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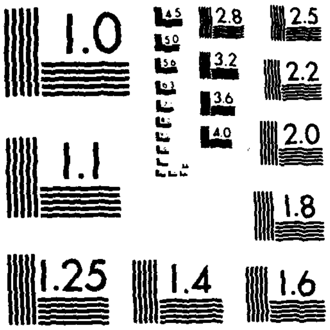
UNCLASSIFIED NDU/ICAF-83/047 F/G 15/3 NL



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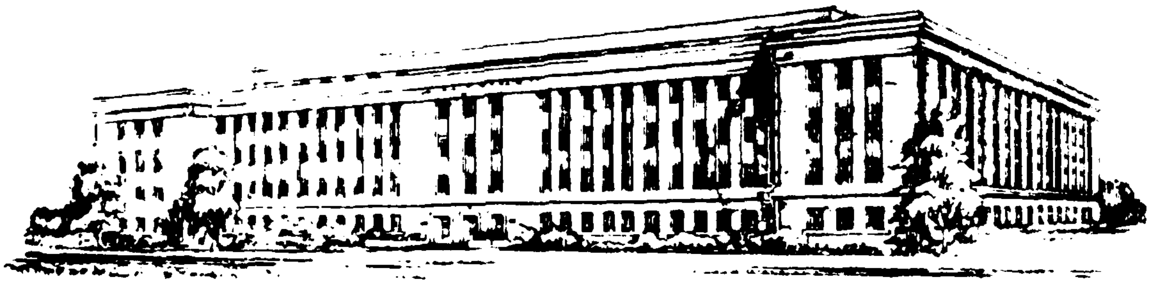
IDENTIFICATION OF BOTTLENECKS AND CAPACITY CONSTRAINTS



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This [illegible] approved
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distributio[illegible]

83 11 08 139

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER
NDU/ICAF 83/047

2. GOVT ACCESSION NO.
AD-A134 029

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
IDENTIFICATION OF BOTTLENECKS AND CAPACITY CONSTRAINTS IN F-14, F-15, F-16, and F/A-18 AIRCRAFT PRODUCTION

5. TYPE OF REPORT & PERIOD COVERED
MSP #41, AY 82/83

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
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8. CONTRACT OR GRANT NUMBER

9. PERFORMING ORGANIZATION NAME AND ADDRESS
INDUSTRIAL COLLEGE OF THE ARMED FORCES
FORT LESLEY J. MC NAIR
WASHINGTON, DC 20319

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS

11. CONTROLLING OFFICE NAME AND ADDRESS
INDUSTRIAL COLLEGE OF THE ARMED FORCES
FORT LESLEY J. MC NAIR
WASHINGTON, DC 20319

12. REPORT DATE
APRIL 1983

13. NUMBER OF PAGES
106

14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)
NATIONAL DEFENSE UNIVERSITY
FORT LESLEY J. MC NAIR
WASHINGTON, DC 20319

15. SECURITY CLASS. (of this report)
UNCLASSIFIED

15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)
UNLIMITED APPROVAL FOR PUBLIC RELEASE

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)
N/A

18. SUPPLEMENTARY NOTES
N/A

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)
N/A

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This paper examines the aerospace industry capacity for surge production of tactical fighter aircraft in response to a national emergency. It provides a conceptual overview of the aerospace industry, some general industrial production factors, and a discussion of the 1966-67 F-4 production surge. A vertical slice study of each of the four aircraft under consideration is then provided, followed by a horizontal slice study which addresses major critical production factors and ongoing corrective actions.

THE INDUSTRIAL COLLEGE OF THE ARMED FORCES
NATIONAL DEFENSE UNIVERSITY

MOBILIZATION STUDIES PROGRAM REPORT

IDENTIFICATION OF BOTTLENECKS AND CAPACITY CONSTRAINTS

IN

F-14, F-15, F-16, AND F/A-18 AIRCRAFT PRODUCTION

by

JOE G. CABUK, JR., COL, USAF
THOMAS J. DUNCAN, CAPT, USN
IRVING L. HOFFMAN, LTC, USAF
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A RESEARCH REPORT SUBMITTED TO THE FACULTY

IN

FULFILLMENT OF THE RESEARCH

REQUIREMENT

RESEARCH SUPERVISOR: DR. HERMAN STEKLER

THE INDUSTRIAL COLLEGE OF THE ARMED FORCES

APRIL 1983

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ABSTRACT OF STUDENT RESEARCH REPORT
INDUSTRIAL COLLEGE OF THE ARMED FORCES

NAME OF RESEARCHER (S)	TITLE OF REPORT
Joe G. Cabuk, Jr., Col, USAF Thomas J. Duncan, Capt, USN Irving L. Hoffman, Lt Col, USAF David V. Nowlin, Lt Col, USAF	Identification of Bottlenecks and Capacity Constraints in F-14, F-15, F-16, and F/A-18 Aircraft Production
SECURITY CLASSIFICATION OF REPORT	REPORT NUMBER
Unclassified	M

ABSTRACT

Problem Statement: This paper examines the aerospace industry capacity for surge production of tactical fighter aircraft in response to a national emergency. It provides a conceptual overview of the aerospace industry, some general industrial production factors, and a discussion of the 1966-67 F-4 production surge. A vertical slice study of each of the four aircraft under consideration is then provided, followed by a horizontal slice study which addresses major critical production factors and on-going corrective actions.

Findings/Conclusions: There are numerous bottlenecks and capacity constraints affecting the ability to surge the production of F-14, F-15, F-16, and F/A-18 aircraft. From the day a surge is ordered, a nominal six months would elapse before the first additional aircraft rolled off the production line. It would be approximately three years before sustained production rates reached the inherent surge potential capacity of each plant.

Recommendations:

1. Efforts to obtain funding for an additional year of long lead items should be strongly supported.
2. Efforts should be made to place these and other aircraft for which a production surge is contemplated on multi-year contracts.
3. Aircraft procurement programs should be funded at a level that will allow production near the most economically efficient rate.
4. Manufacturing technology improvement programs should be applied as soon as possible.
5. An indepth study of the F-4 surge production experience should be made to preserve the lessons learned.
6. The aerospace labor market should be studied, and, if necessary, a program to train workers in critical skills should be established.
7. Further horizontal slice studies should be made of various subcontractor sectors to determine the approximate total capacity to produce the critical items identified.

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ICAF FORM 56
1 FEB 75 (REVISED)

EXECUTIVE SUMMARY

This study examines the aerospace industry capacity for surge production of the F-14, F-15, F-16, and F/A-18 aircraft. The goal of the study is to identify bottlenecks and capacity constraints which would hinder a surge in the production of these aircraft in response to a national emergency. The paper provides a conceptual overview of the aerospace industry and presents some general industrial production factors. Next, a discussion of the 1966-67 F-4 production surge is provided, followed by a vertical slice study of each of the aircraft under co[illegible] [illegible] examine the interrelationships which may [illegible] bottlenecks and capacity constraints, a horizontal slice study is also presented in which the ma[illegible] production factors and on-going corrective actions are discussed.

The study concludes that there are numerous bottlenecks and capacity constraints affecting the ability to surge the production of F-14, F-15, F-16, and F/A-18 aircraft. From the day a surge is ordered, a nominal six months would elapse before the first additional aircraft rolls off the production line, and it would be approximately three years before sustained production rates reached the inherent surge production capacity of each plant. Two major factors creating this time delay are:

- The time to assemble and deliver an airplane is approximately one year.

- The reorder lead time for many aircraft parts exceeds two years.

Critical long lead parts include:

- Avionics
- Canopies and Windshields
- Electric Power System Components
- Engines
- Environmental Control Systems
- Forgings and Castings
- Fuel, Hydraulic, and Pneumatic system valves, gages, actuators, pumps, and components
- Landing Gear
- Machine Tools
- Titanium Skin
- Wheels and Brakes
- 20mm Gun

In addition to these items, shortages of skilled labor and materials are identified as potential problems.

The study recommends:

- The Industrial Preparedness Program efforts to obtain funding for an additional year of long lead items should be strongly supported because it can significantly increase the surge capability.

- Efforts should be made to place these aircraft and other aircraft for which a production surge is contemplated, on multiyear contracts.

- Aircraft procurement programs should [illegible] level that will allow production near the most [illegible] efficient rate for a one-shift, 40-hour week [illegible]

- Manufacturing technology improvements should be applied as rapidly as possible.

- An indepth study of the F-4 surge production experience should be made to preserve the lessons learned.

- The aerospace labor market should be studied and, if necessary, a program to train workers in critical [illegible] should be established within the Industrial Preparedness Program or in conjunction with other federal "jobs programs."

- Further horizontal slice studies should be made of various subcontractor sectors to determine the approximate total capacity to produce the critical items identified in this paper. These findings should then be compared to the total prime contractor surge demand, thereby determining where the potential demand exceeds the potential supply. A balanced corrective program should then be prepared and presented to Congress for funding.

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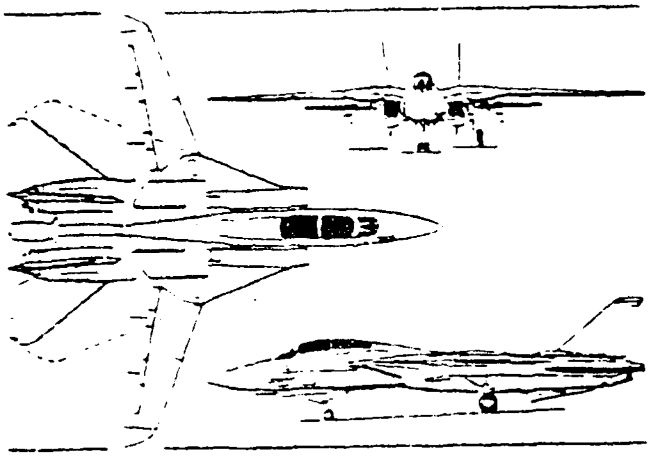
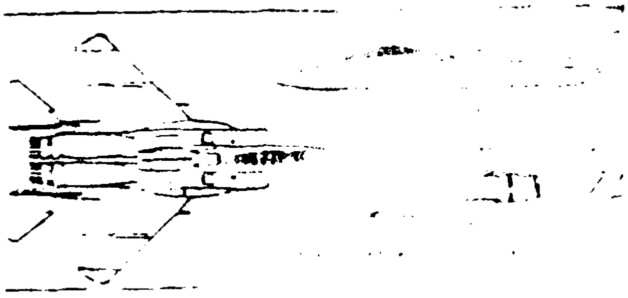
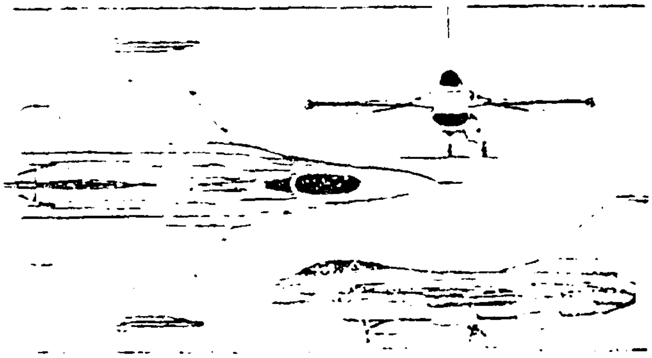


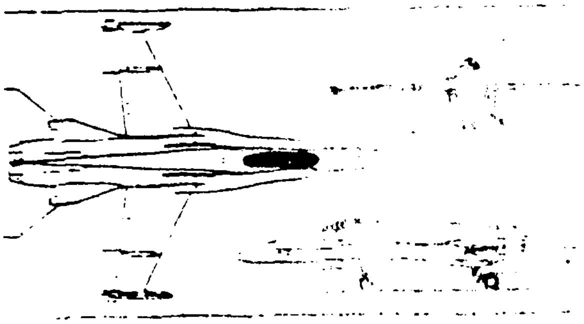
Grumman F-14A Tomcat carrier-based multi-role fighter (Pilot Press)



McDonnell Douglas F-15C Eagle [illegible]



