documented. Formal contractor–customer pro– gram reviews were held regularly and keyed to the pace of the program (from every six weeks to every quarter). Small program offices and close, regular communications minimized the need for formal reports, documentation, and more frequent program reviews.

LESSONS LEARNED

Before addressing the Lessons Learned in managing Life Cycle Cost (LCC), the elements of LCC need to be put into perspective. For a manned fighter, the O&S cost is the major element of the 10 year LCC, constituting about 55% of the LCC with acquisition about 40% and RDT&E the remaining 5%. For bomber and transport aircraft, the 10 year O&S cost is more like 65% (due to much more peacetime flying than a fighter), and 30% and 5% for acquisition and RDT&E respectively. The manpower cost to support flying operations is the major cost item in the O&S, constituting over 50 percent. Fuel costs, on the other hand consitute only 12 to 20 percent. For a fighter aircraft the breakdown of the acquisition cost is approximately 50% for airframe, 25% for avionics, 20% for propulsion and 5% for the remainder (crew station, armamaent, etc).

Program Planning

Implement Kelly's 14 Rules

The 14 Rules work ... so use them! The only hitch is that the customer has to agree to use them or they will not work.

Shoot the Cost Estimators

When the program is starting up and cost estimates are being developed, every effort should be made to develop a "bottoms up" cost estimate without using historical data. If you are trying to "break with tradition" and reduce costs, you should not have your cost targets set by esimators using historical cost data bases.

COST is King

The program priorities need to be established at the very beginning and COST better be #1. When "push comes to shove" and things need to be compromised, the program priorities establish how things are going to be traded off. Putting COST #1 means that everything else (performance, signature, etc) will be traded before COST is touched. This priority list has to be ruthlessly enforced, otherwise the performance and signature gremlins will sneak their favorite technologies onto the system and the cost will explode.

Quite often the company culture is that performance or signature is King. In this case there will need to be a cultural change since cost, performance and signatuare are in conflict. Often in the past, the metric was "cost effectiveness" which always meant more performance at the expense of cost (cases of reducing cost at the expense of performance are extremely rare). The cultural change will not be easy for most people and some will never change. Once people agree that COST is King there will have to be an almost daily reinforcement.

LMSW is working on two contracts where the customer established COST as King and is holding to it. The first is the DARPA contract for the low signature, high altitude, long endurance reconnaissance aircraft Tier 3– Darkstar. DARPA is asking for the best altitude, endurance and signature for a unit cost of $10M for units 11 through 20. The $10M unit cost drove the empty weight, interior volume, low signature treatment design such that altitude, endurance and signature was a fall out. The second contract is with the US Air Force for JASSM (Joint Air–to–Surface Standoff Missile). The contract is asking for a unit cost of less than $500K ($1995) for 2500 units. It should be noted that JASSM replaced the cancelled TSSAM (Tri– Service Standoff Missile, AGM–137). TSSAM also had a unit cost of $500K ($1985) and was cancelled in early 1995 when the unit cost increased to $2.3M.

Get the Best People

It is a fact that in any given organization there is small percent of the people that do the majority of the work. If you get the wrong people on the program you are in trouble meeting cost and schedule. For example, it is not uncommon to find a small group of designers that can turn out three times the number of drawings as the average designer.

Design to Empty Weight

Acquisition cost, to first order, is driven by empty weight as shown in Figure 2. This means that as soon as the cost target is established, it should be translated into an empty weight and weight budget. From then on the weight budget is tracked daily and any deviation from the budget is the cause for intense scrutiny.

Tailoring the Specs

Tailoring the specs means negotiating the mission requirements, acquisition requirements and manufacturing specs to give the designer, program manager and manufacturing manager

