Assembling and Supporting the Joint Strike Fighter in the UK

Issues and Costs

Cynthia R. Cook
Mark V. Arena
John C. Graser
Hans Pung
Jerry Sollinger
Obaid Younossi

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National Security Research Division

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PREFACE

In October 2002, the United Kingdom's Ministry of Defence (MOD) commissioned RAND to investigate certain issues relating to the procurement of the Joint Strike Fighter (JSF). The MOD plans to procure up to 150 of the short-takeoff/vertical landing (STOVL) variant of the JSF to meet its Future Joint Combat Aircraft (FJCA) requirement. This research was intended to inform the MOD about the overlap between JSF final assembly and repair, to assess the suitability of four UK aerospace companies as potential sites for JSF final assembly, to determine the costs of moving JSF final assembly to the UK, and to look at certain potential technology transfer–related implications of such a move.

This book should be of special interest not only to the Defence Procurement Agency and to other parts of the MOD but also to service and defence agency managers and policymakers on both sides of the Atlantic. It should also be of interest to aerospace companies in the United Kingdom. This research was undertaken for the FJCA Integrated Project Team jointly by RAND Europe and the International Security and Defense Policy Center of RAND's National Security Research Division (NSRD), which conducts research for the U.S. Department of Defense, allied foreign governments, the intelligence community, and foundations.

For more information on RAND's International Security and Defense Policy Center, contact the Director, Jim Dobbins. He can be reached by e-mail at James_Dobbins@rand.org; by phone at 703-413-1100, extension 5134; or by mail at RAND, 1200 South Hayes Street, Arling-

ton, Virginia, 22202-5050. More information about RAND is available at www.rand.org.

CONTENTS

FIGURES

TABLES

SUMMARY

BACKGROUND AND PURPOSE

The Ministry of Defence (MOD) of the United Kingdom (UK) has selected the short-takeoff/vertical landing (STOVL) variant of the U.S. Joint Strike Fighter (JSF) as the replacement for its Harrier aircraft. Current plans call for the UK to procure up to 150 aircraft at a potential cost of up to £10 billion (then-year £). The MOD also wants to develop a capability to maintain, repair, and upgrade its JSFs, which would require investments in facilities, equipment, and labour force. Because many of these capabilities apply to the final assembly and checkout (FACO) of the aircraft, the question arises about what such investments would imply for the cost-effectiveness of performing JSF FACO in the UK.

The UK MOD asked RAND Europe to address this question. Specifically, it asked RAND to accomplish the following:

- Assess synergies between a repair and FACO facility.
- Examine potential UK facilities for JSF FACO.
- Analyse the cost of a UK FACO facility.
- Consider issues regarding the export of technology.

RESULTS OF ANALYSIS

The results of our analyses are as follows.

Synergies Between Repair and FACO

FACO and maintenance, repair, and upgrade (MR&U) tasks overlap. Advantages and disadvantages of doing both activities differ, depending on whether the activities take place at the same location or are divided between two. The advantages of carrying out both activities in the same location include an easier transition from FACO to MR&U, a smaller engineering workforce, and a potential to adjust and level workload more easily. The FACO manufacturing space and tooling could also be used for MR&U, which could reduce total required investments. Additionally, technical support could be consolidated at one site. Disadvantages include the need to manage two processes rather than one and the possibility that the unpredictable nature of MR&U work might interfere with FACO activities.

Dividing FACO and MR&U could enable the MOD to open future repair work to competition, possibly leading to lower costs and higher efficiency. Two sites would broaden the aircraft industrial base and reduce the susceptibility of both processes to influence by such local issues as concerns about aircraft arrivals and departures.

Potential Facilities

The MOD suggested four sites as potential locations for FACO or MR&U. In alphabetical order, these are BAE SYSTEMS, the Defence Aviation Repair Agency (DARA), Marshall Aerospace, and Rolls-Royce. We conclude that three of the four sites could carry out either process, although their different existing facilities and capabilities mean that different levels of investment would be required at each site to enable JSF FACO. We eliminated Rolls-Royce as a candidate largely because the company's strategic focus on propulsion means that it does not have the facilities or past experience in airframe assembly, maintenance, or overhaul to host JSF FACO.

Cost[1]

What would it cost to establish a JSF FACO facility in the UK? To protect the business sensitivity of the cost data, we present our

[1]The cost figures are reported in FY 2003 £, undiscounted.

results as the incremental cost of assembling the JSF at a UK location compared with the same aircraft assembled at Lockheed Martin's Fort Worth, Texas, plant. In other words, 'How much more will it cost the UK?' (Note that the baseline costs for FACO of the UK aircraft in the United States are approximately £112 million [FY 2003].[2]) This difference is determined by comparing estimates of the FACO portion of the work done in Fort Worth and the UK, including how moving that work affects certain other costs (described below). We then report the average (arithmetic mean) result over all three UK sites.

There are three possible scenarios for establishing a JSF FACO facility in the UK:

- FACO Only—A FACO facility is established in the UK independent of an MR&U facility. This is also the case where there is negligible MR&U work for the JSF.
- Combined Facility—Both FACO and MR&U are done for the JSF in a combined facility. Initially, the facility produces the JSF and eventually makes the transition to an MR&U facility. Therefore, FACO investments could be reused for MR&U, reducing the cost of MR&U activities.
- FACO Added to an Existing JSF MR&U Facility—FACO activities are added to a planned and fully funded UK JSF MR&U facility. This approach assumes that common facilities, equipment, and tooling would be acquired earlier than needed for MR&U work; thus enabling FACO activities. This scenario is somewhat contrived because it reflects neither the actual sequence of decisions that would have to occur nor the way that the money would be spent. The FACO facility would have to be established *before* the maintenance depot.

The main difference between the last two scenarios is the baseline against which the incremental costs are calculated. The baseline for the second scenario does not include any UK work. The incremental costs for this include the total cost effects from putting a combined

[2]This value encompasses several assumptions, among which is a constant exchange rate of \$1.61 = £1, which is based on an annual average from the past 16 years, the period for which data were readily available in electronic form.

FACO and MR&U facility in the UK. The baseline for the third scenario incorporates the costs of an MR&U facility. The incremental costs for this include only the cost effects of moving FACO to an existing MR&U facility. The total cost to the UK for FACO and MR&U activities is the same in both cases.

To facilitate cost comparisons, we break them into four components: (1) the FACO costs themselves—the actual incremental cost of moving FACO from the United States;[3] (2) the effect on UK MR&U costs for the JSF if FACO work is performed at the same site; (3) the effect on other JSF component costs (i.e., the forward and aft fuselage, the wings, and the tail) caused by moving FACO away from Fort Worth and to a UK site, thereby reducing work at Fort Worth and increasing the overhead rate there; and (4) the effect of adding FACO to other (non-JSF) MOD work being done at a UK site, thereby affecting the overhead rate for the other programmes.[4] The total effect of the decision to move JSF FACO to the UK needs to incorporate all of these costs and not simply the cost of FACO activities. Table S.1 shows the incremental costs for each scenario.[5]

Table S.1

Incremental Cost of Moving JSF FACO to the UK (FY 2003 million £)

Cost Component	A FACO Only	B Combined Facility	C FACO Added to an Existing JSF MR&U Facility
FACO costs	34.7	35.6	35.6
MR&U	0.0	–10.0	–10.0
JSF components	1.4	1.4	1.4
Other MOD programmes	10.8	5.7	–14.1
Net Total Costs	46.8	32.7	12.9

[3]This includes the additional required facilities, tooling, and equipment; differences in labour and overhead rates; any royalty costs or licencing fees for technology transfer; costs of other support Lockheed Martin would provide; and a number of other cost components.

[4]These other programmes vary by location.

[5]The assumptions that led to these estimates are discussed in greater detail in the report, along with tests of the sensitivity of the results to changes in the assumptions.

Not surprisingly, Table S.1 shows that establishing a FACO-only facility has the greatest incremental costs. A combined facility reduces the incremental cost by nearly a quarter through savings in MR&U investments and a general reduction in overhead rates. The last scenario shows that the incremental investment to add FACO to an existing JSF MR&U facility is quite modest. (Total costs to the MOD are the same for B and C, but the MR&U investments for C are treated as 'sunk costs', providing the marginal cost for FACO.) Another caution is that the airframe MR&U concept for the JSF has not been fully defined. Therefore, true costs and the exact requirements for MR&U are unknown. The most conservative approach in estimating the possible costs to the MOD for a UK JSF FACO site would be to assume the FACO-only scenario (+£47 million).

Technology Transfer

For a UK site to carry out JSF FACO, certain technologies must be transferred from the United States to the United Kingdom. This process is complex and bureaucratic. When the transfer involves classified technologies, as the JSF does, the process becomes even more complicated and can take a long time. This issue becomes particularly important when the timelines of the JSF are taken into account. A FACO facility needs to be in place by the end of 2009, and we estimate that this will take two years to construct. No organisation would build such a facility without knowing that the transfer of the technology had been approved. Therefore, the transfer process must be completed by the latter part of 2007 at the latest. The process is complex, and the complexity makes the timing unpredictable. Thus, this issue merits immediate attention.

CONCLUSIONS

We conclude that FACO and airframe MR&U activities and investments overlap, so the potential for synergies is significant. Any of three UK facilities evaluated could carry out both processes with different required levels of additional investment and capability development. The mean incremental costs range from about £33 million for a combined, collocated facility to about £47 million if MR&U is not collocated or if no MR&U is required. If the UK MOD decides to create a domestic airframe MR&U facility for the JSF and fully factors these costs into its plans, the incremental cost to add FACO production is about £13 million. Technology transfer issues are complicated and require resolution before funds are spent to establish either FACO or MR&U facilities. These issues need to be resolved no later than 2007.

We finally note that military aircraft programmes have historically changed during system development and demonstration (SDD). Typically, aircraft design, weight, and procurement plans all change. Any such changes would affect the results of our analysis, which is based on data collected primarily just before SDD began.

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ACRONYMS

AECA	Arms Export Control Act
ASTOVL	Advanced short-takeoff and vertical landing
BUR	Bottom-Up Review
C4ISR	Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance
CAD/CAM	Computer-aided design/computer-aided manufacturing
CALF	Common Affordable Lightweight Fighter
CDP	Concept demonstration phase
CLS	Contractor logistics support
CMI	Classified military information
CTOL	Conventional takeoff and landing
CV	Carrier variant
CVF	Carrier version future
CVS	Carrier version strike
DARA	Defence Aviation Repair Agency
DARPA	Defense Advanced Research Projects Agency
DoD	Department of Defense
DTI	Department of Trade and Industry
DTSI	Defense Trade Security Initiative
ECA	Enhanced Capital Allowance
ECS	Environmental Control System

EO/IR	Electro-optical/infrared
FACO	Final assembly and checkout
FCBA	Future Carrier-Borne Aircraft
FCCM	Facilities Capital Cost of Money
FJCA	Future Joint Combat Aircraft
FMS	Foreign military sales
FTE	Full-time equivalent
G&A	General and administrative
GAO	General Accounting Office
GPA	Global Project Authorization
GSA	General Security of Military Agreements
ICS	Interim contractor support
IPT	Integrated project team
ITAR	International Traffic in Arms Regulations
ITL	Incomplete task log
JAST	Joint Advanced Strike Technology
JCA	Joint Combat Aircraft
JSF	Joint Strike Fighter
LO	Low observable
LOA	Letter of offer and acceptance
MLA	Manufacturing Licence Agreement
MOD	Ministry of Defence
MOU	Memorandum of understanding
MR&U	Maintenance, repair, and upgrade
MRF	Multirole fighter
NDP	National Disclosure Policy
NDPC	National Disclosure Policy Committee
NSDM	National Security Decision Memorandum
OBIGGS	On-Board Inert Gas–Generating System
OBOGS	On-Board Oxygen-Generating System

ODTC	Office of Defense Trade Controls
OEM	Original equipment manufacturer
ORD	Operational requirements document
PAA	Primary aircraft authorisation
QMAC	Questionnaire on Methods of Allocation of Costs
R&R	Remove and replace
RAF	Royal Air Force
RAM	Radar-absorbing material
RAS	Radar-absorbing structure
RCS	Radar cross section
RF	Radio frequency
RN	Royal Navy
SBAC	Society of British Aerospace Companies
SCP	Security cooperation participation
SDD	System development and demonstration
STOVL	Short-takeoff/vertical landing
TAA	Technical assistance agreements
TAI	Total active inventory
URF	Unit recurring flyaway (cost)
USAF	U.S. Air Force
USMC	U.S. Marine Corps
USML	U.S. Munitions List
VAT	Value-added tax
VOC	Volatile organic compound
WBS	Work breakdown structure

Chapter One

INTRODUCTION

HISTORY OF THE JOINT COMBAT AIRCRAFT REQUIREMENT[1]

In 1996, the United Kingdom began the formal procurement process to examine options for a Future Carrier-Borne Aircraft (FCBA) to succeed the Royal Navy's Sea Harrier in 2012. The 1998 Strategic Defence Review White Paper confirmed that the Royal Navy (RN) and Royal Air Force (RAF) Harrier forces would be combined into a new Joint Force 2000. After this, the FCBA requirement was widened to include replacement of the RAF's GR.9 and T10 ground-attack Harriers around 2015, thus providing the UK with a joint land- and sea-based expeditionary air-power capability. To reflect this change, the programme was renamed Future Joint Combat Aircraft (FJCA) in 2001. FJCA is to replace current Joint Force Harriers with a multirole fighter-attack aircraft, on approximately a one-for-one basis.

The U.S. Joint Strike Fighter (JSF) has been identified as having the best potential to meet the requirement, resulting in the signing in January 2001 of a memorandum of understanding (MOU) that called for the UK to enter the system development and demonstration (SDD) phase of the JSF programme as a Level I partner (see below for definition). The UK has committed some £1.4 billion to the JSF programme. This occurred after successful UK participation in the con-

[1]History from http://www.mod.uk/dpa/projects/jca.htm.

cept demonstration phase (CDP[2]) of the JSF programme, which involved development and test flights of the Boeing X-32 and the Lockheed Martin X-35. This flight test programme supported the JSF source-selection process, which included an extensive assessment of the ability of each contractor to develop and deploy a family of advanced strike aircraft to meet the requirements of the U.S. Air Force, Navy, and Marine Corps and the UK Ministry of Defence (MOD) FJCA programme. Following the conclusion of this source-selection process, it was announced in October 2001 that Lockheed Martin had been selected as prime contractor to take the programme forward. The UK participated in the source-selection process.

On September 30, 2002, the UK announced that the short-take-off/vertical landing (STOVL) variant of JSF had been selected to meet its requirements, in preference to the carrier variant (CV). The total procurement cost to the UK may be as high as £10 billion.[3]

HISTORY OF THE JOINT STRIKE FIGHTER

The JSF emerged from technology and aircraft development efforts in the early 1990s as a joint aircraft designed to meet the long-term air-to-ground needs of the three U.S. services that operate strike aircraft. It originated from several previous aircraft programmes. In 1983, the Defense Advanced Research Projects Agency (DARPA) began a project examining an advanced short-takeoff and vertical landing (ASTOVL) capability. This was established as a joint U.S.-UK programme in 1986, when the two countries signed an MOU. (A second MOU was signed in 1994 after the 1986 MOU had expired.) In 1991, the U.S. Navy began planning efforts for the two-engine, technologically complex Advanced Attack/Advanced Attack Fighter (A-X or A/F-X) meant to replace the A-6, in lieu of the cancelled A-12 programme. Also in 1991, the U.S. Air Force (USAF) multirole fighter (MRF) was conceived as a relatively inexpensive single-engine replacement for the F-16.

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[2]In this report, we follow U.S. Department of Defense (DoD) acquisition terminology for 'CDP', using it to refer to the JSF programme phase leading up to source selection. In the UK, 'CDP' is the Chief of Defence Procurement.

[3]http://www.mod.uk/dpa/projects/jca.htm.

In 1993, the U.S. Department of Defense (DoD) initiated a Bottom-Up Review (BUR) of DoD forces and modernisation plans. Recommendations for aviation included the cancellation of the A-X and MRF programmes, curtailment of the F-16 and F/A-18C/D programmes, and the beginning of the Joint Advanced Strike Technology (JAST) programme.[4] JAST goals included the development of a joint aircraft with advanced technologies but with reduced life cycle costs. Within the next year, more work was consolidated into the effort; including the DARPA Common Affordable Lightweight Fighter (CALF) programme.[5]

The aircraft derived from JAST programme technology, as a next-generation multimission aircraft, was planned to replace and augment a number of other aircraft for different services. For the United States it was planned to replace USAF F-16s and A-10s and complement the F-22; augment carrier-based U.S. Navy (USN) F/A-18E/Fs, and replace U.S. Marine Corps (USMC) AV-8Bs and F/A-18C/Ds. It was also planned to replace RAF and RN Harrier aircraft.

In December 1994, four companies—Boeing, Lockheed Martin, McDonnell Douglas, and Northrop Grumman—were awarded 15-month concept definition and design research contracts. Northrop Grumman, McDonnell Douglas, and British Aerospace then agreed to form a team. After various programme reviews, Boeing and Lockheed Martin won concept demonstration phase prime contracts in November 1996. Boeing then merged with McDonnell Douglas, while Lockheed Martin began working with Northrop Grumman and British Aerospace (later, BAE SYSTEMS). By this time, the programme had been renamed the JSF.

After five years of the CDP, on October 26, 2001, DoD awarded the SDD contract of almost $19 billion to the Lockheed Martin team as the final step in the winner-take-all competition.[6]

When completed, the JSF programme will be one of the largest aircraft acquisition programmes in U.S. history, worth some $300 bil-

[4] www.jsf.mil.

[5] www.jsf.mil.

[6] A description of the announcement can be found at http://www.defenselink.mil/news/Oct2001/b10262001_bt543-01.html.

lion (then-year dollars) over the next quarter-century. The aircraft will be produced in three configurations—a conventional takeoff and landing (CTOL) variant, a STOVL variant, and a CV.

The original acquisition plans called for the USAF to buy 1,763 CTOL aircraft. The USN was to buy 480 of the CV aircraft, and the USMC was to buy 609 STOVL aircraft. (More recently, the combined USN and USMC buy was reduced by 409 aircraft,[7] although this information became available too late to be included in the cost analysis described in this report.) To meet its FJCA requirement for the RN and RAF, the UK MOD will procure up to 150 STOVL variant JSF aircraft. It is estimated that other nations could purchase an additional 3,000 aircraft. Indeed, a number of countries have already committed to participating in the programme.

JSF IS AN INTERNATIONAL COLLABORATION

As a 'collaborative development partner', the UK has been given more insight into the programme than is typical in a foreign military sales (FMS) agreement and in fact has input into the air system, particularly the STOVL variant design. The UK Operational Concept, part of the JSF operational requirements document (ORD) of March 2000, lays out a vision for commonality with the following statement:[8]

> The principal missions of the UK will be day and night adverse weather, anti-air attack and reconnaissance operations from Main Operating Bases (MOB), other airfields, austere bases, Carrier Version Strike (CVS) and Carrier Version Future (CVF) carriers. Sorties will be preplanned or alert status and comprise pair package formations. Warlike operations will not be normally conducted as singletons and may range from self-escort autonomous operations to those requiring detailed integration and data linking to other C4I entities including air and surface units. Through air-to-air refueling (probe and drogue) and/or the carriage of external drop tanks, future air commanders will be provided with operational flexibility.

[7] http://www.defenselink.mil/news/Apr2003/b04122003_bt232-03.html.

[8] JSF ORD signed in March of 2000.

> Through commonality with USMC, the UK seeks to maximize the potential for combined operations.

One goal of the JSF programme is to create a new model for international collaboration that provides specific entry and exit criteria for the programme's non-U.S. participants. This model allows individual countries enough insight into the programme to decide whether the JSF is the right platform for their national security needs. They are also allowed to use JSF modelling and simulation technologies to validate their requirements.

The degree of involvement of each country is determined by the level of their investment in the programme. There is a formal structure that includes four possible levels of partnership:[9]

Level I Partners (collaborative development partners) have significant access to most aspects of the programme as well as the ability to influence requirements and the design solutions. The UK is the only nation in this category. The total UK funding contribution makes up about 10 percent of the SDD budget. The UK has 10 staff members fully integrated in the programme office. The development nonrecurring recoupment charges are waived for the UK, and they will receive a share of the levies on sales to third parties. (The purpose of these levies is a partial distribution of the development costs to those nations who did not contribute towards the cost of JSF SDD.)

Level II Partners (associate partners) have limited access to the core programme and technologies. Italy and the Netherlands are in this category. Their funding contribution is about 5 percent of the SDD budget each. They will receive a proportional share of levies on sales to third parties. These partners are allowed to have three to five staff members integrated into the programme office.

Level III Partners (informed partners) are provided enough information to evaluate the utility of the JSF family for their specific needs. Australia, Canada, Denmark, Norway, and Turkey fall in this category. Their funding contribution ranges from 1 to 2 percent of the SDD phase. They will receive a proportional share of levies on sales to third parties. The office representation is limited to one

[9]Information largely based on the JSF website at www.jsf.mil.

national deputy. Level III partnership opportunities officially closed on July 15, 2002.

Security Cooperation Participation (SCP) will be based on a letter of offer and acceptance (LOA) with individual countries. This involvement will be valued at approximately $50 million of tasks for each participating country. The JSF programme will provide individual countries enough information to evaluate the JSF family of aircraft as potential FMS purchases to meet their security needs. Singapore and Israel are in this category.

A summary of international participation is shown in Table 1.1.

Table 1.1

JSF International Participation

International Participant	Level of Partnership	Type of Agreement	Date of Agreement	Investment
United Kingdom[a]	I	MOU	January 2002	$2.06 billion
Italy[b]	II	MOU	June 2002	$1.03 billion
Netherlands[c]	II	MOU	June 2002	$800 million
Turkey[d]	III	MOU	July 2002	$175 million
Canada[e]	III	MOU	February 2002	$150 million
Australia[f]	III	MOU	October 2002	$150 million
Denmark[g]	III	MOU	May 2002	$250 million[h]
Norway[i]	III	MOU	June 2002	
Singapore[j]	SCP	FMS/LOA	February 2003	~$50 million
Israel[k]	SCP	FMS/LOA	February 2003	'tens of millions'

[a]http://www.jsf.mil/.

[b]http://www.ugsitalia.it/pdf/casi/3_07.pdf.

[c]http://www.defenselink.mil/news/Jun2002/t06172002_t0617jsf.html.

[d]http://www.janes.com/defence/air_forces/news_briefs/jdw020718_02.shtml.

[e]Joint Strike Fighter Canada, Current Project Status available at http://www.alberta-canada.com/avaero/pdf/jsfcanadaoct2002.pdf.

[f]http://www.defense-aerospace.com/data/communiques/archives/2002Jun/data/2002Jun10913/.

[g]http://www.asdnet.org/news/view.asp?content_id=245.

[h]Contribution reflects both the Denmark and Norway investment.

[i]http://www.janes.com/regional_news/europe/news/jdw/jdw020628_2_n.shtml.

[j]http://www.aerotechnews.com/starc/2002/082302/singapor_jsf.html; Lemke, 2003, p. C17.

[k]http://www.jsf.mil; Zacharia and Gutman, 2003.

For the JSF programme, international participation does not automatically bring with it the traditional offset agreements, in which the prime contractor agrees to put work for the aircraft into that country (perhaps by buying components there).[10] One of the features of the JSF programme has been that industrial participation during the production phase is invited on a best-value basis, rather than on a traditional offset basis in which some workshares are formally allocated to participating countries. Each company that receives a subcontract must be competitive on quality and cost to be selected in this best-value approach. Countries do not have the ability to require that local companies become part of the programme as a basis for their participation. However, officially, one of the benefits of international participation is that it will provide a 'conduit for foreign industry to engage U.S. industry in the formation of future partnerships'.[11]

First-, second-, and third-tier contractors[12] in the UK have won a substantial portion of the JSF business. For example, as a principal subcontractor to Lockheed Martin, BAE SYSTEMS will be responsible for producing the rear fuselage and the tail of the aircraft. Rolls-Royce is responsible for the lift system, with the lift fan and roll posts being produced in the UK. A number of other UK companies are contributing a variety of systems and components. Martin-Baker will produce the ejection seat. Estimates of UK jobs created during the SDD phase are at about 3,500, with as many as 8,500 during the production phase (Fletcher, 2002).

BRITISH ASPIRATION TO REPAIR UK AIRCRAFT

As a partner in the JSF programme from the early days of JAST and with the predecessor DARPA ASTOVL programme, the UK MOD has been closely linked with the U.S. DoD in many areas, including the development of the ORD. The framework for this relationship is laid

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[10]Offset agreements sometimes involve the investment into or purchase of unrelated items.

[11]www.jsf.mil.

[12]The tiers refer to where the contractors are in the supply chain. First-tier contractors sell directly to Lockheed Martin. Second-tier contractors sell to the first tier, and so forth.

out in the JSF Engineering and Manufacturing Development Framework MOU.[13] This compilation of agreements, letters, and supporting language includes many details of the U.S.-UK relationship.

The key aspect is the 'exchange of letters' between Geoffrey Hoon, UK Secretary of State for Defence, and William Cohen, U.S. Secretary of Defense. In Hoon's letter, dated January 15, 2001, he lays out a number of issues, including the aspiration for 'a UK-based logistics support infrastructure to safeguard national capability'. His letter goes on to say, 'In addition, the UK MOD envisages an appropriate role for UK industry on merit within the JSF global support system, should this emerge as the most cost-effective option.' Further words describe the issue of the sharing of technical information to meet UK national needs. In his response, U.S. Secretary of Defense Cohen acknowledges receipt of the letter and 'confirms that the understandings set out in your letter are acceptable to the U.S.' This could be understood to lay the groundwork for the development of a UK support capability above and beyond the usual organisational-level support conducted at operating bases. It is too early to tell what this might involve, as the JSF support concept is not developed, but such a domestic capability would presumably include everything up to depot-level repair, with the caveat that some equipment would be 'remove and replace', with the broken items returned to the original manufacturer for repair. The capability could include regular depaint and recoating, repair of battle-damaged aircraft, planned modifications or upgrades for the fleet, and implementation of emergency action technical changes, in which all the aircraft must be repaired or modified quickly. (This broad collection of activities all comes under the rubric of maintenance, repair, and upgrade [MR&U].) The conceptualisation of the necessary production and support MOU that would be required for UK MR&U is just beginning.

If the UK were to develop an organic, full-fledged support capability, this would require some investment in facilities, equipment, and work skills. A reasonable question that follows is how the develop-

[13] The full title of this document is the 'Memorandum of Understanding Between the Secretary of Defense on Behalf of the Department of Defense of the United States of America and the Secretary of State for Defence of the United Kingdom of Great Britain and Northern Ireland Concerning the Cooperative Framework for Engineering and Manufacturing Development of the Joint Strike Fighter.'

ment of an MR&U capability would impact other decisions. For example, could the MR&U investments be somehow leveraged and used for other work, such as JSF final assembly and checkout (FACO)? (The investments would be first used for FACO and later for MR&U.) As the name of the FACO process implies, workers during 'final assembly and checkout' assemble major components and check out the aircraft system performance. The process, which Lockheed Martin calls mate-through-delivery and is also commonly referred to simply as final assembly in the UK, includes four major activities: structural mate, tail installation and systems mate, final assembly, and systems checkout and tests. Overlap occurs between some MR&U and FACO activities, particularly if the aircraft must be taken apart for the repair and then reassembled. Given the aspiration for the most cost-effective investment in repair and FACO, a natural question is what additional investments would be required to initiate a full-up FACO line.

PURPOSE OF THE STUDY

The UK MOD asked RAND Europe to examine certain issues relating to the potential establishment of a UK FACO line. Tasks include determining the potential synergies between such a facility and one for airframe repair and maintenance,[14] the different UK facilities that might be appropriate for JSF FACO, the costs of doing this work under different scenarios, and assessing the effect of technology export issues.

Assess Synergies Between a Repair and FACO Facility

As described above, the UK-U.S. exchange of letters implies an aspiration for a UK JSF repair facility to meet the UK's operational needs. The hope would be to perform most airframe maintenance and repair in the UK, rather than sending aircraft back to the United States or elsewhere outside the UK. (Such a facility could conceivably also provide depot-level repair services to other European pur-

[14]Repair of the other two major parts of the aircraft—i.e., avionics components and engine repair/overhaul—is a separate issue from repair and maintenance of the airframe. See complete discussion in Chapter Two.

chasers of the JSF and to U.S. JSF aircraft situated in Europe.) RAND Europe addressed some questions that came out of this aspiration. What activities are common between repair and FACO for the JSF? Would a complete FACO line require additional investment beyond that required for MR&U? How would servicing and assembling a mix of JSF variants affect the required investment?

Examine Potential UK Facilities for JSF FACO

RAND Europe surveyed UK private and government-owned facilities to assess their capabilities for FACO. The four sites studied were suggested by the MOD and include BAE SYSTEMS, DARA, Marshall Aerospace, and Rolls-Royce. Each company has a unique collection of experience and facilities. They have different levels of tooling, equipment, and infrastructure. The sites have different combinations of specific expertise and experience, including a skilled worker base with FACO capabilities, a history of aircraft programme management or integration, and knowledge of commercial practices. We do not make a recommendation to select one or the other, except to say that Rolls-Royce is not a likely candidate for airframe depot or FACO work because its core competencies lie in the propulsion area. However, we do describe some of the relative strengths of the three other organisations as sites for FACO and/or MR&U.

