INTRODUCTION

While not prescribing a JSF FACO approach, the congressional language calling for this study required an examination of alternate FACO strategies. The language focused principally on various factors that would affect the cost at the different potential FACO sites. While cost is a predominant consideration, other issues must be explored as well to ensure an informed decision regarding the sharing of FACO activities among multiple sites.

This chapter initially focuses on issues relating to splitting production. In addition, it presents an overview of several policy considerations that will affect FACO strategy. Finally, this chapter provides an overview of historical examples of split production.

GENERAL POLICY ISSUES RELATED TO SPLITTING DEFENSE PRODUCTION

Several reasons are potentially valid for splitting any kind of defense production. The most common, from an acquisition viewpoint, is to generate competition to gain its attendant benefits. These benefits are generally thought to include better product performance, higher production efficiency and lower unit costs, and greater contractor responsiveness. While the JSF procurement will not incorporate competition, as will be discussed, it is useful to describe competition to clarify the issues involved in splitting FACO and how they will differ.
Classic market competition does not occur in the procurement of major defense systems: There are no cases where a large number of sellers provide similar goods and services to many buyers. In the defense industry, there is, usually, one major buyer and a limited number of sellers.

Given this environment, holding a true competition, where the contractor (seller) with the best value bid (lowest price and/or best performance) can win 100 percent of the business, has some distinct disadvantages. For example, the losing contractor must bear considerable costs at the conclusion of the competition—e.g., costs associated with laying off workers, having to rehire and retrain them later on. Furthermore, a contractor who loses the competition might be forced out of the business because of these costs. After that, the remaining contractor no longer faces the competition that works to keep costs down and value up. Hence, competition in the defense industry often features either directed buys, where the production is divided according to some predetermined formula, or a continued competition, e.g., where the work shared between two or more companies varies over time as a function of their performance.

Splitting production has associated costs. These include duplicate facilities and tooling, loss of learning economies, and increased overhead that occur when production is split between two or more sites.

The benefits and costs of splitting production in the procurement of major defense weapon systems have been repeatedly examined. The question is whether the benefits of competition outweigh the additional costs. This has never been completely resolved. Indeed, the answer likely differs for different classes of weapon systems as well as in different individual procurements. It has even been shown that analyzing the effects of competition on costs for one weapon system using different methods can produce different results.

Usually, the definition of “competition” is two or more separate organizations vying for sales to DoD, contrasted with a single con-

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1For example, in Birkler et al., 2001; Birkler, Dews, and Large, 1990; and Birkler and Large, 1990.

2Birkler, Dews, and Large, 1990
tractor building one system. In reality, a range of alternatives can be found along a continuum (depicted in Figure 2.1) that can be labeled “level of competition,” or, more accurately, “procurement production alternatives.”

Each of these production alternatives has distinct features and involves the maintenance of a different set of skills by single or multiple companies.

Having multiple sources for any weapon system—“competition”—can take several forms. The fullest form of competition is to have completely different weapon systems that would support similar missions competing for government orders (the far right-hand side of Figure 2.1). These should have enough functional similarities that, to some extent, they can substitute for one another. The government theoretically has a choice, for example, in procuring more F-15Es versus more F-16s. In reality, many factors, from the different capabilities of the aircraft to the branch of the armed forces for which the aircraft was originally developed, shape the choice to a great extent. The companies involved in this competition have the most freedom in terms of design, program management, production approaches, and so forth.

Often the government already has an existing weapon system for which it wishes to develop competition. Given this, two alternatives exist when introducing competition in weapon system acquisition. One is to qualify a second source to develop a system that is func-

![Figure 2.1—Continuum of Procurement Production Alternatives](image-url)
tionally the same but with a different design, known as a “form-fit-function” approach. The goal is for the two systems to be essentially substitutable for each other because their capabilities and performance would be identical from the user’s perspective. The form-fit-function approach can be expensive because it essentially duplicates the effort involved in the development process while limiting the ability to provide new capabilities or design approaches. The second source is given fixed specifics to design to, reducing alternatives, and must shape its own internal capabilities and expertise to develop something functionally the same as that developed by a firm with different capabilities and approaches to design. At the same time, the second source does maintain independent design and program integration expertise. Military engines are an example of this kind of market, where the government can pick between Pratt & Whitney and General Electric Aircraft Engines versions of the same engine.