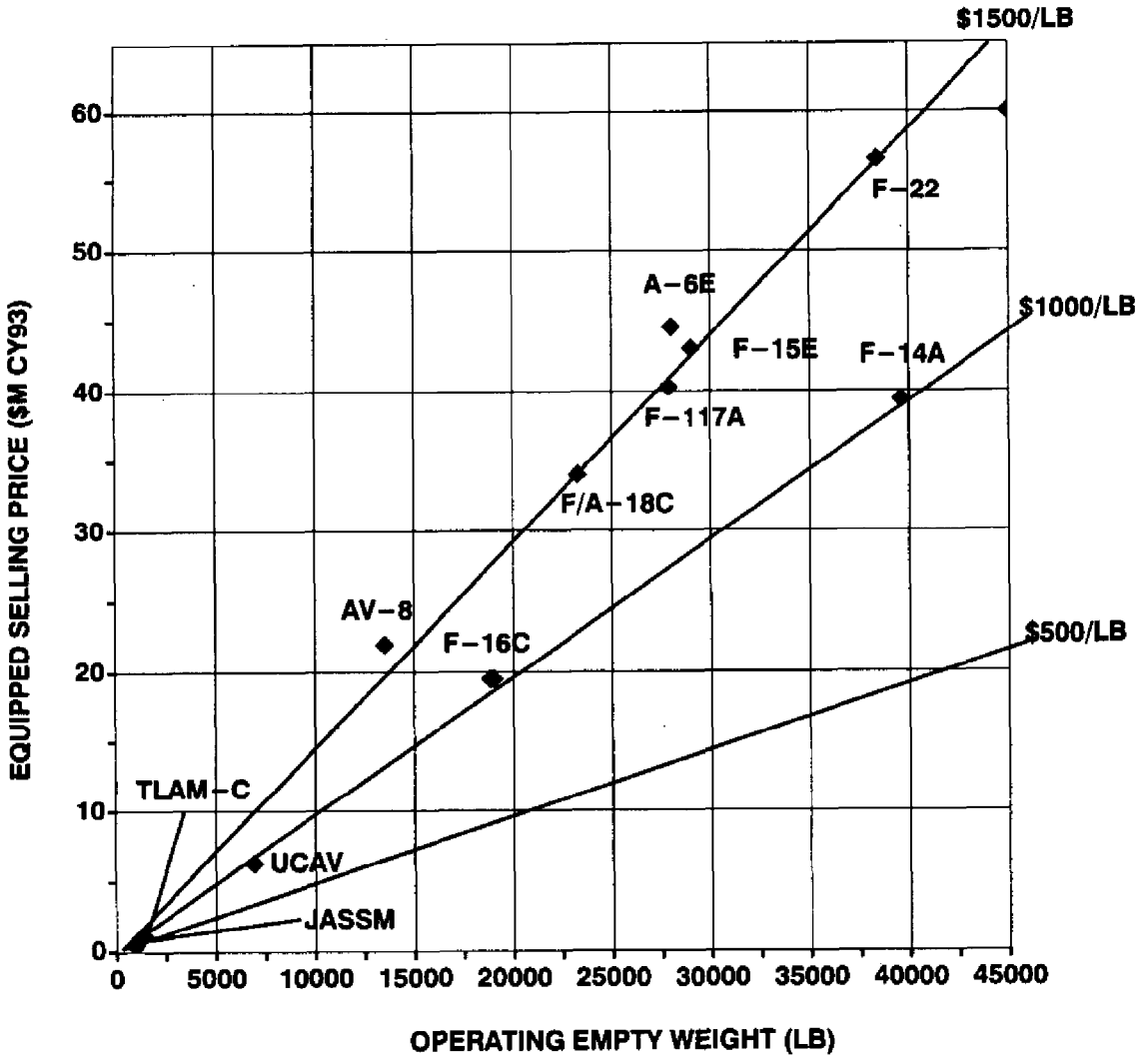

Figure 2 Cost trends for manned and unmanned systems

as much freedom as possible.

The Lockheed Skunk Works' practice is to tailor specifications to meet the unique requirements of a contract. The emphasis is on use of functional specifications defining "what" is to be achieved, and not "how" it is to be accomplished. Size and detail are minimized. Only critical performance parameters are specified as requirements. Peripheral standards and specifications are defined only as guidelines, to the greatest extent possible.

The model spec size in number of pages for Skunk Works aircraft is as follows:

Aircraft	Year of Spec	Spec Size (Pages)
U-2	1954	35
SR-71	1962	54
Have Blue	1975	25

F–117	1977	62
TR–1	1979	91
Tier 3–	1994	1
JASSM	1996	20

The original U–2, SR–71, Have Blue, F–117 and TR–1 model specs were all relatively small and highly tailored as compared to normal procurement programs. However, even within the Skunk Works, there has been a trend away from simple, brief specifications, particularly once a program transitions from specialized management to conventional management procedures. This is believed to be a bureaucratic phenomena and is not, and should not, be inevitable. The Tier 3– is a recent example of a Government trend to return to simple and brief specifications. The one page spec from DARPA on the Tier 3– simply specified best altitude, endurance and signature for a $10M ($94) unit cost for units 11 through 20. JASSM's 20 pages could have been condensed to something less than 5.

The F–117 program is a good example of the Skunk Works tailoring of specifications. The Air Force and Skunk Works focused on the key F–117 weapon system characteristics, and agreed to specifications and warrantees of three critical performance parameters — the radar cross section for all critical frequencies and aspect angles, the weapon delivery accuracy for guided and unguided weapons, and the aircraft mission radius. The F–117 met these specified requirements. The other, less critical performance parameters were defined only as "goals," rather than hard specified numbers.