Three-view drawing of General Dynamics F-16A Fighting Falcon (Pilot Press)



McDonnell Douglas F/A-18A Hornet [illegible]

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CHAPTER I

INTRODUCTION

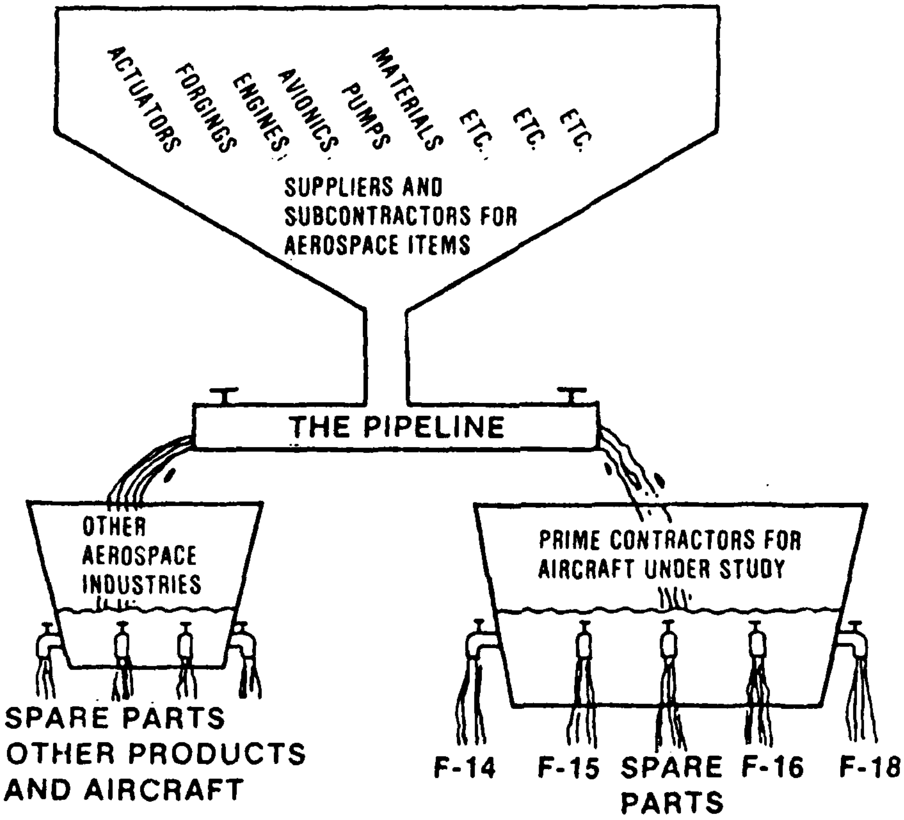
> "The bottom line is that even if we [illegible] for mobilization of our resources, we wou[illegible] to deliver significantly larger aircraft quan[illegible] in the first 24 month period. A chilling [illegible] is that after nearly 18 months under surge conditions, we could expect to get ... no additional F-15s and F-16s than ... the currently contracted delivery schedule." -- General Alton D. Slay, Commander, Air Force Systems Command, 13 November 1980 (29:III-18)

The statement above, and many others like it leads one to ask why such a condition exists. It appears that the United States, the legendary "Arsenal of Democracy" in World War II, cannot simply gather its muscles and in a matter of months, if not weeks, produce fighter aircraft faster than pilots can be trained to fly them. Such a capability seems important since peacetime budgets have not allowed the United States nor its allies to produce enough aircraft to match the numbers of modern fighters being fielded by the Soviet Union and its clients. For each of the last ten years, the Soviet Union produced over 1,000 fighter aircraft per year while the U.S. produced roughly half that number. (33:21,25 Thus, the United States, and its allies are faced with a [illegible] superior threat composed of technologically [illegible] aircraft. This threat could prevent the deterrence of war or the exercise of other desirable policy options because the U.S. could not bring sufficient forces to bear or have the numerical depth to sustain the losses necessary to prevail in a major conflict.

This study will attempt to identify the bottlenecks [illegible] capacity constraints which might affect the capability [illegible] rapidly increase the production of F-14, F-15, F-16, and F/A-18 aircraft. Research included numerous previous studies, briefings, and publications bearing on the subject, plus interviews with Department of Defense and contractor representatives having knowledge of the aircraft industry. The highlight of the research effort was a visit to the McDonnell Douglas Aircraft Company in Saint Louis, Missouri, to obtain first hand knowledge about the F-15 and F/A-18 production process and capability.

Early in the study it became evident that identifying specific bottlenecks and constraints would be a monumental task. Since each of these aircraft is built of parts supplied by literally thousands of subcontractors, it would not be possible to accomplish an in-depth analysis of the subject within the time and resources available. Narrowing the study to focus on only one of the aircraft [illegible] selected because a meaningful study of bottlenecks and constraints must consider the effect of several services simultaneously attempting to surge or mobilize their production lines. To illustrate, consider the aerospace industry to be represented by the system shown in Figure [illegible]. The output flow of F-14s, F-15s, F-16s, F/A-18s and spare parts is dependent first upon the prime contract[illegible] represented by the bucket with five output flows. Regardless of the prime contractor capacity, [illegible] output flow cannot exceed the input flow [illegible] subcontractors. However, for the short term, the output flow can be increased if there is an excess of "liquid" assets in the prime contractors' bucket. Obviously, a short term output surge can be continued only until the excess liquid [illegible] drained off, unless the input flow is simultaneously increased. One way to obtain such an input increase is to reduce the flow of items in the pipeline branch which pours into the bucket labeled "other aerospace industries." This flow diversion could be accomplished either by assigning a higher priority at the subcontractor level to those items needed to produce the aircraft in question, or by cutting out other production altogether.

Another factor to be considered in Figure 1 is maintaining a useable mixture of items within the prime contractor's bucket. For example, the input flow of engines must contain the proper numbers of the various engines needed



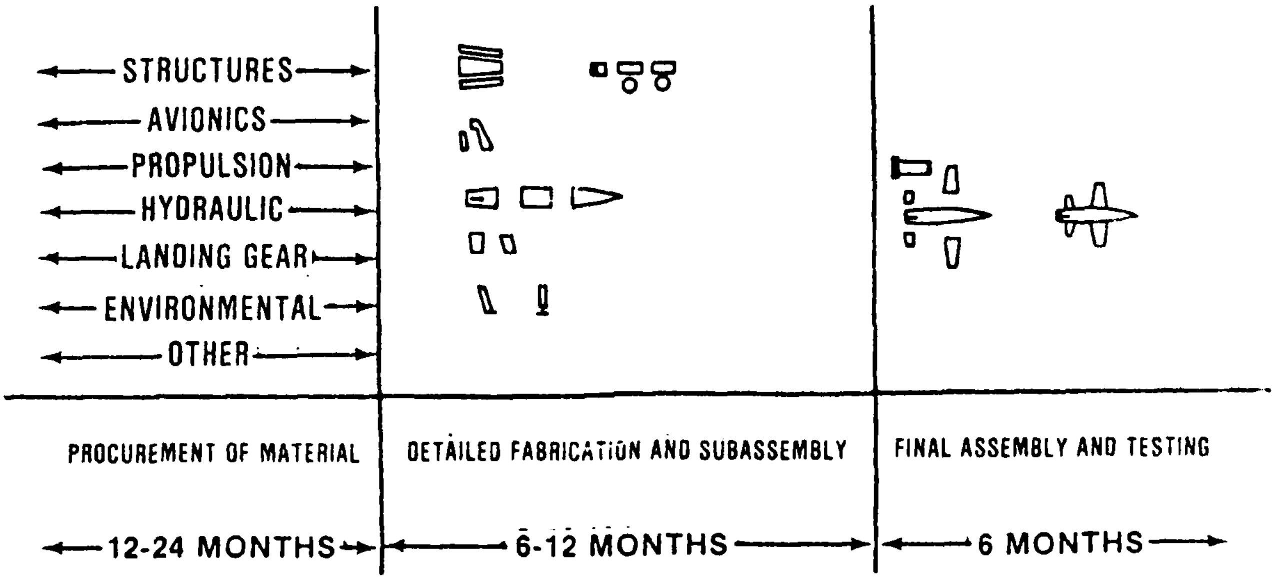
THE AEROSPACE INDUSTRY PIPELINE

FIGURE 1

by each aircraft if all output faucets are flowing at the planned rate. Thus, the subcontractors' production capacity has a direct influence on a prime contractor's output.

In addition to this conceptual look at the overall industry, one must consider the production flow for each aircraft. Figure 2 shows a typical production flow divided into three phases: (1) procurement of material, (2) detail fabrication and subassembly, and (3) final assembly and testing. Representative times for each phase for the type aircraft under consideration are shown along the bottom of Figure 2. To this time can be added the time required for the contracting and the funding processes, and one begins to see why General Slay is pessimistic about our ability to produce large numbers of aircraft upon short notice.

With this introduction to the conceptual framework of the study, we will turn in the next section to a discussion of the general industrial production factors which must be considered in the search for bottlenecks and capacity constraints which affect production of the F-14, F-15, F-16, and F/A-18 aircraft.



AIRCRAFT PRODUCTION FLOW

FIGURE 2

CHAPTER II

INDUSTRIAL PRODUCTION FACTORS

TERMS OF REFERENCE

Before discussing the findings, some terms of reference must be established. The following are definitions commonly used by experts on the subject.

- Normal capacity - The production rate based on one shift, 40-hour work week.

- Surge capacity - A rapid production increase using 1.4 shifts, 40-hour week.

- Mobilization capacity - Three full shifts, 48-hour week. (34:12)

Table 1 shows that each of the aircraft examined in this study is currently being produced at a rate well below the surge capacity. As will be shown, over 24 months would be required to increase production from the existing rate to the surge level. Since Table 1 shows considerable prime contractor capability standing idle, one might conclude that the surge potential would be enhanced; however, this is not the case, as will be seen in the next section.

* * *

Table 1. Annual Surge Capacity Vice Current Production Rate

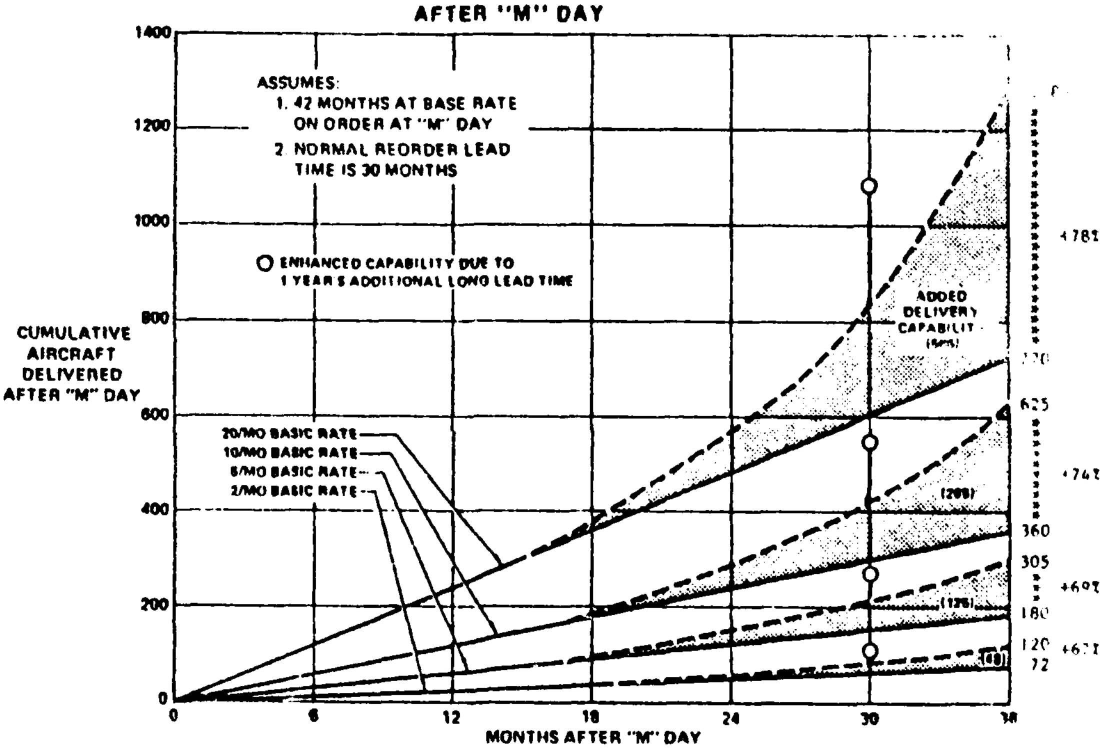
	F-14	F-15	F-16	F/A-18
Surge Capacity	96	144	228	204
FY 33 Production	24	52	120	84