The other approach is the “build-to-print” method, where the second contractor builds the same system as the prime contractor. This is also known as the “leader-follower” approach. The original prime contractor must share the blueprints and various processes with the second source, which may raise some intellectual property issues. The goal is to have an identical weapon system. A downside is that the second source likely will not participate in the design process. The second source does decide how to organize production and the supply chain, not necessarily duplicating all of the prime contractor’s choices. This approach has been followed in developing second sources for missiles. For example, the original producer of the Tomahawk missile was General Dynamics/Convair, with McDonnell Douglas integrating the guidance system. At the government’s request, the contractors shared technical information so that each could produce the identical missile.3

Each of these three approaches (system competition, form-fit-function, and build-to-print) involves the sort of competition not under consideration here, as will be discussed below. The alternatives considered in this study are: teaming with multiple sites, one contractor with multiple sites, and one contractor with a single site.

3Birkler and Large, 1990.
One production alternative is to have a second company do some of
the work but have the two companies participate in a “teaming”
arrangement. Here, designs and processes are shared as well as the
organization of production and the supply chain. A single contract
may be used to purchase procured goods and services for both
manufacturers. A second team of company managers is involved in
the work and in program management but does not develop an
original approach. Two sets of industrial engineers can analyze the
work. Some duplication of effort is involved, but this is limited.

In a second alternative, a single company may choose to split pro-
duction between two sites that it controls. This may be done for
capacity or for some other reason. Here, the duplication is even
more limited, specifically, of the two teams of workers skilled at
doing the same kind of work, as well as some duplication of manu-
factoring engineers.

Finally, the most restricted production alternative, on the far left-
hand side of Figure 2.1, is a single company building all units at a
single site. Here, there is one design team, one program manage-
ment team, one plant management group, one set of manufacturing
and industrial engineers, and one group of workers performing the
labor.

The production alternatives are summarized in Table 2.1.

**JSF**

With a single weapon system under consideration, true competition
between the JSF and some other system is not at issue here. From
the outset, the acquisition strategy for the JSF has differed from
either the form-fit-function or build-to-print approaches. The goal
of those two approaches is to garner the benefits of competition by
letting the firms compete for some of or the entire buy. From the
beginning of the CDP, DoD tried to induce the best efforts from the

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4This is the third alternative from the left on the continuum of procurement produc-
tion alternatives.

5This is the second alternative from the left.
Table 2.1
Skills Maintained by Range of Production Alternatives

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Design Engineering</th>
<th>Program Management/Integration</th>
<th>Production/ Mechanical Engineering</th>
<th>Touch Labor</th>
</tr>
</thead>
<tbody>
<tr>
<td>System competition</td>
<td>Multiple independent teams</td>
<td>Multiple independent teams</td>
<td>Multiple independent teams</td>
<td>Multiple, with independent skills</td>
</tr>
<tr>
<td>Form-fit-function</td>
<td>Independent design, but to constrained specifications</td>
<td>Multiple independent teams</td>
<td>Multiple independent teams</td>
<td>Multiple, with independent skills</td>
</tr>
<tr>
<td>Build-to-print</td>
<td>Single</td>
<td>Multiple independent teams</td>
<td>Multiple independent teams</td>
<td>Multiple, with independent skills, may have same management approach</td>
</tr>
<tr>
<td>Teaming</td>
<td>Single</td>
<td>Multiple teams, second team has limited impact</td>
<td>Multiple, with interaction and sharing</td>
<td>Multiple, with independent skills, same management approach</td>
</tr>
<tr>
<td>Multiple sites</td>
<td>Single</td>
<td>Single</td>
<td>Some duplication</td>
<td>Multiple, with independent skills</td>
</tr>
<tr>
<td>Single site</td>
<td>Single</td>
<td>Single</td>
<td>Single</td>
<td>Single</td>
</tr>
</tbody>
</table>

contractors by awarding the JSF as a winner-take-all program. The winner, if it so desired, would be able to bring the losing contractor onto the program, possibly to gain capabilities or even to win support for the program from Congress. Whether this cooperation would take place at all, as well as what activities the losing contractor would perform, would be negotiated by the contractors themselves and not directed by DoD. The goal of the program has been to have one contractor completely responsible for producing the weapon system.