Cost Analysis of a UK FACO Facility

RAND Europe evaluated the costs of performing FACO in the UK. This cost analysis included the facilities investments and the differential costs of moving the work away from Fort Worth, where the UK aircraft would benefit from 'learning' improvements from aircraft built for the United States. Different learning assumptions were made to test the sensitivity of the results to them. In the analysis, we identified and assessed all the costs that would change when moving FACO to the UK, which include higher costs of shipping U.S.-made components to the UK, lower costs of shipping UK-made parts to a UK FACO site, and lower costs of delivering the aircraft (including fuel and tanker aircraft support) to the UK from a facility within its borders. RAND Europe developed and assessed several different scenarios regarding total numbers and production rates of aircraft produced at the UK FACO facility. Scenarios included a range of quantities from the baseline of 150 up to 1,150 aircraft, with a mixture of STOVL and CTOL aircraft.

Questions Regarding the Export of Technology

The JSF is an advanced tactical aircraft and as such incorporates many technologies whose exports are controlled. RAND Europe investigated issues regarding technology transfer and developed a timeline to provide insight into the dates when certain technology-transfer questions must be resolved to create a FACO line in time to produce the first UK units.

Methodology

This research has been a relatively compressed effort, beginning with questionnaire development at the end of October 2002, site visits in January 2003, and initial results presented in March 2003. RAND developed a model to estimate costs of performing FACO in the UK under a variety of scenarios. We collected data during site visits and plant tours at Rolls-Royce, DARA, BAE SYSTEMS, and Marshall Aerospace. Lockheed Martin allowed us to reuse data collected for an earlier study on U.S. JSF FACO alternatives (Cook et al., 2002) and provided some new data in support of this study. We interviewed a number of officials in the U.S. government, at the JSF programme office and elsewhere in DoD. We interviewed the FJCA Integrated Project Team (IPT) and other employees of the MOD. We talked to the UK Department of Trade and Industry (DTI) and the Society of British Aerospace Companies (SBAC) to gain a broader perspective on the UK aerospace industry.

HOW THIS REPORT IS ORGANISED

This report is organised into seven substantive chapters. Following this introduction, Chapter Two describes the FACO and the MR&U processes and how they overlap. Chapter Three contains information on the alternative UK sites we assessed as possible locations for FACO and MR&U. Chapter Four introduces the model used to assess the costs of performing FACO in the UK and describes the different cost inputs. In Chapter Five, we describe the cost results and the sensitivity analyses. In Chapter Six, we describe some of the challenges in putting FACO in the UK, which relate to questions of technology transfer. Finally, conclusions and a discussion of policy implications are presented in Chapter Seven.

The report also has two appendices. Appendix A includes the questionnaire used to assess the sites. In Appendix B, we discuss the issue of production gaps and restarts and their potential effect on cost.

Chapter Two

AIRFRAME FACO AND AIRFRAME MR&U

This chapter begins by providing background on the FACO and aircraft maintenance processes as well as depot costs associated with several U.S. aircraft. It then describes the three MR&U scenarios we designed to bound the range of work that might reasonably be expected at a UK depot-level facility. It then compares FACO work with that included in airframe depot-level MR&U. The chapter concludes with a description of the overlap in tools, facilities, and workforce that occurs between FACO and MR&U processes.

BACKGROUND ON FACO PROCESSES[1]

The original plan for FACO developed during CDP called for a simple FACO process. The CDP JSF design incorporates very few attachment points compared with older aircraft. The airframe mate of the 'fully stuffed'[2] major subassemblies was to be accomplished through a numerically controlled laser alignment system. Plans were to join electrical and hydraulic systems using adapter plates. Given these technologies, which facilitate the assembly process and reduce the need for complex assembly tools, jigs, and fixtures, Lockheed Martin's total expected time for mate through delivery was 40.8 work-

[1]This section draws heavily on the previous RAND report on JSF alternative FACO locations (Cook et al., 2002, pp. 5–10). The FACO process described here was the one current when the JSF contract award was made in October 2001. Historically, such process and design evolution has commonly occurred during SDD of major systems, and it has in this case as well.

[2]This refers to subassemblies arriving at the final assembly line with most or all interior components already installed.

days. It should be noted that this describes the JSF FACO process as developed during CDP. Lockheed Martin has indicated that this "quick-mate" design has been abandoned during the subsequent evolution of the SDD configuration (insufficient data were available to incorporate SDD modifications into this analysis)..

As the name of the process implies, FACO involves workers assembling major components and 'checking out' the aircraft system performance. The process, which Lockheed Martin also calls 'mate through delivery' and is known in the UK as simply 'final assembly', includes four major activities: structural mate, tail installation and systems mate, final assembly, and systems checkout and tests. Figure 2.1 shows the assembly process.

Structural mate joins the four primary aircraft components (the three portions of the fuselage—aft, centre, and forward—to the wing) and installs the main landing gear. First, the wing is attached to the cen-

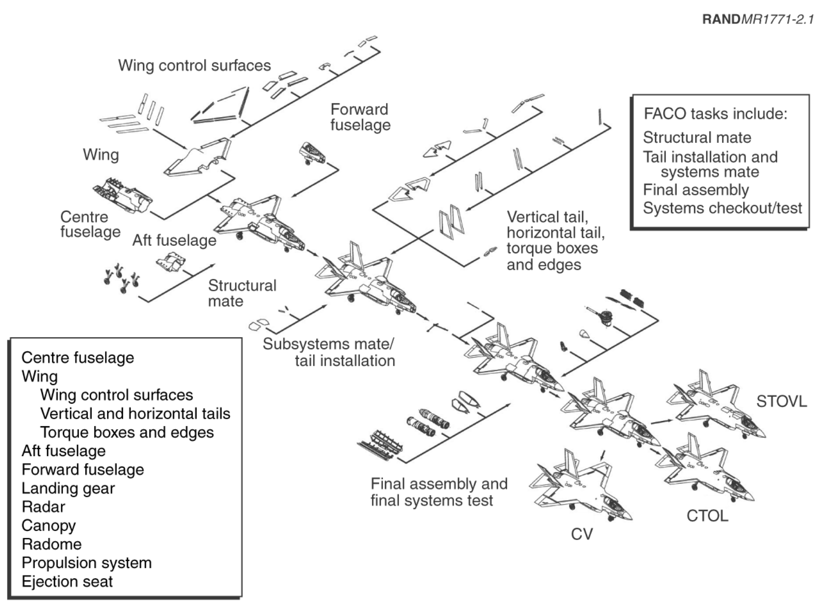

Figure 2.1—Final Assembly and Checkout

tre fuselage, then the aft fuselage to the centre fuselage, and finally the forward fuselage to the centre fuselage. These components already contain most of the electronics and hydraulic subsystems. Edges may or may not be installed on the wing before final assembly. During tail installation/subsystems mate, the remaining systems are installed, and the vertical tails and horizontal stabilisers and main landing gear access doors are also installed. The electrical, hydraulic, and fuel systems are connected across the mate joints. Necessary checks are made to ensure proper function and connections. Other miscellaneous systems and structural parts are also installed.

Final assembly and final systems test involves installation and test of the ejection seat, canopy, propulsion system, engine bay doors, weapons bay doors, radome, high-dollar components,[3] and gun (CTOL variant only). All systems are to be checked out using either built-in-test or special test equipment. Final assembly and testing are complete at this point.

Final finish and low-observable verification work during FACO are not extensive because most of the paint and special coatings are applied at the subassembly/module level. Remaining areas of the aircraft will be robotically coated. To verify the low-observable characteristics of the JSF, the aircraft will be mounted on a turntable and its signature will be tested. In the fuel barn, the aircraft is fuelled for the first time, any leaks are identified and repaired, and the fuel system is calibrated.

Finally, field operations include testing of certain components and performing a number of operations, including

- fuel/wet system test indicators,
- engine feed checkout,
- fuselage transfer tank,
- fuel/wet systems test transfer,
- fuel level sense,

[3]Lockheed Martin plans to install certain expensive components, such as the lift fan, engine, and radar, during final assembly operations to save a few weeks of inventory costs on those items.

- remote input/outputs—fuel, hydraulics,
- fuel/ground refuel receptacle operation,
- fuel/aerial refuel receptacle fuel functioning,
- OBIGGS (On-Board Inert Gas–Generating System) testing,
- escape system checkout,
- survival kit/seawars system checkout,
- green engine run (auxiliary power unit, environmental control systems, engine),
- engine starter/general checkout,
- bleed air/emergency power mode, integrated power package checkout,
- Environmental Control System (ECS) ground test,
- cabin pressure checkout,
- On-Board Oxygen-Generating System (OBOGS) checkout,
- green engine run (preflight and mechanical),
- Crash-Survivable Functional Data Recorder download/clear,
- Prognostic Health Management checkout,
- flight readiness checkout,
- company functional check flights numbers 1 and 2, and
- delivery to the customer.

The total direct labour hours required for these tasks are divided into the categories of fuselage structural mate, subsystems mate, final assembly/test, flight operations, manloads/incomplete task logs (ITLs),[4] and final finishes. Total support labour required for FACO is divided into the categories of manufacturing engineering, tool engineering, tool manufacturing, quality control, engineering, and mate-

[4]This category refers to the labour that must be done to delivered subassemblies to ready them for FACO.

rial inventory. (Note that these categories are specific to Lockheed Martin.)

The JSF will be the first fighter programme that attempts to satisfy the needs of three different U.S. services, the UK RN and RAF, and many different other customers using three highly common variants of a single design. The programme goal has been that each variant would have high commonality with the other two variants, on the order of 70–90 percent. In theory, such commonality should make the JSF more affordable during production and throughout the service life of the aircraft. Because FACO activities for each variant of the JSF are highly common, it is reasonable to build the multiple variants on a single production line. Lockheed Martin has indicated that this is its manufacturing plan. Similarly, if a FACO line were established in the UK, building variants other than the STOVL on the same line should also be possible.

Some variants require unique activities. The CTOL and the STOVL are the more highly common, but the STOVL FACO has some additional activities during the FACO stage, primarily in the installation of the lift system. The U.S. CTOL has a gun, which the other variants lack. The CV is the least common with the other variants. Much of its uniqueness is incorporated before FACO—at the fabrication and assembly stage—as the structures of the aircraft are strengthened for carrier takeoffs and landings. At the FACO level, the CV has some stronger structures, such as landing gear (although the process for installing them should be similar or the same as the process for installing CTOL and STOVL gear), and a different, larger wing with a wing fold.

The JSF plan took advantage of recent advances in aircraft design tools and concepts, which were supposed to improve the quality and shorten the cycle time for the required FACO processes. These included advances in tooling concepts and improvements in computer-aided design/computer-aided manufacturing (CAD/CAM) including three-dimensional solids modelling tools. As mentioned, Lockheed Martin's total expected time for mate through delivery was 40.8 workdays. The time can be broken out as shown in Table 2.1. By way of comparison, Lockheed Martin's planned FACO cycle time for the 257th JSF aircraft was expected to be half that of the F-16, an aircraft that is much less complex than the JSF.

Table 2.1

Cycle Time Required for FACO Activities

Activity	Days to Complete
Structural mate	2.4
Subsystems mate and tail installation	4.8
Final assembly and systems test	12.0
Final finishes	10.8
Field operations	10.8
Total workdays	40.8

FACO activities make up a relatively small portion of the total aircraft cost. Lockheed Martin estimated that the JSF FACO cost (as of the October 2001 design) should be about 2 percent of unit recurring flyaway[5] (URF) cost. Other airframe work totalled 35 percent of costs, propulsion 19 percent, and other nonairframe items totalled 44 percent of URF costs.

The 2 percent figure is a lower FACO percentage than other recent programmes have experienced. Historically, FACO has been a larger portion of the total manufacturing effort because most of the electronics and subsystems were integrated into the airframe during this stage. Also, old design and manufacturing approaches led to part and subassembly variability problems. Often these problems were discovered during final assembly and resulted in considerable rework. Thus, historically, the FACO percentage of the total manufacturing cost has been higher than is projected for the JSF.

The FACO portion for the F-22 has been estimated to be some 3.3 percent (not including engines and some support). Reports indicate that the F/A-18E/F's FACO percentage is higher still. The original F-22 production plan was to have all major assemblies arrive 'fully stuffed' with all the components, subassemblies, avionics, and so forth, rather than to have them installed during FACO. According to interviews with DoD personnel, some difficulties occurred during the

[5]Definition used by the JSF programme office includes all recurring airframe, propulsion, avionics/mission systems, and armament costs, as well as Engineering Change Order costs.

initial production, with more work than expected taking place during FACO. There have been attempts to resolve these difficulties.

The JSF CDP design was predicated on use of the quick-mate process, wherein fully stuffed components are assembled using a minimum of attachment points, as described above. However, based on input from Lockheed Martin, this process has been abandoned during the refinement of the SDD design. The net effect of this will probably be an increase in work content – and schedule and costs – to the final assembly stage. (The relevant data were not available to incorporate into our analysis.)

In our analysis of the UK FACO options, we assume that the FACO process at a UK location would be the same as that carried out at Fort Worth, with the same work instructions, tooling, and subassemblies delivered to the UK location. We also assume that engineers and others from the two sites will share their experience and learn from each other. Differences in transportation costs, annual production quantities, and other key factors have been incorporated into the RAND cost model and are discussed in the cost chapter.

BACKGROUND ON AIRCRAFT MAINTENANCE

Like most sophisticated machines, modern fighter aircraft must receive regular servicing to sustain proper levels of performance, availability for operational use, safety, and forecast useful life. To accomplish this, the military services have established procedures used by large maintenance and supply organisations to ensure that their aircraft are combat ready. The UK military services organise the personnel and maintenance activities into three different 'levels' and four different categories of effort, namely Organisational, Intermediate, Government Depot Maintenance, and Contractor Depot Maintenance.[6]

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[6]U.S. maintenance is similarly organised, although generally contractor and government depot maintenance activities are not distinguished from each other in the categorisation.

Organisational Level

'O-level' maintenance is normally performed by personnel of the unit to which the aircraft are assigned, normally a squadron. Their activities are performed on or in close proximity to the aircraft themselves and are often called 'on-equipment' maintenance. Typical O-level activities would include the following:

- Preflight inspections and servicing with fuel, oil, lubricants, oxygen, munitions, and ammunition.
- Launch and weapons arming.
- Postflight recovery and weapons dearming.
- Servicing with fuel, oil, lubricants, oxygen, etc.
- Postflight inspections.
- Periodic inspections (required by either flying hours accumulated or the passage of time).
- Testing and troubleshooting of discrepancies discovered by the aircrew during flight or by maintenance personnel.
- Removal and replacement of defective reparable or consumable items to correct discrepancies.
- Corrosion prevention inspections and repair.
- Aircraft washing.[7]
- Aircraft painting or appliqué removal and replacement.[8]

Intermediate Level

The concept behind an I-level repair facility is to move component repair work away from the operational unit to keep the 'footprint'

[7]In a previous RAND study (Raman et al., 2003), it was estimated that 20 percent of the O-level activities on U.S. fighters were related to washing, corrosion inspection, and painting. The remaining 80 percent of the activity related to repair.

[8]The JSF programme is investigating the use of appliqués, thin sheets of materials applied to aircraft surfaces in lieu of or complementary to painting the external surfaces. This technology has not yet been proven operationally.

(space and equipment required for a unit) as small as possible. 'I-level' is often referred to as 'off-equipment' maintenance. Activities at this level take place outside the basic squadron area but may be collocated on the same air base or on the same aircraft carrier as the O-level maintenance. In other cases, these activities can take place at a regional repair site that might support several bases. Intermediate maintenance activities include calibration, repair, and replacement of parts, components, or assemblies and technical assistance to O-level units. Centralising component repair allows for specialisation by maintenance personnel (especially on high-value, reparable parts) and a reduction of support equipment required for the testing and repair of sophisticated aircraft parts. Parts repaired at the I-level could be from the airframe, engine, or avionics systems, but maintenance on the nonremovable parts of the airframe itself is performed either at the O-level or at the depot, depending on the complexity of the maintenance or repair required.

Depot Level

'D-level' maintenance includes the activities involved in performing major overhauls or maintenance on aircraft, installation of safety or increased capability modifications, component repair and overhaul, and associated support equipment maintenance and repair at centralised repair depots, contractor repair facilities, or on site by depot teams. Depot maintenance activities are designed to support O- and I-level maintenance through overhaul, repairs, and modifications of aircraft, engines, support equipment, and their components that are beyond the capabilities of those organisations or that are placed at a depot for efficiency reasons (such as specialisation or centralisation of repair on components used on more than one type of aircraft).[9] A past RAND report (Marks and Hess, 1981) identified five major categories of depot maintenance:

- Airframe rework—inspection and repair of airframe structural components to correct the effects of corrosion or fatigue. This category refers to the whole aircraft, rather than to the individual

[9] In a RAND report on the F-4 aircraft maintenance capabilities (Kamins, 1973), it was found that 80 percent of the capabilities required to perform base-level inspection tasks could be performed at the depot. No comparable UK data were available.

components of an aircraft, which can be removed at the O-level and repaired anywhere. This category also includes modification kit installation. An aircraft may be sent to a depot facility for a modification alone or for both modification and maintenance work. Airframe rework tasks overlap with new aircraft FACO because the actions performed on the airframe involve the installation of new or rebuilt components into the aircraft and the reassembly and test of the aircraft. Airframe rework often involves more work than FACO because of the need to disassemble parts of an aircraft, analyse their condition, and then make the required repairs before commencing other repair or modification actions.

- Engine overhaul—performed periodically during the life of a turbine engine, this involves disassembling engines to their components, inspecting and replacing worn components, and reassembling the engine with new or rebuilt parts. Depending on the condition of the engine on arrival in the depot, the number of parts replaced may be few or many. For a severely damaged or worn engine, very little may remain from the original engine after a major overhaul, with mostly new parts installed during the overhaul (Nelson, 1977, p. 33).
- Airframe component repair—involves the inspection and repair of airframe components that have been removed at the O-level or D-level, replaced with a serviceable component, and sent to a central repair facility. Included in this category of components would be landing gear, tail hooks, hydraulic actuators, and small aerodynamic surfaces (flaps, slats, etc.).
- Engine component and accessory repair—refers to the repair of components of an engine or its accessories; these components may be removed and replaced on engines at the O-level or during depot engine overhaul.
- Avionics component repair—refers to the repair of components of the cockpit displays, radar, communications, navigation, identification, or electronic warfare systems and includes line-replaceable units (‘black boxes’). These are tested at the O-level and defective units are replaced and either shipped to an I-level facility for further testing and repair or forwarded to a depot repair facility.

Some depot maintenance activities occur at intervals ranging from several months to several years. Overhaul or aircraft rework includes programmed depot maintenance, analytic condition inspections, and unscheduled depot maintenance, which may be caused by an aircraft accident, battle damage, or significant and unforeseen fatigue-induced failures. Major aircraft subsystems (e.g., engine, avionics, armament, and support equipment) can have different overhaul cycles. Only depot work on the airframe itself requires the aircraft to be flown to a depot (or transported there by some other means if damage is so severe that it cannot fly). Therefore, airframe rework is done only at a facility with a runway and sufficient space to work on a number of aircraft indoors. Engine overhauls and component repairs of all types can be accomplished by transporting the engine or components to an overhaul facility by air or ground. Thus the overhaul facility for engines or aircraft components can be located virtually anywhere with sufficient room and tooling for a repair line, including the factory where the parts were originally manufactured.

Depot-level maintenance can be divided into activities performed by government organisations and by contractors. Government depot organisations (such as DARA at St. Athan or the air or logistics centres in the United States) were established long ago as a means to provide a rapidly expandable depot-level repair capability for wartime by providing continuous support during peacetime, thereby maintaining skills, processes, and facilities. In the United States, depot workload was awarded almost automatically to selected government depots with little or no competition. In recent years, the tendency has been either to let government and private organisations compete for depot work or to outsource all depot maintenance to commercial contractors to capture perceived efficiencies of competition and the private sector and to free military and government civilian workers for other, wartime-essential and related tasks. (In the United States, outsourcing is subject to the legal limitation of 50 percent of the overall military depot workload under Title 10, U.S. Code.)

Contractor maintenance can be performed using contractor personnel, material, equipment, and facilities or with contractor personnel using government-furnished material, equipment, and facilities. Contractor support may be dedicated to one or multiple levels of maintenance and may take the form of interim contractor support (ICS), if the services are provided on a temporary basis, or contractor logistics support (CLS), if the support extends over the operational life of a system. ICS aims to provide total or partial logistics support until a government maintenance capability is developed. Other contractor support may be purchased for engineering and technical services. However, even if a government depot provides maintenance and repair, contractor support may still be employed in specific functional areas, such as sustaining engineering, software maintenance, simulator operations, design of modifications, and other intermediate or depot maintenance functions. 'Sustaining engineering support' refers to activities related to systems engineering and programme management oversight to ensure the integrity of a system, to maintain operational reliability, to approve design changes, and to ensure system conformance with established specifications and standards. (Given that aircraft undergoing MR&U may be in very different conditions—perhaps stemming from specific, isolated accidents—and require different corrective actions, this kind of engineering judgement is an important component of MR&U.)

With the increased sophistication of modern combat aircraft and their increased reliance on software, software maintenance activities have assumed more importance. This support can be provided after system deployment to the operating forces by depot-level maintenance activities, government software centres/laboratories, or contractors. These efforts would involve supporting the update, maintenance and modification, integration, and configuration management of software. Software maintenance includes operational, maintenance, and diagnostic software programmes for the primary system, support equipment, and training equipment. Not included in software maintenance activities but often performed by the same organisation are the activities related to major redesigns, new development of large interfacing software, and modifications that change functionality.

DEPOT MAINTENANCE COSTS

Despite the importance of these depot maintenance activities and the visibility they often receive (especially as a source of skilled manufacturing jobs in government or contractor-run depots), airframe depot maintenance activities only constitute a small part of the overall through-life cost of a modern fighter aircraft. Using costs from the USAF fighter aircraft[10] fleet, Figure 2.2 shows that airframe-related depot maintenance costs constitute less than 5 percent of the

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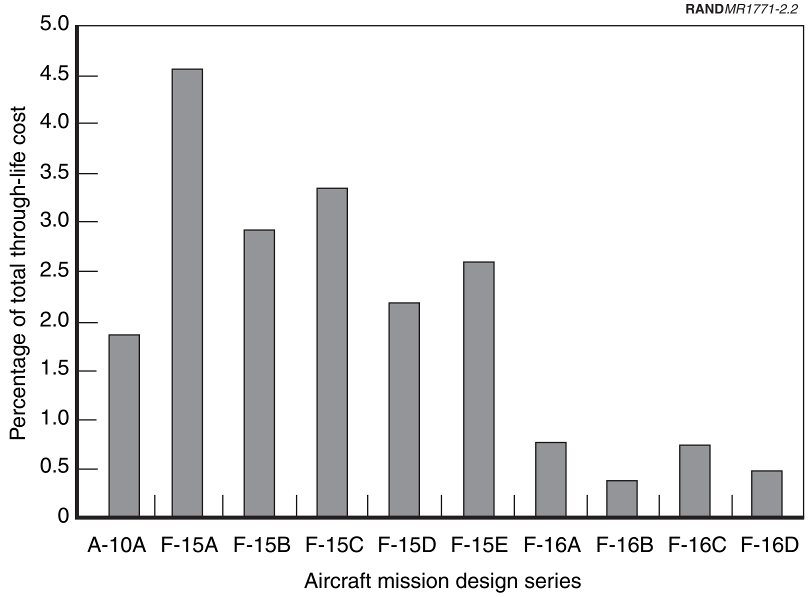

SOURCE: Taken from Raman et al., 2003, p. 63.

NOTE: The variable costs shown are those that can be directly attributable to each aircraft and include organic labour, consumable materials, contractor costs, and Government-Furnished Materials and Government-Furnished Services. These represent about 60 percent of the total depot-related airframe costs for each aircraft shown. The fixed costs of operating the depots and the management structure are not included in the variable costs but are part of the denominator used to calculate the percentage of through-life costs. In our analysis of MR&U for the JSF, all depot costs are included. The ones in the figure are shown only for comparison purposes and to help delineate the scope of the variable workload compared to all other aircraft through-life costs.

Figure 2.2—Percentage of Total Through-Life Costs Attributable to Variable Airframe Depot Maintenance

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[10]Attempts to get similar data from UK aircraft were unsuccessful. Because the JSF is predominantly a U.S.-designed aircraft, the experience from other U.S. aircraft is likely highly relevant. However, the RN and RAF may well use their aircraft differently, which would result in a different cost profile.

total through-life cost of each aircraft. The logistics concept for both the F-15 and F-16 initially did not have a requirement for periodic depot visits for recurring maintenance.[11]

Like the F-15 and F-16 initial support planning, the current logistics planning for the JSF does not include periodic visits to a depot for airframe maintenance and repair, according to our interviews with officials at the JSF programme office and at Lockheed Martin. Base-level maintenance personnel will remove and replace (R&R) defective components, and the parts will be shipped to designated locations for repair. For the JSF engine, some repairs will be done at the organisational level with a modular R&R concept, with major repairs performed at an engine depot facility. For some early modifications/upgrades, a field team dispatched from Lockheed Martin would probably install the modified equipment into JSFs at operational bases. So the question might be asked, what would drive the UK to establish an in-country airframe depot maintenance capability? There are several potential reasons.

First, the MOD might want to have its own capability to repair battle-damaged or crash-damaged aircraft that require extensive airframe repairs beyond the capability or practicality of base-level organisations and facilities. There is a risk in relying on another nation's repair capability, especially if the nation where the repair capability is located might refuse to repair aircraft if it disagreed with the military action that caused the damage.

Second, the MOD might want to have the capability to install aircraft modification kits as the JSF evolves and new threats and operational requirements emerge. The MOD may be able to have more control over the process if it does not have to involve a second government.

Third, the MOD might want to support the UK industrial base by developing in-country repair capability.

Fourth, the JSF may need periodic depot visits despite the current plans that do not include them. As noted above, both the F-15 and the F-16 were originally planned to require no periodic depot main-

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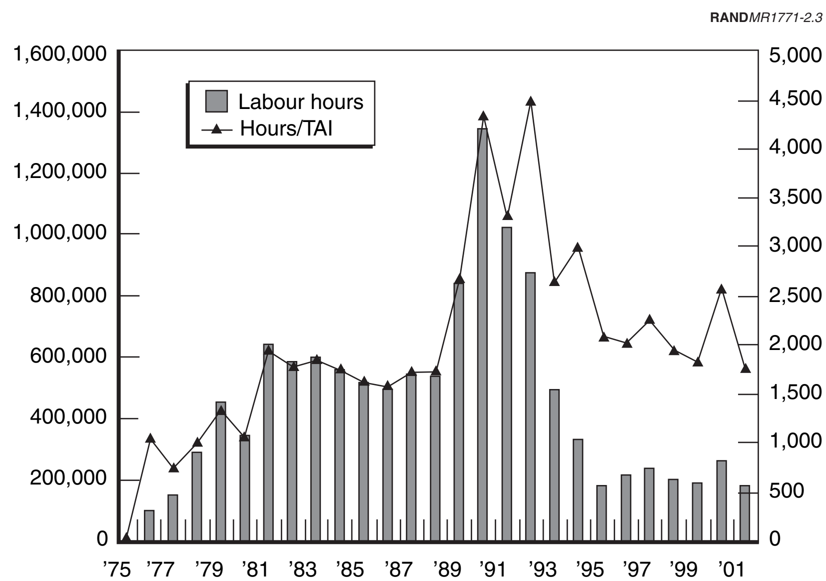
[11]Based on discussions with HQ USAF logistics and F-15 System Program Office personnel.

tenance. However, data on airframe past depot-level workloads for these two USAF[12] fighters reveal that, despite a philosophy that eliminates depot visits for these aircraft, significant airframe depot workload has been performed after these fighters joined the operational fleet. Shown in Figure 2.3 is the annual workload (in actual depot hours expended) for airframe depot maintenance for programmed maintenance, repairs, and modification kit installations. (The modification installation numbers do not include the hours to fabricate the modification kits themselves.) If history repeats itself, there may well be sufficient reason to plan for an airframe depot maintenance capability for the JSF in the UK for some time in the



SOURCE: USAF Weapon System Cost Reporting System.
NOTE: First operational F-15 delivered to fleet in 1974.

Figure 2.3—F-15A Airframe Depot Labour Hours and Hours per Total Aircraft Inventory

[12]Again, no data on UK aircraft were available.

future. As shown in the figure, in terms of expenditure of depot labour hours on the airframe (excluding engine, avionics, or airframe component depot hours), the F-15A experienced about 1,000 hours annually per aircraft early in its life. This later grew to just under 5,000 hours per aircraft as the average life of the F-15As reached about 15 years. In the latter stages of its life, the annual airframe depot hour expenditure fell to about the 2,000-annual-hour level. Thus, if a depot visit had occurred every three years, each visit per aircraft would be three times the annual rate, or somewhere between 3,000 and 15,000 hours per aircraft per depot visit.

For the F-16A (as shown in Figure 2.4), the increase in airframe depot maintenance hours was not as dramatic, with the annual labour hour expenditures growing to approximately 1,000 annually per aircraft (or roughly 3,000 for each depot visit if they occurred once every three years).