* * *

PRODUCTION ACCELERATION CAPABILTY

Figure 3 shows the results of a McDonnell study of fighter production capability. The study assumes 42 months of aircraft at various monthly production rates are on order at M-Day, and a 30 month reorder lead time. As shown by the figure, the first aircraft ordered on M-Day would not be delivered for approximately 18 months, regardless of the starting production rate. The study also showed a direct correlation between higher delivery rates and best surge potential. For example, the popular idea of maintaining a "warm base" is represented by the lowest curve on the graph, a production rate of two aircraft per month. In this case, 72 aircraft would be in the pipeline on M-Day for delivery within 36 months. A surge from this condition would produce 48 additional aircraft within this 36 months, a 67% increase above the warm base production rate. On the other hand, the figure shows that surging from a production rate of 10 aircraft per month would increase the quantity delivered by

HIGH PERFORMANCE AIRCRAFT PRODUCTION ACCELERATION



SOURCE: McDonnell Aircraft Company

FIGURE 3

74%, from 360 to 625 aircraft at the 36 month [illegible] Although there is only a small difference in the percentage increase between these two cases, 67% vice 74%, the absolute numbers differ by a factor of more than 5.5 to 1 (265 vice 48 additional aircraft). Thus, the "warm base" is relatively inefficient as a basis for producing large numbers of aircraft in response to a surge requirement.

Another important factor which varies with the [illegible] production rate can be seen by examining the relative upward slopes of the dashed lines at the 36 month point in Figure 3. The steeper the upward slope, the higher the production rate at the end of the period. Again, the "warm base" does not compare favorably as its slope is relatively flat. This difference apparently results from two benefits associated with higher production rates. For the airframe manufacturer, it provides a network of subcontractors accustomed to supplying raw materials, forgings, or detailed parts on a regular basis at a high level, which encourages investments in modern equipment and trained personnel. The same response is required by the airframe manufacturer; he must also expand and upgrade his facilities and expand the pool of trained manpower.

A key item of interest in Figure 3 is the significantly higher number of aircraft which could be produced if one year's additional long lead time items were on hand prior to

M-Day. The analysis shows that in every case, the [illegible] quantity delivered could be approximately twice that provided by the basic rate at the 30th month if one year's long lead items were procured in advance each fiscal year. McDonnell Douglas drew several conclusions from this study:

- An airframe manufacturer's capability to accelerate weapon system deliveries is significantly constrained by the capability of suppliers of critical complex items where [illegible] or three viable sources exist for each, and the cost of maintaining standby suppliers is prohibitive. These [illegible] items include
    - Engines
    - Radars
    - Inertial Navigation Systems
    - Environmental Control Systems
    - Large Forgings

- The existing industrial capability for fighter aircraft (because of low production rates for existing programs) would require substantial periods of time to produce contingency aircraft inventories.

- The capability of a single source to accelerate system deliveries from a given basic rate of production is equal to or greater than two sources each producing at half the given rate and the premium cost of maintaining multiple sources for identical or similar purpose systems or components is considerable.

- The capability to acquire added aircraft earlier and in greater quantities could be enhanced by:
    - Stockpiling complete aircraft.
    - Increasing the current basic rate of deliveries of systems in production.
    - Buying long lead items concurrent with each planned fiscal year procurement for the next fiscal year. (5)

McDonnell Douglas' findings have been confirmed others examining the problem. For example, a "Joint Department of Defense, Office of Management and Budget Aircraft Industry Capacity" study stated:

> "Assuming a 1-year warning, with appropriate mobilization actions, existing warm production lines would begin to compensate partially for losses in 18 to 24 months... ." (34:7)

The DoD/OMB study also identified surge production constraints related to:

- Engines
- Radars
- Landing gear
- Some numerical control equipment
- Some fabrication shop work
- Shortage of tooling engineers
- Large forging capability (34:32)

Finally, the DoD/OMB study pessimistically concluded:

> "Comparing attrition and surge production estimates raises a question about the utility of surge production." (34:33)

It is therefore apparent that there are significant capacity constraints, and that prime contractors are currently producing well below their normal capacity.

TRENDS IN LEAD TIME

One important indication of the existence of capacity constraints and bottlenecks is the amount of lead time required to obtain an item. In late 1980, General Slay testified that the lead time for titanium forgings was 117 weeks. (29:III-17) This long lead time resulted from "a 1978 surge of new orders of jetliners [which] sparked a [illegible] upturn in the industry's aircraft production backlog. . . . [1978] Aircraft deliveries of all types numbered 19,960, the highest figure since the post-World War II record year of 1966." (1:30,31) The 1979 delivery figure was also over 19,000 aircraft; however, deliveries decreased to 14,678 in 1980, and then to 11,954 in 1981. These reduced deliveries resulted in shorter lead times. By late 1982, the 117 week lead time for large titanium forgings had decreased to 39-42 weeks, as shown in Table 2. Unfortunately, the lead time decrease shown for large titanium forgings and, indeed, all the items in Table 2 cannot be attributed to the presence of any new suppliers. Rather, an across-the-board decrease in lead time for all items is a result of the decrease in aircraft orders during the current economic recession. It seems reasonable to expect the lead time for each item to quickly return to a much higher value in the event of economic recovery or a surge in orders, such as would occur if civilian aircraft production were to be increased. Based on the expectation that the longer lead times shown in Tab. 2 are representative of a surge situation, there mav be significant constraints in the capacity to produce all the items listed. These items will be discussed in more detail in the following pages.

****

Table 2. Aerospace Products Lead Time Trends
(Weeks) (5)

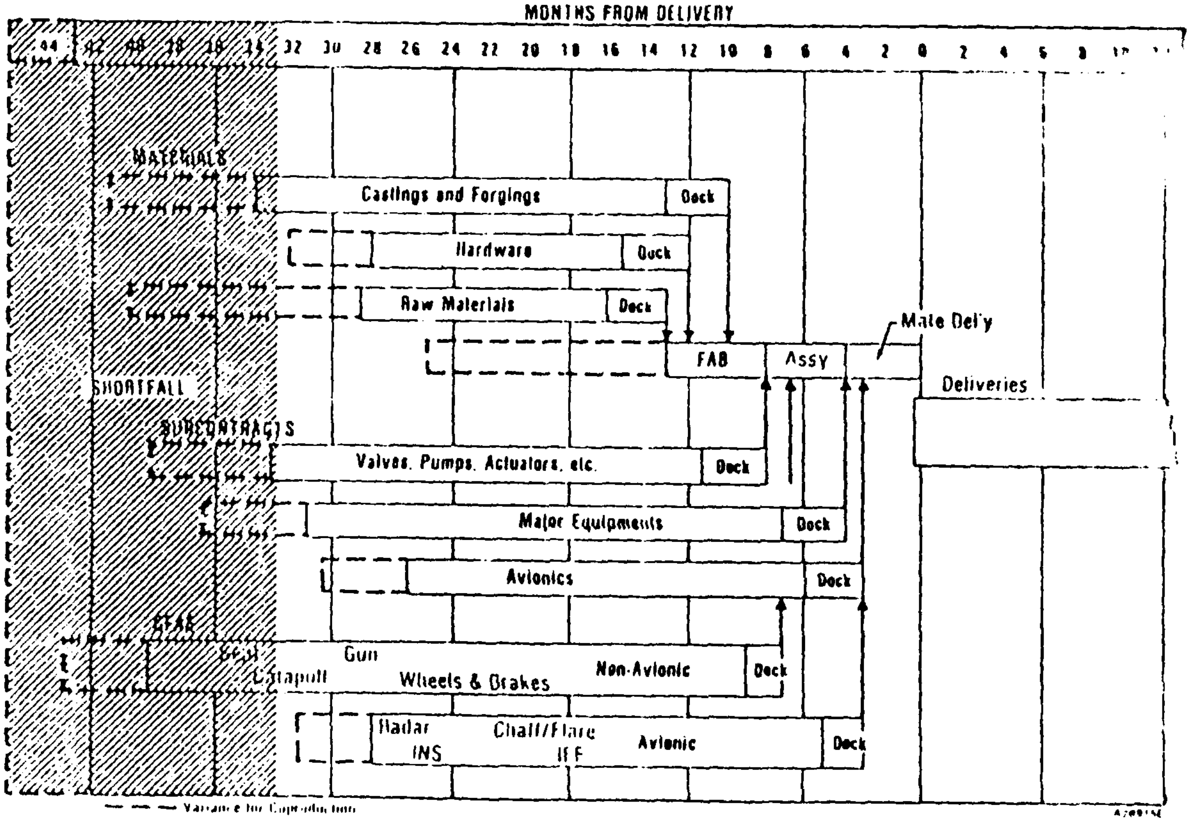
	PEAK DEC 79	CURRENT OCT 82	CHANGE
ALUMINUM EXTRUSIONS	70-85	12-16	-69
ALUMINUM SHEET/PLATE	48-72	12-26	-46
BEARINGS	52-86	24-30	-56
CASTINGS - LARGE	46-48	26-36	-12
COBALT/MOLY STEEL BAR	44-52	26-36	-1[illegible]
ELECTRICAL CONNECTORS	26-68	16-28	-40
ELECTRICAL WIRE	52-60	12-16	-44
FASTENERS	34-38	8-22	-16
FORGINGS - ALUMINUM & STEEL	70-115	34-40	-75
FORGINGS - TITANIUM - LARGE	100-120	39-42	-78
HINGES	72-90	25-28	-62
HYDRAULIC FITTINGS	80-84	32-40	-44
MACHINING - LARGE	34-36	24-30	-6
ROD ENDS	52-65	24-30	-35
RUBBER PRODUCTS	18-26	12-16	-10
TITANIUM - SHEET/PLATE	55-85	12-20	-65

****

EFFECT OF LEAD TIME ON PRODUCTION

The effect of these long lead times on a prime contractor's ability to increase his production rate is shown in Figure 4. Castings and forgings must be ordered at least

AIRCRAFT MANUFACTURE vs MATERIAL LEAD TIMES



Source: General Dynamics

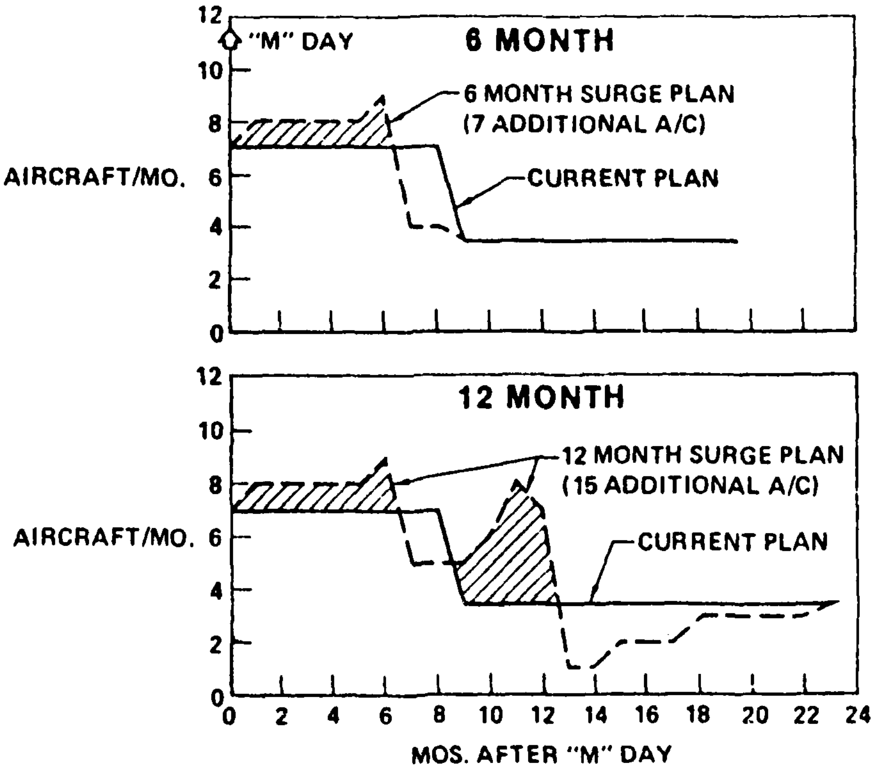
FIGURE 4

24 months before they are needed in the fabrication process. Likewise, valves, pumps, and actuators must be ordered approximately 24 months before they will be needed; some government furnished items, such as ejection seat catapults, must be ordered even earlier. Add to these items the 13 months shown for the prime contractor to assemble and test the aircraft, and it becomes apparent that aircraft orders placed on M-Day will not be delivered until approximately 2 1/2 to 3 years later.