For reasons that appear in the next chapter, this report examines only locations that either Lockheed Martin or Lockheed Martin with its JSF partner, Northrop Grumman Air Combat Systems, control.
This approach to FACO of the JSF corresponds to the “single site,” “multiple sites,” and “teaming” alternatives described above. (A complete description of the site-selection process appears in Chapter Three.) The participating companies would not be in competition with each other, so they would not have the incentives that competition generates in an open market. At the same time, the partners should be willing to share lessons learned, so some of the learning could transfer between sites. Sites under consideration include Lockheed Martin facilities in Fort Worth, Marietta, and at Site 10 in Palmdale, along with Northrop Grumman’s Sites 3 and 4 in Palmdale.

ARGUMENTS FOR AND AGAINST SPLITTING PRODUCTION

A directed split of final assembly and checkout between two different locations controlled by the same firm or by a firm and a partner organization would be a new arrangement for modern aircraft procurement. An assessment of the costs and benefits reveals that the costs can usually be better estimated than the benefits, which often take an intangible form. In this report, we use the RAND cost model to address the cost issue. The analysis is described in Chapter Ten. In this chapter, we assess the intangible benefits typically cited in support of having competition or multiple sites in weapon systems procurement programs: contractor performance, industrial base, capacity, risk, buffer, and the sharing of economic benefits.

Contractor Performance

The JSF competition was structured so that a single prime contractor (which turned out to be Lockheed Martin), would win the JSF. Even if the decision were made to develop multiple FACO sites, there would be no competition between the sites in the traditional sense. Hence, it is RAND’s estimation that splitting FACO would not create the benefits of competition in its classic sense, which include better product performance, higher production efficiency along with lower unit costs, and greater contractor responsiveness, as distinct competitors fight to increase their market share. Even without traditional competition, it is conceivable that a type of cost competition could be set up in house, with each site being encouraged to be more efficient than the others. Employees could be offered incentives to win
the “competition.” Merely tracking and publicly reporting which plant did better could result in a Hawthorne effect\(^6\) that could improve local performance.

However, incentives in defense production for cost savings by the contractor are limited, potentially limiting the willingness of firms to create this kind of in-house competition. Even firm-fixed-price contracts are often based on the previous year’s cost. Cost-based contracts provide a disincentive to cut costs. These contract types may have slowed the adoption of industrial best practices by the defense industry.\(^7\) Furthermore, and more dangerously, if the sites competed with each other, it is less likely that they would share learning. Knowing that their performances are being directly compared could make the sites less willing to share lessons learned and process improvements with each other. This could result in costs from loss of learning that might even outweigh potential benefits from this staged competition. If different sites gradually developed different approaches that they did not share with each other, the result could be a kind of “configuration drift,” as the aircraft built at the different sites became less common. (This would be a risk even though there presumably would be conscious effort on the part of DoD to manage this.) The result of less commonality could be greater life-cycle costs.

One reason cited in historical cases for adding a second source in weapon procurements is insufficient or even bad performance by the initial prime contractor. The F-100 engine is an oft-cited example of this. According to some sources, Pratt & Whitney was unresponsive to its most important customer—DoD, which then developed General Electric Aircraft Engines as a second source.\(^8\) Better contractor performance is one of the benefits of competition. However, dividing JSF FACO activities among the sites considered in this research would not create or reflect a competitive situation. Although there may be variation in performance, having a single corporate management team interacting with the customer would mean individual

\(^6\)Researchers investigating ways to improve worker performance noted that management attention led workers to increase their effort. This research was conducted at the Western Electric plant in Hawthorne, Ill., in the 1930s (Roethlisberger and Dickson, 1939; Mayo, 1945).

\(^7\)See, for example, Cook and Graser, 2001.