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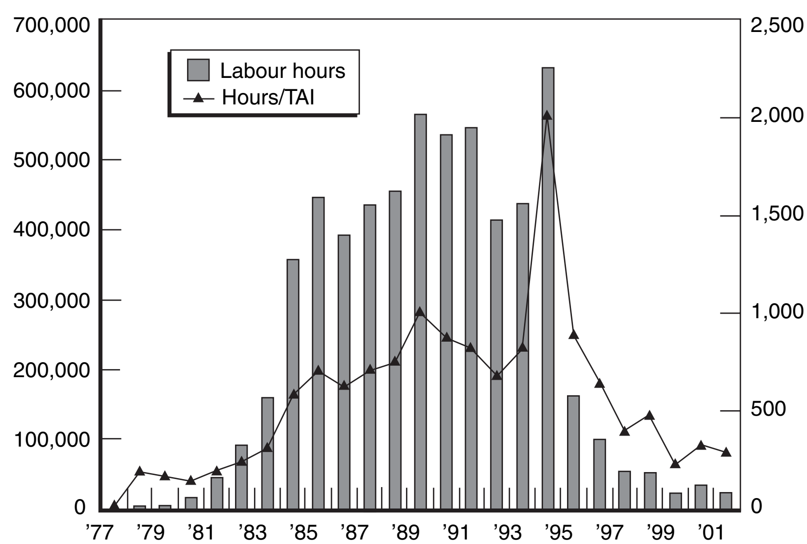

SOURCE: USAF Weapon System Cost Reporting System.
NOTE: First operational F-16 delivered to fleet in 1978.

Figure 2.4—F-16A Airframe Depot Labour Hours and Hours per Total Aircraft Inventory

In the case of the USN, the expenditure of depot hours for airframe maintenance shows a similar pattern for the F/A-18C/D (see Figure 2.5), although not as high in terms of hours per aircraft. In contrast to the F-15 and F-16, the F/A-18 was not designed or expected to operate without periodic depot maintenance.

The reader is cautioned to avoid comparing the USAF and USN data directly for the relative costs, depot support requirements, or other factors. Both services' reporting systems treat certain data somewhat differently. The data are only offered to show patterns in depot hour expenditures, not for comparison among the three aircraft. The point is that both the USN and USAF have expended effort of some magnitude at their depots maintaining, repairing, or upgrading these aircraft. The lag between introduction into the operational inventory and the expenditure of effort at the depots has been consistently about three years.

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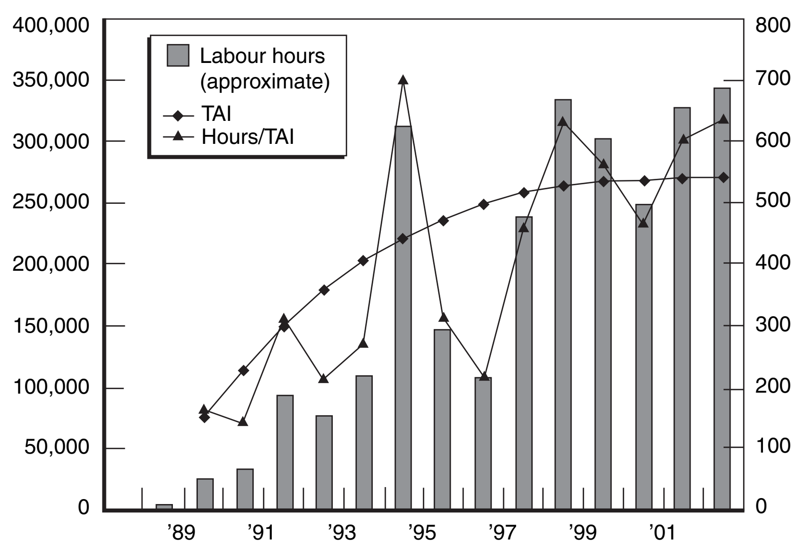

SOURCE: Navy Visibility and Maintenance of Operations Support Costs System Data.
NOTE: First operational F/A-18C delivered to fleet in 1987.

Figure 2.5—F-18C/D Airframe Depot Labour Hours and Hours per Total Aircraft Inventory

The current support plan for the JSF does not call for regular depot visits. However, a conservative approach for the JSF is to expect a series of depot visits to deal with regular work, planned upgrades, and technical surprises. History has shown that even aircraft designed to avoid regular depot maintenance did in fact require it. It also should be noted that the MR&U experience reported here includes activities conducted over several decades. Thus, estimates derived from these numbers include the experience from both peacetime and wartime.

MR&U SCENARIOS

RAND developed four MR&U scenarios for analysis that covered the range of depot activities likely to be undertaken by the MOD in managing its JSF aircraft:

- **Zero UK Depot MR&U:** No scheduled airframe depot maintenance would be required for the JSF during its entire operational life (emerging airframe requirements are addressed by field teams dispatched from a common JSF depot) or no airframe depot MR&U would be performed in the UK.
- **Light Depot MR&U:** A light requirement for airframe MR&U would consist of about 3,000 hours (for the hundredth visit, or T100) of direct labour per aircraft per visit. This requirement would commence five years after an aircraft was introduced into the operational inventory, with subsequent visits every five years thereafter. Each airframe would accumulate about 1,500 flight hours between depot visits. Each of these visits would take about 36 workdays to complete, based on a one-shift operation. An aircraft would generally be in one workstation or docking station for most of the maintenance, repair, or upgrade portion of the depot visit (as opposed to the moving line for FACO) and move to a paint facility for two or three days, transfer to a preflight station for fuelling and final inspection, have an acceptance test flight, and be returned to its home station.
- **Moderate Depot MR&U:** A moderate requirement for airframe MR&U would consist of about 5,000 hours (at T100) of direct labour per aircraft per visit. This requirement would commence three years after an aircraft was introduced into the operational

inventory, with subsequent visits every three years thereafter. Each airframe would accumulate about 1,000 flight hours between depot visits. Each of these visits would take about 60 workdays to complete, based on a one-shift operation. An aircraft would generally be in one workstation or docking station for most of the maintenance, repair, or upgrade portion of the depot visit (as opposed to the moving line for FACO) and move to a paint facility for two or three days, transfer to a preflight station for fuelling and final inspection, have an acceptance test flight, and be returned to its home station.

- **Heavy Depot MR&U:** A heavy airframe depot maintenance requirement would consist of about 10,000 hours (at T100) of direct labour per aircraft per visit. This requirement would also commence three years after an aircraft was introduced into the operational inventory, with subsequent heavy visits every three years thereafter. Each airframe would accumulate about 1,000 flight hours between depot visits. Each depot visit would take about 100 workdays to complete, based on a one-shift operation. Under this scenario, an aircraft would be partially or completely disassembled, moved to a major mate and alignment station, and then returned to a work/docking station for the completion of the remaining maintenance, repair, and upgrade actions. Following that, the sequence of events would be similar to the moderate scenario.

Without a final design of the JSF, or its logistics support concept finalised, the details of the work involved in such visits cannot be determined at this time, and a combination of light, moderate, or heavy visits, perhaps longer intervals between depot visits, or even an unexpected increase in MR&U requirements stemming from battle damage may occur. However, we judged that analysing all possible combinations and permutations of these kinds of visits would not provide additional insight in terms of making basic decisions on FACO and MR&U capabilities for the MOD. These scenarios were developed to provide the possible range of cost differentials. As the SDD phase continues, airframe depot requirements will clarify, and more detailed scenarios can be generated for analysis.

FACO PROCESSES COMPARED TO AIRFRAME DEPOT MR&U PROCESSES

In our discussions of both FACO and MR&U processes, procedures, and requirements with various groups in the aircraft industry, it became clear that FACO, despite the connotations of industrial prowess associated with the building of a new aircraft, is probably easier than MR&U, especially once the basic FACO line is established and running and early problems resolved. In the case of a UK JSF FACO line, the UK site would have the benefit of some early assembly problems having been resolved at Fort Worth in the initial production aircraft. (This does not say that there would be no start-up difficulties at a UK FACO facility.) In FACO, the assembly process and procedures are repetitive and lend themselves to refinement over time (i.e., the learning curve) because they have established processes, procedures, work instructions, and repeatability after the initial start-up of a FACO line. With such modern manufacturing processes as computer-aided three-dimensional design and very tight tolerances, assembly of new parts into a complete aircraft lends itself to more accurate manufacturing planning and predictability of workload. Scrap and rework should be reduced with both better 'fit-ups' of parts as they are assembled and the more uniform nature of each part as it is introduced into the FACO process. As quantities increase, engineering and manufacturing problems should decrease, given that the same configuration is maintained over time.

MR&U, on the other hand, will likely vary with each aircraft. Unlike FACO, where every part is new, an existing aircraft airframe is a combination of parts, some of which may be of different ages, operational exposures, and repair histories. Analysis of the condition of each aircraft after its induction into an airframe depot is an important step in the overall MR&U process, and individual aircraft may present unique complexities. Depending on how the aircraft is flown, components may change shape because of different kinds of stresses and wear. Aircraft may be flown in humid, severe salt, or otherwise corrosive environments. These and other factors may mean that an aircraft that has undergone MR&U would not fit together as easily as one with new parts meeting tighter tolerances.

Table 2.2 compares the major processes of FACO with our assumptions for 'light', 'moderate', and 'heavy' depot visits. These three scenarios were developed to cover a wide range of possible depot activity. The steps involved are typical for a fighter aircraft; companies in the aircraft assembly or depot business often have unique terms or processes. The processes are shown in general chronological order, but work in one phase may continue after work in the next phase has begun.

Key activities in each of the phases are listed below. Note that not all steps described for each phase may be required for light or moderate visits, depending on the condition of the inducted aircraft and the planned work to be done.

Induction Phase: The aircraft is flown from an operational or training unit to the depot location, defuelled, drained of hydraulic and other fluids, explosive cartridges are removed from pylons, its ejection seat is removed, and other systems are made safe. The aircraft is moved into the work or docking station inside a maintenance facility.

Assessment Phase: Technicians and airframe engineers inspect the aircraft, noting discrepancies and status of equipment. They update aircraft records, develop and document maintenance and repair

Table 2.2

Comparison of FACO with JSF Airframe MR&U Scenarios

Phase	FACO	Light and Moderate MR&U	Heavy MR&U
Induction		X	X
Assessment		X	X
Disassembly			X
Repair of parts/ components		X	X
Assembly/reassembly	X		X
Installation/ reinstallation	X	X	X
Testing	X	X	X
Painting	X	X	X
Preflight	X	X	X
Acceptance flight	X	X	X
Delivery to operational unit	X	X	X

requirements, assess status for upgrades, develop an overall work plan and schedule for the aircraft, and introduce or update the aircraft into the overall workload schedule for the depot. During this phase, doors and panels are opened and components may be removed to provide access to the airframe for inspections.

Disassembly Phase: Major and minor parts of the airframe are removed for repair or to provide access for other work. In the heavy scenario, this would include removal of the wings, control surfaces, landing gear and hydraulic actuators, demating of the fuselage, and storage or return to the supply system of removed components. If the visit included an upgrade, the old components would be removed and salvaged or discarded.

Repair Phase: Removed major components are repaired, corrosion or cracks are fixed, the individual parts depainted and repainted, and all parts prepared for reassembly. (Alternatively, new parts could be used during MR&U, or parts could be 'cannibalised' from other aircraft.) In a light or moderate visit, much of the repair work is done on the airframe itself, rather than on a disassembled airframe as would be more typical of a heavy visit.

Assembly/Reassembly Phase: All parts of the airframe are joined and mated, equivalent to the first phase of FACO. In this phase, in a heavy visit, the major portions of the fuselage and wings are moved into a major mate tool, and laser alignment is used to ensure alignment standards are met. Heavy MR&U and FACO tasks are similar in this stage, the difference being that FACO involves new parts, while the reassembly of an existing aircraft involves mostly repaired parts. However, reassembly is likely to be a more difficult task under MR&U, as components may have changed shape slightly during operational use when the aircraft are flown in stressing situations. After alignment and rejoining of major parts, the heavy-visit aircraft is returned to the workstation, although it could be placed into a FACO-like moving assembly line instead. (Performing less predictable MR&U on the same line as FACO has the potential to interfere with regular assembly work.) In a light or moderate visit, this stage involves minor work and the aircraft does not have to be placed into a major mate/alignment station.

Installation/Reinstallation Phase: After the major structure of the airframe has been assembled, such other components as actuators, pumps, hydraulic lines, electrical cables, the ejection seat, and avionics components not previously installed in the subassemblies are installed/reinstalled into the airframe. Engines may be reinstalled at this phase or following the testing phase.

Testing Phase: All electrical, hydraulic, fuel, avionics, and other support systems are tested using sophisticated equipment during this stage. Most testing sequences are computerised, with technicians monitoring the tests and fixing discrepancies as they arise. Low-observable testing would also be accomplished for FACO and heavy MR&U and perhaps for light and moderate MR&U, but after aircraft painting.

Painting Phase: Aircraft are moved to an environmentally controlled paint facility (unless the JSF appliqué process is used) and robotically painted. This process should take two to three days.

Preflight Phase: The aircraft is fuelled, other fluids are added or checked, and the aircraft receives a final, detailed inspection prior to its first flight or first flight after maintenance.

Test/Acceptance Flight Phase: A test pilot from the FACO or depot organisation flies the aircraft and checks the operation of all systems. For a new aircraft, this may require two flights. For the STOVL aircraft, a hover flight may be done before the first extended flight or as part of it. After the test flight, discrepancies are fixed and the aircraft makes another test flight, or, if the test flight discrepancies are minor, an acceptance pilot flies the aircraft. Following a successful test/acceptance flight, the operational user or a designated representative accepts the aircraft.

Delivery Phase: The aircraft is flown or shipped to its operational or training unit.

OVERLAP OF TOOLING AND FACILITIES

Because of the similarities between the activities in the later stages of both FACO and MR&U, much of the tooling can be similar. In our analysis of the workstations required for MR&U, we estimated that the MR&U-unique tooling would be relatively minor, with much of the tooling and worker stands, etc., either being common to FACO or relatively inexpensive compared to the tooling required to establish a FACO line. (Facilities costs were estimated as a function of total required floor space.[13]) Major cost drivers in terms of tooling and facilities would be the environmentally conditioned buildings (at least for FACO and heavy MR&U), the major mate and alignment tool, test equipment, and the painting facility. We did not discretely estimate MR&U-specific facilities that would not be used for FACO, such as depaint facilities, composite repair tooling (which could be the same as the tooling used at the operational base maintenance facilities), and any disassembly tools for the heavy maintenance scenario. Our estimates for manufacturing space included what we assessed was adequate storage space for aircraft parts removed from aircraft undergoing MR&U or new parts awaiting installation. Chapter Four includes more details on the assumptions of the tooling and the overlap in usage. Figure 2.6 provides a conceptual view of the overlap (although it does not provide insight into the timeline of FACO, then MR&U).

COMMON AND UNIQUE WORKER SKILLS AND LEARNING REQUIRED

Because of the variance in the condition of arriving aircraft at a depot and the complexity of an aircraft modification, it is very difficult to estimate the total hours required for MR&U activities. As part of the front-end work of MR&U, each aircraft must be analysed, disassembled, repaired or upgraded, and then reassembled. The worker skills required for the initial stages of MR&U are, therefore, as much related to those of repair technicians as they are to those of assembly workers. Our interviewees generally expressed the opinion that the

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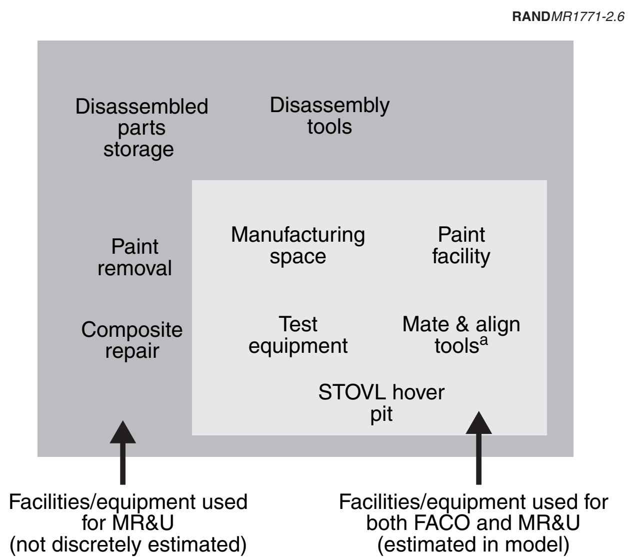
[13]We assume that the UK site uses the same production processes as Lockheed Martin, which is planning for an assembly line. Given the lower rate of UK production, docking stations similar to that used for the Typhoon production would be a reasonable alternative for the JSF. These stations cost on the order of £500,000 each, and the UK might need about two for the baseline FACO of only 150 aircraft, without additional FACO or MR&U. Other costs might be reduced, but we do not have the detail required to adjust the facilities costs to incorporate a change in production methodology.



[a]Only needed for heavy MR&U.

Figure 2.6—Notional Overlap of Facilities, Tooling, and Equipment Between FACO and MR&U

engineering support for MR&U is at least the same as for FACO, if not greater, and remains relatively constant over time, as new problems are found and corrected in aircraft returning to a depot. We used a somewhat flatter cost improvement curve for MR&U compared to FACO, based on that achieved for depot work on historical programmes. This flatter curve is consistent with the fact that even the reassembly of an aircraft in a depot is not as predictable as it should be for FACO because not all the repaired parts may be uniform because of age, operational use, etc.

In worst-case depot scenarios of severely damaged aircraft, the workload is not only significantly greater, but it also requires greater skill, both by the engineering staff and by the 'hands-on' workforce, to analyse the damage, disassemble parts of the aircraft requiring repair or replacement, and then reassemble the aircraft. Although we lack a precise number because of the wide range of possible damage scenarios, our interviews with people familiar with aircraft maintenance procedures indicated that MR&U on a seriously damaged aircraft could involve twice the direct labour hours that FACO requires, arising from the time and effort in the assessment, disassembly, and repair stages.

Although MR&U includes activities that are not part of FACO, our assessment is that the mix of worker skills for assembly/reassembly through delivery is similar to the FACO mix, with the number of workers of each skill dependent on the condition of each aircraft undergoing MR&U. Aside from an upgrade, in which the work is somewhat more standardised, the mechanics involved in performing MR&U in general would probably require more experience than would those performing only FACO. However, workers experienced in either activity could probably be used in the other, with additional training for the FACO workers. Some UK aerospace organisations sponsor apprentice training programmes for aircraft technicians, which improves the overall skill base of their mechanics.

As to hiring and training a workforce to perform FACO of the baseline 150 aircraft, the peak workload requires just over 100 direct labour technical work years annually. For the light depot scenario, peak workload is about 44 work years. For the moderate depot scenario, peak workload is about 125 work years. For heavy maintenance, the peak is under 250 work years annually. Given the current workforce at the three locations judged to be feasible, coupled with augmentation from the UK-wide apprentice programme, there would be little problem for any of them finding the types and numbers of workers required under any scenario, aside from the typical on-the-job training for the unique features of the JSF.

Another set of skills that could differ between FACO and MR&U are those in the management function. These skills should overlap a great deal but may differ in some areas. For example, managing suppliers is likely to be different between FACO and MR&U. FACO inputs tend to be large subassemblies produced by major first-tier suppliers. MR&U inputs can vary greatly and include a multitude of individual parts. Demand for MR&U input is also less predictable. MR&U management must be more flexible to deal with the likely unique condition of each aircraft, with potential differences in workload flow, content, and sequence, while FACO is much more predictable. In U.S. aircraft companies, MR&U and FACO are commonly separated into different business units with different overhead rates, as repair is a notoriously low-margin and competitive business. There may be other issues as well. However, we assume that given the generally high level of experience and expertise in aerospace, managers with experience in one area would be flexible enough to work in the other.

Potential Advantages of Collocating FACO and MR&U

Given the overlap in the stages of FACO and MR&U, certain advantages of having the activities at the same location are apparent.

First, familiarity with an aircraft FACO has the potential to allow for easier transition into a subsequent MR&U environment. The engineering staff and technicians working on FACO would be familiar with the work content, processes, and sequence of assembling the JSF. When the time came to reverse the process, particularly for heavy MR&U, such familiarity might allow for more efficient MR&U.[14] In addition, lessons learned could be cross fed, and engineering changes developed as a result of MR&U activities could be addressed more readily in FACO manufacturing processes. (Because maintaining commonality is an important goal of the programme, we would assume that Lockheed Martin would have significant involvement in any engineering decisions.)

Second, airframe engineering skills could address either FACO or MR&U problems as they arose, thus reducing the total engineering workforce required. Once the FACO line was up and running, the basic engineering tasks should decrease to more of a problem-solving mode, unless follow-on engineering change order work was significant, and then the issue of whether it would be done in the UK or in Fort Worth would have to be addressed. (The issue of maintaining commonality arises here as well.) The engineering work required by MR&U could be a vital supplement to the FACO engineering workload, thereby allowing better utilisation of the engineering staff

[14]Although we estimate the overlap in work between FACO and MR&U could be as high as 50–70 percent, we did not merge the common work on the same direct labour learning curve because the actual content of both cannot be known until the design of the JSF airframe is finalised for production. Merging the two on a continuous learning curve would imply more accuracy than is known at this point about either workload.

between the activities and perhaps the ability to retain more specialisation amongst the engineers.

Third, worker skills, aside from perhaps engineering assessments for MR&U, are basically the same for either, so levelling workload may be easier. Although categories vary somewhat by company/organisation, major categories of workers involved in either activity would include manufacturing engineers, assembly technicians, electricians, testers, flight line personnel, painters, tool maintainers, quality control/assurance inspectors, and indirect manufacturing support. Given that MR&U is more complex and difficult than initial FACO, on-the-job training would be required to move workers from FACO to MR&U, but basic skill training should not be necessary. (Trained MR&U workers could more easily perform FACO.)

Fourth, overall manufacturing facilities and equipment requirements could be reduced if the FACO manufacturing space and equipment were also employed for MR&U as part of a dual-use scenario. As more detailed planning continues and a decision on collocating FACO and MR&U in the UK is made, more precise manufacturing space savings assessments can be done. (See Chapter Four for more details on manufacturing space required.) Overall equipment costs could be reduced, especially for low-usage, expensive test equipment or tooling, such as the major mate/laser alignment tool. Again, with many details of the FACO manufacturing process to be refined during SDD, it is difficult to assess how much common equipment would be involved at this point. However, in our scenarios, the major mate/laser alignment tool is a requirement for both FACO and heavy maintenance. Our heavy scenario required an additional tool, even if collocated with FACO. However, if the two activities were separated, another set of major mate/laser alignment tools would also be required. Other expensive test equipment, such as for whole-aircraft low-observable testing, would also have to be duplicated if the activities were at separate locations.

Fifth, on-site technical support from Lockheed Martin and major suppliers could be combined in a collocated FACO and MR&U facility. In our scenarios, we assumed that Lockheed Martin and suppliers of major subassemblies and equipment would provide some sort of on-site support for a FACO operation, with more presence initially, and a gradual phasing down as production continued. These consultants would be in the mode of troubleshooting and providing consultation to the FACO workers as problems arose. However, they would likely not be fully occupied at all times, so they could also be available to provide the same expertise to the MR&U activity as well. This might be especially valuable on matters concerning low-observable technology.

Sixth, technical assistance agreements (TAAs) and other agreements would only have to be worked for one location, thereby reducing approval times and number of people involved and eliminating a second set of approvals for a different organisation. It would also reduce the exposure of highly classified technologies to just one location.

Potential Disadvantages of Collocating FACO with MR&U

Of course, adding MR&U workload to a FACO location could involve certain inefficiencies or difficulties. The first might be in managing the two processes. The expectation of the predictability of workload, such as with FACO, would not necessarily be true with MR&U. Because of the potential differences in the condition of aircraft arriving for MR&U, management's approach to the workload and the workers might have to be more flexible than at a facility dedicated solely to FACO. Workloads with customers will have to be negotiated after induction assessments are completed. In the United States, stability and predictability of workload for MR&U is notably less stable than that for FACO, where long funding lead times allow for better predictability for the FACO effort because FACO is the last step in the overall procurement and manufacturing process of a new aircraft. In addition to potential funding instability for MR&U, aircraft availability for induction into MR&U is affected by operational considerations, so workload predictability is less certain.

Another benefit from having two sites might be the fostering of competition in the awarding of MR&U contracts. One site might be set up for FACO, but that does not mean it will necessarily be the best-value location for MR&U. Having a second site qualified to do MR&U would likely keep costs down and quality high because two sites would be competing for the work. This would involve some additional costs of facilities and equipment, so an analysis could be done to investigate whether setting up a second site for MR&U would likely result in savings.

Although collocation may be desirable from an efficiency standpoint, political pressure may arise to spread coveted jobs in the aircraft industry to a greater number of locations. Local politicians are acutely aware of the effect of defence activities on jobs in their districts and might try to use their influence to direct at least some of the workload to defence-related facilities in their districts, despite the advantages in efficiency that collocation may offer.

Collocation of the FACO and MR&U activities would reduce the industrial base for the JSF to one location in the UK and could thus constrain growth potential for either additional FACO production or wartime or unforeseen MR&U growth. Realistically, however, any requirement for 'surge' could probably be met by adding additional workers or shifts to the first production site. Expansion of either activity and the associated hiring and training of workers may be more difficult at a 'megacentre' at one location, with a more limited local population from which to draw workers, than at multiple locations in the UK.

In the same vein, collocation increases the susceptibility of both FACO and MR&U to local issues, such as environmental activism. In particular, the STOVL variant of the JSF is expected to be loud. An increase in the number of aircraft engine runs or movements per day may cause problems with the local community.

Chapter Three

POTENTIAL SITES FOR JSF FACO OR MR&U IN THE UNITED KINGDOM

This chapter describes the four organisations suggested by the UK MOD as potential JSF FACO or MR&U sites. The four sites, BAE SYSTEMS, DARA, Marshall Aerospace, and Rolls-Royce, are the largest UK aerospace contractors. BAE SYSTEMS is involved in both FACO and MR&U. DARA and Marshall Aerospace are primarily MR&U firms. Rolls-Royce focuses on propulsion—engines and STOVL lift systems. This chapter also addresses the major plant and facility requirements for any FACO and airframe depot MR&U location within the United Kingdom.[1]

THE UK AEROSPACE INDUSTRY

The UK aerospace industry has a combined military and civil aviation world market share of 13 percent, trailing only the United States. According to the Society of British Aerospace Companies, the industry directly employs 147,000 workers, indirectly supports three times that many in the supply chain (Society of British Aerospace Companies, 2001, p. 4), and has the capability to produce a complete range of aerospace products (Department of Trade and Industry, 2002, p. 6). In 2001, the industry had sales of £18.42 billion, with 63 percent of that value exported outside the United Kingdom (Department of Trade and Industry, 2002, p. 6). Military sales accounted for 45 per-

[1]As stated before, these requirements were current as of the Lockheed Martin team's JSF baseline manufacturing approach used for the JSF downselect made in October 2001. The manufacturing processes and techniques may change as the SDD phase of the JSF progresses, and this may affect how FACO is actually performed when production begins in 2006.

cent of the total industry turnover, with approximately £4 billion in sales to the UK Ministry of Defence and £4 billion in military exports (Department of Trade and Industry, 2002, p. 6). The UK and U.S. aerospace markets are highly integrated, with the United Kingdom exporting £10.4 billion to the United States from 1994 to 1998 and importing approximately £14.8 billion during the same period (American Institute of Aeronautics and Astronautics, 2001, p. 3).

The UK has not been exempt from the consolidation and rationalisation trends in the worldwide aerospace industry. Fifty years ago, the UK had 18 of the 38 aircraft manufacturers in the world. Twenty years later, the UK had two of the world's 16 aircraft manufacturers. Today, the UK has one major aircraft manufacturer (BAE SYSTEMS). However, the UK aerospace industry remains globally competitive. Its export shares are nearly double the UK national average, 9.3 percent versus 5.1 percent for other industries (Department of Trade and Industry, 2001, p. 36). The UK controls 12 percent of the 2002 world civil aircraft market and 30 percent of the world aerospace engines market (Department of Trade and Industry, 2002, p. 10). Additionally, military exports are expected to rise from 5 percent to 15 percent of world market value in the next 10 years (Society of British Aerospace Companies, 2001, p. 30).[2]

Within the UK, a number of significant aerospace organisations manufacture, repair, or support military aircraft. The following four firms were suggested by the FJCA IPT for further study as potential repair and FACO sites because of their demonstrated expertise in the military aircraft industry (see Figure 3.1 for a map of their locations):

- BAE SYSTEMS, Air Systems Group (Warton, Lancashire, and other locations);
- DARA (St. Athan, Wales, and other locations);
- Marshall Aerospace (Cambridge, Cambridgeshire); and
- Rolls-Royce (Bristol, Sommerset, and Avon, and other locations).

[2]New exports of Eurofighter are expected to help increase this share.