Another effect of long lead time on surge production capability is shown in Figure 5. The figure shows that the production rate can begin to increase immediately after M-Day by consuming parts which are on hand and those which arrive through the pipeline as a result of old orders. Once these parts are used, however, production must fall off dramatically until a new supply of long lead items arrives. Figure 5 will be discussed further in the section of this paper which presents the F-15 vertical slice study.

It must be noted at this point that almost all the data available concerning surge production seems to reflect a "business as usual" assumption. Several of the persons interviewed said that surge production response time could be greatly reduced if the government established priorities and used mobilization powers to allocate resources. Comparing the F-4 surge actual experience, which will be discussed

F-15 SURGE CAPABILITY



Source: McDonnell Aircraft Company

FIGURE 5

later, to the surge predictions for the F-14, F-15, F-16, and F/A-18 seems to indicate that current projections are somewhat conservative. Nonetheless, the degree to which these estimates may be biased was impossible to determine, so all predictions are presented without any attempt to quantify the degree of conservatism.

EFFECT OF TOTAL REQUIREMENTS BUILD-UP

The build-up of requirements for materials, parts, and labor frequently exceeds the capacity of various sectors of the industry, creating an increased lead time for a given item. For example, Figure 6 illustrates how this requirements build-up occurs for the F-16 program. The prime contractor's requirements for items to support USAF production, foreign military sales programs, war readiness, the surge program, spare parts, modifications, and repairs generate orders for vendors. These vendors have a finite productive capacity, and, as the figure shows, are also receiving competing orders. Frequently, the vendor's capacity is exceeded. This situation has the following effects:

- Material lead time is increased.
- Increased turn around time for repairs.
- Increased product price.
- Delay and lack of support in the field.

Effects of Total Requirements Build-Up

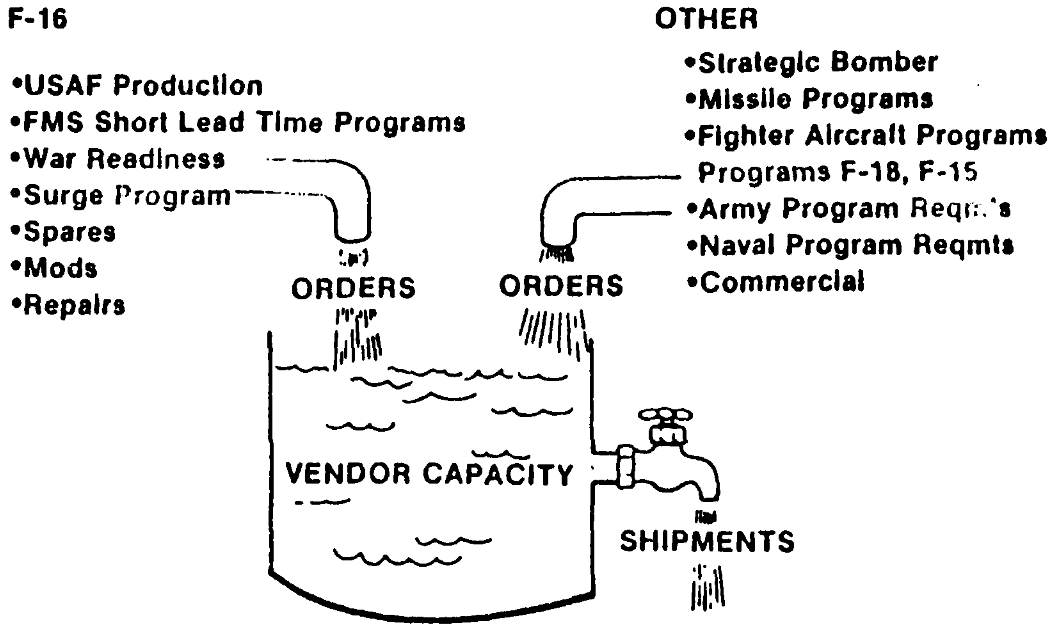


FIGURE 6

- Serious program impacts from field support emergencies.
- Reduced capability to accomplish modification programs.
- Vendors are forced into making priority decisions. (22)

Obviously, then, there are complex inter-relationships functioning within the aerospace industry to create production bottlenecks.

Another important factor to be considered, is the demand for parts to support the operational forces. It is likely that any situation requiring surge or mobilization of aircraft production would also require a greatly increased level of flight activity for the operational forces. Of course an increased operational tempo would cause a corresponding increase in the rate of spare parts consumption, and , thereby, create a competition in demand between parts for production versus parts for existing forces. Further, if there is a shooting war, then battle damage will almost certainly create demands for parts and structural members not normally consumed in peacetime. It is likely that lead times will increase in this situation.

This look at the general industrial scene sets the stage for an examination of specific cases. In the next chapter a vertical slice study is presented for each of the subject aircraft. Additionally, experience gained during the surge in F-4 production for the Vietnam War is summarized.

CHAPTER III

VERTICAL SLICE STUDIES

In the process of obtaining information for this paper vertical slice studies of the F-14, F-15, F-16, and F/A-18 were conducted. In addition, a vertical slice study was made of the experience gained during the Vietnam War surge in F- production. The results of these studies are presented in this chapter.

PART I

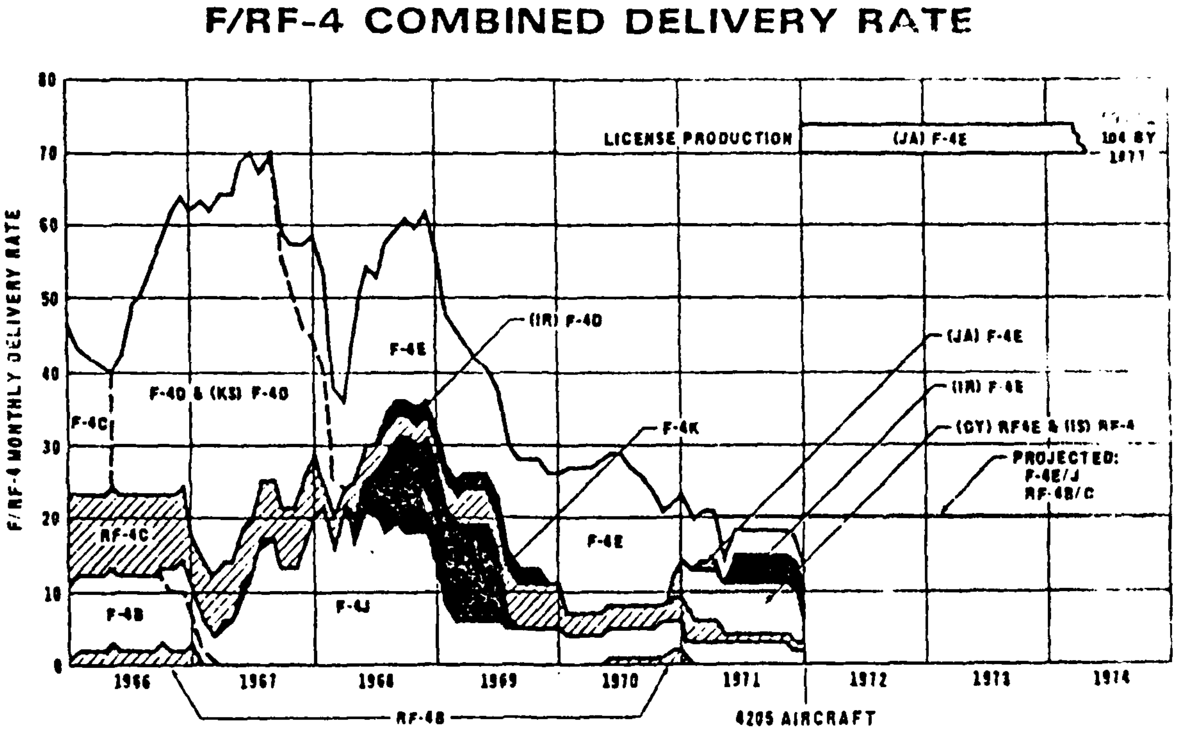
THE F-4 PHANTOM II CASE STUDY

During the period 1953-1979, McDonnell Douglas manufactured 5,057 F-4 Phantom II fighter aircraft. As part of the Vietnam era buildup, McDonnell dramatically increased the production rate of the F-4 aircraft. Their experience in surging the production of this modern fighter should be studied by anyone contemplating surge production preparedness for a future national emergency.

F-4 aircraft deliveries in 1966/67 were accelerated from a rate of 45 aircraft per month to a peak of 71 aircraft per month, generating 35, 360, and 590 additional aircraft 12,24, and 36 months from go-ahead. The additional quantities delivered were 26%, 39%, and 43% greater at 12, 24, and 36 months after go-ahead than would have been produced at the planned rate of 38 aircraft per month. The increased production was accomplished by the use of many unskilled new employees, and the same make/buy plan and supplier team existing at the time the production acceleration was ordered. During 1966-67, the normal time span from ordering until delivery of additional F-4 aircraft was 21 months. (5)

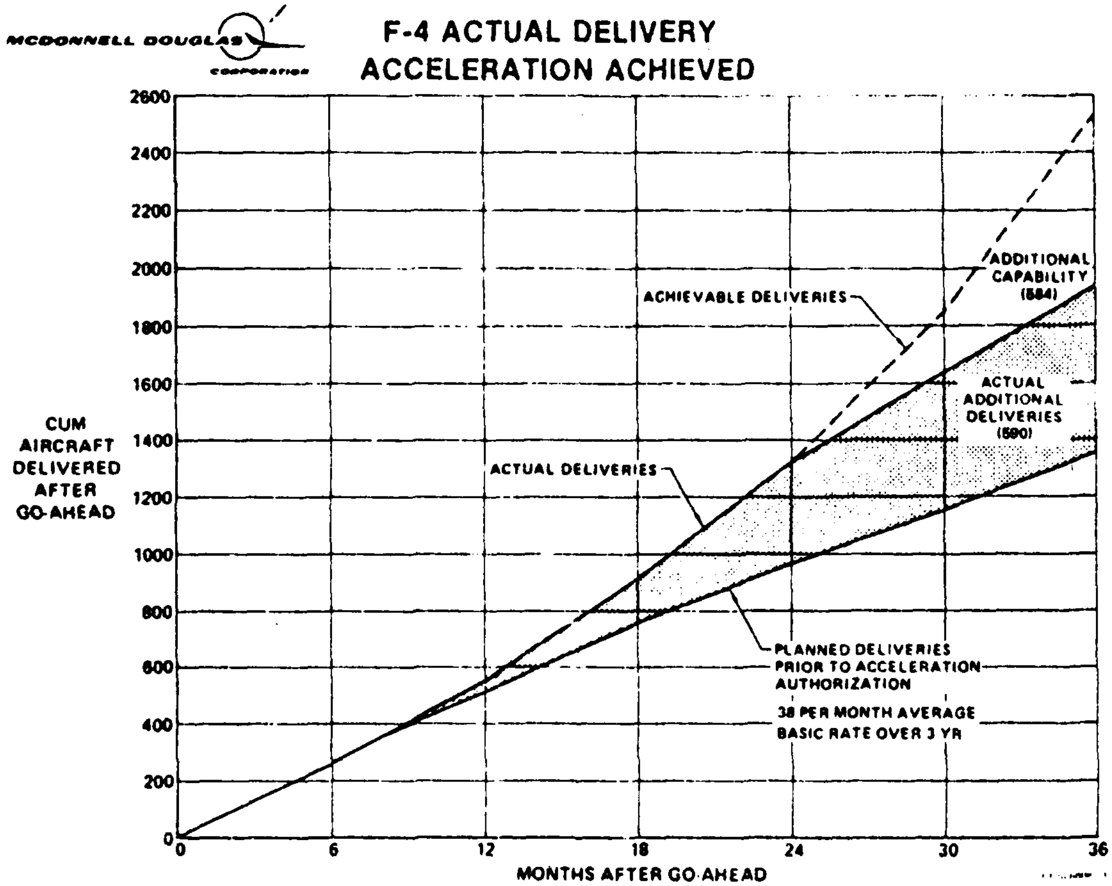
McDonnell Douglas undertook the accelerated production with a "letter-of-intent" contract and endeavored to maximize production of F-4 aircraft with no specific end in sight. From their perspective, it was more like full mobilization than a surge. Figure 7 shows the F/RF-4 combined delivery rate. Figure 8 shows the actual delivery acceleration achieved. Note that beyond 24 months after go-ahead, McDonnell could have continued to increase production to provide 584 aircraft more than the number finally ordered during the 36 month period, an 85% potential increase in production. (5)