\(^8\)For example, Drewes, 1987.
sites would not necessarily make attempts to be more responsive—or less costly—than the other sites.\textsuperscript{9}

\section*{Industrial Base}

According to current procurement plans, when the F-22 and the F/A-18E/F finish production, the JSF will be the only manned tactical aircraft still being built for the U.S. military (see Figure 2.2). While follow-on orders and orders for foreign military sales may keep the other production lines active after production is scheduled to close, these future orders are unknown. Some in Congress and elsewhere have expressed the concern that having a single tactical aircraft production line with no competition will result in an unacceptable diminution of the tactical aircraft industrial base.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{Figure2.2.png}
\caption{Figure 2.2—Fighter Aircraft Production Schedules}
\end{figure}

\textsuperscript{9}Although Lockheed Martin would certainly have the opportunity to put in place internal corporate incentives to this effect.
The industrial base issue of manned tactical aircraft has been the subject of considerable concern and has been studied repeatedly. In 2002, Congress mandated a new study to look at the strength of the U.S. military aircraft industrial base for all types of aircraft.

In the meantime, this report will address what capabilities FACO sustains and whether having two JSF FACO sites is necessary or preferable in light of those capabilities. One way to approach this issue is to break down the industrial base for tactical aircraft into its component capabilities and assess how well alternate production plans sustain these capabilities. These varied capabilities include overall program management; design and development of aircraft; managing the integration of aircraft, including managing a supplier industrial base; manufacturing and support engineering; and performing the actual labor involved with final assembly and checkout, as appears, for example, in Table 2.1. Certainly, the loss of capability in aircraft design or overall aircraft and program management integration could be a concern if there were only one producer of tactical aircraft (although there is room for disagreement even here). Usually, these are viewed as the most critical capabilities to maintain.

Splitting JSF FACO across two sites owned by the same firm or by teammates who worked on the aircraft development and program integration together, would not maintain the most critical capabilities—design and program integration. The work that would be duplicated includes predominantly touch labor and some support labor, including quality control and engineering. Furthermore, the work involved in JSF FACO is not unique. These manufacturing skills will be supported by work on other aircraft programs, including both manned and unmanned vehicles, and by maintenance activities throughout the life of the aircraft. One company’s assessment was that, while routine depot maintenance checkout is a factor of 10 less complicated than that involved in initial production, if a problem with the aircraft cropped up during depot maintenance, many more of the initial production tasks would be duplicated and the work would approach initial checkout activities.
Avoidance of Risk

Having two or more FACO sites could reduce the risk of losing production capability in the event of a natural disaster or a terrorist attack. Certainly natural disasters cannot be planned for, although in areas of known natural risk, such as Southern California, building codes can mitigate the risk of some disasters, e.g., earthquakes.

Industrial facilities generally do not make good targets for terrorists. One expert on terrorism\textsuperscript{10} assessed the risk of an attack on an industrial location that is not also a major U.S. symbol (such as the World Trade Center was) as low, because targeting industrial resources is highly unusual for insurgent groups. Leftist groups may have been more likely to do so if the site was seen as symbolic of the capitalist system, but this risk has substantially diminished in recent years. Furthermore, splitting FACO does not control the risk that the attack may occur on the critical subcomponent level. Also, security can help mitigate man-made disasters.

Capacity

As discussed below, North American and Boeing produced post–World War II military aircraft (F-86, F-100, B-52) at multiple locations partly for capacity reasons\textsuperscript{11}. A large number of these aircraft were needed quickly for the Cold War. While the JSF program does call for the production of a large number of aircraft, it is spread out over 20 years, reducing the pressure on the capacity of any one plant.

Furthermore, the general approach to aircraft manufacturing has changed dramatically since the 1950s. Then, the producer actually fabricated many of the parts for the aircraft, put together the smaller subassemblies, and then assembled them into an integrated whole. Now, the majority of the final product is generally procured from subcontractors. Prime contractors tend to focus on integrating assemblies and subassemblies, making it less likely that having a

\textsuperscript{10}Daniel Byman, RAND, interviewed February 15, 2002.

\textsuperscript{11}Another reason for the 2nd protection sites away from the coast may have been to protect against a sea-based attack. With the development of more-powerful intercontinental ballistic missiles, however, even production sites in the middle of the country are vulnerable.
single location would create an unacceptable limit on production capacity. The sites considered in this analysis (to be discussed) operate one-and-a-half to two shifts, with a support shift at night. If more capacity were needed, they could each add a full third shift.