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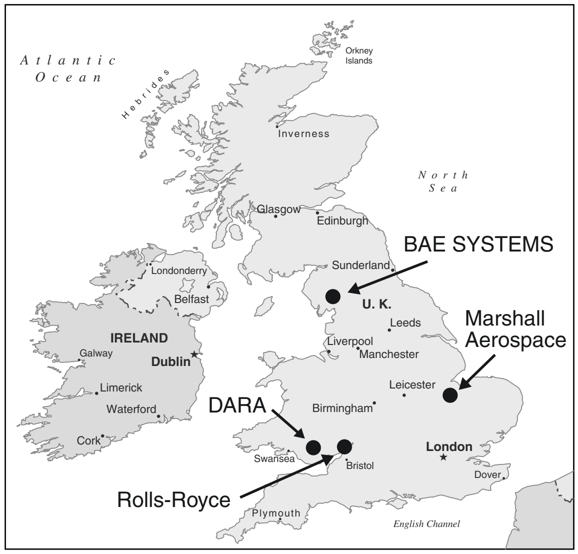

Figure 3.1—Location of Selected Aerospace Firms

BAE SYSTEMS

The predecessor company of BAE SYSTEMS, British Aerospace (BAe) was formed in 1977 as a nationalised corporation by the merger of British Aircraft Corporation, Hawker Siddeley Aviation, Hawker Siddeley Dynamics, and Scottish Aviation. Over the next 22 years, the company engaged in a considerable number of acquisitions and divestitures of various businesses. In 1999, British Aerospace and Marconi Electronic Systems merged, with the successor having the name BAE SYSTEMS.

BAE SYSTEMS is one of the world's largest defence contractors. It operates in a wide range of sectors, designing, manufacturing, and supporting military aircraft, surface ships, submarines, space systems, radars, avionics, C4ISR, electronic systems, guided weapons, and a range of other defence products, many of these with international partners. BAE SYSTEMS' Air Systems Group is the UK's largest aircraft manufacturer and is based at two main sites—Warton/

Samlesbury (Lancashire) and Brough (Yorkshire). The group employs a workforce of 10,000[3] on four separate aircraft businesses—Eurofighter Typhoon, Nimrod, Hawk, as well as the JSF.

The Warton/Samlesbury site has two main plants—Samlesbury, where BAE has manufacturing and tooling facilities for major unit assembly, subassembly, and component manufacture, and Warton, where the majority of aircraft final assembly, testing, and repair and overhaul takes place. Facilities at the Warton site include a 2,421-metre runway, more than 850,000 square feet of ramp space for aircraft, 2.4 million square feet of floor space, as well as additional hangar space, two painting bays for tactical aircraft, flight preparation facilities, wind tunnels, a hush-house and detuner, two separate hover pads for STOVL aircraft, a modern electronic warfare test facility, and a radar cross-section measurement facility. Significant investment has been made at the site, with £478 million spent on site improvements in the last seven years and an additional £81 million planned in further investment in the next five years.

The Warton site currently has two aircraft in production—the Eurofighter Typhoon and the Hawk trainer aircraft. The Typhoon's UK development aircraft has been completed, and BAE SYSTEMS is engaged in production of Tranche 1 of the programme as well as development of the increased Tranche 2 capability. Additionally, the company currently has maintenance, modification, and support contracts for a number of Tornado, Harrier, and Jaguar aircraft. The company has extensive experience in design, programme management, production, and final assembly, having been responsible for all of the major UK combat aircraft in the past 20 or more years, including the Eurofighter Typhoon, Hawk, Harrier, Nimrod, Tornado, Jaguar, Strikemaster, Lightning, and Canberra. Its FACO experiences include the typical activities, such as major component marry-up, mechanical and avionics systems integration, systems test, engine ground tests, final aircraft paint, signature verification, and flight acceptance testing.

BAE SYSTEMS has extensive aircraft maintenance, repair, modification, and upgrade experience. It recently completed a midlife

[3]http://www.baesystems.com/facts/programmes/airsystems/.

upgrade on 142 RAF Tornados as well as maintenance and major upgrade work on RAF Harrier GR.7s and RN Sea Harriers. It also performs aircraft maintenance for other countries, including Omani and Indian Jaguars, Kuwaiti Hawks, and Saudi Tornado aircraft. Its repair experience covers airframe, avionics, and weapons upgrades, major accident repairs, and capability enhancement modifications as well as Level 3 and 4 depot maintenance activities.[4]

BAE SYSTEMS also has experience in international collaborative programmes for military aircraft. It has worked in partnership with almost every major Western aircraft manufacturer at some point during the last 30 years to produce aircraft—either in a joint design effort or under a licencing agreement. The company collaborated with Dassault in the production of Jaguar and with European consortia in the production of both the Tornado and Eurofighter Typhoon. It is a major partner with Lockheed Martin in the development of the Joint Strike Fighter. Additionally, BAE SYSTEMS has been involved with licence agreements for the production of Harrier and T45 Goshawk aircraft with Boeing (through its predecessor company McDonnell Douglas) and with a number of Commonwealth nations for the production of the Hawk trainer.

DARA

DARA, located at St. Athan, Wales, is Europe's largest government-owned facility for the repair, overhaul, and maintenance of military aircraft, systems, and components (DARA, 2002/2003, p. 3) and has 50 percent of the UK market in repair and maintenance of tactical aircraft.[5] Although DARA is government-owned, it operates as a trading fund. Therefore, it has greater freedom to operate as a commercial business but must generate much of its own income, largely through the sale of services to the MOD, other government agencies, or the private sector.

DARA was formed as a result of the 1998 UK Strategic Defence Review that decided

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[4]Defined in Chapter Two.

[5]Interview during DARA site visit, January 15, 2003.

> [a] single Agency will also be created to repair and overhaul all military aircraft. This will amalgamate the Naval Aircraft Repair Organisation (responsible for helicopters) with the bulk of the RAF Maintenance Group Defence Agency (fixed-wing aircraft). The new Agency will become a Trading Fund as soon as practical. (Strategic Defence Review, 1998, Chapter 9, Paragraph 181)

In April 1999, the agency was formed, and it became a trading fund two years later.

DARA is divided into five operational sectors—Components, Engines, Fixed-Wing, Rotary-Wing, and Electronics. This report focuses on DARA's fixed-wing operations, headquartered at RAF St. Athan, just outside Cardiff in Wales. DARA has recently received government approval for the 'Red Dragon' plan, a significant renovation and modernisation project for its St. Athan site intended to be completed by 2004. When finished, the renovated site will have more than 150,000 square feet of ramp space, 474,000 square feet of new production facilities, three large hangars, four full paint booths with active filtration, three detuners, and a hover pit. It currently has an 1,825-metre runway.

Because DARA has always been a repair and overhaul organisation, it has never had prime contractor responsibility for producing a new aircraft. It does hold current contracts for the maintenance and refit for several of the current UK tactical aircraft including the Tornado, Harrier, Hawk, and Jaguar. In all, DARA has repaired or modified more than 500 aircraft in the last three years ranging from major structural repairs to rewiring of electrical systems. DARA also has experience in FACO-type activities including fuselage replacement and reassembly, systems functional checks, and flight-testing activities, which they have recently performed on both Hawk and Tornado aircraft. As described in Chapter Two, major aircraft maintenance overlaps with FACO, especially in rebuilding aircraft and testing them after the maintenance has been completed. While not a production environment, major maintenance does require many skills useful for FACO.

DARA has also participated in a number of collaborative programmes with other aircraft manufacturers. It served as a subcontractor to BAE SYSTEMS for the Hawk Fuselage Replacement Programme, in which it was responsible for stripping the aircraft and for the reassembly and testing using the BAE SYSTEMS fuselage replacement structure. DARA has also worked with Northrop Grumman in an infrared countermeasures programme in Northrop Grumman's electronics group. In its rotary-wing aircraft department, DARA has successful working relationships with both Boeing and Agusta Westland with long-term contracts to maintain Chinook, Lynx, and Sea King transmissions. DARA also works closely with Honeywell for repair of the T55 engine.

Marshall Aerospace

Although its origins lie in the automotive business, Marshall Aerospace has been a key player in the UK aerospace industry since Sir Arthur Marshall opened an aerodrome in 1929. During World War II, the firm serviced many types of Allied aircraft in its Cambridge facilities and expanded its operations in the mid-1950s. At one point in 1958, Marshall Aerospace had the largest capacity for aircraft-servicing in Europe.[6] Based in Cambridge, Marshall Aerospace is the largest privately owned aerospace company in the UK. It focuses on the maintenance, modification, and conversion of large aircraft including the C-130, E-3 Airborne Warning and Control System (AWACS) aircraft, and TriStar military aircraft, corporate jets, and wide-body commercial aircraft such as Boeing 747/777s and Airbus A319/A320/A321. In the 1982 Falklands conflict, Marshall Aerospace installed air-to-air refuelling equipment in RAF Hercules aircraft. The modification was designed, manufactured, installed, and flight tested within 14 days, with the first aircraft operational within three weeks of the initial design request.[7] Since that time, Marshall Aerospace has continued the servicing and modification of many UK aircraft. With a corporate focus on aircraft repair and overhaul, Marshall has not been involved in the production or final assembly of military aircraft.

Marshall Aerospace has some experience with tactical aircraft. It was involved in the maintenance and modification of the RAF Canberra and developed the RAF Buccaneer aircraft to perform avionics trials,

[6]http://www.marshallaerospace.com, History Timeline, 1959.

[7]http://www.marshallsv.com/history.htm.

flying as part of the Tornado development programme. Currently, Marshall Aerospace is in partnership with Brown and Root (part of Halliburton) and has a team of 650 personnel working at RAF Valley supporting the Hawk jet fighter trainer, used for advanced flying and weapons training.

Marshall Aerospace has a 1,965-metre runway, more than 650,000 square feet of production space with additional hangar space, and three paint bays that currently accommodate C-130 and AWACS aircraft. Marshall currently has no hush-house, detuner, hover pit, or radar cross-section facilities. This is because the facility has not recently been associated with tactical aircraft but instead has focused on military transport/command-and-control aircraft, wide-body commercial aircraft, and corporate jets. In the past seven years, the company has built a new control tower, upgraded its runway and approach lighting, and installed a precision approach radar and instrument landing system.

Marshall Aerospace does not have any aircraft in production or final assembly. Its repair programme, however, mirrors most of the activities found in an aircraft FACO. A typical rebuild programme will conclude with reassembly, paint, checkout, and ground/flight tests. All of these activities are integral to an original FACO, and Marshall's ability to perform them argues that it could also complete an original FACO if requested. An example of this is a C-130 modernisation programme that Marshall conducted for the South African Air Force. Marshall has other repair and modification experience, having overseen work on UK, South African, Swedish, Dutch, and other allied C-130 aircraft and UK TriStar refuellers and AWACS aircraft. This work included depot-level maintenance, avionics and structural upgrades, and jet cabin modifications.

Marshall Aerospace has experience in maintenance programmes working with international collaborative partners. Although the prime contractor on the South African C-130 modernisation effort, Marshall subcontracted a portion of the modification work to Denel in South Africa. Marshall has also worked closely with Lockheed Martin (the prime contractor) on both the C-130K and C-130J transport aircraft. The two companies have exchanged on-site representatives and routinely share trial information regarding the upgrades/modifications performed by each firm. This interaction has been significant, with the C-130K collaboration work stretching from 1966 to the present. Additionally, Marshall works closely with Boeing on its support to the UK's C-17 fleet.

Rolls-Royce

Although not an aircraft manufacturer, Rolls-Royce has been an integral part of the UK aerospace industry since World War I. Another firm that began its life as an automobile manufacturer, Rolls-Royce designed and produced its first aero-engine in 1914 and provided military aero-engines for the UK in both world wars. In 1961, Rolls-Royce merged with Bristol Siddeley, the other leading UK engine manufacturer. After being taken into state ownership in the 1970s and being privatised again in the late 1980s, Rolls-Royce acquired the Allison Engine Company in Indianapolis in 1995, giving the company an established U.S. presence and the opportunity to take advantage of Allison's experience in the U.S. defence industry.

Rolls-Royce is the leading European aircraft engine manufacturer and one of the largest engine manufacturers in the world. It employs almost 40,000 individuals worldwide—25,000 in the UK, 5,000 elsewhere in Europe, and 8,000 in the United States.[8]

Rolls-Royce has produced or coproduced aircraft engines for almost every aircraft in the current UK military inventory and for most aircraft in the commercial aircraft business as well. The Harrier (Pegasus), Tornado (RB199), Jaguar and Hawk (Adour), Nimrod (Spey), C-130 (AE2100 and T56), and Eurofighter Typhoon (EJ200) are all driven by Rolls-Royce power plants. Additionally, through its RB-211 and Trent series engines, Rolls-Royce provides engines for most Boeing and Airbus commercial models as well. Rolls-Royce has a twin interest in the JSF. Both the Pratt & Whitney and the General Electric engines employ its lift fan technology. The company also is responsible for about 40 percent of the General Electric F136, the 'interchangeable' engine for the JSF.

Many of these engines have been designed and produced as part of collaborative programmes. Both of the JSF engine options were col-

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[8]http://www.rolls-royce.com.

laborative ventures—the F135 lift system with Pratt & Whitney and the F136 with General Electric. The EJ200, which powers the Eurofighter Typhoon, is produced by Eurojet—a multinational company owned by Rolls-Royce, Motoren & Turbinen-Union GmbH (Germany), Fiat-Avio (Italy), and Industria de Turbopropulsores S.A. (Spain). Rolls-Royce also has collaborated with Boeing, Honeywell, SNECMA, and Turbomeca in a variety of joint ventures to power an assortment of aircraft from the future A400M transport aircraft to the Harrier to various Airbus models.

Although Rolls-Royce would be a strong candidate to maintain and repair the lift fan components that it produced, and to repair and overhaul the F136[9] (either for only UK JSFs or for all JSF aircraft based in Europe), it does not have the facilities or past experience in aircraft *airframe* assembly, maintenance, or overhaul to be a real contender to host the JSF FACO, should the UK decide to pursue an independent assembly line. As such, it is not considered as a potential FACO site for the purposes of this report and is not included in our later analysis.

FACO FACILITY REQUIREMENTS

According to Lockheed Martin, the specific plant and major facilities required to conduct JSF FACO at any given site would be as follows:

- A runway at least 8,000 feet long and 150 feet wide.
- A published, government-approved, instrument approach and controlled airfield environment.
- Arresting gear.
- Taxiways and sufficient ramp space.
- An environmentally conditioned assembly building, including assembly storage and office space.

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[9]Conceivably Rolls-Royce could also perform maintenance for the F135, if licensed to do so by Pratt & Whitney. Both the F135 and F136 engines contain certain sensitive components that would have to be returned to the original equipment manufacturer in the United States for repair.

- An environmentally controlled paint facility (this may be a section of the main assembly building).
- A low-observable testing and verification building (or section of the main assembly building).
- An aircraft flight operations run building (or section of the main assembly building).
- A 'hover pad' and a hover pit for ground operation of the STOVL variant.
- Road access from a major highway system.
- Sufficient reliable and economical electrical power for all FACO operations.
- Sufficient space or other means to allow for noise dissipation.

However, given the reduced quantities likely to be manufactured in the UK compared with the United States, and the current MOD activities at the three candidate sites we analysed, we feel that some of the above requirements can be modified as discussed in the notes of Table 3.1. The table summarises how each of the three sites compares to the requirements for FACO and MR&U. In addition, it lists capabilities in the workforce that either are vital to JSF FACO or provide an advantage to a potential site that has them. In general, if the facilities at a site can support a FACO activity for JSF, they could also handle MR&U activities if additional manufacturing space and tooling and equipment were added. It should also be noted that additional issues relating to organisation and culture might contribute to the successful development of a JSF capability. However, the specific contributing factors are difficult to assess and measure and hence are not included in this table.

We found no 'show stoppers' at any of the three locations in terms of supporting FACO or MR&U for the UK JSF aircraft. Certainly, with varying levels of investment, the work could be done at any of the three sites. (Indeed, with enough investment, the MOD could select a 'greenfield' site and develop a new capability.) Each assessed site offers a unique package of skills and experience.

Table 3.1

Facilities and Other Capabilities for FACO and Airframe Depot MR&U

	Warton—BAE SYSTEMS[a]	St. Athan—DARA[b]	Cambridge—Marshall Aerospace
Runway[c]	2,421 metres	1,825 metres	1,965 metres
Instrument approach	Yes	Yes	Yes
Arresting gear	Yes	Yes	No
Taxiways and ramp space (number) for fighter-sized aircraft	Yes (21)	Yes (10)	Yes (0 designated)
Building (15,000 square metres)	Yes	Yes	Yes
Environmentally controlled assembly building	No	No	No
Environmentally controlled paint facility (number of positions)	2+1	4	2+1
Robotic paint equipment	Semirobotic (man-mover)	No	No
Low-observable test and verification building or space for full aircraft testing	Yes	No	No
Flight ops run building[d]	No	No	No
Hover pad and hover pit	Pads—Yes(2) Pit—No	Pad—Yes Pit—No	Pad—No Pit—No
Motorway access	Yes	Yes	Yes
Adequate electrical power	Yes	Yes	Yes
Backup generators—production centres	No	No	Yes
Explosives storage for FACO materials	Yes	Yes	Yes
Experienced fighter-type FACO workforce	Yes	No[e]	No
Experienced fighter-type MR&U workforce	Yes	Yes	Limited
Familiarity with JSF	Yes	No	No
TAA/ITAR familiarity[f]	Yes	Very limited	Yes
Low-observable experience	Yes	No	No
Percentage of workforce with Secret security clearance	~70%	>50%	~25%
Digital design and work instructions experience	Yes	No	No
Experience with composite materials	Yes	Limited	Fibreglass only
Experience with resin transfer moulding	Yes	No	No

Table 3.1—continued

	Warton—BAE SYSTEMS[a]	St. Athan—DARA[b]	Cambridge—Marshall Aerospace
Experience with metal fabrication	Yes	Yes	Yes
Commercial aircraft experience (FACO or MR&U)	Limited—new fabrication for Airbus	No	Yes—M&R

[a]Certain capabilities that could easily be transferred from BAE's Samlesbury to Warton sites are included—i.e., workers with experience with fighter assembly operations.

[b]Capabilities for DARA St. Athan are as forecast after the Red Dragon initiative is completed in 2004.

[c]Although Cook et al. (2002) established a requirement for a minimum 8,000-foot (2,462-metre) runway, the RAF regularly flies fighter aircraft out of Warton and St. Athan using the shorter runways and has flown from Cambridge in the past. This was deemed adequate for UK FACO and MR&U, especially considering the potential reduced takeoff roll of the STOVL version of the JSF.

[d]Although it would be preferable to have this in a separate building because of aircraft being fuelled and possibly defuelled in this facility, this activity could be collocated with other activities in a common building or even performed on a ramp.

[e]Although DARA has not been involved in the FACO of new aircraft, it has performed FACO-equivalent work as part of the Hawk Fuselage Replacement Programme.

[f]BAE SYSTEMS has some specific experience with JSF TAA requirements; Marshall has experience working with Lockheed Martin on C-130 TAAs.

BAE SYSTEMS has the most relevant experience to JSF FACO. It is the only site that has done production FACO of tactical aircraft. It is also familiar with the JSF in particular, being a major subcontractor to Lockheed Martin—BAE SYSTEMS has worked closely with Lockheed Martin for several years and has a number of engineers located full-time in Fort Worth. The two companies have worked closely together on technology-transfer issues, because Lockheed Martin is transferring technology required to produce the rear fuselage and the tail to BAE SYSTEMS. BAE SYSTEMS also has a great deal of relevant experience in technologies and materials and in performing MR&U. The Warton site would need some investments in facilities and equipment, as would all the sites.

DARA has extensive experience with fighter aircraft. While it does not perform FACO in a production setting, its experience with significant upgrades of a large number of aircraft has provided it with FACO-like experience. Its Red Dragon programme will result in the building of modern facilities that can be set up for new aircraft programmes. It, too, would require some further investment. DARA does not have significant experience working through issues regarding the transfer of technical data.

Marshall Aerospace has the least relevant experience for JSF FACO, because its experience with tactical aircraft is comparatively limited. It does have military experience—for example, on C-130s—and has experience with TAAs. Marshall Aerospace also has the most commercial experience, competing for the MR&U of aircraft of commercial airlines. Conceivably the pressure of competition in the commercial market could enhance its ability to provide low-cost, high-quality work on fighter aircraft for the MOD. Again, Marshall Aerospace would need investments in equipment and facilities.

All four organisations we visited as part of the data collection had an impressive collection of skills and experience. Airframe FACO (and airframe MR&U) would be a completely new sector for Rolls-Royce, but each of the other three could perform JSF FACO, with a varying level of investment and risk. BAE SYSTEMS has the most relevant experience and the most capabilities pertaining to JSF FACO. However, DARA and Marshall Aerospace could also be used for JSF FACO. While not a site for JSF FACO or MR&U, Rolls-Royce could be considered as a potential MR&U site for the JSF propulsion system.

RAND Europe was asked to assess the cost of collocating MR&U and FACO, so that was the focus of cost analysis and modelling work. However, the MOD has several alternatives. FACO and MR&U could be at the same location or split into two locations. Furthermore, not all airframe MR&U needs to take place at the same location. The small amount of intermediate-level maintenance (on wheels and brakes, for example) could be done separately from the rest of MR&U. Or early inductions of aircraft into the depot could take place at the FACO site, but, as the need for depot work ramped up, a second facility could be established. The MOD could usefully assess the advantages and disadvantages[10] of these alternatives to determine whether it is worthwhile to keep its options open by not deciding in advance to collocate all JSF work.

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[10]These are described at length at the end of Chapter Two.

Chapter Four

COST ASSESSMENT

When evaluating policy alternatives, one of the fundamental issues that decisionmakers need to understand is the effect on their budget. These budget implications are especially important for acquisition programmes in which affordability and value are part of a broader set of trade-offs being considered. In this chapter, we describe a cost methodology and model for assessing the cost of the JSF FACO location alternatives. The goal is to assess the budget implications of (1) changing the FACO location for the UK's JSF aircraft from Lockheed Martin's plant in Fort Worth to various sites in the UK and (2) combining a UK FACO facility with an MR&U facility.

METHODOLOGY

Which Budget?

This chapter describes a model to quantify the budget implications of moving FACO activities from the United States to the United Kingdom. However, the question arises as to which budget costs are we assessing? The goal of this work is to assess the budget implications to both the FJCA IPT and MOD as a whole. Given this broad definition of 'budget', we must analyse more than just the FACO cost for the UK's JSF aircraft. We must also consider other costs. There are four costs that we will quantify (for clarity of discussion, we will call these items the 'Cost Basis'):

- FACO for UK JSF—These costs are for the FACO of the UK's JSF aircraft.

- MR&U Depot Work for the JSF—These costs are for the airframe depot maintenance for the UK's JSF aircraft.
- Non-JSF MOD Costs—All the UK sites have additional repair or manufacturing work for the UK MOD other than that for the JSF programme. Thus, adding JSF FACO work to a facility will affect the cost of other programmes because they share indirect costs.
- JSF Component Work—Two of the sites also produce components (major subassemblies) for the JSF. Lockheed Martin Fort Worth will manufacture the forward fuselage and the wings. BAE SYSTEMS will manufacture the aft fuselage and the tail at its Warton/Samlesbury complex. Therefore, shifting UK FACO work will indirectly change the costs of manufacturing these items.

In the discussion of the model structure and methodology that follows, we mostly focus on the first cost basis listed above—the FACO costs. However, assessment of the other three cost bases follows an identical methodology; we use the same procedures to calculate these costs as we do the FACO costs. The major difference is that many of the factors included in the costs are FACO-specific (e.g., supplier support, royalties) and, therefore, do not apply to the other bases. In the model, we track each of these cost bases separately. As a separate calculation, we address the costs to the U.S. DoD if the FACO work is moved from Fort Worth to a UK site.

Overview of the Cost Modelling Approach[1]

Analysing the production costs of a major military system acquisition is a complex task. For the case of alternative UK FACO locations for the JSF, several scenarios, potential sites, and cost factors should be considered. For example, such cost factors as labour efficiency, taxes, facilities requirements, environmental constraints, shipping, and original equipment manufacturer (OEM) and prime contractor support all affect the cost of having additional or alternative FACO sites for JSF production. It is difficult to predict the combined influence of all these cost effects. Some factors might increase the total production cost of using an alternative site—most notably, the need

[1]This section comes largely from Cook et al. (2002).

for redundant facilities, tooling, and equipment. If the company purchases these, their costs will be added to the site's overhead rates, affecting all programmes at the site. Other factors may *decrease* the total FACO cost for one site relative to another. One such factor is the differences in wrap rates (fully burdened cost per hour of direct labour) between facilities. How all the various factors combine to result in a higher or lower FACO production cost is not obvious. Furthermore, if work is added to a site, its wrap rate will decrease through the spreading of fixed costs over more direct work hours. Therefore, the cost of other work will be reduced. We have no way of knowing whether a particular FACO strategy is more or less expensive without accounting for all the relevant factors in a consistent manner.

The fact that costs may not be independent of one another complicates the accounting. Some factors that directly influence the cost also affect other factors. For example, environmental regulations may require additional facilities investments, such as a thermal oxidiser to reduce emissions of volatile organic compounds (VOCs). These investments will, in turn, increase power usage, maintenance costs, and depreciation and thus increase the overhead costs at the site. Accurately assessing the dependencies among cost factors is important to a correct determination of the budget implications of UK FACO options.

MODEL STRUCTURE

Overall Description

The RAND model to quantify the budget implications of alternative UK FACO strategies was developed in a programme called 'Analytica', produced by Lumina Systems.[2] The advantages of this system over the more traditional spreadsheet have been described elsewhere (Johnson et al., 2003).[3]

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[2]For more information, see www.lumina.com.

[3]Analytica has several advantages over traditional spreadsheet modelling tools. It uses influence diagrams to structure models. This type of structure is graphical, so that a representation of the model structure and interactions can be easily conveyed. It handles multidimensional problems highly efficiently through the way it processes arrays. Therefore, it is relatively simple to perform sensitivity analysis or expand the dimen-

The RAND model consists of 11 different modules that correspond to discrete components of cost or major factors. These elements, the major cost drivers for FACO activities, are production quantities, production hours (direct labour), direct cost, burden (indirect costs, such as overhead and general and administrative [G&A] costs), facilities costs, equipment and tooling, taxes, transportation, prime management and supplier management support, royalties, and fees. Generally, each module calculates the appropriate cost for each fiscal year[4] of production. Some costs, such as labour, are incurred over the entire production run (called 'recurring costs'), while others, such as tooling and equipment, might be one-time costs or periodic (called 'nonrecurring costs'). In this section, we describe the methodology and assumptions used to evaluate each cost element. A graphical representation of the model is in Figure 4.1. It shows how high-level cost components of the model interact.

To describe the complexity of the model, it is useful to discuss the logic for some of these connections. In one example of how the modules interconnect, the site's FACO and MR&U plans (i.e., production quantities) will determine the needed investment in facilities, tooling, and equipment (both contractor-owned and government-owned) necessary for the various activities. The greater the rate of work at a site, the more investment will be necessary. These investment costs may be for JSF-specific items (government-owned) and, therefore, get charged directly to the programme. Other investments (contractor-owned) get recovered through depreciation charges included with overhead. Certain investments might be taxable—thus the linkage to 'Taxes and Benefits'.

So following one major thread, production quantities (for both FACO and MR&U) will affect needed facilities investments, operating costs,

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sionality of the issues being considered. It also has a built-in Monte Carlo capability for uncertainty analysis.

[4]For the FACO activity, we assume that actual costs are incurred two years after the U.S. government fiscal year in which the funds are appropriated (the gap between order and delivery). All costs are assumed to be budgeted up front (at order) and not on delivery. Given the differences between U.S. and UK fiscal years, there might be some slight fiscal year discrepancies during the period when production is ramping up and down. However, the overall total is correct.

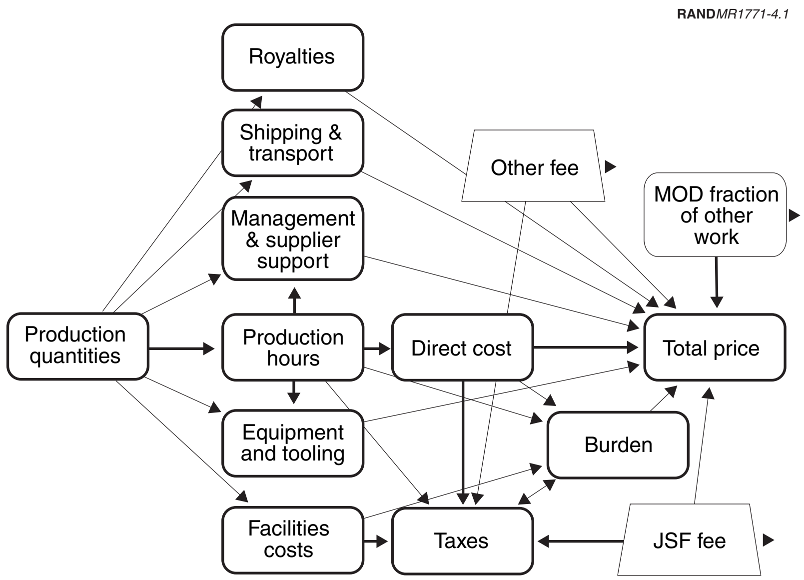

Figure 4.1—Cost Model Influence Diagram

and maintenance costs. These facility costs, in turn, will affect taxes (through property tax) and burden rates (overhead) through increased depreciation and operations and maintenance costs. The burden (indirect) costs are scaled with the direct costs and contribute to the total price for the work.