The mission requirements should be absolutely what is needed and nothing more. Don't make the 3–Sigma, all possible eventualities a requirement without doing the trade study to understand both the cost and benefit. The mission requirements should be balanced so that one requirement doesn't drive the design. And, most important, they should be negotiable and changeable once the "cost" of each requirement becomes known.

The acquisition requirements should be streamlined and require minimum reviews, documentation and approval levels. The funding should be multi–year and cost–type. The contract should never be fixed price (every fixed price development contract awarded in the US during the early 80s has either been terminated or the contractor has lost money). The Skunk Works approach is a good example of tailored acquisition.

Tailoring the manufacturing specs means letting the manufacturing group specify the material and process specs, be a party to establishing tolerances and be able to adopt best commercial practices.

Manufacturing Friendly Design

Manufacturing friendly means that manufacturing personnel are influencing the design daily from the very beginning. The design adheres to the following time–proven guidelines for reducing manufacturing (fab and assembly) hours:

- KISS (Keep It Small and Simple)
- Minimum part count
- Minimum touch labor

- Minimum holes drilled (major source of rejected parts)
- RHS/LHS part interchangeability
- Self locating features on all parts
- Maximize room temperature processes

Keep It Simple is very important. Any complicated feature or new technology must "buy" its way onto the design. Both industry and government have been guilty in the past of inserting technology into a system solely for the sake of technology (making it more modern or state–of–the–art). This practice invariably drives the cost and risk up.

A good example of this is the use of composites. It is very difficult to beat the cost associated with a metal product because of our experience with metal and the associated learning curve. But yet, composites are very often used where there is not a compelling reason (such as reduced weight or increased stiffness). Most of industry would associate a learning curve of about 80 percent for aluminum fab and assembly and 88 percent for composite. This 8 percent difference in learning curve has a powerful leverage over a production run. For example, the cost of the 1000th unit in metal would be 0.11 of the cost of the first unit. For a composite structure with an 88 percent learning curve the cost of the 1000th unit would be 0.28 of the first unit.

Off–The–Shelf Equipment

Using off–the–shelf (OTS, either Mil–Spec or commercial) equipment is very important as it reduces the risk of concurrent development. The form/fit penalty of using OTS equipment needs to be carefully traded with the cost and risk of developing a new item which presumably gives better performance. The rule should be that a new piece of equipment, just like a new technology, must "buy" its way onto the design. This means that the performance gain is substantial or the requirement cannot be met without it. The equipment items that drive schedule and cost are: engines, landing gear, flight control computers and actuators. Avoiding concurrent development is a good rule to follow.

Design For Operation and Support

The operation and support (O&S) cost needs to be reduced by paying careful attention to the maintainance, support and training of the weapon system. Since peacetime training accounts for most of the Life Cycle Cost, the training strategy should receive extensive attention. As much training as possible should be conducted through synthetic environment or simulation and not by actually operating the weapon system. If this can be done, then the aircraft would be maintained in flyable storage resulting in significant savings in peacetime O&S.

Every effort should be made to reduce the manpower required for maintaining and supporting the weapon system. Design for maintainability means having adequate access panels and installing the equipment chest high and one deep. Unique tools need to be minimized. Consideration should be given to future modifications (engine, avionics, weapons, etc) and design accordingly with easy access, extra volume and growth power capability.

Prototypes and Technology Demonstrators

The merit of prototypes and technology demonstrators in terms of reducing the overall program cost has been the subject of heated discussions for decades. There are circumstances where prototypes and technology demonstrators have considerable value in terms of proving a concept or validating a critical system feature, such as maneuver performance or vehicle separation. Other circumstances such as validating production cost or weight, prototypes have little value unless they duplicate the production structural design, fab and assembly ... in which case they could hardly be called prototypes.

Concurrent Engineering or Integrated Product Development (IPD)

Concurrent engineering or IPD is a systematic approach to the integrated design of products and of their related processes, including manufacturing and support functions. The "manufacturing friendly" design discussed earlier demands the in–depth participation of manufacturing from the very beginning of the design process. The design process needs to be carried out through integrated work teams with the participation of all the involved functions. This means having everyone involved in the early design when the cost of a design change is small so that the design changes during EMD and production are few (when the cost of design change is large).

SUMMARY

In order to manage a weapon system's cost you must first establish cost as the #1 priority and then incite the program manager and give him the means necessary to hold to the cost. Establishing cost as #1 is a company edict and may require a cultural change. The program manager must be a zealot about cost because he will be pressured daily to relax cost in favor of more traditional metrics (ie; performance, cost effectiveness, signatuare, etc.). Kelly's 14 Rules gives the program manager the authority and environment necessary to control the cost.