Finally, studies have shown that the aircraft industry currently has excess production capacity. The existing capacity at the major aircraft manufacturing sites means splitting FACO is unlikely to be needed to meet capacity requirements. Chapter Three shows the facilities and investment increases needed at the candidate FACO sites to support full-rate JSF production—they are small.

**Strategic Buffer**

The issue of maintaining an adequate buffer in production is related to the capacity issue. Here, the goal is to maintain facilities and expert workforces at both sites so that if a surge in production capacity were suddenly needed, two trained workforces would be available to handle it. This could be required if a serious global competitor building up its own tactical aircraft capacity arose, if smaller contingencies requiring tactical aircraft response increased, or if mission requirements changed.

Several counterarguments weigh against the strategic buffer approach. First, it is highly unlikely that a strategic competitor would arise so quickly that production at the first FACO facility could not speed up in time or that a second line could not be added elsewhere in response to the threat. U.S. intelligence would likely be able to ascertain if a country were building up its tactical aircraft capacity in time for the United States to counter. An increase in small contingencies is more likely, but the level of the increase in FACO that would be required in this case is not clear. As far as changing mission requirements, generally this is a longer-term process that can be met with the usual procurement procedures.

Furthermore, the long lead time on many procured items going into the subassemblies means that a speedy increase of FACO would be

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12 Gholz and Sapolsky, 1999/2000.
very difficult unless an increase in capacity were developed for the entire JSF value stream, not just for FACO.

**Share Economic Benefit**

An argument can be made that defense production is not the same as commercial production. In commercial production, maximizing profit is usually the overriding goal. Defense production has a public policy component. Even if inefficiencies result from splitting FACO, there may be policy reasons to do so, such as sharing the economic benefit from a major weapon system program. Splitting FACO could mean that two or more communities get these benefits, rather than just one.

The currently planned JSF program is large. Although FACO activities make up a small portion of the total, around 2 percent, they still amount to several billion dollars for the planned 3,002 production run, and more if additional exports occur. Having multiple FACO sites would share the economic benefits among more communities. If FACO is spread across locations, two or multiple communities will maintain major final assembly lines, complete with multiple skilled labor forces. If the work is split, the initial site will lose some jobs as the second site gains them.

Splitting production does not come without costs, which we will describe later. Each additional site will require the facilities, equipment, and tooling needed to perform FACO operations. Furthermore, spreading production among multiple sites means that the efficiency benefits from learning will likely be reduced. The result will be more labor hours and more workers required to perform FACO.

The additional facilities, equipment, tooling, labor hours, and workers directly translate into increased costs for the total weapon system without a concurrent improvement in warfighting capability. These costs must be covered somehow, and are, by the taxes that citizens in all communities pay. In Chapter Ten, we estimate the differential costs of splitting FACO. As will be seen, they are rather small when compared with the cost of the total program, but are still significant in their own right. It is a policy decision on the part of the U.S. gov-
ernment to determine whether the economic benefits from sharing FACO across multiple sites outweigh these costs.

Note also that production for the JSF is already spread across the United States. Many states participate in the production of subassemblies and components (see Figure 2.3). Subcontractors to these suppliers are further distributed across the United States.

Finally, because a decision to split FACO to spread the economic benefit might take into account economically depressed areas, we provide the December 2001 unemployment rates\(^\text{13}\) at the following three potential FACO sites considered in this report:

- Palmdale: 5.7 percent (average monthly rate for 2001—5.5 percent).

\(^\text{13}\)http://www.bls.gov.

**Figure 2.3—States with Significant Involvement in JSF Production**
• Fort Worth: 4.7 percent (average monthly rate for 2001—3.68 percent).
• Marietta: 4.2 percent (average monthly rate for 2001—3.4 percent).

The average national unemployment rate was 4.8 percent in 2001. While Palmdale has a higher unemployment rate than the other two locations, its unemployment rate does not indicate a depressed economy.