Two McDonnell employees, Mr. Leo C. Brethauer, Director - Plans and Schedules, and Mr. Donald F. Guempel, Manager - Production Scheduling, vividly recall the F-4 surge experience and provided the following insights on lessons learned and relationships to current production aircraft. (15)



Source: McDonnell Aircraft Company

FIGURE 7



Source: McDonnell Aircraft Company

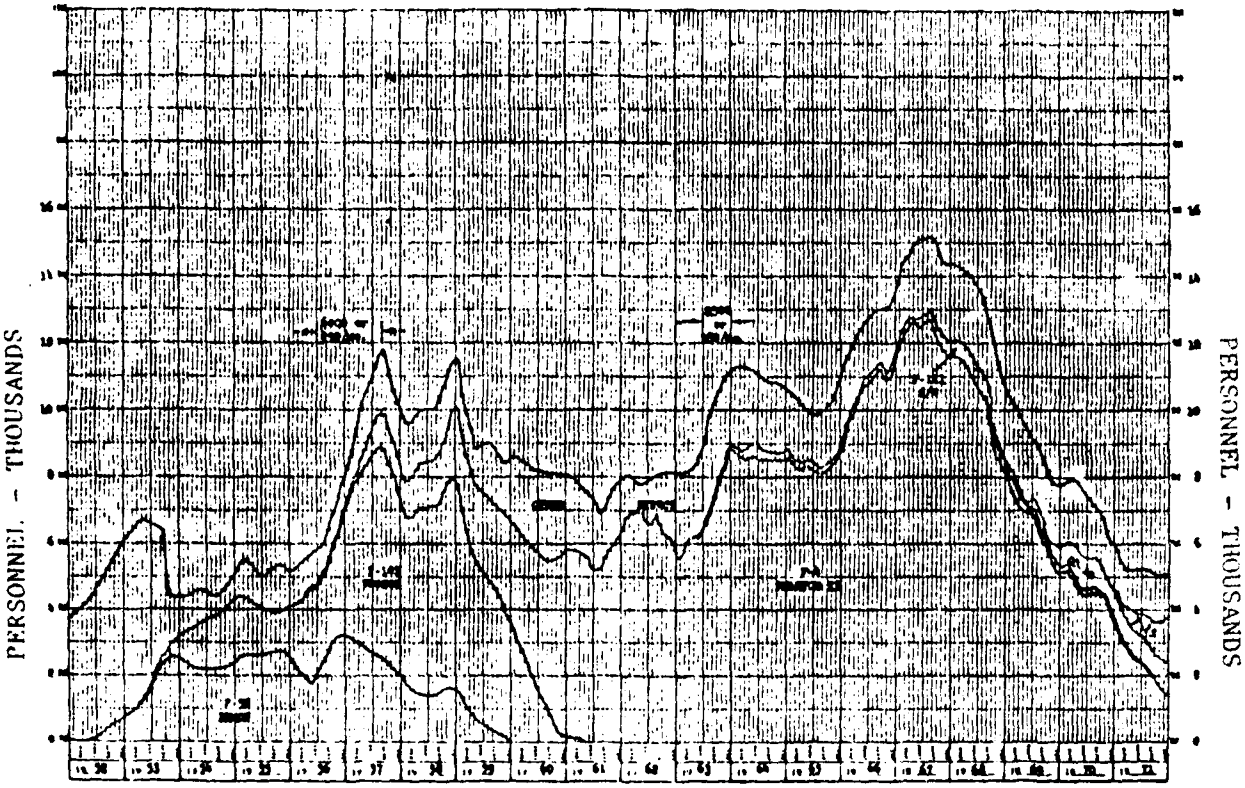
FIGURE 8

The main benefit to future surge production from studying the F-4 experience would probably be in the area of "management" rather than the production process. The F-4 was "assembly intensive", requiring a lot of sheetmetal work and riveting; whereas, for newer aircraft such as the F-15 and F/A-18, the fabrication process is much different, requiring large machined components and composites. Composite materials must be shaped and bonded by hand, and then heated and pressure treated in a small number of large, in-house autoclaves. The production of these materials may create bottlenecks which did not exist in the F-4 sheet metal era.

For the F-4, as many actions as possible, including machining, were removed from the immediate assembly area to nearby buildings. No serious problem was encountered in obtaining additional building space nearby, and "brick and mortar" is not expected to be a constraint if McDonnell should have to surge current production aircraft.

Labor was not a constraint for the F-4 surge; ample and sufficiently skilled employees were available. Some adjustments, of course, had to be made, and there was a large training requirement, but it was manageable. Employees already on the payroll worked increased shifts, and were used to train new employees. This allowed a rapid expansion of the workforce. Figure 9 shows the build-up of direct

McAIR DIRECT PRODUCTION PERSONNEL HISTORY



Source: McDonnell Aircraft Company

FIGURE 9

production personnel during the F-4 surge.

For F-4 assembly, the critical path was through the cockpit, where there was only room for one worker at a time. The key to solving this bottleneck was to spread out the production and assembly process so that more and more units could be put in flow. This solution should also be applicable to current production lines.

As the F-4 manufacturing accelerated, demands for sub-assemblies and spare parts to supply both production and operational requirements caused a competition for these assets, which required DoD arbitration. Attrition and high utilization rates in the operational forces in a future national emergency could also be expected to increase spares demand at the same time that surge production is relying for its success on the same parts and sub-assemblies. The shortage now, however, could even be more severe than for the F-4. In avionics, for example, many U.S. sources for electronic parts are drying up. Several U.S. electronics firms have been bought out by foreign competitors. McDonnell Douglas employees reflecting on the F-4 era feel that early parts procurement is the key to successful surge production.

The initial surge in F-4 production consumed long lead items such as forgings, engines, and landing gear much faster than the pipeline could provide. Once the parts on hand were used, a drop in production occurred while awaiting receipt of more long lead items. The best way to avoid this situation in a future surge would be to keep a larger rolling stock of such items on hand.

One of the major lessons learned from the F-4 experience was that the larger the existing production rate, based on a one shift, 5-day work week, the greater the surge potential. From this standpoint, it may be better to have one manufacturer producing at, for example, 20 units per month rather than two sources each producing at only 10 units per month. In the latter case, not only is the surge potential less, but also, the two manufacturers may be producing well below an economically efficient level, which may force one or both to cease production of that item.

These are only some of the highlights as recalled by Messrs. Brethauer and Guempel. Many of the personnel who accomplished this feat are no longer with McDonnell Douglas, including top management. Most of the remaining employees who did participate are nearing retirement and will take with them the lessons learned during this surge production experience. An indepth study of the F-4 surge should be accomplished to record this valuable experience in the fighter aircraft industry. Additional information on the F-4 Phantom II surge is provided in Appendix A.

PART II

THE F-14A TOMCAT

DESCRIPTION

The F-14A Tomcat is a twin seat, variable sweep wing, supersonic fighter manufactured by the Grumman Aerospace Corporation, Bethpage, Long Island, New York. It is powered by two Pratt and Whitney TF30 turbofan engines, each capable of producing 20,900 lbs of thrust using afterburner. Capable of operating from aircraft carriers, the F-14A has a maximum design speed of Mach 2.0+, and a service ceiling in excess of 50,000 feet. The Tomcat's variable-sweep wing is automatically positioned for best lift throughout its flight envelope. The wings sweep to 68 degrees for high-speed maneuvering, but when fully extended, permit take-offs in less than 1,000 feet and landings in less than 2,000 feet at speeds below 120 knots. The F-14 is equipped with the AWG-9 Weapons Control System, which is capable of controlling six Phoenix missile launches while simultaneously tracking 24 targets in all weather conditions. In addition to the Phoenix missiles, the F-14 can carry 6 Sparrow missiles, 4 Sidewinder missiles, and one 20mm Vulcan cannon. The F-14 was designed to replace the F-4, and is currently operational with the U.S. Navy.

PRODUCTION RATES

The F-14 made its first flight in December of 1970. By March of 1983, Grumman Aerospace had delivered 456 F-14s to the U.S. Navy, and had sold 80 to Iran. F-14 production has been set at a comparatively low rate for the last few years, not requiring an expansion of facilities or major purchase of new equipment. Only two deliveries per month are planned during FYs 84-86. Grumman is also producing the A-6E, EA-6B and E-2C, each at a rate of 6 aircraft per year. In addition, Grumman has reopened the C-2 line to support the Department of Defense FY 84 funding request for 8 C-2 aircraft. (8:93)

Grumman's major manufacturing facilities are located on Long Island, New York, in Nassau and Suffolk Counties, where the majority of the F-14 airframe is manufactured and assembled. Additional Grumman manufacturing sites operating in support of the F-14 program include plants at Stuart, Florida, where subassemblies are manufactured, Milledgeville, Georgia, where composite material is produced, and Glen Arm, Maryland, where machined parts are produced.

PRODUCTION FLOW

Grumman's current F-14 manufacturing flow is about 22 months. Procurement lead time for raw materials and/or subsystems lengthen total flow time for production to approximately 44 months. Raw materials to support production of the F-14 have a lead time of 5 to 12.5 months, while certain forgings without machining are 12.5 to 16 months; major titanium forgings are 20 months. Subassemblies such as the landing gear and nacelle inlets have lead times of 49 and 59 months respectively, while certain actuators take up to 48 months.

While lead times for titanium and aluminum sheets, plates, extrusions, rods and bars, and forgings have decreased recently, lead times for electronic components such as integrated circuits, connectors, and transistors continue to increase, currently running at 7.5 to 12 months. Avionics components such as transmitters have lead times as long as 20 months. Relays and contactors can take up to 25 months. (12)

POTENTIAL PRODUCTION RATES

Based on an advanced draft report entitled "Industrial Preparedness Planning, Fiscal 1934" submitted to the Naval Weapons Engineering Support Activity in October 1982 by the Grumman Aerospace Corporation, the company has the capability to simultaneously expand production of the F-14A, A-6E, EA-6B, and E-2C provided certain prerequisites are satisfied. Grumman's analysis considers four conditions: (1) Surge without stockpiling long lead items, (2) Surge with long lead items stockpiled, (3) Mobilization without stockpiling long lead items, and (4) Mobilization with long lead items stockpiled. Surge is defined as " a state of national concern wherein maximum efforts are applied to selected programs to advance delivery within the capability of existing facilities and equipment in a peace-time environment." Mobilization is defined as "a state of national emergency or crisis wherein contractors and suppliers are given Government direction to satisfy DoD requirements." The ground rules and Grumman's analyses assumptions include:

- The data used to support the analysis would be from Grumman's FY82 experience with M-Day considered to occur on 1 October 1981. Grumman's business base is per the March 1982 Corporate Master Delivery Schedule.