Direct labour production hours for FACO production offer another example. As with the other elements, the direct hours will vary with the production rate at the site. The direct hours for the work will affect the site's burden (overhead and G&A rates). Direct hours will have tax implications as well. The fee earned from the labour will count as taxable income for the firm. The production hours also indirectly affect the equipment and tooling costs for the UK MOD. This effect arises because tooling and equipment costs are shared across programmes based on the overall percentage of labour in the various programmes. Thus, if all UK JSF FACO is done in the UK, and no JSF FACO for other countries is done in the UK, then the MOD would pay for all the equipment and tooling. In the cases where JSF FACO sales are made to other countries or the work is done in the United States, the UK MOD pays only a fraction of the total equipment and tooling costs. A similar process occurs for sharing of the management and supplier costs—the MOD pays a prorated share (based on FACO production hours) for these costs if the work is done in the United States.

General Assumptions

Before describing the details of the cost model, it is useful to describe some of the broader assumptions and factors that underlie the analysis.

- FACO production hours, equipment, tooling, and facilities requirements are based on Lockheed's CDP estimates. These values may change during SDD, as discussed previously in this report.
- Currency conversion between dollars and pounds is done at a rate of \$1.611 = £1. This rate is based on an annual average from the past 16 years.
- The activities and hours for FACO are identical for the U.S. and UK JSF aircraft. All sites have the same T1 relationship between the level of FACO activity, including cumulative production, and labour hours required.
- All costs and rates are given in FY 2003 dollars or pounds.
- Lockheed Martin retains 'prime' programme and configuration control for the UK aircraft.
- We analyse the period FY 2006 through FY 2026 (the planned production run for JSF).

Discussion and Treatment of Individual Cost Factors

Production Quantities. *New Aircraft Production Rate.* This component of the model tracks the quantities of aircraft produced by each site for the various scenarios on an annual basis. We categorise the production rates as follows:

- UK Production—The JSF production that the UK acquires is assumed to be 150 of the STOVL variant over U.S. fiscal years 2008 through 2021.
- Other Baseline Production—These quantities are JSF production unique to a site and do not vary based on the scenario. For this analysis, the only site with this type of production is Lockheed Martin's Fort Worth plant.
- Production for Other Countries—Given that several countries in addition to the United States and United Kingdom have expressed interest in the JSF programme, the potential exists for sales beyond the 3,002 aircraft as envisioned in the baseline programme. Indeed, as described in Chapter One, there are seven other partners along with the United States and the United Kingdom. Therefore, a UK site has the potential to do FACO work for more than just the UK production, provided the relevant stakeholders agree. We have created four different scenarios for potential production of non-UK JSFs at a UK site. This additional production includes both CTOL and STOVL variant aircraft.[5] Specifics are presented in Table 4.1:
    - +0 aircraft—the baseline programme, includes only the 150 STOVL aircraft the UK plans to acquire.
    - +150 aircraft—a modest increase in production quantities, doubling the production at a UK site.
    - +503 aircraft—based on information provided by the FJCA IPT on potential sales to other countries. It assumes that all the work would go to the UK site.
    - 1,000 aircraft—almost doubles the quantities of the preceding scenario (+503) by increasing the production rates and extending the production period.

For comparison with the scenarios in which Lockheed Martin–Fort Worth produces all the UK aircraft, these additional aircraft are included in Fort Worth production quantities as well.

[5]We assume that a single production line can be used for both variants. The different JSF variants were designed to be highly common to enable this, part of the programme's affordability goals.

Table 4.1

Buy Quantities by Fiscal Year Under Different Scenarios

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Base Case												
STOVL	5	9	12	12	12	12	12	12	12	12	12	12
CTOL	0	0	0	0	0	0	0	0	0	0	0	0
Total	5	9	12	12	12	12	12	12	12	12	12	12
+150												
STOVL	5	9	12	12	19	19	23	23	12	12	12	12
CTOL	0	2	14	16	16	12	12	12	13	13	4	0
Total	5	11	26	28	35	31	35	35	25	25	16	12
+503/FMS												
STOVL	5	9	12	12	36	36	48	48	12	12	12	12
CTOL	2	8	48	54	56	42	42	22	46	44	16	3
Total	7	17	60	66	92	78	90	70	58	56	28	15
+1,000												
STOVL	5	9	12	36	36	36	48	48	48	48	48	36
CTOL	2	21	48	54	64	70	86	92	82	64	56	52
Total	7	30	60	90	100	106	134	140	130	112	104	88

Table 4.1—continued

	2020	2021	2022	2023	2024	2025	2026
				Base Case			
STOVL	12	4	0	0	0	0	0
CTOL	0	0	0	0	0	0	0
Total	12	4	0	0	0	0	0
				+150			
STOVL	12	4	0	0	0	0	0
CTOL	0	0	0	0	0	0	0
Total	12	4	0	0	0	0	0
				+503/FMS			
STOVL	12	4	0	0	0	0	0
CTOL	0	0	0	0	0	0	0
Total	12	4	0	0	0	0	0
				+1,000			
STOVL	12	4	0	0	0	0	0
CTOL	21	12	0	0	0	0	0
Total	33	16	0	0	0	0	0

MR&U Depot Induction Rate. For MR&U depot activities, the analogous rate to the production rate for FACO is the depot induction rate. In Chapter Two, we described scenarios about MR&U depot activities for the JSF. Our assumption is that JSF aircraft will return to the depot every three to five years, depending on the scenario. The rate of MR&U induction thus depends on the delivery schedule of aircraft and the inventory. To determine the induction rate, we track all the aircraft in the inventory and calculate the number that reaches an integer multiple of three or five years from delivery. The aircraft inventory is a function of the delivery schedule and aircraft attrition. For the attrition rate, we assumed a rate identical to the F-16C/D (1.3 percent per aircraft equivalent).[6] The attrition is assumed to be uniform. This attrition value is comparable to the attrition rate used by the JSF programme office for its calculations of total aircraft quantities required.

Direct Production Labour and Cost

Labour is one of the largest cost components for FACO. The labour associated with FACO activities is comprised of two distinct types: 'touch' and 'support'. Touch labour is the direct work in the production of the aircraft, including such activities as structural mate, testing, and flight operations. Support labour is direct labour that facilitates FACO touch work, including engineering, quality, material inventory, and the like. For all these elements, we used the work breakdown structure (WBS) employed by Lockheed Martin for FACO activities and modelled each as a separate component of the overall production labour. The WBS is as follows:

- Direct Labour
  - Fuselage structural mate
  - Subsystem mate
  - Final assembly and test

[6]USAF, Aircraft Peacetime Attrition Losses at Selected FH Intervals, AFI 65-503, Attachment A52-1 (based on data as of December 31, 2001, available at http://www.saffm.hq.af.mil/).

  - Flight operations
  - Manloads/ITLs[7]
  - Final finishes
- Support Labour
  - Manufacturing engineering
  - Tool engineering
  - Tool manufacturing
  - Quality
  - Engineering
  - Material inventory.

For each of the above components of production labour, we calculate the number of hours of work on a yearly basis at each site. (This calculation includes learning effects, which are described below.) These hours are then multiplied by a direct labour rate to determine the direct labour cost. Not all components have the same direct rate. Some components are more expensive on a per hour basis than others. For example, the hourly direct rates for engineering are higher than those for structural mate.

Only direct labour is explicitly included in our cost model, and our FACO direct labour requirements are based on Lockheed Martin data. However, for some of the UK sites, some of the labour tasks in these direct labour requirements are not treated as direct, but as indirect. For each site, we used data collected at the site to reduce the direct labour requirement based on the site's practice. The site's burden rate then implicitly accounts for the remaining labour. We reduced MR&U direct labour requirements by the same proportion as we reduced direct FACO requirements.

Unit Learning Curve. The number of work hours per aircraft assembled falls with cumulative production. It has long been under-

[7]This category includes residual work that must be accomplished after delivery at the FACO location on purchased subassemblies before they can be incorporated into final assembly.

stood that manufacturers generally become more efficient at producing identical items over time. This observation is the so-called learning effect (Asher, 1956). We cannot simply determine the hours worked each year by a multiplication of the production rate times a fixed number of hours per aircraft.

To reflect experience-based gains in efficiency, we use the unit learning curve that represents the production hours per aircraft as a power function of cumulative production. The equation takes the general form:

$$T(n) = T(1) \times n^{\frac{ln(slope)}{ln(2)}} . \tag{1}$$

The variable n is the cumulative number of units produced. $T(n)$ is the number of hours for the nth unit. $T(1)$ is the number of hours for the first unit. The variable *slope* is the improvement rate and represents the quantity by which the number of hours gets multiplied each time the production unit number doubles. For example, a slope of 0.95 implies that the unit hours decrease by 5 percent for each doubling of quantity. So if unit one takes 1.0 hour, unit two takes 0.95 hours and unit four takes 0.903 hours.[8,9] We use the unit learning curve approximations for the series summation.[10]

For cost bases other than FACO we use a somewhat simpler approach because of limited data availability. MR&U work is modelled as a single learning curve and learning slope (the slope is based on historical data). For the other component work, we do not have

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[8]The insight that hours required to perform manufacturing functions decline at a set rate as the production units successively double was a foundation of formal cost estimation (Asher, 1956).

[9]It should be noted that Lockheed Martin uses a compound learning curve that changes slope at three points in the production. Its curve mimics an “s-shaped” improvement curve. We have used constant-slope curves for our analysis, in line with what the JSF Program Office and the Office of the Secretary of Defense Cost Analysis Improvement Group have done. A comparison analysis using a learning curve like Lockheed Martin’s and a simple single-slope curve reveals that the difference in labour hours is only about ±3 percent. The difference depends on the point at which a second FACO source is introduced.

[10]Chapter 18, *Pricing Handbook*, http://fast.faa.gov.

learning information, only an average cost over the entire JSF production run. Thus, the JSF component costs are treated as a constant unit cost.

To determine the number of hours for each of the 12 components of FACO labour requires, at a minimum, calculation of 12 learning curves. However, the RAND model incorporates more complexity. Two additional aspects to production labour for JSF FACO are addressed (and were incorporated into the cost model) to reflect the unique nature of this program: the possibility that learning can transfer between sites and the fact that what is being produced is not a single aircraft, but three variants of a single aircraft with a high level of commonality.

Transferable Learning. As described in Cook et al. (2002), the efficiency improvement that the unit learning curve reflects results from a combination of factors, including improvements in production methods and experience gained by workers. All of the FACO scenarios under examination rely on a single contractor (Lockheed Martin) controlling configuration and methods (although the work may take place at another organisation's facilities). Therefore, some, although not all, of the efficiency improvements could plausibly transfer between the U.S. and UK FACO sites. Engineering or process improvements (e.g., including new methods, simplifications of the way the work is done, and tooling improvements) are more likely to be transferable. This improvement in the way work is done can be captured in documentation, shared by engineers travelling between locations, or even through video- or teleconferences. Another kind of learning is not so easily transferred. This less transferable learning would include start-up or training expertise required to do a task, manual dexterity ('learning by doing'), and undocumented tricks or shortcuts that workers might not even be able to articulate.

Commonality of Variants. The original vision of the JSF programme included the cost advantages of having three variants of a single aircraft meet the needs of multiple services rather than having each service pay for separate development and production programmes. Commonality among the variants is expected to save significant design and production costs (and perhaps maintenance costs for the life of the aircraft). For the production costs specific to FACO, these benefits should also apply.

To represent the effect of the commonality among the three variants, labour requirements are calculated in the model by a combination of a common and a unique learning curve. In this analysis, 'cousin' aspects of commonality are treated as 'common' because the assemblies are similar enough to allow for learning transfer among cousin parts.[11] In particular, while cousin parts might have internal differences that affect cost during the fabrication or subassembly process, the interface properties of cousin assemblies and parts are close or identical. Therefore, the shared learning among variants is expected to be high for FACO activities.

As described in Cook et al. (2002), we can use the following functional form of the learning curve, which includes transfer of learning and variant commonality effects.

$$T_j(n_{j,i}) = T_j(1)\left\{\theta_j \gamma n_{j,all}^{\frac{ln(slope)}{ln(2)}} + (1-\theta_j)\gamma n_{all,all}^{\frac{ln(slope)}{ln(2)}} + \theta_j(1-\gamma) n_{j,i}^{\frac{ln(slope)}{ln(2)}} + (1-\theta_j)(1-\gamma) n_{all,i}^{\frac{ln(slope)}{ln(2)}}\right\} \quad (2)$$

Here, j is the index of variant and i is the index of location, $n_{all,all}$ is the cumulative number of units produced of all variants at all locations, $n_{j,all}$ is the cumulative number of units produced of variant j at all locations, $n_{all,i}$ is the cumulative number of units produced of all variants at location i, $n_{j,i}$ is the cumulative number of units produced of variant j at location i, $T_j(n_{j,i})$ is the number of hours for unit $n_{j,i}$, and $T_j(1)$ is the number of hours for the first unit of variant j, assumed to be location independent.

The constant θ_j is the work fraction that is unique for the variant j. We based the values for θ_j on commonality values for the airframe as provided by the programme office. Values of θ_j are 0.133 for CTOL, 0.481 percent for CV, and 0.344 percent for STOVL.

The constant γ is the fraction of learning that can be transferred between sites. Determining a reasonable value for γ is problematic.

[11]Common parts are exactly the same among variants. Unique parts are completely different—the STOVL lift fan, for example. Cousin parts are similar in shape and size but may vary slightly. Thicker spars for increased strength on the CV are one example.

Learning curve analysis has been typically done at an aggregate level where the cause and effect of the efficiency improvements have not been isolated. One analogy for learning transfer is the case where a gap in production occurs, with a stop and restart in the manufacturing line. We use the percentage of learning that was retained after a production restart as a surrogate. The production restart situation has been thoroughly studied (Andelhor, 1969; Birkler et al., 1993). The restart cases essentially represent an extreme in the transfer of learning. That is, when production is restarted, all of the learning benefit stemming from the workers becoming more efficient will have disappeared. The efficiency gains caused by methods improvements should have been captured in the processes used to analyse and implement engineering changes. Recasting the data slightly from that reported in Birkler et al. (1993), we find that on average 64 percent[12] of the overall learning (in hours) is retained for production labour, with a range of 30 percent to 88 percent. We do present a sensitivity analysis of key results to the value of γ. The cost model assumes that improvements in production efficiencies transferred between sites are delayed by one year.

Indirect Costs (Burden). Indirect costs include overhead, G&A expenses, and other components of indirect cost listed later. Overhead costs, the larger of the first two, are costs related to fabrication and assembly activities that cannot be allocated on a direct basis to a particular product for reasons of either practicality or accounting convention. Overhead includes the costs of fringe benefits, indirect labour, depreciation, building maintenance and insurance, computer services, supplies, travel, and so forth (DSMC, 2001). G&A expenses relate more to the company as an entity and may not relate to activity levels at only one plant. The G&A expenses include general business costs, such as executive salaries, human resources costs, and the costs of such staff services as legal, accounting, public relations, and finance.[13] G&A costs are generally incurred and

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[12]Percentage of learning retained is defined as follows: $\frac{T(1) - T(R)}{T(1) - T(L)}$,
where *T(1)* is the hours for the first unit, *T(R)* is the hours for the first unit after restarting, and *T(L)* is the hours for the last unit before the production break.

[13]Contract Pricing Reference Guides, Volume 4—Advanced Issues in Contract Pricing, Chapter 2—Evaluating Indirect Costs, Department of Defense Procurement website, http://www.acq.osd.mil/dp/cpf/pgv1_0/pgv4/pgv4c2.html.

accounted for at a corporate level, whereas overhead is a site-specific cost.

While these indirect costs are related to and vary with the total direct labour for a site, the relationship is not proportionate. Indirect costs include both fixed and variable components. As the number of direct labour hours at a site increases, the overhead and G&A rates decrease because the fixed costs are spread over a greater number of hours. To represent the relationship between direct hours and the indirect cost rates at site *i*, we use the formulation

$$rate_i = A_i \big/ TotalHours + B_i, \tag{3}$$

where $rate_i$ is the indirect rate, and A_i and B_i are constants.

To estimate these constants for each site, we surveyed them concerning rate information and the sensitivity of those rates to changes in labour base. Each UK site provided the sensitivity of their total wrap rate. Therefore, we were unable to break down these indirect costs into more detail. However, we were able to determine the constants A_i and B_i for each by fitting the data they provided (the FY 2003 rate at several hypothesised labour hour levels) to Equation (3).[14]

By using the current indirect rate information from each of the sites, we assume that no significant changes to the site or its business structure occur. This assumption is very tenuous because changes to what each site will be producing over the next decades are almost inevitable. It is impossible to predict what these changes might be over the UK JSF production period, which does not even begin until FY 2008. The potential FACO sites did provide a workload forecast for the next few years.[15] We have assumed a flat workload after the last year that each site provided. This is the best estimate possible at this time.

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[14]We are not able to present the results of this analysis due to its proprietary nature.

[15]We have assumed that all the FACO work for a given FY lot is completed in one calendar year. FACO is expected to take only about 40 days, so overlap would be relatively insignificant. However, there is an offset of two years between the fiscal year (year of purchase) and the year that FACO activities complete for the lot.

The FACO activities for JSF will also change the fixed component of overhead for the sites.[16] For example, some new facilities will be necessary, which will lead to additional depreciation charges, corporate taxes, and property taxes. For the changes to the fixed components of indirect costs caused by FACO, we calculate each item explicitly and add it to the overhead costs (from Equation (3)) to determine a new effective overhead rate. These explicitly modelled components of overhead are:[17]

- facilities depreciation and maintenance,
- corporate profit taxes,
- property taxes, and
- additional power costs.

Because increasing the workload at a site typically lowers indirect rates, there is a cost benefit to other work located at a JSF FACO site. The increased workload will decrease the allocated indirect costs to other programmes. We calculate the indirect cost change for these other programmes as the difference between rates with and without the FACO activities, multiplied by an average direct wage rate and the number of forecast hours for the other work.

JSF component-related costs are also influenced by changes in indirect rates. Lockheed Martin and BAE SYSTEMS will produce their respective components using the same overhead pool under which JSF FACO will be done. Thus moving FACO activities away from Lockheed Martin's Fort Worth plant will increase the component costs for the forward fuselage and wings. Similarly, moving FACO work to BAE SYSTEMS will affect the component costs for the aft fuselage and tail sections.

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[16]The formulation of G&A expenses is assumed to be unaffected by FACO activities. That is, the fixed portions of G&A costs do not change when FACO work is added.

[17]In our initial study of U.S. JSF FACO alternatives (Cook et al., 2002), we examined some additional overhead components. The additional components were mostly tax credits or new hiring costs. For this study, none of the sites had appreciable tax credits nor did we estimate that any of the facilities would need to hire a significant number of new workers.

Facilities, Equipment, and Tooling Costs. To undertake FACO and MR&U activities for the JSF, a site will need a variety of facilities, equipment, and tooling investments, which have been described in Chapter Three. We have grouped the discussion of these cost components together because they are treated very similarly in the model. The major difference between the items is who owns them, government or contractor. There are two types of investments:

- Contractor-Owned: These investments are not specific to the JSF programme—i.e., they could be used for other aircraft production programmes. An example of such an investment is a paint facility. Contractor-owned facilities, equipment, and tooling are typically subject to property and sales taxes. Cost recovery for these items is through depreciation and cost of money components of overhead. Generally, facilities fall into this category.
- Government-Owned: These investments are specific to JSF activities. An example of a government-owned investment is unique tooling used for JSF work. Government-owned items are not subject to tax. The government generally reimburses the contractor in full for these investments. Typically, equipment and tooling fall into this category.

The investment cost at each site is modelled as a function of the rate of production (the FACO rate) and the rate of MR&U depot induction at the site. For example, the manufacturing floor space required will increase as the annual production or repair rate increases.

We used three steps to determine investment costs.

- Determine requirement—The investment requirement is based on a weighted sum of FACO production and MR&U induction each year, with the weight on FACO being one. The weight on MR&U induction then indicates the use of the investment item per MR&U induction relative to the use per FACO production. For example, an MR&U weight of two means an aircraft going through MR&U uses the investment item for twice as much time as an aircraft undergoing FACO does. MR&U weights for each MR&U process level are shown in Tables 4.2 and 4.3.

Using both the FACO and the MR&U rate, we determine the required level of investment at a site. The rate dependence of demand for these items is modelled as a step function. Lockheed Martin provided these rate dependencies for FACO. For a value between two steps, the requirement is linearly interpolated. The step function can have an arbitrary form, including having only one step. For example, a STOVL pad is a requirement for each facility where FACO or MR&U activities for that variant will take place. One pad is sufficient to handle the highest total annual rate now planned for that variant.

- Determine facilities/equipment/tooling already available—Some sites might have existing infrastructure not currently being used and not set aside for other work, so a particular investment might be reduced or not needed at all. This step determines the *usable* facilities, equipment, and tooling existing at a site. This information was obtained though surveys submitted to the sites and through follow-on data collection with the sites.
- Calculate cost of needed investment—If the requirement exceeds what is already available, the site will need to make an investment. We estimated the cost of such investment based on existing information on such factors as dollars per square foot, dollars per unit, etc. Lockheed Martin provided most of this investment cost information.

Where equipment and tooling differs from facilities investments is in the timing of the investment. For equipment and tooling, the investment occurs incrementally—that is, the investment occurs when needed. For facilities, investment occurs in full up front. This difference arises from the fact that facilities investments are generally less expensive when planned and completed at one time. Also, some facilities might require a significant lead time to complete.

Three other variables are calculated along with the investment costs: depreciation, residual asset value, and operations and maintenance costs. Depreciation is tracked because it is an allowable overhead expense for contractor-owned items. Therefore, adding contractor investments to a site will increase the overhead rate through increased depreciation.

All the locations examined have property taxes on manufacturing facilities.[18] Therefore, the residual asset value must be tracked for a new contractor-owned investment to estimate the property tax implications (property tax itself is an allowable cost charged to the MOD). The residual value for a contractor-owned investment is also tracked to calculate the appropriate facilities cost of money, which is part of overhead. Each year, the residual asset value for these FACO-specific contractor-owned facilities is multiplied by the cost of money rate (where applicable) to determine the Facilities Capital Cost of Money (FCCM) charge. We assume that the cost of money rate is 4.25 percent[19] for the United States and 0 percent (not an allowable charge) for the UK sites.[20]

Some investments might require significant annual maintenance or result in significant operating expenses. An example of such an investment would be a thermal oxidiser for pollution control of VOCs. These units require a significant amount of natural gas to operate and are expensive to maintain. In these cases, the annual level of operations and maintenance cost is modelled as a function of the size of the facility or investment.

Another consideration for the operating cost of the facilities is electrical power consumption, which is typically an indirect cost charged through overhead. We have estimated the additional power costs arising from FACO activities. The estimate has two components. The first component is a general facility demand based on square footage of manufacturing space. The power estimate for this purpose is 31.2 kWh/ft^2/yr, which is independent of the annual production rate. (This power is mostly for lighting, heating, and air conditioning, so the power usage is based on facility size.)

The second component of power cost depends on the annual FACO and MR&U rate, consisting of the power for high draw equipment needed for FACO and MR&U activities. This equipment includes run stations, the fuel facility, the paint facility, and LO testing equipment.

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[18]As stated elsewhere, we have assumed that DARA becomes a commercial entity by the time JSF FACO work begins. Therefore, it would be subject to these taxes.

[19]This is the current (2003, January–June) cost of money rate as published by the U.S. Treasury (http://www.publicdebt.treas.gov/opd/opdirsemi.htm).

[20]Per "Appendix to Ministry of Defence Guideline for Industry No. 16," 1999.

Each piece of equipment has a fixed power usage per year per station, if run at full capacity. Each station is assumed to operate at full capacity or not at all. The number of stations assumed to operate in a year depends on the number of JSF aircraft undergoing FACO or MR&U. For example, a total of eight paint stations might be at a site, but only six may be needed because of workload. Lockheed Martin was unable to determine the power usage, at this time, for each of these facilities. As an approximation, we used the same average power usage per square foot for these items as for manufacturing floor space.

To arrive at a power cost, the added power demand for the year is multiplied by the site's power rate ($/kWh). We assume that the power rates remain stable (in constant dollars) over the production run because it is very difficult to forecast future utility prices. Each contractor provided the appropriate rates for their site.

Table 4.2 summarises the contractor-owned investments tracked along with the cost scaling approach, the specific depreciation and cost methodology used, the variants whose production requires these assets, and the MR&U scaling factor. Table 4.3 summarises similar information for the government-owned investments. Because these items are not depreciated and are general to all variants, depreciation method and variant requirement are applicable and thus are not listed.

Transportation. Typically, the majority (50–70 percent) of the value of any aircraft is produced by subcontractors and then incorporated into the aircraft by the primary assembler (Cook and Graser, 2001). In the case of the JSF, the prime contractor's contribution is even lower than that average. Lockheed Martin estimates that it will have an 18 percent share of the total production value. Much of the material, purchased equipment, and major subassemblies for the production of the JSF are manufactured at locations other than Fort Worth and must be shipped to the FACO site. The major aircraft components that must be available to each FACO site include

- forward fuselage,
- centre fuselage,
- aft fuselage and tail,

- wings,
- edges,
- doors,
- weapon bay doors,
- engines, and
- radar.

Table 4.2

Investments Required for FACO (Contractor-Owned)

	Cost Factor	Depreciation Type[a]	Variants	MR&U Scaling Factor[b]
Manufacturing space	$/sq ft	Plant/hangars/storage	All	1.2, 2, 4
Flight ops run stations	$/unit	Plant/hangars/storage	All	1
Paint facility building	$/sq ft	Plant/hangars/storage	All	1
Robotic paint equipment	$/unit	Cranes/other equipment	All	1
Paint pollution control	$/unit	Cranes/other equipment	All	1
Storage area	$/sq ft	Plant/hangars/storage	All	1.2, 2, 4
Administration space	$/sq ft	Plant/hangars/storage	All	1
LO verification building	$/sq ft	Plant/hangars/storage	All	1
LO turntable	$/unit	Cranes/other equipment	All	1
Runway arresting gear	$/unit	Cranes/other equipment	All	1
Fuel barn	$/sq ft	Plant/hangars/storage	All	1
270V power transformer	$/unit	Cranes/other equipment	All	1
Hover pit	$/unit	Cranes/other equipment	STOVL	1
Hover pad	$/unit	Cranes/other equipment	STOVL	1
HVAC[c]	$/sq ft	Plant/hangars/storage	All	1.2, 2, 4
Building refurbishment	$/sq ft	Plant/hangars/storage	All	1.2, 2, 4

[a]The U.S. depreciation rates for these categories come from *IRS Pub 946,* Chapter 3. For the UK we assumed a uniform 4 percent depreciation for all items except 'cranes/other', which follow the UK's Enhanced Capital Allowance (ECA) scheme guidelines of a 25-year declining balance with 25 percent in the first year.

[b]For a light, medium, or heavy MR&U requirement.

[c]HVAC = heating, ventilation, and air conditioning.

Table 4.3

Investments Required for FACO (Government-Owned)

Item	Cost Method	MR&U Scaling Factor[a]
Hydraulic test system—aircraft level	$/unit	1
Laser trackers	$/unit	0, 0, 1
Surface finish and appliqué testing	$/unit	1
General-purpose test equipment	$/unit	1
Avionics diagnostic equipment	$/unit	1
Mate alignment tool	$/unit	0, 0, 1
Dollies and stands	$/unit	1.2, 2, 4
Support equipment	$/unit	1
Maintenance test equipment—direct	$/unit	1

[a]For a light, medium, or heavy MR&U requirement.

Changing the FACO location will change transportation costs. For example, Lockheed Martin plans to build the components that it is responsible for, including the wings and forward fuselage, at its Fort Worth facility. If Fort Worth is the FACO site used by the MOD, these items will have no transportation costs. For FACO sites in the UK, these items will need to be shipped to the final assembly location.

Lockheed Martin plans for truck delivery of all components manufactured in the United States to Fort Worth. For non-U.S. sources, we assume that these items are transported by container ship to a common port. From that port, the items are trucked to Fort Worth. If FACO activities occur in the UK, we assume that most of the components will be transported by container ship to a UK port and then trucked to the FACO facility. The exception, of course, is the aft fuselage and tail, which is manufactured at BAE SYSTEMS and can be trucked within the country. (Other, smaller items are manufactured in the UK and in other countries, but the cost of shipping these is not separately estimated.)

For the shipping costs of the major components to Fort Worth, we used the values provided by Lockheed Martin from the earlier study (Cook et al., 2002). For shipping costs to the UK sites, we used a combination of data provided by Lockheed Martin and BAE SYSTEMS for transatlantic transportation costs. These transportation costs were approximately $\$9/ft^3$.[21] We used this value in our study. It is higher than one might find for commercial container shipping costs, but it also includes crating and preparation charges, trucking charges, and some modest security costs.

Another transportation cost that must be considered is the cost to ferry the completed UK aircraft to the acceptance site. It has not yet been determined whether the aircraft would be accepted in the United States and either flown or shipped to the United Kingdom or accepted in the United Kingdom. Both outcomes are possible. In this analysis, we assume that aircraft are accepted in the United Kingdom and that aircraft completed in the United States will be flown across the Atlantic. However, aircraft completed in the United Kingdom could be accepted at the site of final assembly and would incur minimal transportation costs to their destination. Therefore, transportation costs are higher for aircraft assembled in the United States compared with those assembled in the United Kingdom. We will address these higher costs.