To summarize, splitting FACO would benefit more than one locality, but this benefit comes at a cost to all taxpayers and may affect the ability of DoD to invest its resources into the military capabilities that it needs. Significant JSF work is already spread throughout the country, benefiting a number of local communities. None of the areas under consideration for FACO has serious economic problems. Hence, the need to share economic benefits further does not appear to be a compelling reason to split FACO activities among multiple sites.

THE U.S. EXPERIENCE

The United States has limited postwar experience with multisite production of aircraft. In fact, no aircraft in production is undergoing final assembly at multiple sites. This holds true for commercial as well as for military aircraft. There are some instances of split production from other defense systems, such as missiles and ships. The following summary does not attempt to be an exhaustive review of all of the cases.

Three Post–World War II Aircraft: F-86, F-100, and B-52

Three examples of post–World War II aircraft built in two locations within the United States are the North American F-86 Sabre and F-100 Super Sabre and the Boeing B-52. Production for both the F-86 and F-100 began in Southern California, and second production lines

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\[14\] If multiple sites offered economic benefits, presumably, profit-seeking commercial manufacturers would split their production.
were later opened for both aircraft in Columbus, Ohio. The B-52 was produced first in Seattle, Wash.; later, production took place in both Seattle and Wichita, Kan., concurrently.\textsuperscript{15} In all of these cases, the prime contractor controlled both sites.

Rich et al. (1981, pp. 61–66) present evidence on how different categories of costs of the F-100 and the B-52 programs were affected by having multiple production sites for the aircraft. For engineering, the B-52’s second site required about a 10-percent increase in the hours required to produce the 172 aircraft manufactured in Wichita. For the F-100, however, engineering hours to produce the 359 aircraft at the second site actually declined by about 48 percent. Rich et al. postulate that a smaller fixed engineering staff at the second site explains the reduction in cost, but the savings could have been driven by a design that was easier to produce or by some other factor.

For both the F-100 and the B-52, tooling requirements for the second facilities were significant and added substantial costs. Nonrecurring tooling hours for the F-100 at Columbus were 96 percent of those required for the work in Los Angeles, even though the maximum production rate was 40-percent less. If costs are scaled for production runs of the same size, nonrecurring tooling hours would have increased by 344 percent at the second site for B-52s and by 388 percent for F-100s. The authors report that for manufacturing, producing at two facilities rather than extending the original production at the original site led to a significant increase in manufacturing labor hours. They also note that increases in material costs associated with multiple sites can be kept to a minimum if purchasing is centralized or coordinated.

Rich and his coauthors note that indirect costs, including overhead and general and administrative costs, make up a large portion of the cost of any aircraft. Each facility generally has its own overhead rates, although some companies\textsuperscript{16} have moved to consolidate as many of these costs as possible across locations to develop a single overhead rate or at least rates more similar across sites. The authors

\textsuperscript{15}Rich et al., 1981, p. 61.

\textsuperscript{16}Including Lockheed Martin, which has consolidated its Fort Worth, Marietta, and Palmdale facilities into one unit—the Lockheed Martin Aeronautics Company—headquartered in Fort Worth.
argue that moving production to a site with a lower overhead rate may result in overall savings if the reduction in cost exceeds the increase in overhead costs that will result at the first facility.

While the B-52 and F-100 offer interesting examples of multisite productions, lessons may be limited for aircraft developed and produced some 50 years later. Vastly different design philosophies, manufacturing technologies, and communication technologies between sites make direct comparison in the search for lessons learned problematic. For example, aircraft manufacturers in the 1950s tended to do much more of the work on site compared with current practice. Today, aircraft assemblers are much more likely to contract out parts and subcomponents and act more as integrators than as fabricators.

Coproduction of an Aircraft

Split production of the same aircraft has often been done because overseas production lines have been established either to encourage overseas sales or as a condition of such sales. Rich et al. (1981, pp. 131–133) present an exhaustive list of aerospace systems (including fixed-wing aircraft, helicopters, and missiles, along with tanks, howitzers, armored vehicles, and projectiles) that had been coproduced in multiple countries from World War II until that report’s publication. The many examples of aircraft produced abroad as well as in the United States include the F-86, F-104, F-4, F-15, F-16, and AV-8A/B. (This last aircraft, also known as the Harrier, was first produced in the United Kingdom and later in St. Louis by McDonnell.)