- Grumman would simultaneously increase production of the F-14A, A-6E, EA-6B, and E-2C to maximize mobilization rates.

- Preferential treatment and priority would have been accorded by the government to DoD suppliers.

- The stockpiling of long lead items under conditions 2 and 4 would provide materials and parts when required for manufacturing.

- Government furnished equipment would be provided as required.

- Trained manpower would be available.

- Additional requirements for machining, particularly those requiring gantry machine tools, could be subcontracted. (12:III-2,3)

The 1982 Grumman report is still in draft, and specific data for the time to produce the first additional aircraft under surge conditions, or to achieve a sustained production rate at mobilization levels was not available. However, valuable information in terms of work week and shift requirements, manufacturing cycle time, and additional facilities and equipment requirements were provided.

Under condition 1, surge with no stockpiling, production is limited by the unavailability of long lead items. One full shift working 40 hours over 5 days with unscheduled overtime as necessary will maintain production; however, there would be a need to add second shifts in some departments. Total aircraft flow time would be reduced to 28 months by shortening forging time, machine time, and in-house manufacturing time. Under condition 2, surge with stockpiling, two 6 day, 56 hours per week shifts would be required, and total aircraft flow time could be reduced from 28 to 16 months. (12:III-2,IV-4) An earlier study reported by the Naval Air Systems Command in June 1981 confirmed that Grumman's ability to surge with or without stockpiling was the same for the first 15 months. The elapsed time to reach maximum capability was reduced from 36 to 24 months by stockpiling long lead items. (35:10)

Under Conditions 3 and 4, mobilization without and with stockpiling respectively, manpower would increase to three 7 day shifts, 56 hours per week until the maximum production rate is achieved. It would then be reduced to two 6 day shifts, 56 hours per week. Total aircraft flow time would be reduced to 14 months. The 1981 Naval Air Systems Command study stated that Grumman could start acceleration in 21 months, reaching a maximum of 8 aircraft per month in 28 months without stockpiling. With stockpiling acceleration is reached in 17 months and maximum production in 21 months.

If Grumman was required to simultaneously surge or mobilize production of the F-14A, A-6E, EA-6B, and E-2C, additional space and equipment would be required. Grumman's in-house machining capacity would be saturated, even with use of subcontractor support. If the outside machined parts industry is also saturated, additional equipment and space would be required. Grumman's facilities on Long Island would be able to support surge of the F-14A if the production of the other aircraft were not surged.

BOTTLENECKS AND CONSTRAINTS

Of all the factors that affect a company's ability to increase its production rate, one of the most important is current delivery rate. The capability to surge F-14A production is limited by the low delivery rate. The F-14A production rate has decreased to 2 aircraft per month as production approaches the planned total buy of the aircraft. Therefore, unless the U.S. Navy decides to increase its total buy of F-14s, or foreign military sales are made, the current delivery rate of F-14s will remain low. To make matters worse, the other aircraft currently being produced by Grumman, the A-6E, EA-6B, and E-2C are also being produced at a very low rate. Even the reopening of the C-2 line is associated with a small buy of aircraft at a low production rate. While Grumman's analysis shows the capability of increasing production of the F-14A by a high percentage during surge or mobilization, only 5 additional aircraft per month are being produced after this increase. Increased production above this rate is possible, but the lower the current delivery rate, the longer it takes to deliver the first additional aircraft, and the smaller the total number of aircraft delivered over a given period of time.

The quantity of aircraft on order has an impact similar to that of the "current delivery rate." The greater the quantity of aircraft on order, the easier it is to accelerate the flow of material in the pipeline to support surge production. To maintain production at the desired mobilization rate, lead time would have to be reduced enough to fill in the vacuum created by the initial surge usage of items in the pipeline. Acceleration of items in the pipeline can be improved and the impact of the initial surge vacuum can be decreased by the stockpiling of long lead items. Once again, this becomes more difficult in the case of the F-14 as deliveries approach the planned total buy. At the point in time considered by the Grumman analysis, stockpiling of one year's long lead items for production at mobilization rates would exceed the planned peacetime program total! In addition, certain suppliers would complete work two or three years before the planned program end, and would have stopped production unless funded to keep their line open with no deliveries.

The ability of suppliers to accelerate and/or increase production of long lead items is a major bottleneck in an attempted surge or mobilization. The major long lead items associated with the production of the F-14 are shown in Table 3. In addition, numerous avionics/weapon system components

* * *

Table 3. F-14A Major Long Lead Items (36)

ITEM	SUPPLIER	LEAD TIME (MONTHS)
INLET	ROHR	40
LANDING GEAR	BENDIX	40
ACTUATOR	HAMILTON STANDARD	33
FIN & RUDDER	FAIRCHILD	33
FLAT/SLAT DRIVE	CURTIS WRIGHT	33
JOINT	ARKWIN	33
RUDDER	BENDIX	33
LAUNCHER	RAYTHEON	33

* * *

used in the F-14 are common to other U.S. Navy tactical aircraft. The Inertial Navigation Set, Electronic Altimeter, TACAN Navigation Set, Accelerometer Counting Group, Interrogater Radar Set, Receiving Decoding Group, Radar Beacon, UHF Radio, ECM System, Guided Missile System, and 20mm Gun System are used by both the F-14A and F/A-18. (36) It can be assumed that many other items critical to the production of tactical aircraft come from the same supplier or group of suppliers. The ability of some suppliers to support the surge or mobilization production rate of two or more aircraft simultaneously must be questioned. The challenge is to determine who those suppliers are at any point in time, and then provide them the incentive that will allow for a timely and substantial increase in production.

The remaining item to be considered is the availability of trained manpower to support the higher production rates associated with surge or mobilization. Grumman has conducted an extensive analysis for each of their facilities impacted by a need to accelerate production of Navy aircraft. In order to increase production to meet mobilization requirements, Grumman would have to significantly increase its work force. The bulk of that increase would be in the manufacturing area, with machinists and electronic technicians being the most difficult to recruit. Grumman has maintained a fairly level work force since the early 1970's, and thus does not have a meaningful "call back" pool from which to draw in order to increase its work force quickly. Lack of a pool of trained personnel will require expansion of Grumman's training program. Grumman feels this expansion can be accomplished in a timely fashion with a modest addition of resources. Due to material lead time and production build-up, there would be adequate time from M-Day to recruit and train new hires. The availability of manpower to enter these training programs varies with each of the Grumman facilities. On Long Island, where 80% of the additional manpower is required, the labor market availability is evaluated as FAIR. In Stuart, Florida, it is VERY GOOD; in Milledgeville, Georgia, it is GOOD; and in Glen Arm, Maryland, it is POOR. To quote Grumman:

> Reality must be faced when thinking of recruiting personnel for what probably would be considered a short duration job. Unless the Government would say 'you must', an iffy 1-to-3 year job would not seem to be attractive to the type of personnel who would be desired. Possibly added incentives would have to be considered. (12:V-19)

PART III

THE F-15 EAGLE

DESCRIPTION

The F-15 Eagle is a fighter aircraft employed by the U.S. Air Force, the Israeli Air Force, the Royal Saudi Air

Force, and the Japanese Self Defense Force. The F-15 is constructed at the McDonnell Aircraft Company, Saint Louis, Missouri, in the same plant which produces the F/A-18 Hornet and AV-8B Harrier. The Japanese are also producing the F-15 in Japan for their own use. The Japanese production is not considered by McDonnell officials to have a significant impact on the U.S. production of the F-15, therefore it will not be addressed in this paper. Powered by two Pratt and Whitney F100 jet engines, the F-15 is built in both a one-seat (F-15A and F-15C) and a two-seat (F-15B and F-15D) configuration. Although the two-seat F-15 is used for training pilots, it is also fully capable of performing all the tasks accomplished by the single seater. The F-15C and F-15D are the models currently in production.

PRODUCTION RATES

The F-15 entered production in 1973. By 1 January 1983, 773 F-15s had been delivered as follows:

- USAF - 419 A and B models
  222 C models
  37 D models
- Israel - 40
- Japan - 8
- Saudi Arabia - 47

To date the highest annual procurement was 124 aircraft during 1977.

F-15 orders through fiscal year 1983 and deliveries through calendar year 1981 are shown in Table 4. Note that the orders shown in Table 4 do not correlate directly with the numbers

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Table 4. F-15 Orders and Deliveries

Orders

FY	73	74	75	76	77	78	79	80	81	82	83
USAF	30	62	72	132	106	97	78	60	42	36	39
FMS				3	18		6	35	46	2	13
TOTAL	30	62	72	135	124	97	84	95	88	38	52

Deliveries

CY	73	74	75	76	77	78	79	80	81
TOTAL		2	33	102	124	114	109	86	77

SOURCES: Orders - Telecon with Maj Jack Saunders, HQ USAF/RDPN, 4 March 1983.

Deliveries - Telecon with Aerospace Industries Association Data Research Service, Washington, D.C., 11 March 1983.

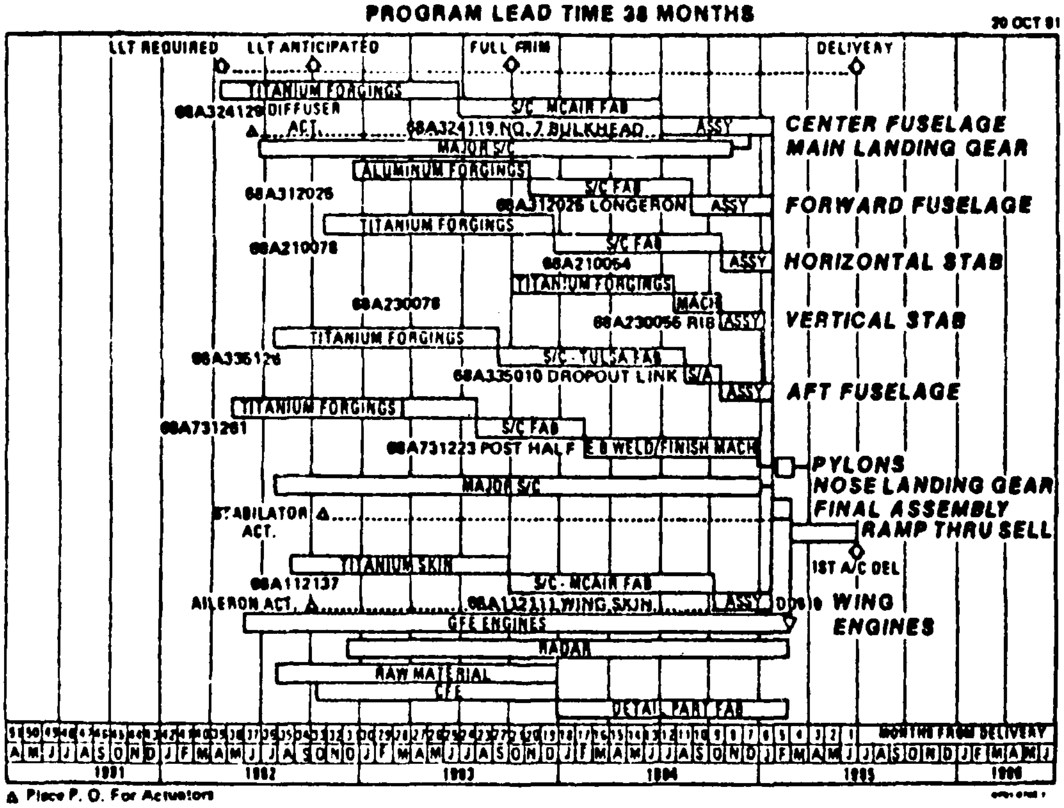
****

delivered, except by coincidence in 1977. This difference represents the time required to produce the aircraft after an order is placed. For example, the McDonnell production rate during early 1983 is approximately 7 aircraft per month as the FY 1981 order of 88 aircraft is being produced. Likewise, the FY 1983 order of 52 aircraft will be delivered at an approximate rate of 4 aircraft per month between July 1984 and June 1985, 21 to 32 months after the fiscal year of funding. (23) According to the FY 1984 DoD Annual Report to the Congress, funding is being requested for 48 F-15s in FY 1984, 72 in FY 1985, and 96 in FY 1986 and beyond. (33:168)

PRODUCTION FLOW

According to its FY 1984 production plan, illustrated in Figure 10, McDonnell Douglas can deliver an F-15 approximately 38 months after placing orders to subcontractors for long lead items. Much of the production flow time is required to fabricate titanium and aluminum forgings, engines, radar, and major subcomponents. The assembly of the center fuselage and main landing gear begins 12 months before delivery. Final assembly of the aircraft begins approximately five months before delivery, resulting in roll-out of the aircraft four months prior to delivery. These final four months are needed for system tests and aircraft acceptance flights. The production flow shown in Figure 10 is based on a five-day work week using one shift per day <u>except</u> for some items which require around-the-clock operations to produce parts. Assuming that bottlenecks

F-15
FY 84 PROCUREMENT PLAN
PROGRAM LEAD TIME 38 MONTHS



Source: McDonnell Aircraft Company

FIGURE 10

created by these current around-the-clock operations could be overcome, the F-15 production flow could be reduced by increasing the work force to two or three shifts per day.