As an estimate for these ferrying costs, we assumed the following:

- Aircraft would be flown in flights of four to the United Kingdom.
- U.S. pilots would fly the aircraft.
- The planes would be accompanied by a KC-135R for refuelling.
- JSF fuel consumption rate is 1,052 gallons per hour.
- The flight distance between the United States and the United Kingdom is 4,800 nautical miles.

We obtained costs for the pilots and KC-135R flying hours from the Assistant Secretary of the Air Force (Financial Management and Comptroller) website.[22] Combining all these data, the average costs to ferry an aircraft across the Atlantic is approximately $31,000/aircraft.

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[21]Our research on shipping costs showed that for parts similar to these, costs are dominated by packing volume rather than weight.

[22]http://www.saffm.hq.af.mil/.

Taxes. Taxation issues are complicated, often requiring experts to resolve different interpretations of tax law. It is not feasible within the bounds of this report to examine all the possible tax implications. As a simplification, the cost model incorporates two kinds of taxes: corporate profit taxes and property taxes. For the sites under consideration, there are no substantial tax credits or incentives.

Corporate taxes are payments made to governments for operating a revenue-generating entity. In the United States, corporations are subject to both federal and state (franchise) taxes of this type. In the United Kingdom, the corporations pay an overall tax to the government. We assume that the tax differences arising from alternative FACO strategies are equal to the corporate income tax rate times the fee associated with FACO. Extremely detailed financial data from each of the sites would be required to do the tax calculations more precisely. (The additional accuracy of cost estimates did not justify this level of resource expenditure in the study.) For the United States, the overall corporate tax rate is 39.5 percent (35 percent federal and 4.5 percent state). For the United Kingdom, this tax rate is 30 percent (the highest corporate tax bracket).

Property tax calculations are straightforward compared with corporate tax calculations. These taxes are levied by local councils in the United Kingdom and state governments in the United States. As discussed above under the 'Investments' subhead, the model tracks the residual asset value (original cost minus accumulated depreciation) of FACO property over the analysis period.[23] Property taxes are calculated as the product of residual asset value and the property tax rate. For the United Kingdom, the council property tax is actually based on 'Rateable Value' and not strictly the asset's net value. As an approximation, we assume that the council tax is 4 percent of the residual asset value.[24] We note again that this calculation is applicable only for contractor-owned investments, not the tooling and equipment owned by the government.

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[23]As a simplification, we have used a common set of depreciation schedules for all sites based on IRS rules for U.S. facilities. For the United Kingdom, we use a uniform 4 percent depreciation except for the category 'cranes/other'. The cranes/other category follows the ECA guidelines for accelerated depreciation using a 25-year declining balance with 25 percent depreciation for the first year.

[24]40 percent (tax rate) $\times$ 10 percent (rateable value to residual asset value ratio).

There are two other important taxes in the UK that we do not include in our cost estimates: value-added tax (VAT) and import duties. In our conversations with personnel from the UK sites, they judged that JSF FACO activities would not be subject to VAT. However, they were all careful to add a caveat to this statement by saying that they are not VAT experts and that the answer is uncertain. In this report, we assumed that VAT would not apply to JSF FACO. The site personnel also expressed the view that import duties would not apply to either whole aircraft or components. Again, they were careful to state that their opinion was not based on an in-depth knowledge of the rules. In any case, any duties that might be collected would pass through to the UK government (although they would represent an additional cost for the IPT). These duties would, in essence, be transferring money from the IPT back to the treasury. We have assumed for the analysis that the import duties are not applicable.

Fee. Fee represents the 'profit' earned by contractors on the cost of the work they perform. Typically, the fee is negotiated between the government and the contractor beforehand. To determine a total price, we apply a fixed fee to the direct labour, support labour, and indirect costs. We assume that transportation costs and tooling and equipment costs are passed directly through to the customer (i.e., with no fee added) with the administration expenses associated with those purchases already included in the indirect rates.

Lockheed Martin and Supplier Support Costs. Having multiple FACO locations will result in additional management, oversight, travel, and communications efforts by Lockheed Martin and its suppliers. To estimate these costs, we assumed that a fixed number of dedicated prime contractor management and supplier representatives will be on site to assist the FACO activities at any non–Fort Worth location. The estimate in the model is that 13–28 full-time equivalent (FTE) representatives[25] would be required, including both Lockheed Martin and supplier employees, per year for the first two years of production and then five FTEs per year thereafter. These values were based on information Lockheed Martin provided on its experience in supporting FACO work on other programmes outside

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[25]The exact number for each site depends on its familiarity with fighter aircraft and the JSF programme.

the United States. The additional FTE requirement for the first two years stems from the additional set-up, information transfer, and training burden. To arrive at an estimate of the effect of the support costs for the site, the total FTE value was multiplied by an estimated cost of $150,000 per FTE (fully burdened) times a location factor adjustment (cost of living) of 1.4 (a net result of $210,000/FTE).

Royalties/Licencing Fees. Lockheed Martin has generally charged a licencing fee for setting up FACO facilities outside the United States and has indicated that its expectation would be to charge such a fee for alternate JSF FACO sites. We expect this would be true even if Lockheed Martin had overall responsibility for FACO conducted at another organisation's facility, as compensation for technology transfer, for example. However, Lockheed Martin did not provide an estimate of the costs of such a fee. As an approximation, we assumed that the company would charge $170,000 per aircraft. This number is approximately the lost fee resulting from moving FACO activities from Fort Worth to the UK. Realistically, this value is subject to negotiations and could be much higher or lower than we assumed. We explore the sensitivity of the results to this value in Chapter Five. It should be noted that support from Lockheed Martin is critical to the success of a UK FACO line.

Chapter Five

RESULTS OF COST ANALYSIS

INTRODUCTION

This chapter presents our estimates for the cost implications of shifting FACO production to the United Kingdom and the effect of creating a dual-use facility for both FACO and airframe depot-level MR&U in the United Kingdom. This analysis employs the cost model described in Chapter Four to quantify the differences between the baseline plan (FACO of UK aircraft at the Lockheed Martin facility in Fort Worth) and alternative FACO and MR&U facilities combinations in the United Kingdom.

We provide the initial estimates of the cost of performing JSF FACO in the United Kingdom. We then test the sensitivities of our results to critical inputs, including additional quantities, varying MR&U workload, different levels of learning transfer, different royalty fees, and variation in exchange rates. We also perform a Monte Carlo analysis, allowing uncertainty in a number of the key parameters.

To protect the business sensitivity of the cost data, we present our results as the *incremental* cost of assembling the JSF at a UK location compared with the same aircraft assembled at Lockheed Martin's Fort Worth plant. In other words, 'How much *more* will a UK FACO line cost the United Kingdom?' (Note that the baseline costs for FACO of the UK aircraft in the United States are approximately £112 million [FY 2003].[1]) This difference can be determined by comparing

[1]This value encompasses several assumptions, including a constant exchange rate of $1.61 = £1, which is based on an annual average from the past 16 years.

estimates of the FACO portion of the work done in Fort Worth and the United Kingdom, including how moving that work affects certain other costs (described below).

CALCULATING COST DIFFERENCES OF UK ALTERNATIVES

In the current JSF programme baseline, FACO is performed in the United States at Lockheed Martin's Fort Worth facility. There is either no depot-level MR&U or it is done outside the United Kingdom, perhaps at a regional support facility in another European country or even in the United States. The calculation of the cost of doing the FACO work for UK aircraft in the United Kingdom instead of the United States is relatively straightforward. First, the total costs for performing FACO for 150 JSF aircraft at Fort Worth are subtracted from the total costs of establishing and performing JSF FACO at a UK location. Then, the cost impact (positive or negative) on other programmes at both locations is calculated and added to the first result. The effect on other programmes is the result of increased investment at the United Kingdom location and different workloads at the two locations, which affect indirect rates. 'Other programmes' that will be affected include both JSF components and other (non-JSF) MOD work.

Calculating the incremental costs of alternatives involving MR&U conducted at the same UK site as FACO is more difficult because no baseline MR&U programme has been defined against which UK costs can be compared. In our analysis of these alternatives, we add the costs and workload of MR&U to selected UK locations and assess the differential cost effects for MR&U against the forecast workload at each location.

There are three possible approaches or assumptions for looking at the establishment of a JSF FACO facility in the United Kingdom:

A. FACO Only—A FACO facility is established in the United Kingdom independent of an MR&U facility. This is also the case where there is negligible MR&U work for the JSF. We present an estimate of a FACO-only facility because this represents the most conservative baseline for making the decision to move FACO (essentially a scenario with no shared investments or overhead between FACO and MR&U).[2]

B. Combined Facility—Both FACO and MR&U are done for the JSF at a combined facility in the United Kingdom. Initially, the facility produces the JSF and eventually transitions to an MR&U facility. Therefore, FACO investments could be reused for MR&U, reducing the cost of MR&U activities.

C. FACO Added to an Existing JSF MR&U Facility—FACO activities are added to a planned and fully funded UK JSF MR&U facility. This alternative assumes that common facilities, equipment, and tooling could be acquired earlier than needed for MR&U work; thus enabling FACO activities. This scenario is somewhat contrived because it reflects neither the actual sequence of decisions that would have to occur nor the way that the money would be spent. The FACO facility would have to be established *before* the maintenance depot.

The main difference between the last two assumptions (B and C) is the baseline against which the incremental costs are calculated. The baseline for B does not include any UK work. The incremental costs for assumption B include the total cost effects from putting a combined FACO and MR&U facility in the United Kingdom. The baseline for approach C already incorporates the costs of an MR&U facility. The incremental costs for C include only the cost effects of moving FACO to an existing MR&U facility. However, the total cost to the United Kingdom for FACO and MR&U activities is the same in both cases. It is just the baseline that shifts. In other words, the MR&U investments for C are treated as 'sunk costs'.

This analysis focuses on the cases where FACO and MR&U are done in the same facility in the United Kingdom. However, after investing in FACO, the MOD may later choose to have locations compete for MR&U. This could result in a split in which FACO is done in one

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[2]While each alternative has its strengths and weaknesses, those where MR&U is done outside the UK may be less desirable from a strategic point of view because the UK will not have full control over the maintenance and repair of its own aircraft. Putting both FACO and MR&U in the UK would give the UK MOD more control over the MR&U process, increase the domestic industrial base, and provide more comprehensive access to the JSF technologies.

location and MR&U at another or where FACO and some MR&U is done in one location and the rest of MR&U in another.[3] We do not evaluate these alternatives from a cost perspective because such an analysis is beyond the scope of this report. A qualitative discussion of the advantages and disadvantages of collocating FACO and MR&U can be found at the end of Chapter Two.

We assume that the process used for FACO in the United Kingdom would be identical to the process in Fort Worth. The base hours (T1s) and efficiency improvements (learning slopes) would be the same. Also, the facilities, tooling, and equipment required would be the same as those required in Fort Worth with some adjustments for local environmental regulations.

COST ELEMENTS

As stated in the previous chapter, one of the goals of this work is to quantify the budget implications to both the FJCA IPT and the MOD. Another economic perspective on the cost and budget implications of a decision to change the FACO location could focus on the overall effect of such a strategy to the United Kingdom as a whole. For example, locating a FACO facility in the United Kingdom would establish domestic aerospace manufacturing jobs there. These jobs would enhance the longer-term skills of the United Kingdom workforce and thereby help keep UK firms competitive for other, similar work. Furthermore, these jobs could create local investment and improvement. Both of these items could lead to increased tax revenues and potentially reduced government outlays for unemployment and regional assistance. To the extent workers in jobs are simply transferred from other industries who then lose some competitive advantage because their better workers are gone, these advantages are reduced and could be reversed. Thus, the creation of a UK facility will have broader effects than from a solely military budget perspective. But quantifying these is extremely difficult, requiring complex economic models. Such an analysis is beyond the scope of this report. We focus on the more tractable issue of examin-

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[3]The benefits from MR&U competition may offset some of the costs of having redundant facilities at two UK sites. However, a cost analysis of this is beyond the scope of this report.

ing the direct MOD budget implications of FACO in the United Kingdom. Nonetheless, the reader should be aware of these other potential effects.

In the prior chapter, we discussed our definition of the term 'budget'. To recapitulate, moving the JSF FACO work for the UK aircraft will affect more than just the costs for FACO activities. All the potential UK sites we examined will have other MOD work under way. Furthermore, one of the sites, BAE SYSTEMS, will be producing major subassemblies for the JSF. Moving FACO work to any of the UK sites will change the total indirect costs for the facility and, therefore, change the cost of doing other work. To capture the full effects of moving the FACO work we examine the cost differences of four cost elements associated with the MOD budget:

- FACO—This element includes all the costs for FACO activities of the United Kingdom's JSF aircraft as described earlier. These costs include direct labour, overhead, royalties and fee, tooling, component transportation, and contractor support. Material and equipment costs are not included because they would be the same for any location.
- MR&U—These costs entail the costs to undertake MR&U activities. These costs include direct labour, overhead, and tooling. Material and equipment costs are not included.
- JSF Components—These costs are related to the JSF components made at one of the sites possibly doing FACO work on UK JSF aircraft. These items are the forward fuselage, aft fuselage, and tails. The costs include direct labour, overhead, and fee. Transportation costs are covered in FACO costs. Material and aircraft equipment costs are not included.
- Other (non-JSF) MOD—These costs are for the other MOD work ongoing at a site, except other JSF work. Examples of this type of work are MR&U for other aircraft, new aircraft production, and other miscellaneous support. These costs include direct labour, overhead, royalties, and fee. Material and aircraft equipment costs are not included.

Note that these items do not uniquely correspond to a specific MOD or IPT budget. The first three items would all be part of the JSF IPT budget costs over the programme life cycle or the operations budget for the UK military. The last item could be part of several budgets, such as the Typhoon and other aircraft support and maintenance programmes (depending on the site). We chose this cost breakdown to include all of the effects of moving FACO to the UK. The results presented are not intended to be specific budget ‘adjustments’.

A limitation is that we are not able to fully assess the costs for the second item, MR&U. The maintenance philosophies and plans for the JSF are not yet defined well enough to figure these costs fully. Furthermore, the current maintenance philosophy is significantly different from the historical experiences of other programmes. Thus, using the historical costs for airframe depot maintenance is of limited value. The MR&U non-labour costs we account for are those that overlap with FACO, namely facilities, tooling, and equipment.

BASELINE ASSUMPTIONS

As described in Chapter Four, there were numerous inputs to the cost model. For our baseline analysis, we employed the following assumptions (and later relaxed them as part of a sensitivity analysis):

- Only 150 UK STOVL aircraft are assembled, with no additional JSF FACO work.
- MR&U depot work for JSF is moderate.
- 64 percent of all learning is shared between U.S. and UK sites (with a one-year lag).
- The long-term exchange rate is $1.611 = £1.
- Costs are reported as FY 2003 £.

THE COST DIFFERENCE BETWEEN ALTERNATIVES

Using the model described in Chapter Four, we compare the specific incremental costs of doing FACO and MR&U in the United Kingdom versus the costs of the programme baseline (where FACO is performed in the United States and there is either no MR&U or MR&U outside the United Kingdom) for the four cost items in Table 5.1.

Table 5.1

Incremental Cost for a Combined UK FACO and MR&U Site Minus Baseline of All Work Outside UK—Assumption B (FY 2003 £)

Cost Element	Average Delta Cost (M £)
FACO	35.6
MR&U	–10.0
JSF components	1.4
Other MOD	5.7
Total	32.7

Note that we report the average cost differences for the three UK facilities resulting from business sensitivities and the proprietary nature of the results. Again, a positive number means that the alternative is *more* expensive (a cost penalty) than the baseline alternative (performing FACO in Fort Worth).

As anticipated, moving the FACO work from the United States to the United Kingdom increases costs, partially due to the fact that the facilities, equipment, and tooling costs are no longer shared with the U.S. JSF production. Further, the United Kingdom facility does not gain the same learning benefit that U.S. workers do.[4] The U.S. quantity of JSF aircraft is more than an order of magnitude greater than the United Kingdom's potential purchase of 150. As described in Chapter Four, we include the increase in certain other costs from FACO in the United Kingdom, such as overseas support from Lockheed Martin and suppliers, along with royalties or licencing charged by Lockheed Martin. Certain increases in costs are somewhat mitigated by the fact that fully wrapped labour rates for the aerospace sector are lower in the United Kingdom.

Note that the incremental MR&U costs *decrease* for this assumption. This decrease results from the reuse of the FACO facilities for MR&U. The cost of other MOD work increases because of additional costs for the FACO and MR&U facilities, which are spread across overhead for

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[4]As discussed in Chapter Four, we assume that some learning would be shared between the two FACO sites, but it is not 100 percent.

all activities at a site. Finally, moving UK FACO from the United States to the United Kingdom generally increases the JSF component costs the United Kingdom pays because Fort Worth performs a significant portion of the component work. (Moving FACO away from Fort Worth increases the cost of the components that Lockheed Martin plans to produce there stemming from an increase in its overhead rate because of less workload to absorb the fixed overhead costs.)

Table 5.2 shows the incremental costs where FACO is done in the United Kingdom, but at a FACO-only facility—assumption A. This is the difference in costs if JSF FACO is moved to the United Kingdom, without any consideration for MR&U costs. (Note that the cost differences for MR&U are zero.) The assumption is that MR&U activities are minimal, are performed at a non-UK facility, can take place at the O level, or are done by mobile support teams dispatched from a central JSF depot location. Thus, the United Kingdom may have to pay for MR&U, but the costs and investments for this work do not affect FACO costs. The cost of other MOD work increases because of the higher overhead rates caused by the JSF facility investments that are borne by all programmes at the FACO location.

Here, delta costs for FACO activities, other JSF components, and other MOD work are higher than when all work is done outside the United Kingdom. One interesting comparison between this and the analysis presented in Table 5.1 is that the delta cost increase for other MOD work is about half that when the FACO facility is combined with an MR&U facility. This results from reducing the overall over-

Table 5.2

Incremental Cost for a FACO-Only UK Facility Minus U.S. FACO—Assumption A (FY 2003 £)

Cost Element	Average Delta Cost (M £)
FACO	34.7
MR&U	0.0
JSF components	1.4
Other MOD	10.8
Total	46.8

head rate through an increased business base. The delta FACO costs are slightly *higher* for the combined facility. This stems from the increased facilities, equipment, and tooling burden from MR&U.

Given that depot MR&U costs are unknown, deciding whether to move FACO to the United Kingdom could be reasonably done without considering the MR&U costs. Based on Table 5.2, an estimate for moving FACO to the United Kingdom is approximately £47 million, or more than £312,000 for each of the 150 aircraft.

For the previous assumptions (A and B), we explored the cost differences between the baseline programme plan and two alternatives where JSF FACO is done in the United Kingdom. However, the MOD might approach the FACO decision assuming that the decision to perform MR&U work in the United Kingdom had already been made and the corresponding investments included in plans. The results are presented in Table 5.3.

What is immediately noticeable when comparing Table 5.3 to 5.1 is that the total cost delta is much lower. This difference is caused by the other MOD cost differences, which are *negative* for the case where an MR&U facility 'exists'. That is, once a decision has already been made to set up a domestic UK MR&U facility and those costs are incorporated into any resourcing plans (including an increase in other MOD costs because of increased overhead arising from the additional facilities for MR&U), the other MOD costs are then reduced through lower overhead rates generated by the addition of FACO. The additional facilities costs are spread over more labour

Table 5.3

Incremental Cost for Adding a UK FACO Facility Given an Already Planned and Budgeted MR&U Facility—Assumption C (FY 2003 £)

Cost Element	Average Delta Cost (M £)
FACO	35.6
MR&U	–10.0
JSF components	1.4
Other MOD	–14.1
Total	12.9

hours. We caution the reader that the full cost to the MOD is not lower for this path; just that the *marginal* costs of moving FACO to the United Kingdom are different because the baseline for each case is different. In one case the costs of MR&U are fully factored into the baseline, and for the other case they are not.

SENSITIVITY ANALYSIS

The previous analyses are based on a set of assumptions and estimates of certain information. While we have attempted to use reasonable and informed values (e.g., learning transfer percentage), these values are uncertain. To provide decisionmakers better information on the implications of these assumptions, we present in this section a sensitivity analysis of the average cost differences to certain input values. These inputs are

- production quantities,
- extent of MR&U workload,
- learning transfer percentage,
- royalty charge, and
- long-term exchange rate.

Finally, we end this section with a general uncertainty analysis.

Additional FACO Production

A UK site could perform FACO activities for more than just the aircraft that the MOD buys. For example, a number of European countries are participating as Level II and III partners in the JSF programme, as discussed in Chapter One. This leads to the question of how the results presented above change when the FACO workload is increased. In Chapter Four, we described notional profiles for possible additional FACO production at the United Kingdom site. The four scenarios are the baseline of +0 aircraft (150 total), +150 aircraft (300 total), +503 aircraft (653 total), and +1,000 aircraft (1,150 total). The additional aircraft include a mix of CTOL and STOVL variants, which will be assembled on the same production line.[5] Figure 5.1 shows the sensitivity of the total cost deltas to different quantities.

As one might expect, the incremental costs to the United Kingdom of having an organic FACO/MR&U site initially decline when additional production work is added to the UK site. The source of the decrease is increased efficiency through learning, and an increase in labour hours over which the costs of the investments are spread via the overhead rate.

However, as production increases, costs do not continuously decrease. At the lower FACO production rates, the facility, equip-

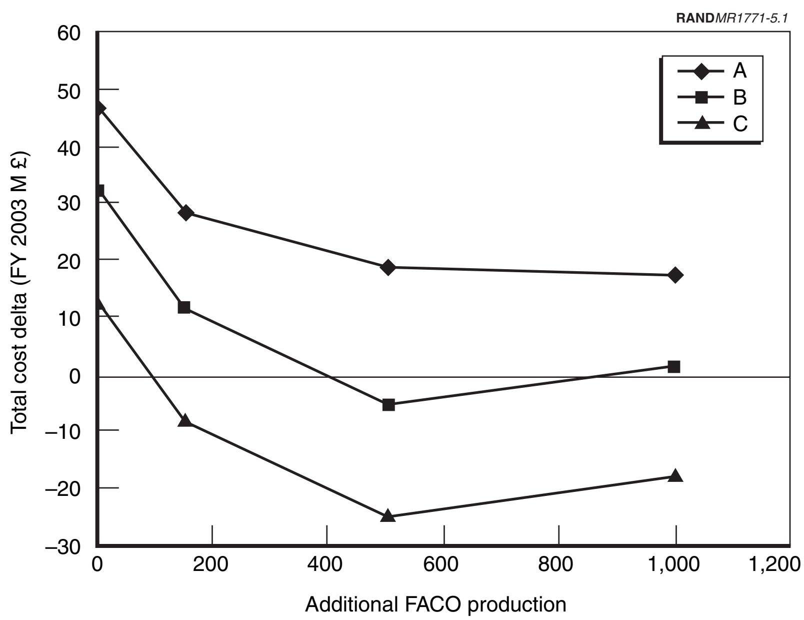

Figure 5.1—Sensitivity of Net Cost Delta to Additional Production at UK FACO Site

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[5]JSF programme goals include maintaining commonality among the different variants to achieve affordability in production. A single FACO line is also planned at Fort Worth.

ment, and tooling investments are driven by the rate at which aircraft enter the MR&U depot. The FACO facilities can be fully reused for MR&U work when FACO ends, thus requiring lower MR&U investment costs. Therefore, moderately increasing the FACO production rate does not increase these investment costs, and the incremental cost for the United Kingdom decreases through efficiency and sharing of the fixed costs over a greater production base. However, at a certain point, the requirements to meet the higher FACO quantities dominate the additional new investment required. At that point, MR&U and other costs increase as the facilities for FACO drive higher overhead rates, which are levied on all activities at the site. Furthermore, MR&U and other work must pay for additional depreciation and taxes on facilities that are not required for the level of MR&U work. Thus, the site is 'overinvested' for the level of MR&U work. These component deltas are shown in Figure 5.2 for assumption B.

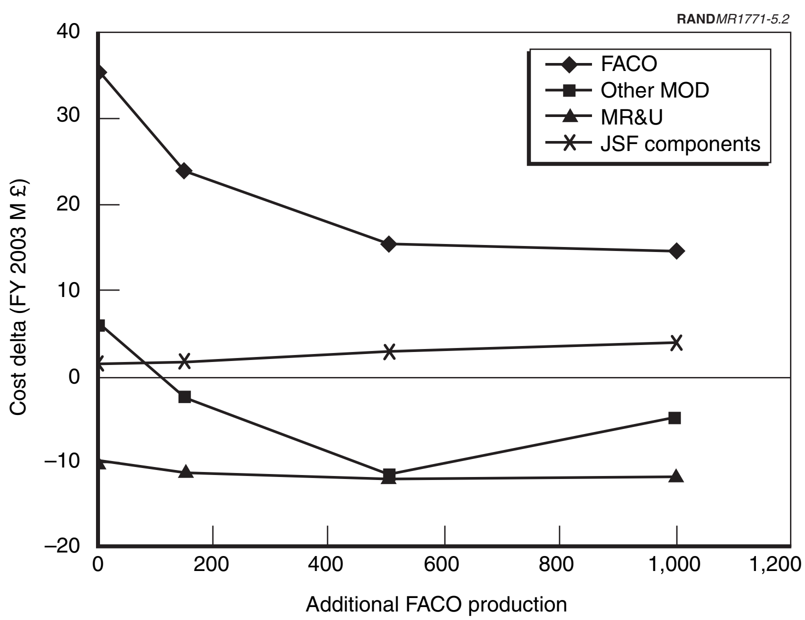


Figure 5.2—Cost Element Deltas for FACO and MR&U in UK Versus Baseline as a Function of Additional FACO Production for Assumption B

The important observation is that there may be some *optimal* level of production that a combined UK FACO and MR&U site could achieve. Some amount of added FACO production is beneficial by lowering costs, but too much creates overinvestment at a facility for which the other MOD and MR&U components must pay increased overheads.

This analysis assumes that Lockheed Martin always retains prime contractor programme and configuration control. We assume that any additional sales of UK-assembled aircraft must be made with agreement from the stakeholders. One possible scenario is that Lockheed Martin could turn to a second site for JSF FACO because of space constraints in the United States, especially if it allows earlier sales to countries outside of the original partnership group. Other JSF partner nations may appreciate this if it enables them to collect their levies on sales to other countries sooner. As described in Chapter One, these levies are aimed at collecting a fair share of the aircraft development costs from countries that did not help fund SDD.

Extent of MR&U Workload

As we have discussed in several places in this report, the airframe depot MR&U workload for the JSF is not fully defined, although Lockheed Martin and the JSF programme office hold the position that no programmed airframe depot work will be required for the JSF. Based on historical data from other fighter aircraft, it would be highly atypical if the JSF would need no airframe depot maintenance. For this report, we assumed that some regular airframe depot activity would be necessary. Our assumption has been that a 'moderate' level of MR&U will be needed for the JSF (as presented in Chapter Two). What if the MR&U workload changes to a 'light' or 'heavy' level? Table 5.4 shows the average delta cost for Path 1 with the three MR&U assumptions (light, medium, and heavy). Interestingly, the other MOD and MR&U costs decrease because of a reduction in overhead rates caused by a doubling of the MR&U workload.

Learning Transfer Percentage

In Chapter Four, we described an approach for modelling learning transfer between the FACO sites. As a proxy for the fraction of learn-

Table 5.4

Incremental Cost for FACO and MR&U in UK Versus Baseline (Assumption B) with Different MR&U Assumptions (FY 2003 £)

Cost Element	Mean Delta Cost (M £)		
MR&U Level	Light	Medium	Heavy
FACO	35.1	35.6	35.1
MR&U	–8.2	–10.0	–14.7
JSF components	1.4	1.4	1.4
Other MOD	7.1	5.7	–5.5
Total	35.3	32.7	16.3

ing transferred between sites, we used information based on production restarts. The baseline value we chose was 64 percent transfer. Figure 5.3 shows the sensitivity of the total cost delta for the total costs of moving FACO and MR&U to the United Kingdom to different assumptions of learning transfer. Not surprisingly, the cost delta increases as the learning transfer percentage decreases. That is, a higher cost penalty results from moving FACO work from the United States to the United Kingdom.

Royalty Charge/Licencing Fees

Lockheed Martin has indicated that it typically charges a licencing fee when other countries assemble its aircraft designs outside the United States. It did not provide any guidance as to the level of this fee and we were unable to obtain historical information on similar programmes. As an assumption, we used a royalty value that was based on an estimate of Lockheed Martin's lost profit when FACO work is removed from Fort Worth. We assumed $170,000[6] per aircraft. Of course this value would be subject to negotiation between Lockheed Martin and the MOD. In fact, other royalty arrangements could arise, including a lump-sum licencing fee. To explore the

[6]Because the value is based on Lockheed Martin's lost profit, we present the dollar figure. However, in the analysis, the numbers were converted to pounds.