The F-16 aircraft is probably the most comparable to the single-engine JSF (its ultimate replacement). F-16 aircraft final assembly took place in the Netherlands by Fokker; in Belgium by SABCA; in Turkey by TUSAS Aerospace Industries; in South Korea by Samsung Aircraft; as well as in Fort Worth. Despite the lower wages paid at several of these locations, the international production of the F-16, in the opinion of Lockheed Martin personnel interviewed by RAND, was never done for efficiency reasons. Rather, the governments in the countries where this work was performed were concerned about their own industrial base and with developing certain capabilities, in spite of the cost premium. According to previous RAND research,
“Belgian officials admit that direct purchase would be about 10 percent cheaper” than having a local production line. However, if additional jobs were created in Belgium by Belgian F-16 production, the resulting taxes may have meant that the Belgian government saved money by producing it domestically.

THE EUROPEAN EXPERIENCE

Another example of multinational production is offered by the new all-European fighter, the EF-2000 Typhoon (the Eurofighter) aircraft, which will be produced by a consortium of manufacturers in four countries: the United Kingdom, Germany, Italy, and Spain. Each nation will manufacture different components, and each will have its own final assembly sites. Production workshares will be specifically related to the number of aircraft ordered by each partner nation (232 for the United Kingdom, 180 for Germany, 121 for Italy, and 87 for Spain). BAE Systems will assemble the UK version in Warton; Alenia Aerospazio, a Finmeccanica company, will assemble the Italian aircraft in Turin; Construcciones Aeronáuticas S.A. will assemble the Spanish aircraft in Madrid; and DaimlerChrysler Aerospace AG will assemble the German aircraft in Munich. These last two companies, also known as CASA and DASA, are part of the multinational defense consortium EADS (European Aeronautic Defence and Space Company).

Unquestionably the costs of producing the Eurofighter at multiple locations will be greater than if there was a single final assembly line. According to Latham (1989, p. 101),

All four participating countries plan to establish their own final assembly lines, and this will necessarily tend to reduce the benefits derived from specialisation. However, as final assembly typically accounts for only about 10 percent of European production costs, the collaboration premia associated with duplication can be as little as 1 to 2 percent of final production expenditures.

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Later evidence\textsuperscript{18} suggests that the costs of EF-2000 FACO will be even lower, on the order of 4 percent, so any cost of duplication of final assembly lines would be scaled by that smaller amount. Having separate final assembly lines may raise costs for each nation, but the FACO activities are seen as critical to developing an adequate maintenance capability for the aircraft, as some of the activities and relevant experience overlap. And because each nation plans to maintain its own aircraft, multiple FACO lines may be the most reasonable approach to developing this capability.

Collaborating on a cross-national program is significantly less expensive than having individual national programs, as Latham (1989, p. 101) argues:

> Considering both the benefits derived from scale and learning economies and the penalties associated with duplication, it would seem that a base order of 800 units for the EFA program could be expected to reduce unit costs by as much as 30 percent of the cost of a national program (although 15 to 20 percent is perhaps a more reasonable estimate).

\textbf{COPRODUCTION OF NAVY SYSTEMS BY MULTIPLE CONTRACTORS}

While no current examples of U.S. aircraft are undergoing final assembly at multiple locations, other defense programs have multiple final assembly locations, and these might provide useful lessons for a multisite FACO strategy for the JSF. The production of ships and submarines for the U.S. Navy probably offers the most similarities because they are very complex weapon systems. Four are particularly notable. The DDG-51 \textit{Arleigh Burke} destroyer is being produced at both General Dynamics Bath Iron Works in Maine and Northrop Grumman Ship Systems Ingalls Operations in Mississippi. The original program structure of LPD-17 \textit{Landing Platform Dock} had it being manufactured at General Dynamics Bath Iron Works in Maine and Northrop Grumman Ship Systems Avondale Operations in New Orleans. \textit{Virginia}-class submarine (SSN-774) production is