POTENTIAL PRODUCTION RATES

McDonnell officials stated that the Saint Louis plant can simultaneously produce 144 F-15s, 240 F/A-18s, and 78 AV-8Bs per year based on a five-day work week using one and a half shifts per day for most of the work force, plus some around-the-clock work on a number of critical path items. (5) This combined total of 462 aircraft per year compares favorably with the F-4 surge experience described earlier. They felt that production could reach 180 F-15s per year using a seven-day work week with one and a half shifts per day. Plant officials have not seriously studied the option of going to a full around-the-clock, seven day week because there are so many capacity constraints in the production of items such as machined titanium bulkheads that an around-the-clock assembly line could probably not be sustained by the existing parts pipeline. (15)

McDonnell officials also provided information concerning a short term surge of the F-15 production line. They have studied two alternative short term surge situations:

- Six month surge duration

- Twelve month surge duration.

Their study assumed the following factors:

- "M" Day (Go Ahead) - 1 Oct 82.
- Baseline production rate - 7 aircraft/month.
- Extended work week
- Additional shift manpower loading.
- No increase in facilities.
- Consumer supplier and government furnished equipment on hand. (5)

The results of the McDonnell short term surge study are shown in Figure 5 on page 17. In the six month surge case an additional seven aircraft could be produced, a gain from 42 to 49 aircraft. In the twelve month case, the gain would be 15 aircraft, an increase from 94 to 109 aircraft. In both cases, however, note that the long term effect of either a six or twelve month surge is a significant reduction in the production rate for many months following the surge. This effect occurs because of the lead times required to replace the components consumed during the surge. Thus, a surge of six or twelve months duration would result in only a small increase in the production of aircraft, while at the end of the surge the plant and its work force would be largely idle, unable to produce even a small portion of its normal sustained capacity, until the long lead items began to arrive through the pipeline.

McDonnell's ability to surge F-15 production for the 24 month period beginning 1 October 1982 was estimated in the Form DD-1519 submission for fiscal year 1983. According to this estimate, 49 aircraft could be delivered during the first six months, 30 during the second six months, and 64 during the second year. (23) This 24 month cumulative total of 143 aircraft is only about one-half the estimated plant surge capacity of 144 aircraft per year because more than 24 months are needed to obtain many critical parts. The DD-1519 estimate was based on a two-shift per day workforce and assumed that 55 aircraft were to be ordered for FY 1983 (52 were actually ordered). Other assumptions made for the DD-1519 estimate are discussed later in this paper.

BOTTLENECKS AND CONSTRAINTS

McDonnell has identified some potential bottlenecks which they plan to eliminate or reduce through in-house production or identification of second sources. (15) Nonetheless, there are a myriad of bottlenecks and capacity constraints which would prevent a sustained significant increase in the production of the F-15 for at least three years from the time a decision is made to do so.

The critical long lead items for the F-15 are given in Table 5. Of the items listed, only the jet engine can be conveniently bypassed in production since it is not installed until the entire airframe has been assembled. Considering that both the F-15 and the F-16 use the F100 engine, this item may be a bottleneck for both these aircraft. Unfortunately, the time and money available to this study group did not permit an examination of the factors affecting the F100 engine lead time. This item is recommended for further examination in future studies.

* * *

Table 5. F-15 Fiscal Year 1984
Major Equipment Long Lead Items (5)

ITEM	SUPPLIER	ARC (MONTHS)
JET ENGINE	PRATT & WHITNEY	30
FIRE CONTROL SYSTEM	HUGHES AIRCRAFT	27
RADAR	HUGHES AIRCRAFT	27
JET FUEL STARTER	GARRETT TURBINE	24
SWITCH-OVER VALVE	KELSEY-HAYES	22
AIR CYCLE AIR CONDITIONING	AIRESEARCH	21
DIFFUSER RAMP ACTUATOR	NATIONAL WATERLIFT (NWL)	20
FIRST RAMP ACTUATOR	NWL	20
MAIN LANDING GEAR	BENDIX	20
STABILATOR ACTUATOR	NWL	20
HYDRAULIC FLAP ACTUATOR	NWL	20

SOURCE: MCAIR

* * *

The remaining ten long lead items in Table 5 are supplied to McDonnell by only six companies, and there are apparently no alternate sources which could provide these items more rapidly. Note also the nature of these long lead items -- two are major electronic devices (the radar and fire control system), four are actuators (all supplied by one company, National Waterlift), three are complex aerospace industry unique items (jet fuel starter, switch-over valve, and the air cycle air conditioning), and one item involves a large forging (the main landing gear). Again, we recommend these items for further study as the time and money allocated did not permit a specific analysis of each of these items.

The DD Form 1519, DoD Industrial Preparedness Program Production Planning Schedule, for the F-15 was reviewed. (23) The assumptions stated on the Form 1519 and comments on them follow:

- F/A-18 and AV-8B will also be accelerated.

This is an important assumption because the McDonnell plant at Saint Louis also produces these aircraft side-by-side with the F-15. It is interesting to note that the DD Form 1519 system apparently allows manufacturers to consider only the effect of a simultaneous production surge for aircraft built in their own plant. Since a mobilization surge would almost certainly result in an increased demand for all aircraft currently in production (eg. F-14, F-15, F-16, F/A-18, AV-8B, F-20, A-10, A-6), it is possible that the collective demand for forgings, avionics, actuators, engines, skilled (trainable) labor, etc. might limit production of these aircraft to a level well below each plant's assembly capacity.

- GFAE (Government Furnished Avionics and Engines) will be available as required.

For the reasons cited above, this assumption alone may invalidate the DD Form 1519 projections.

- Fabrication and assemblies can be diverted to McDonnell Tulsa or leased areas and overtime used as required.

This seems to be a reasonable assumption. The officials we talked to were unanimous in their opinion that floor space and other facilities were not a constraint, and that expansion of production facilities into leased or newly constructed buildings would not cause a production bottleneck. (15)

- Reorder lead time is in excess of 40 months for the F-15. Therefore, priorities and allocations relative to current commercial aircraft orders must be provided by the U.S. Government at M-Day in order to allow accelerated deliveries of the F-15 in the M-Day plus 24 month time period. These priorities must be both for critical materials and suppliers capacity, including time on 5-axis profilers and large forging presses. DX or directive type priority required.

This is a critical factor. There seems to be general agreement that forgings and machined parts are produced by only a handful of manufacturers. However, no agency has yet effectively related the production capacity of these manufacturers to the demand for their products which will exist at various levels of military and civilian aircraft production. While it is probably impossible to analyze the industry down to every nut, bolt, and rivet, it should be relatively easy to determine the major subcontractors' capacity to produce items such as engines, titanium bulkheads, landing gear struts, hydraulic actuators, radars, fire control systems, etc. Likewise, the demand for these items should be easily established since the aircraft manufacturers know in detail how many of each part is required for building one of their aircraft. The absence of such an analysis probably leads the DD Form 1519 system to produce forecasts of production which are overly optimistic because the system is not designed to determine the effect of subcontractor capacity constraints or simultaneous surge effects.

- Local labor market supply of skilled labor is more than adequate to meet the requirements of the 24 month mobilization plan.

The McDonnell plant officials stated their belief that labor would not be either a constraint nor a bottleneck. They cited their past experience in hiring and training large numbers of people and offered a convincing arguement that skilled labor is not a problem, even during good economic times. With today's recessionary economy, they believe there is a large pool of previous McDonnell employees in the Saint Louis area who would be available to work as soon as jobs were made available. This appears to be a reasonable assumption.

PART IV

F-16 FIGHTING FALCON

DESCRIPTION

The F-16 Fighting Falcon is a single seat multirole fighter designed to complement the F-15 as an air superiority fighter. The production F-16 is powered by a single Pratt and Whitney F100 engine, but a variant is also flying with the General Electric J-79 engine. The production program is unique in that the aircraft is being coproduced in the United States and in Europe to serve in the following air forces:

- USAF
- Netherlands
- Belgium
- Norway
- Denmark
- Pakistan
- Venezuela
- Korea
- Egypt
- Israel

The primary contractor for production of the F-16 in the United States is General Dynamics, with the aircraft being built at an Air Force plant in Fort Worth, Texas.

The single seat F-16A and the two seat F-16B are the current production models. Both are designed as "swing" aircraft having the capability for both air-to-ground and air-to-air combat. Modifications are now in work to provide future production models with an enhanced capability for both air-to-air combat and air-to-ground weapons delivery.

PRODUCTION RATES

The F-16 entered production in 1978. By 28 February 1983, 540 F-16s had been delivered, with 18 aircraft per month being the highest production rate achieved during the period. The Air Force plans to purchase 120 F-16s per year through 1985, and then increase production to a more efficient rate of 180 aircraft per year. (33:168)

The F-16 production base is composed of over 5000 suppliers. Except for the forward fuselage, all major structural subassemblies are coproduced by European concerns. Aircraft assembly lines are located in three countries: the United States, Belgium, and The Netherlands. Engine assembly lines are located in the United States and Belgium. To minimize dependency on foreign sources in this multinational program, the U.S. maintains an American source for every major component in the aircraft.

PRODUCTION FLOW

The current F-16 worldwide production rate capacity is 25 aircraft per month, with the Fort Worth plant having a capacity of 19 aircraft and 25 forward fuselages per month.