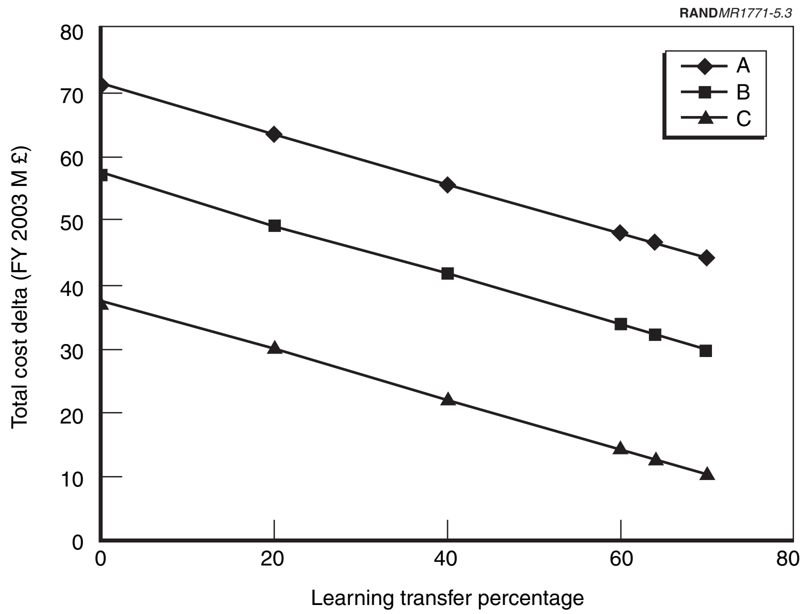


Figure 5.3—Learning Transfer Percentage Sensitivity Analysis

sensitivity of our results to the royalty assumption, we plot the total delta cost with royalty fees of $0, $85,000, $170,000, and $340,000 per aircraft. The results are presented in Figure 5.4.

The figure shows that royalties or licencing fees have major cost implications to which the United Kingdom MOD should pay careful attention.

Long-Term Exchange Rate

We have assumed an exchange rate of $1.611 per £1 based on an analysis of historical rates (as described in Chapter Four). The exchange rate will influence the cost delta as UK purchasing power increases or decreases relative to the dollar. A stronger pound (i.e., more dollars per pound) favours keeping FACO in the United States. In Figure 5.5, we show the total cost delta sensitivity to the exchange rate. We strongly caution the reader that the value shown is the

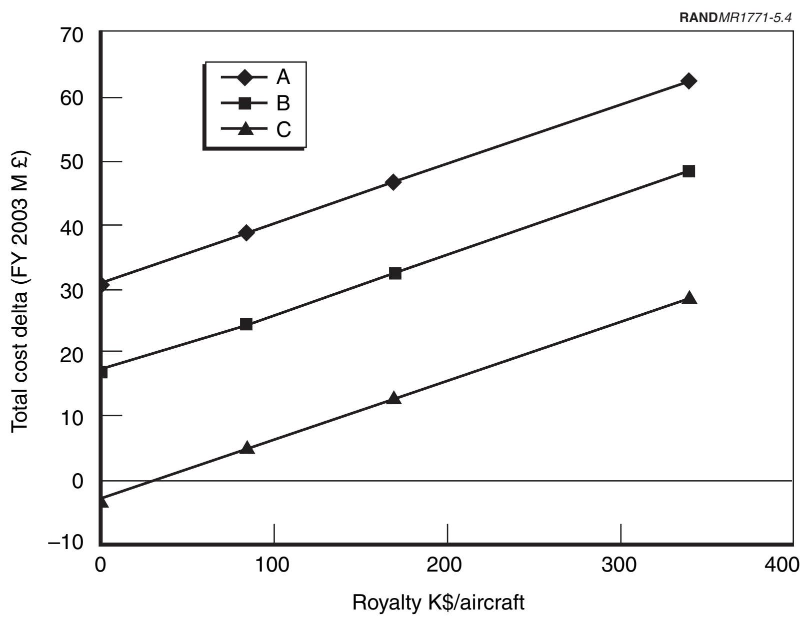
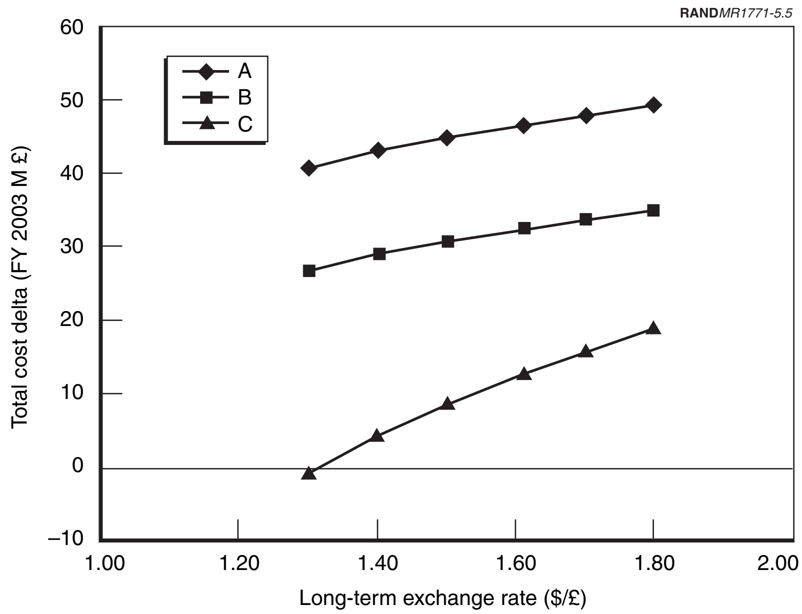


Figure 5.4—Total Cost Delta Sensitivity to Royalty Fee

impact of the same postulated exchange rate over the entire analysis period, from 2006 to 2026. Therefore, one should not make decisions based on short-term rate fluctuations but rather on long-term expectations for the average rate.

Monte Carlo Uncertainty Analysis

Monte Carlo analysis offers a way to help place the different sensitivity analyses in context. The previous sensitivity analyses show how varying a single input changes the cost estimates. They vary only one factor at a time while holding all the others fixed. Thus, if two factors interact in some complex way, the sensitivity analysis shown so far will not display this interaction and its effect on the estimate. Furthermore, the sensitivity analyses provide no guidance to the reader as to how likely one particular result is over another.



NOTE: The exchange rate on April 16, 2003, was $1.58 per £1.00.

Figure 5.5—Long-Term Exchange Rate Sensitivity for Total Cost Delta

Inevitably when presenting a cost estimate, one is asked, 'How good is the estimate?' The Monte Carlo estimate presented in Table 5.5 is an attempt to partially answer this question, allowing multiple inputs to vary together. This analysis does not include uncertainty for all inputs, just four of the key parameters. Therefore, the uncertainty results are indicative and not absolute. We use the normal distribution (truncated at zero) to represent the uncertainty associated with the parameters. Other distributions could be assumed, but without better information this is a reasonable approach. The standard deviations used are the following:

- Exchange Rate = 0.12 (historical, annual deviation).
- Burden Rate = 5 percent of the 2003 value.
- Other Work Hours = 5–20 percent depending on site and their forecast.

Table 5.5

Average Incremental Cost—Monte Carlo Analysis

Cost Element	A FACO Only (M £)	B Combined Facility (M £)	C FACO Added to MR&U Facility (M £)
Minimum	29.2	17.0	–2.5
Mean	49.4	36.3	15.3
Maximum	74.1	61.7	39.2
Standard deviation	9.2	9.3	8.0

- Learning Transfer = 19 percent, based on historical programmes (Birkler et al., 1993).

FMS and MR&U workload were fixed at their baseline levels (0 and 'moderate', respectively). Table 5.5 reports the summary statistics of the Monte Carlo analysis of the net delta cost.

The results of the analysis show that the standard deviation, a measure of the dispersion, is approximately 20 percent of the mean value for a FACO-only facility (A), 25 percent of the mean value for a combined facility (B), and approximately 50 percent for a combined facility where FACO is added to an existing MR&U capacity (C). The inference that should be made is that the accuracy of results does not support meaningful distinctions between small cost differences.

SUMMARY

Our analysis shows that moving a FACO line to the United Kingdom will likely result in cost increases to the MOD. An optimistic approach, where FACO is added to an already planned (and budgeted) MR&U facility, results in an average cost increase to the United Kingdom of £12.9 million. The total incremental mean costs of developing a combined FACO and MR&U site are £32.7 million. Finally, if it turns out that the United Kingdom does not develop an organic repair facility or the JSF support concept does not in the end include airframe depot-level repair, the average increase in costs to the MOD for a FACO facility would be £46.8 million. This is the most conservative approach.

One scenario where the United Kingdom's buy of 150 aircraft might cost about the same or even less than that of aircraft assembled in the United States is where additional aircraft for other buyers are assembled at a UK facility. This combined production would help reduce overhead rates and offer learning benefits. However, given that a UK facility is not being set up as a competitor to the U.S. FACO facility and any additional FACO work will come as a result of some negotiation, this additional production cannot be planned for with any certainty. A conservative approach would be to make the decision to move FACO without considering any additional production.

It should finally be noted that moving FACO to the United Kingdom will result in an increase in the costs for the aircraft that the United States purchases. This increase stems from both a reduction in learning and a decreased business base in Fort Worth that would lead to increased overhead rates. We used a cost model developed in support of a previous study[7] to estimate the increased costs for the United States. The additional U.S. costs for JSF FACO would be about $26 million if the work were to be moved. Costs to DoD would increase by a total of $51 million, a number that includes the increased cost of JSF FACO and also of other DoD work, including JSF forward fuselage and wings and the F-22 centre fuselage.[8] However, it is common in aircraft procurement programmes for perturbations of one sort or another, including changes in quantity, to affect the costs. In this case, the USN plans to reduce its buy of JSF aircraft by some 409 compared to the original baseline,[9] so the United Kingdom can expect to face increased costs from this decision.

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[7]See Cook et al., 2002.

[8]Theoretically, the expected sales to other nations beyond the 3,002 aircraft baseline would offset some of these additional JSF FACO and DoD costs. But these costs would still be higher with a UK FACO facility than in an all–Fort Worth scenario, provided there was sufficient capacity at Fort Worth to assemble all the aircraft.

[9]This reduction was included in the JSF Selected Acquisition Report for the December 31, 2002, reporting period, and publicly mentioned in http://www.defenselink.mil/news/Apr2003/b04122003_bt232-03.html. It is also described in Bolkcom and O'Rourke (2003).

Chapter Six

JSF TECHNOLOGY-TRANSFER ISSUES

To this point, this analysis has assumed that the United Kingdom will be able to assemble and repair the JSF. There is little doubt that the United Kingdom has the necessary advanced manufacturing capabilities and technical skills. However, other factors affect the decision to locate a JSF FACO and/or MR&U capability in the United Kingdom. One of the most significant factors is the availability for export of critical military and proprietary technical information and tools to accomplish this task.[1] The United Kingdom can do the work. It is not certain that the United States will allow the work to be done there.

This chapter discusses the U.S. policies that control technology transfer to foreign nations and some of the JSF technologies required for FACO or MR&U that may be affected by those policies. We include a generic discussion of the U.S. policies on transfer of defence-related goods and technologies to foreign nations.

Because of the unclassified nature of this report, we did not address the exact nature of the specific technologies whose export will be controlled. In our research, we relied entirely on unclassified data, including those available in the open literature, received from U.S. government sources, and provided by Lockheed Martin. Based on these sources, we know that one of the classes of technology of particular concern is that relating to the stealth, or low-observable

[1]Military critical technologies are all material and processes included in the U.S. Military Critical Technology List available at http://www.dtic.mil/mctl/, accessed April 11, 2003.

(LO) characteristics of the aircraft. Some aspects of LO are installed during the FACO stage of aircraft manufacturing and therefore raise issues with respect to technology transfer. Also, some level of understanding of LO technology will be required to properly maintain and support the future UK fleet of JSFs.

BACKGROUND AND U.S. POLICY ON MILITARY TECHNOLOGY TRANSFER[2]

The U.S. DoD entered into an agreement with the UK MOD through an MOU signed by both parties in January 2001. The MOU describes the cooperative framework for the JSF's SDD phase.[3] This document is intended to be the main vehicle for U.S.-UK JSF SDD cooperation. It provides a detailed outline of the programme objectives; the scope of work to be performed; financial and contracting provisions; and other terms and conditions, such as security provisions, disclosure and use of information, and other key matters. The MOU does not specifically address the technology-transfer issue. However, a number of U.S. laws, directives, and regulations govern the transfer of technical information.

Several major laws, Executive Orders and Presidential Decision Directives, and departmental regulations govern the U.S. policy on transfer of military technology. The transfer of unclassified critical technology or industry proprietary data from the United States is subject to the Arms Export Control Act (AECA) of 1976 and the International Traffic in Arms Regulation (ITAR). The U.S. National Disclosure Policy (NDP) regulates the transfer of all classified military information. Together, these establish the foundation for disclosure of information to foreign governments and international organisations. Generally, the information is releasable only when it is deemed that such disclosure would clearly benefit the U.S. national interests. The following sections provide more detail on AECA, ITAR,

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[2]This section is largely based on *International Programs Security Handbook* (U.S. DoD, 1993), published and maintained by the Office of the Deputy Under Secretary of Defense (Policy) for Policy Support. This section provides a general discussion of the topics. Readers interested in more detailed background are referred to the handbook itself.

[3]JSF EMD Framework MOU, signed January 2001.

and NDP as well as a discussion of the process and organisations that may be involved in assessing the technologies required for constituting a FACO and MR&U capability in the UK (U.S. DoD, 1993).

Arms Export Control Act of 1976 (AECA)

This U.S. law governs the procedures for the sales and export of defence equipment, technical data, and services to foreign countries for their self-defence and internal security. The State Department, in consultation with the DoD, determines which articles, data, and services are of a military nature. In general terms, these items are included in the U.S. Munitions List (USML) contained in the ITAR.

AECA requires that the recipient meet the following three conditions prior to the delivery of the relevant equipment, data, and services:

- The recipient must agree not to transfer the equipment, data, or services to a third party without prior U.S. government consent.
- The recipient must agree not to use the equipment, data, or services or permit their use for other than the purpose for which they were provided without prior U.S. government consent.
- The recipient must agree to provide the same degree of security as the U.S. government for the equipment, data, or services provided.

These conditions form the legal basis for the security assurances and requirements associated with any JSF-related parts, equipment, and data. AECA also requires the State Department to notify Congress of any JSF-related international transactions via a Letter of Offer and Acceptance (LOA).[4]

ITAR

This document provides licencing and regulatory provisions for the import and export of defence articles, technical data, and services. It

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[4]An LOA is a DoD letter to Congress by which the U.S. government offers to sell a foreign buyer U.S. defence articles and services pursuant to the AECA. The LOA lists items or services, establishing costs, terms, and conditions of the sale.

is issued by the State Department's Office of Defense Trade Controls (ODTC). The export of all unclassified technical information and materials to any foreign nation is subject to ITAR. ITAR requires a licence issued by the Department of State for each defence-related export, or an exemption from licencing. The application for the disclosure of classified or unclassified information, which is needed for defence services, requires a TAA. Similarly, the application in support of a foreign production line requires a Manufacturing License Agreement (MLA). Exemptions from licencing and approval of the TAA and MLA in order to export military services and information are granted by the ODTC.

National Disclosure Policy (NDP)

ITAR addresses only the transfer of unclassified information. The transfer of classified information, such as JSF LO technical or manufacturing data, which includes some aspects that are classified, is subject to the NDP rules.

U.S. government policy with respect to classified military information (CMI)[5] is to protect it as a national security asset and therefore to disclose it to a foreign government or an international organisation only when there are clear advantages to the United States. Such disclosures must be consistent with U.S. foreign policy objectives and military security requirements and be limited to information necessary to the purpose of the disclosure. The ability to assemble or maintain JSFs in the United Kingdom will involve access to some classified information. In the United States, classified military information is grouped into the following eight categories:[6]

- Organisation, Training, and Employment of Military Forces.
- Military Material and Munitions.
- Applied Research and Development Information.
- Production Information.

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[5]CMI is information for military use and protected in the interest of national security. It is designated as Top Secret, Secret, or Confidential.

[6]For a detailed discussion on each of the eight categories the reader is referred to the *International Programs Security Handbook*.

- Combined Military Operations, Planning, and Readiness.
- U.S. Order of Battle.
- North American Defence.
- Military Intelligence.

The fourth category (Production Information) covers JSF FACO and MR&U. It includes designs, drawings, chemical and mathematical equations, specifications, models, manufacturing techniques, software source code and related information necessary to manufacture or substantially upgrade military materials and munitions. Production information is further categorised into the following three classes: manufacturing information, build-to-print information, and assembly information.

Manufacturing Information is the most sensitive and covers both manufacturing process details and software source code information. It includes detailed instructions for manufacturing, testing, and upgrading materials or munitions. It also includes design information and tooling and manufacturing process data. Software source code information includes a set of instructions that describe the software and provides development procedures. Software documentation that provides insight into the classified algorithms or design rationale requires National Disclosure Policy Committee (NDPC) approval. Other software information needed for minor maintenance, interface/integration, or to make software administrative changes can be handled through normal technology-transfer channels and does not require NDPC approval.

Build-to-Print Information is considered less sensitive than manufacturing information but more sensitive than the assembly information. It assumes that the foreign country obtaining this information already has the manufacturing capability in place. NDP allows the release of supporting documentation, but the disclosure of any information on design methods and detailed manufacturing information for a weapon system or its subsystems is considered manufacturing information and is subject to NDPC approval.

Assembly Information is normally associated with hardware and the information that would allow for its assembly and testing. It normally would only involve top-level technical information. Disclosure of this information can be handled through normal technology-transfer mechanisms.

The NDP authority governing the disclosure of U.S. classified military information is set forth in a National Security Decision Memorandum (NSDM) approved by the President. The NSDM assigns responsibility for controlling disclosure of U.S. CMI to the Secretaries of State and Defense. For disclosure to a foreign government, they may consult, as appropriate, with the Secretary of Energy, the Director of Central Intelligence, and heads of other departments and agencies.

The interagency document that implements the NSDM is the National Policy and Procedures for the Disclosure of CMI to Foreign Governments and International Organizations, in short, National Disclosure Policy or NDP-1. It is issued by the Secretaries of State and Defense with the concurrence of the other appropriate departments and agencies. Further, the NSDM charges the Secretaries with the responsibility for establishing and managing an interagency mechanism and procedures to implement the disclosure policy. That mechanism is the NDPC, which is responsible for the following:

- The promulgation of specific disclosure criteria and limitations.
- The continuing review of intelligence and the conduct of on-site surveys to determine the foreign recipient's capabilities.
- The submission of an annual report on disclosure activities to the National Security Council.
- The negotiation of General Security of Military Agreements to determine a foreign recipient's security arrangements and intent to protect U.S. classified military information.

The Secretaries of State and Defense have designated the NDPC as the central interagency authority within the Executive Branch of the United States government responsible for the formulation, promulgation, administration, and monitoring of the NDP. By agreement between the Secretaries, the Secretary of Defense appoints the chair and provides administrative support for the NDPC. The NDPC is composed of general and special members. General members are those with a broad interest in all aspects of committee operations, while special members are those with a significant interest in some, but not all, aspects of committee operations. The special membership varies depending on each organisation's involvement and interest in the technology being considered for transfer.

The general members represent the Secretary of State, Secretary of Defense, three service secretaries, and Chairman of the Joint Chiefs of Staff. The special members represent the Secretary of Energy; the Director of Central Intelligence; the Under Secretary of Defense for Policy; the Under Secretary of Defense for Acquisition, Technology, and Logistics; the Assistant Secretary of Defense for Command, Control, Communications, and Intelligence; the Assistant to the Secretary of Defense (Atomic Energy); the Director, Defense Intelligence Agency; and the Director, Ballistic Missile Defense Organization.

Technology-Transfer Process

Transfer of technology to foreign countries is regulated by the policies and procedures just described. They are both time-consuming and cumbersome. An August 2000 General Accounting Office (GAO) study outlines several examples of export control requests by U.S. companies in support of military products owned by foreign governments that have taken three to seven months. Most of these countries are NATO members with good relations with the United States (U.S. GAO, 2000b).

There have been some efforts to improve the process. In 1998, the U.S. DoD examined a series of initiatives to ameliorate the export control system and procurement policies to better position the U.S. military products in the international marketplace. Specifically, the Defense Trade Security Initiative (DTSI) grants ITAR exemptions for unclassified exports to certain foreign governments and industries.[7] The most significant initiative is the Global Project Authorization (GPA) with respect to the transfer of unclassified JSF technologies. This initiative is expected to reduce the cycle time for authorisation that must be obtained before allowing the export of a critical technology. These exceptions do not apply to classified military infor-

[7]DTSI includes 17 initiatives designed to streamline the process of munitions export licences. For more information, visit http://www.dsca.osd.mil/dtsi/DTSI_links.htm, accessed April 9, 2003.

mation or contractor proprietary information.[8] The JSF U.S. and UK interested parties are currently working to obtain the necessary licencing requirements to facilitate and streamline the technology-transfer process. A specific agreement is in place that has the goal of improving U.S.-UK bilateral cooperation, the Declaration of Principles, which was signed by the U.S. Secretary of Defense and the UK Secretary of State for Defence on February 5, 2000. This document established working groups to implement policies and specific agreements on future collaboration (U.S. GAO, 2000a). However, the transfer of military technical information from the United States to the United Kingdom has not been a smooth process in spite of the agreements in place (Wall, 2003).

JSF FACO AND MR&U TECHNOLOGIES AFFECTED BY THE NDP

In summary, all unclassified critical military information requires export licences or ITAR exemptions, and the disclosure of the classified information is subject to NDPC review and approval. The JSF technologies subject to export control are far too numerous to be addressed in this report. Furthermore, many of these technologies are still in development, so their final content is unknown. One significant and telling area of effort includes both materials and technologies on the USML that are subject to U.S. regulatory and statutory controls. It covers those used for JSF LO during FACO and MR&U.[9] This section provides a high-level unclassified discussion on the JSF LO manufacturing technologies that might be involved in FACO or MR&U.

An Overview of the JSF LO Requirements

The foundation of JSF LO is the collection of technologies that affect aircraft signature. These include critical aspects of radar, infrared, visible, laser, magnetic, and acoustic signatures.

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[8] http://www.clw.org/atop/xrefor/reform3.html, accessed March 25, 2003.

[9] Another area is the source codes for software that controls all aspects of the aircraft's flight control and weapons systems, without which the UK will be unable to adapt the aircraft to its own operational requirements (Odell, 2002, p. 2).

In general, aircraft LO is achieved through a complicated mix of airframe shape and structures, special structural and coating materials, special embedded sensor technologies, and special devices incorporated into the inlet and exhaust of the engine. All these characteristics are designed to reduce aircraft signature and therefore the ability of the opposition to detect, track, and attack the aircraft. Here, we discuss technology-transfer issues relating to the potential establishment of a JSF FACO production capability in the United Kingdom. (Similar issues would likely pertain to an MR&U facility.)

JSF LO characteristics are created by the overall design of the airframe through shaping of the outer mould line, radar-absorbing structures, radar-absorbing materials, special sensors and avionics, and special engine devices. The JSF design incorporates the following features to achieve stealth:

- Radio frequency (RF) signature control to minimise susceptibility and maximise the probability of survival against projected RF threats.
- Electro-optical/infrared (EO/IR) technology to minimise susceptibility and maximise the probability of survival against projected EO/IR threats.
- Covert lighting technology to minimise susceptibility to projected threats' optical and night vision systems.
- Ability to eliminate, reduce, mask, or control electronic emissions to minimise detection, tracking, or engagement by a threat with minimal degradation to mission effectiveness.
- Ability to minimise the threat posed by an acoustic tracking system.

Manufacturing of JSF Airframe LO Features[10]

JSF subassemblies will be delivered in modules with many of the subsystems, including some special stealth technologies, already integrated. For example, avionics 'boxes' containing controlled

[10]The following is based on the available CDP data.

technology will be integrated into relevant airframe subassemblies and components before the FACO stage. During the manufacturing process of the subassemblies, paints, coatings, and sealants will already have been applied. In many cases, before the FACO stage, surfaces will have been cleaned and prepared, the fasteners will have been filled and faired, and the surfaces sprayed, coated, and sealed. Lockheed Martin estimates that about 70 percent of the work related to stealth will be done before FACO.[11] This should reduce the need for critical information required by the UK industry to establish a FACO or MR&U facility.

The airframe low radar signature is achieved through two main approaches: radar-absorbing structures (RAS) and radar-absorbing material (RAM). The JSF airframe will employ innovative approaches in achieving the LO requirements, which should reduce the effort required during the FACO stage. The JSF stealth approach minimises the use of time-consuming manufacturing processes, including the application of sheets of radar-absorbing coating material and finishing materials that require long cure cycles. Also, use of new design tools should allow for early verification of the proper assembly of RAS.

During the final finishes step of FACO, the aircraft will need to be coated with RAM. An appliqué material is under development for potential use as the final topcoat. These efforts are projected to be about 28 percent of the FACO operation's standard hours.[12] Significant attention to the fidelity of the aircraft outer mould line is required, and it will be verified using a turntable mechanism. Finally, the JSF airframe will be tested in an anechoic chamber where its radar cross section will be tested and recorded.

LO-Related Resources Required During JSF FACO

In addition to the labour required for stealth implementation during the FACO process, JSF FACO stealth processes have four main tooling and facility requirements. In addition to the FACO space, another

[11]Lockheed Martin's response to RAND questionnaire, February 2002.

[12]Lockheed Martin briefing to RAND, May 7–8, 2001.

environmentally controlled, secure facility or secure space in the facility of about 200 by 200 feet with special radar-absorbing (anechoic) features is needed to test and verify the LO features of the airframe. An LO verification turntable device, required to test the aircraft radar cross section, must be located in this secure facility. A ground test radar is required to collect radar cross section signature information, which will then be analysed by dedicated computers and other analytical tools. A certain number of tools are needed for the coating, including robotic coating devices, appliqué equipment, and surface finish test equipment. Only workers with security clearances can perform this work. The facilities, tools, and equipment required to ensure and verify stealth will be needed at all sites and have been included in the RAND cost model.

Lockheed Martin estimates that not all FACO workers will need clearances, perhaps only 20 percent. Given the number of workers at the UK sites considered in this study who already hold clearances, we estimate that cleared workers can be transferred from other programmes that will be finishing as JSF production begins. Alternatively, new employees can be hired into jobs for other programmes that do not require clearances, and cleared workers can be transferred to the JSF work.

TECHNOLOGY-TRANSFER NEGOTIATIONS AND THE JSF PROGRAMME PRODUCTION SCHEDULE

Application of the LO materials and the testing process consumes a significant share of the FACO labour. Therefore, if the UK government decides to establish a FACO or an MR&U facility, it is critical that the site gain some access to unclassified and proprietary data, and some classified data, to accomplish the necessary work. As previously discussed, the transfer of unclassified and proprietary information is regulated by ITAR. BAE SYSTEMS, a major JSF Lockheed Martin subcontractor/partner responsible for the airframe aft fuselage, has been working closely with Lockheed Martin on the development of the TAAs needed to gain access to some proprietary technologies related to the production of their share of the work. These agreements are quite time-consuming and have taken, occasionally, in excess of nine months.[13] On the other hand, classified technologies are controlled by NDP and require special disclosure agreements between U.S. and UK governments and industries. The technology disclosure approval process is even more convoluted since a number of different government organisations and agencies are involved, and it is currently unclear whether all the classified technologies will be released. The production and support MOU negotiation between the U.S. government and JSF foreign partners is scheduled to begin during summer 2003. These negotiations will include discussions and possible agreements on technologies required for future JSF fleet support and maintenance.[14]

The production timetable drives the decision about when transfer and disclosure agreements will need to be completed. The production of the first UK aircraft will start around the beginning of 2008 and is scheduled for delivery approximately at the end of 2009. FACO occurs only in the last several months of aircraft manufacturing, so the FACO facility does not have to be completed until then. Therefore, a UK JSF FACO facility would have to be ready toward the end of calendar year 2009 to assemble the aircraft for delivery in 2010. Of course, if the United Kingdom decides to wait and perform FACO for only the aircraft in later lots, this date slips to the right accordingly.[15] The construction of this facility and the required assembly tooling and equipment is assumed to take about two years.[16] Given that, all new transfer and disclosure agreements required for the controlled FACO technologies should be identified and negotiations should be complete by that point to ensure that the United Kingdom actually receives the information required to assemble the aircraft. Thus, the TAA negotiations must conclude before the decision to build a FACO facility—that is, during calendar year 2007 at the latest. The processing can continue after the agreements are negotiated with the confidence that the necessary infor-

[13] Telephone conference with BAE SYSTEMS on April 11, 2003.

[14] Discussion with Frank Kenlon, AT&L/IC/P&A, Assistant Director for International Agreements and Cooperative Program Policy, on April 23, 2003.

[15] UK aircraft purchases for the first three years will be 5, 9, and 12 aircraft. A three-year delay in reaching an agreement would mean the UK could still perform FACO for 124 aircraft.

[16] Discussion with BAE SYSTEMS on January 16, 2003.

mation will be available before the final assembly of the first UK aircraft can begin.

However, the negotiation activities are relatively unpredictable because technology disclosure policy is an evolving process. Technology deemed not releasable today might be reconsidered in the future. This process, as discussed earlier, involves many stakeholder and government organisations, and the time to get a clearance on a technology is quite uncertain. A further complexity is that as the JSF technology continues to evolve, the technical content that the TAAs will need to address may also change over time. Thus, the UK government should give this issue immediate attention and commence advance planning.