\textsuperscript{18}Interview conducted in 1999 by Katia Vlachos with a senior manager at Eurofighter GmbH.
split between Electric Boat in Connecticut and Northrop Grumman Newport News in Virginia. Each company is responsible for unique modules; final assembly alternates between the two shipyards. The production of the Los Angeles-class submarines (SSN-688) was also split between these two shipyards.\textsuperscript{19}

We interviewed individuals in the Navy and Office of the Secretary of Defense who were involved with these four programs. There was some disagreement about the reasons these programs had split production. Industrial base issues, the benefits of competition (including lower costs or reduced cost growth), and pure politics were all cited as reasons for the splits, and all probably hold true to some extent. Some capacity issues may exist in shipbuilding as well because the shipyards have a limited number of docks. Whether these limitations truly required the splitting of production for these ships is not clear.

Our interviews revealed a number of production and management issues. While shipyards produce the ships from the same blueprint (and thus should be producing indistinguishable systems), some individuals claim they can easily spot the difference between ships and submarines built by different producers, although these differences are thought to be cosmetic. Another difference is the production techniques employed by different shipyards. One such example is the bending or welding of pipes. One shipyard tends to bend pipes, while the other prefers to weld sections of straight pipe with elbow joints. When changes in design occur, each shipyard has to incorporate the change into its approach, thus adding time and cost.

Sharing information among sites is not always easy. One lesson learned painfully over time was the importance of having compatible design and analysis tools (i.e., for CAD/CAM). Programs with two production locations ran into difficulties when they used different systems. There was consensus that all ship manufacturers were considering CATIA\textsuperscript{20} as their standard CAD/CAM program, so this problem should decrease in the future. But even when these use identical systems, the translation issues mentioned above can create

\textsuperscript{19}Other Navy examples include the Seawolf submarine (SSN-21), the FFG-7, and some sealift ships.

\textsuperscript{20}A design and analysis tool originally developed by Dassault Systemes.
problems if the two companies have different approaches to manufacturing.

An amicable business relationship is important for sharing lessons learned across sites. During our interviews, we learned of cases in which the two corporate managements could not effectively work together, and thus the Navy had to step in to resolve various issues. People from the different companies who worked together directly at the shipyard usually had good working relationships. However, because these sites are not partners, but rather, direct competitors, some concern arose that they would not share all manufacturing experience, which would reduce overall cost or improve performance for all ships being delivered to the Navy. The competitors must share formal ECPs/ECOs, however, they need not share informal lessons learned.

Whatever the original reasons for splitting the production of the ships, one split has recently come under some question. The Navy, Northrop Grumman, and General Dynamics agreed that the two exchange work so that each focuses more on one program. Under this agreement, Northrop Grumman will give up four of its DDG-51 destroyers, which instead will be built by General Dynamics at Bath Iron Works in Maine. In return, Bath Iron Works will give up four LPD-17 amphibious ships. Some DDG-51s will still likely be built by Northrop Grumman. Inside the Navy reports, “the Navy maintains it will reap significant savings in the LPD-17 program by giving one company production of all 12 ships in the class, thus eliminating separate four-ship and eight-ship LPD-17 learning curves at two competing shipyards.” In short, the Navy presumably assumes that savings from a single learning curve will be greater than whatever savings competition would have generated.

The history of split production reflects different rationales. Production may be split because one plant does not have adequate capacity to produce the number of systems needed or because of industrial

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The cost of establishing a second facility and the learning curve costs incurred at the new facility typically increase overall production costs, although one contact argued that competition has helped control contractor cost growth, even if no reductions in cost are obvious.

**CONCLUSION**

Historical experience with multiple production sites for weapon system production indicates that the approach increases costs. While several arguments other than cost can be made for requiring multiple sites for JSF FACO operations, they are not individually or collectively compelling.

The trend in government management of the defense business has been to reduce the amount of oversight and government control. The driving concept of performance-based contracting practices is that telling defense contractors the performance required of the desired weapon system rather than specifically telling them how to build it will encourage them to use their ingenuity to meet government needs most effectively. Requiring Lockheed Martin to split JSF FACO functions among different sites would therefore go against the spirit of acquisition reform.

However, the government might decide that the benefits of splitting FACO outweigh its costs. That is a policy question for the appropriate decisionmakers to address. This research has revealed no compelling case for benefits in support of splitting FACO.