UK SITES' EXPERIENCE WITH TAA PROCESSING

The technology-transfer experiences of the UK sites included in this study are mixed. They range from a significant understanding of the technologies required for FACO, and the associated TAA processing, to little or no understanding and experience.

BAE SYSTEMS, as a major subcontractor/partner to Lockheed Martin for the JSF, has already begun working on and processing technology-transfer issues through an overarching TAA established in 1998 in support of CDP.[17] This agreement related to the transfer of the technologies required to produce the rear fuselage and empennage for the JSF X-35A and X-35B concept demonstrator aircraft. Lockheed Martin and BAE SYSTEMS have a technology disclosure process called the 'TAA Staircase', whereby the transfer of JSF technologies is agreed on through various amendments over time.[18] Each amendment is envisioned to remove some restrictive provisos and to allow progress towards a level of disclosure to enable a successful development and operational testing programme. Although the technologies currently under consideration are not related to FACO, the experience and understanding of the transfer procedures offer BAE SYSTEMS a relative advantage in this area as a potential future JSF

[17]BAE SYSTEMS information provided on April 14, 2003.

[18]BAE SYSTEMS response to RAND questionnaire dated April 11, 2003.

FACO site. Furthermore, this experience demonstrates the need for Lockheed Martin to be closely involved in the TAA process

Marshall Aerospace has some experience in maintaining U.S.-assembled military and civilian aircraft. To obtain key maintenance and other technical documents, it has negotiated TAAs with both the original equipment manufacturers and the U.S. government. (This includes Lockheed Martin, in support of Marshall's work on the C-130.) DARA has very little experience with the TAA negotiation process with U.S. firms. Both Marshall Aerospace and DARA would need to develop their processes and relationships with the Lockheed Martin JSF programme. Given the relatively short time before the TAA negotiations must be completed, both these organisations represent higher-risk sites for meeting the current schedule for the first UK JSF FACO.

SUMMARY

The technical transfer issues involved in developing a UK JSF FACO site are complex and will require the agreement of the U.S. government and the cooperation of Lockheed Martin. The UK government and its industries interested in performing either JSF FACO or future MR&U support will be required to obtain various export licences or an ITAR exemption for unclassified military information, and pursue TAAs and MLAs for critical and proprietary production and design-related information and equipment. Since some JSF FACO technology, including that related to the LO nature of the aircraft, is classified and controlled by NDP, the UK government must plan the TAA process well in advance of a decision to build a FACO or MR&U facility. If the current production schedule holds and the United Kingdom assembles all its own JSF aircraft, the negotiations have to conclude in the later part of 2007, and the processing of necessary paperwork must be complete before the FACO of the first UK aircraft begins. Even with a slip in the TAA negotiation schedule, the United Kingdom could still accomplish the FACO of later-lot aircraft. (However, it might not be as cost-effective with respect to the required upfront facility investment.) This issue requires immediate, concentrated attention by the MOD if it chooses to go ahead with the development of a UK FACO capability.

Chapter Seven

CONCLUSIONS

This study assessed a number of implications regarding the creation of a JSF FACO line in the UK. We found that overlap occurs between FACO and MR&U, so that FACO facilities could serve both purposes. We assessed several UK organisations as potential FACO sites and found that while they have different levels of capabilities and would require different levels of investments, BAE SYSTEMS, DARA, and Marshall Aerospace could all do the work. We estimated the costs of a UK FACO line under a number of different scenarios, and we analysed issues of technology transfer, finding that these could potentially interfere with the creation of a FACO line outside the United States.

OVERLAP BETWEEN FACO AND MR&U

Interviews with company and government personnel, plant tours, and knowledge gained from other studies all support the conclusion that there is significant overlap between FACO and MR&U in terms of facilities, equipment, and worker skills. FACO is more regular, so it offers the simplicity of a repetitive process. In MR&U, the many unknowns, such as the problems to be solved and level of work to be done on each particular aircraft, may pose some engineering challenges and require some advanced worker skills. Broadly speaking, however, an organisation that has skills in one, can, with some investment, do the other.

Given the overlap in the stages of FACO and MR&U, certain advantages accrue to having both of the activities at the same location. First, familiarity with an aircraft FACO should allow for an easier transition into a subsequent MR&U environment. Second, airframe-engineering skills could address either FACO or MR&U problems as they arose, thus reducing the total engineering workforce required. Third, worker skills, aside from engineering assessments for MR&U, are basically the same for either process,[1] so levelling workload may be easier. Fourth, overall manufacturing space could be reduced, especially if the post-FACO manufacturing space could be used for MR&U. Fifth, overall equipment costs could be reduced, especially for low-use, expensive test equipment or such tooling as the major mate/laser alignment tool. Sixth, on-site technical support from major suppliers could be combined with a collocated FACO and MR&U facility. Seventh, TAAs and other agreements need to be completed for only one location, thereby reducing approval times and the number of people involved and eliminating a second set of approvals for a different organisation. (It would also limit the exposure of highly classified technologies to just one location.)

However, collocating FACO with MR&U also has some potential disadvantages. The first might be in managing the two processes, with FACO being more predictable. Collocating MR&U has the potential to interfere with the FACO work, so management's approach to the workload and the workers may have to be more flexible. A second drawback from having a single site might be the absence of competition in the awarding of MR&U contracts. One site set up to do FACO does not mean it will necessarily offer the best value as a location for MR&U. Third, although collocation may be desirable from an efficiency standpoint, there may be political pressure to spread desirable jobs in the aircraft industry to a greater number of locations. Fourth, collocation of the FACO and MR&U activities would reduce the industrial base for the JSF to a single location in the UK. Fifth, collocation increases the vulnerability of both FACO and MR&U to local issues, such as environmental impact. For example, an increased number of aircraft engine runs or takeoffs and landings per day may lead to local opposition.

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[1]Although MR&U likely requires a more highly skilled workforce, the skills themselves are the same as required for FACO.

SUITABILITY OF UK SITES FOR FACO

The UK MOD suggested four organisations as potential sites for JSF FACO. These included BAE SYSTEMS, DARA, Marshall Aerospace, and Rolls-Royce. All have an impressive collection of skills and experience. Airframe FACO and MR&U would be a completely new sector for Rolls-Royce, so we conclude that it would not be a cost-effective candidate for FACO and MR&U. Each of the other three could perform JSF FACO and MR&U. BAE SYSTEMS has the most relevant experience and capabilities relevant to JSF FACO. However, DARA and Marshall Aerospace sites could, with greater development of their capabilities, be used for JSF FACO. While not a site for JSF airframe FACO or MR&U, Rolls-Royce could be considered as a potential MR&U site for the JSF propulsion system.

COSTS FOR A UK FACO FACILITY

The MOD has a number of alternatives to choose among with regard to selecting a site for the UK JSF FACO and MR&U. It can buy aircraft assembled in Fort Worth, or it can develop its own FACO line. It can use whatever global support facility Lockheed Martin develops, or it can establish a facility to perform MR&U on its own aircraft (the outcome to which it aspires). Each combination of these has different implications for total cost.

The United Kingdom has several alternative assumptions or approaches to consider when looking at the costs of JSF FACO. The first is to look at a FACO facility that is independent of an MR&U facility and also represents the case where there is negligible MR&U work for the JSF. The average incremental cost of this approach (over the baseline case where all the work is done in Fort Worth) is £47 million. If the UK were to invest in a facility that was used for both FACO and MR&U, the average incremental cost of FACO would be £33 million. Finally, if FACO were added to a planned and fully funded MR&U facility and represented an incremental or marginal effect, the average incremental costs for FACO would be £13 million. (The total costs for the second and third scenarios are the same. The difference is the baseline against which the incremental costs are calculated, with the second having a baseline of no JSF FACO or

MR&U work in the UK and the third having a baseline of an existing JSF MR&U facility.)

These numbers are best estimates based on a number of assumptions. Varying critical inputs, including JSF FACO quantities, MR&U workload, levels of learning transfer, royalty fees, and exchange rates, changes total costs. We provided sensitivity analyses to show these effects.

It should be noted once again that many of the critical inputs in our analysis, such as total quantities, production plans, and predicted costs, likely will evolve over the course of SDD. We performed our analyses based on data current as of the JSF downselect in October 2001. Historically, many aspects of production programs change during SDD, and indications suggest that this is occurring for the JSF, including the reduction in the combined USN-USMC aircraft buy. If and when the data are available, incorporating information about such changes would affect the results of this analysis.

TECHNOLOGY-TRANSFER ISSUES

The UK government and its industries interested in performing either JSF FACO or future MR&U support in the UK will be required to obtain various export licences or an ITAR exemption for unclassified military information and pursue TAAs and MLAs for classified and proprietary production and design related information and equipment. Both government-to-government and industry-to-industry negotiations will be required.

Some of the technology used to manufacture the JSF is classified and controlled by NDP, especially that related to the LO nature of the aircraft. This could create particular difficulties for the UK's aspiration to carry out either FACO or MR&U in the UK. Hence, the UK government needs to plan the TAA process well in advance of a decision to build a FACO or MR&U facility. If current production schedules hold, the negotiations must conclude in the latter part of 2007, and the processing of necessary paperwork must be complete before the FACO of the first UK aircraft begins. However, this issue would require immediate, concentrated attention by the MOD if it chooses to go ahead with the development of a UK FACO capability.

Appendix A

SITE QUESTIONNAIRE

JOINT STRIKE FIGHTER SITE ASSESSMENT

The 2001 National Defense Authorization Act required the Secretary of Defense to perform a study of final assembly and checkout (FACO) alternatives for the Joint Strike Fighter (JSF) programme. RAND was asked to respond to this requirement. We performed a study that examined the implications of assembly at single/multiple locations, identified all potential JSF/F-35 FACO locations, determined which costs would vary among locations, collected data on these, and finally analysed the costs of performing FACO at the different locations under different scenarios. This report is available to the public at http://www.rand.org/publications/MR/MR1559/.

The United Kingdom's Ministry of Defence (MOD) has asked RAND to conduct a follow-on study, looking at the possibility of developing a separate F-35 FACO line in that country. This is linked to the MOD's aspiration to have a complete indigenous organic F-35 repair capability. Tasks in this study include determining the potential synergies between such a FACO facility and one for maintenance and repair, the different UK facilities that might be appropriate for F-35 FACO, and the costs of doing this work under a number of different scenarios, which will be developed.

In this analysis RAND will make a number of assumptions based on programme strategy. These may be altered as circumstances change or after conversations with the government or contractors.

- UK will purchase 150 STOVL variant aircraft.

- A baseline production run of 3,002 aircraft (1,763 CVs, 480 CVs, and 759 STOVLs) (although there is some uncertainty about final programme structure).
- One FACO location in the United States.
- The UK STOVL variant is 100 percent common with the U.S. STOVL.

Some of the attached questions may not be applicable to your facility; for example, questions on FACO may not apply to a repair facility or vice versa. Please answer the applicable questions.

If you have any questions, please contact:

Dr. Cynthia R. Cook
Principal Investigator
RAND
1200 South Hayes Street
Arlington, VA 22202
USA

Hans Pung
RAND
Grafton House
64 Maids Causeway
Cambridge CB5 8DD
UK

Company Name: ____________________________

City/Mail Code: ____________________________

Point of contact: ____________________________

Phone: ____________________________

E-mail: ____________________________

SECTION 1. AIRFIELD AND GENERAL SITE DATA

a. Provide key dimensions of this site's main runway (length/width/overruns).

b. Ramp Space.

Provide gross square feet of ramp space available at this site. ________________

How many ramp positions are available for tactical aircraft? _________________

c. Is this site in compliance with safety requirements for tactical (Category 5) aircraft? __ Yes __ No

If no, identify deficiencies/waivers

d. Briefly describe any planned capital improvements that are expected to significantly improve the capability of this airfield (e.g. a new runway or runway extension).

e. Are noise or flight path restrictions currently in place that limit the operation of tactical aircraft? __ Yes __ No

If yes, identify restrictions.

f. Do you foresee any airfield encroachment issues that are likely to limit military tactical aircraft operations in the future?

g. How much land is available for future expansion?

SECTION 2. FACILITY DATA

a. Gross floor space (1,000s of square feet 000)

Production (factory) __________________

Administrative (office) __________________

Laboratory __________________

Warehouse __________________

Total Floor Space __________________

b. Hangar Space. Provide key attributes of hangars available/utilised for final assembly and/or repair of aircraft. Please separate high-bay and low-bay space.

Building Number	High-Bay/ Low-Bay Dimensions (L' × W' × H')	Air Conditioning/Humidity Control (Y/N)	Number and Capacity (Tons) of Overhead Cranes	Number of Tactical A/C Dock Positions	Current Capacity Utilisation (%)

c. Paint Facilities. Provide key attributes of hangars available/utilised to paint complete aircraft.

Building Number	Dimensions (L' × W' × H')	Air Conditioning/Humidity Control (Y/N)	Robotic or Manual Application	Number of Bays/ Positions for Tactical A/C	Air Control Activity—Active or Passive Filtration?

d. Flight Prep Facilities. Provide key attributes of hangars available/utilised to prepare aircraft for flight test.

Building Number	Dimensions (L' ×W' ×H')	Air Conditioning/Humidity Control (Y/N)	Fire Suppression? (Y/N) Type?	Number of Bays/ Positions for Tactical A/C

e. Fuel/Defuel Operations. Provide key attributes of fuel operations.

Type (In-Ground or Truck)	Use (Fuel, Defuel, or Both)	Number of Positions	Enclosed (Y/N)

f. Transportation.

1) Is the site easily accessible via motorway? __ Yes __ No

2) Is the site directly accessible via railroad? __ Yes __ No

3) Is the site accessible to Category 6 (large cargo) aircraft (e.g., C-5, 747)? __ Yes __ No

4) If appropriate, provide additional data on restrictions that may limit transportation access to this site (e.g., unusual weight or height restrictions).

g. Hush House/Hover Pit.

1) Does this site maintain a hush house suitable for engine run-up of tactical aircraft? __ Yes __ No

2) If yes, provide number and size of enclosure(s) (L' × W' ×H').

3) Does this site maintain a hover pit suitable for VSTOL aircraft testing? __ Yes __ No

h. Radar Cross Section (RCS)

1) Does this site maintain facilities and equipment to measure the radar cross section of aircraft components (e.g., leading edges) and/or complete aircraft?

Components __ Yes __ No

Complete Aircraft __ Yes __ No

If the answer to either of the two previous questions was yes, on which aircraft is this work done?

____

i. Energy

1) What is the current average yearly energy usage (kWh)? __________

2) What is the average cost per kWh? __________

3) Are there backup generators on site that can be used in the case of power outages? __ Yes __ No

4) Have there been any significant outages in the last five years which resulted in a work stoppage? __ Yes __ No

If yes, please describe (e.g., lightning storm, planned or unplanned outage due to electricity generation limitations).

j. Local Issues

1) What is the general level of public support for this facility? (Check one.)

___The community would support a larger presence (e.g., more flight tests).

__ The community is neither supportive of nor against the facility.

__ There is community pressure to decrease the impact on the local community.

2) If there is community pressure, what form does it take? (e.g., local organised groups or individuals with concerns about noise, pollution, or other environmental impact, etc.) Please describe.

k. Other

1) Does this site maintain the capability to handle and store classified data and equipment? __ Yes __ No

2) Approximately what percentage of the workforce is cleared for classified material?

3) Describe any planned capital improvements expected to significantly alter or replace any of the key facilities identified above.

SECTION 3. ENVIRONMENTAL ISSUES

a. Is this facility in a sensitive area for ozone and particulate matter?
__ Yes __ No

b. What kind of air control technology exists at this site?

___Passive filtration system

___ Active filtration system

___Thermal destruction system

___Other: ____

c. What slack (for emissions) is there in existing permits for:

NOX (nitrogen oxides):

VOCs (volatile organic compounds):

PM10 (particulate matter [PM] with a mass median aerodynamic diameter less than 10 micrometres):

Other: :____

d. Provide a history of violations, fines paid, and work stoppages for the last three calendar years.

e. Describe facilities and permits for handling and storage of hazardous materials (such as paints, solvents, RCS coatings).

f. Are there storage facilities available on site for limited amounts of explosives—i.e., ejection seat cartridges? __ Yes __ No

SECTION 4. EMPLOYMENT DATA

a. Both FACO and repair of aircraft require workers with a variety of skills for production, quality assurance, tooling, general engineering, and indirect labour. Please provide the number of employees in the following key categories. (Note: This table lists categories that are used by some contractors, and is meant to serve as a template. If contractors at your site use different descriptions of skills for production, quality assurance, tooling, general engineering, and indirect labour, provide employee numbers using your contractor's categories.)

Specify Calendar or Fiscal Year	2000	2001	2002	2003
Total employees				
Touch labour				
Subassembly operations				
Aircraft final assembly				
Final paint and coatings				
Ramp, flight test, & delivery				
Other direct labour				
Quality control				
Manufacturing and sustaining engineering				
Tool manufacturing and engineering				
Indirect labour				

b. Are there any particular skills that are in short supply or in heavy demand?

c. How quickly could the site increase its workforce by 50, 100, or 200 workers?

SECTION 5. PRODUCTION EXPERIENCE DATA

a. Number of new production aircraft delivered (by programme).

Programme	2000	2001	2002	2003

b. Number of aircraft undergoing maintenance and/or modification (by programme).

Programme	2000	2001	2002	2003

c. Has this site ever been used for FACO activities for aircraft? __ Yes __ No

If yes, please answer the following:

1) For which programme(s) was the FACO work done?

____

2) What was the cost improvement curve experienced for FACO activities?

3) What types of FACO activities were done?

4) Does the site currently maintain these skills for FACO work?

d. Has this site ever been used for repair of aircraft?

__ Yes __ No

If yes, please answer the following:

1) For which programme(s) was the repair done?

____

2) What was the cost improvement curve experienced for repair activities?

3) What types of repair activities were done?

4) Does the site currently maintain these skills for repair work?

e. Have you experienced a stop and restart of aircraft production, FACO, or repair programme? __ Yes __ No

If yes, please answer the following:

1) For which programme(s) was the stop and restart done?

2) What types of activities were being done for the programme?

3) We are interested in how learning/production efficiency changes after a restart. For each programme with a restart, please fill out the following table on learning curve information:

Programme	Before Restart			After Restart (Only for Production Units After the Restart)			Gap Length
	T1—Initial	Learning Slope	Total Number of Units Produced	Effective T1—Post Restart	Learning Slope	Total Number of Units Produced	Months

f. Have you ever performed FACO and repair for the same aircraft?
__ Yes __ No

If yes, please answer the following:

Please characterise the overlap of activities between the FACO and the repair work by answering the following questions:

1) Were there any synergies or gained efficiencies between FACO and repair?

2) Were the same facilities used for FACO and repair?

3) Were the same workers used for FACO and repair? Same worker skills required?

SECTION 6: COLLABORATIVE PROGRAMMES

Please provide data on any historical experience you have with collaborative programmes.

a. Have you ever worked on a final assembly and checkout programme in collaboration with another UK site or organisation or with an organisation outside the UK? __ Yes __ No

If yes, please describe:

1) Specific programmes

2) During which years?

3) How easily were you able to transfer learning and production improvements from one site to the other?

4) Were there specific programme management issues unique to the collaboration?

5) Were there other problems that resulted from the collaboration?

b. Have you ever worked on a repair programme in collaboration with another UK site or organisation or with an organisation outside the UK? __ Yes __ No

If yes, please describe:

1) Specific programmes

2) During which years?

3) How easily were you able to transfer learning and production improvements from one site to the other?

4) Were there specific programme management issues unique to the collaboration?

5) Were there other problems that resulted from the collaboration?

SECTION 7. GOVERNMENT INCENTIVES

a. Is this site in a region where it is eligible for tax and/or development incentives? __ Yes __ No

If yes, please describe:

b. Does the company utilise any **tax exemptions or credits** for taxes at this site? __ Yes __ No

Local taxes? __ Yes __ No

If yes, provide details, including programme name.

c. Does the company take advantage of any governmental **business development incentives, such as tax-exempt bond financing, loan guarantees, or direct aid** at this site? __ Yes __ No

Local incentives? __ Yes __ No

If yes, provide details, including programme name.

SECTION 8. FINANCIAL

(The purpose of the following questions is to collect data that will allow for an approximation of the impact of adding JSF FACO and/or repair workload to this facility in the future.)

a. Wage Rates. Provide direct and labour fringe rates in the table below.

CY or FY	2000		2001		2002	
	Labour Rate/hr	Labour & Fringe Rate/hr	Labour Rate/hr	Labour & Fringe Rate/hr	Labour Rate/hr	Labour & Fringe Rate/hr
Production[a]						
Quality Assurance						
Tooling[a]						
General Engineering[a]						
Indirect Production Labour						

[a]If possible, break these labour rates into the same categories you used for the number of employees in the table of Section 4a.

What are the projections/agreements as to wage increases?

b. Does this site have a Questionnaire on Method of Allocation of Cost (QMAC) in place? __ Yes __ No

If yes, when was it negotiated? ____________

c. How far into the future are rates analysed and negotiated between MOD and the company at this facility?

d. What is the forecast business base (by programme or activity) used to develop the rates for the contractor at this facility? Please list the hours by year for each programme. (For programmes less than 50,000 hours, they can be lumped together as an ‘other’ category.)

Programme	FY or CY 2002	2003	2004	2005	2006

e. What is the history of the business base at this facility over the last five years in terms of increases or decreases from the current levels?

f. Does the facility have programme specific wrap (i.e., fully burdened or composite) rates? __ Yes __ No

If yes, please provide them.

If a composite wrap rate by major function (manufacturing, engineering, QA, etc.) for the entire facility can also be provided, it would significantly aid the study.

g. If there are multiple overhead cost pools at this site, please identify each. What costs are included in each pool and how are these costs allocated? Which overhead pools would be applied to FACO activities? Repair activities?

h. Do you have models or other methodologies that calculate the impact of additions or reductions of business base on the labour wrap rate at this location? __ Yes __ No

If yes, can you share these with us?

i. Provide the following sensitivities of the composite labour wrap rate and overhead rate to changes from the current (FY 2002) business base.

Change in Current Business Base (in Hours)	Total Hours	Site Labour Rate Plus Fringe	Overhead Rate	G&A Rate	Other (e.g., COM, Programme-Specific, etc.)	Total Wrap Rate
+25%						
+10%						
0%						
–10%						
–25%						

j. Please explain how the composite rate is built up, starting from the basic direct labour through the total wrap rate. Which costs are treated as direct and which costs are treated as overhead/indirect? Is fee/profit included in the rate?

k. What is the facility composite material burden rate by year? What is the base used to calculate the burden rate? Are there different burden rates for contractor furnished equipment, government furnished equipment, high-value items versus low-value items? If so, please provide the rates and bases. What would be the impact of an addition of 10 percent, 25 percent, and 50 percent increase in the base? What would be the impact of a reduction of 10 percent, 25 percent, and 50 percent of the base?

l. Does this site share any overhead costs with other locations in the company? __ Yes __ No

If yes, identify other locations.

m. If applicable, briefly describe how the General and Administrative (G&A) rate is allocated across company sites.

n. Union Representation

Is the workforce at this site represented by a union? __ Yes__ No

If yes, fill out the table below.

Union Name	Number of Employees	Contract Expiration Date	Last Strike Date

Do union agreements cover multiple company locations (i.e., is there a company-wide union agreement)? __ Yes __ No

If yes, identify other locations covered.

Appendix B

PRODUCTION GAPS AND RESTARTS[1]

INTRODUCTION

Production gaps are typically very expensive for both the buyer (government) and the producer (contractor). Such gaps disrupt the workforce, often necessitating layoffs. In an environment of low unemployment, these workers might be difficult to recapture if they have moved to other jobs. Further, a producer often acquires institutional knowledge and skill over the course of a production run, becoming more proficient over time. This skill and added proficiency erodes significantly during a gap. Hence, production after a gap can be significantly more expensive compared to the costs of the final quantities produced just before the break.

One of the issues that the MOD asked RAND to address in the study was the impact of uncertain production levels on the analysis. In Chapter Five, we presented a sensitivity analysis for a range of additional production from European partners in the JSF programme. A production gap and restart is a much harder issue to model because the effect is very dependent on the specifics of when and how the gap occurs. In this appendix, we provide guidance to an analyst seeking to understand the cost effect of a production gap.

[1]The information in this appendix comes largely from Younossi et al. (2001). This RAND report is marked "for government use only" because of the proprietary nature of certain cost data. However, this abstract of the work contains only general discussions and presents only previously released data.

COSTS ASSOCIATED WITH A PRODUCTION GAP

The costs associated with a production gap divide into two categories: recurring and nonrecurring. Nonrecurring costs are costs that accrue during the course of a shutdown and restart of production and do not occur regularly with production past the gap itself. For example, the contractor (and ultimately the government) pays for the facility shutdown costs at the beginning of the shutdown. The retention of critical skills is another example of nonrecurring costs. The costs of keeping critical workers on the payroll are paid only during the gap period.

Recurring costs are costs that accrue before, during, and after the production gap. Sometimes the effect of these costs might be felt for several years after the gap. An example of such a recurring cost is the impact of training and proficiency losses. After a gap, it might be necessary to hire new workers to replace the experienced ones let go. It may take years, in some cases, to train these new employees to a fully productive level. Thus, a cost associated with a productivity loss might extend well beyond the production restart.

Table B.1 outlines typical recurring and nonrecurring costs associated with a production gap.

For JSF FACO in the UK, the most significant costs for a production would likely arise from facility shutdown costs, preservation of tooling, loss of learning, and overhead increases.

Table B.1

Recurring and Nonrecurring Costs Associated with a Production Gap

Nonrecurring Costs	Recurring Costs
Retention of critical skills	Loss of learning for direct labour
Facility shutdown and restart	Training and proficiency losses
Preservation of tooling	Supplier base problems
Termination and rehiring costs	Overhead increases arising from loss of business base

LOSS OF LEARNING

One significant cost associated with a production gap is the so-called 'loss of learning' after the gap. This cost arises because task-specific knowledge and skills are lost as a result of not regularly performing that function. For example, a worker might become very skilled and proficient at making a certain part or subassembly after having repeated the task several times. The worker acquires the manual skill in assembling a specific part as well as the ability to recall the process without having to refer to instructions. Further, he or she might develop tricks to speed or facilitate the manufacture. If the worker, then, does not make the part or subassembly for a year or two, it is unlikely that he or she will retain either the manual skill or the acquired knowledge. Therefore, it takes longer to produce the item after the gap than immediately before the gap.

In 1993, Birkler et al. examined the effect of a production break on 11 aircraft, missile, and helicopter programmes. These programmes were the B-1, C-5, U-2, Jetstar, OV-10, UH-2, AGM-65, F-117, S-3, B-707, and CH-46. The authors came to several major conclusions. First, the length of the gap did not correlate with the recurring costs. This result was somewhat surprising because one might expect the recurring costs (loss of learning) to increase as the production gap becomes longer. One should note, however, that all the programmes examined had production gaps greater than 12 months. Moreover, the average gap was close to 10 years. Therefore, one might hypothesise that, after a certain gap length (relatively short on a programme timescale), no continued loss of learning would occur. These data might not show the sensitivity of loss of learning to a short gap length.

However, the authors did find a positive correlation between gap length and the increased nonrecurring costs. In other words, the fixed costs associated with a gap in production increased as the gap duration increased. This observation makes intuitive sense; one might expect, say, the costs to preserve and store tooling to be directly related to the time that material would need to be maintained. In terms of the magnitude of these nonrecurring costs, they were roughly 10 percent of the original programmes' nonrecurring costs. (It should be noted that the data supporting this observation were quite sparse.)

Younossi et al. (2001) reexamined the data from the Birkler study and observed that the loss of learning was trade/skill dependent. Table B.2 summarises these results. The table shows the following:

- How many units of experience are retained after a gap.
- How the learning slope changes for each discipline.

For example, suppose that a production gap occurred midway through the UK FACO work, occurring at unit 75. After the gap, the production restarts with unit 76. From a learning curve perspective, the starting unit would be lhigher up the learning curve, or equivalent to some unit previous to number 76. For the production trade, the unit number used for learning after a restart would be about unit 11. Furthermore, the learning slope flattens. If the slope before the gap is 86%, then the learning slope after the gap is 93% for the production trade (the square root of the original learning slope). Using these assumptions, the production hours for the first unit after the restart (unit 76) would be approximately 0.60 × T1 hours. Without a gap, the production hours for unit 76 would be 0.39 × T1 hours. If we calculate the total production hours for the entire run, the 150-unit production would require approximately 63.8 × T1 hours without a gap whereas production with a gap midproduction would take approximately 80.1 × T1 hours—an increase of 25 percent. Based on this simple example, one could expect the *direct costs* to increase substantially as a result of a gap.

Note that it is unlikely that a production gap would occur at the Lockheed Martin facility in Fort Worth as production for the U.S. buy is both much greater and continuous across the production run.

Table B.2

Loss of Learning Impacts of a Production Gap

Trade	Units of Experience Retained Post-Gap	Learning Slope Change
Engineering	12%	Square root
Production	14%	Square root
Quality	5%	Square root
Tooling	6%	Square root

Therefore, a gap in UK buys would not incur the same cost penalty as a gap where FACO activities were done in the UK. As an order of magnitude, one might expect the net cost delta for where only FACO is done in the UK to increase by at least 25 percent. The actual increases would be sensitive to the timing of the gap as well as the distribution of hours between the various worker functions.

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