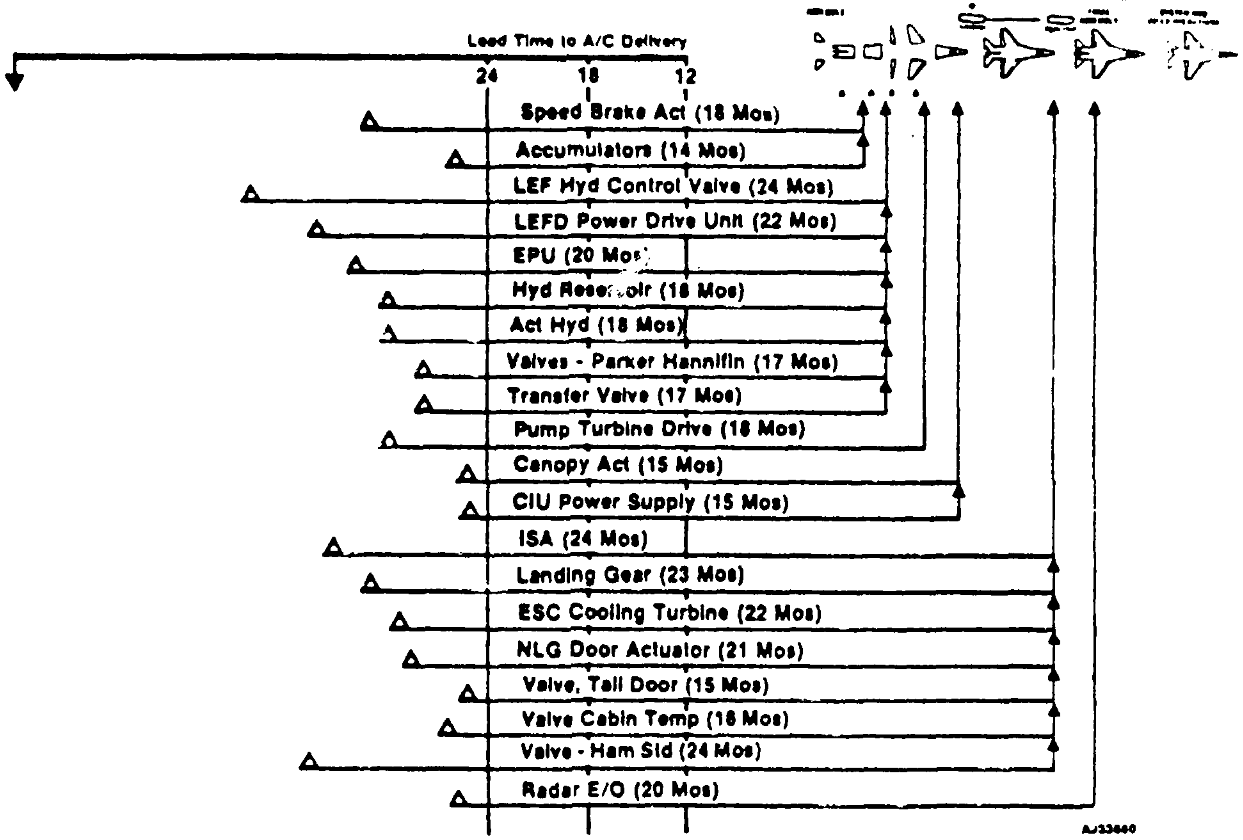
The floor layout plan was originally designed to accomodate production of 45 aircraft per month, and retains that capability today. Unfortunately, tooling is available to support only the current production rate. Lead time to establish the production line to accomodate a full 45 aircraft production rate is 12-18 months.

The factory assembly line, however, is not the constraint in the event of a surge requirement. As with other fighter aircraft, lead time to take delivery on components from subcontractors can be greater than 24 months. Figure 11 shows material/manufacturing flow times for a representative sample of major subcontracted F-16 items. Lead time and subcontractor rate capacity for critical items are depicted in Figure 12.

POTENTIAL PRODUCTION RATES

The F-16 capability to respond to a conventional surge request is shown in Figure 13 as line 1. A "Built-in Surge" study in August 1981 requested an estimated cost required to deliver the first F-16 above current production capacity within six months after surge order, and deliver 60 F-16s within the following 12 months The added capability, at a cost of $12 million, is shown as line 2 in Figure 13. Another study, in support of the Special Defense Acquisition Fund (SDAF), concluded that a 10 percent investment in production

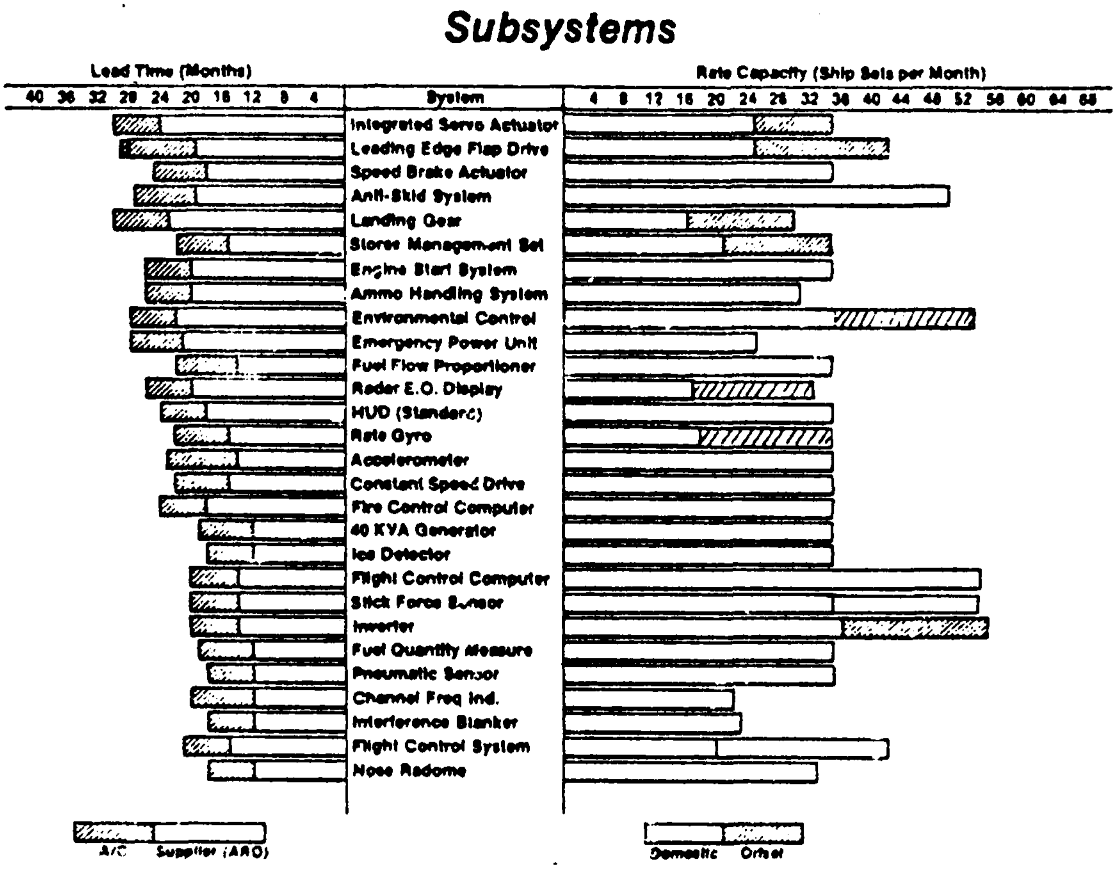
LEAD TIMES FOR MAJOR F-16 SUBCONTRACTORS



Source: General Dynamics

Figure 11

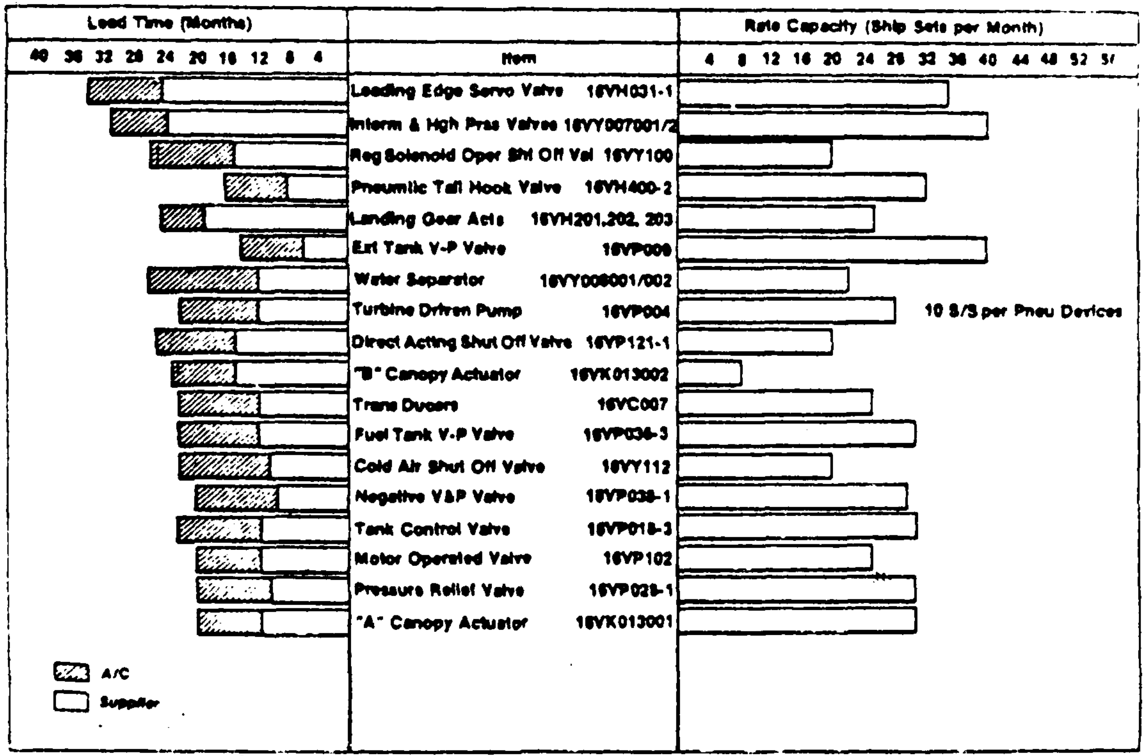
LEAD TIMES FOR MAJOR F-16 SUBCONTRACTORS (CONTINUED)



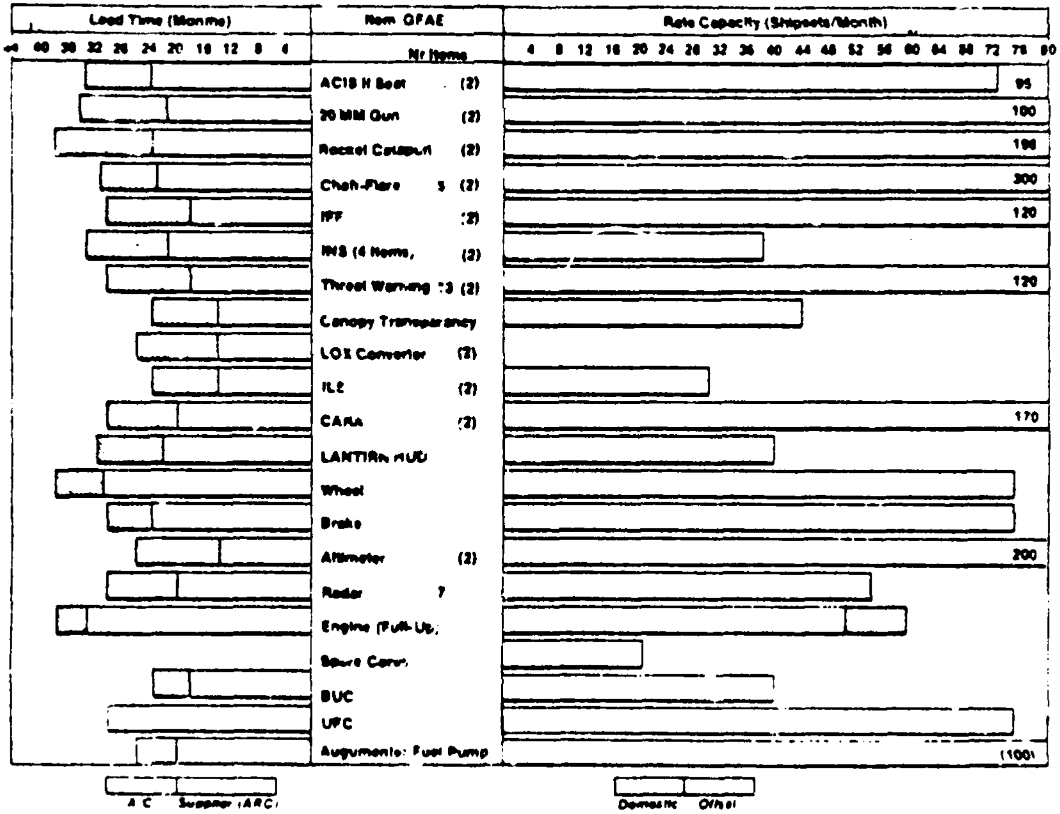
Source General Dynamics

Figure 1. (Continued)

Critical Equipment Items F-16 A/B

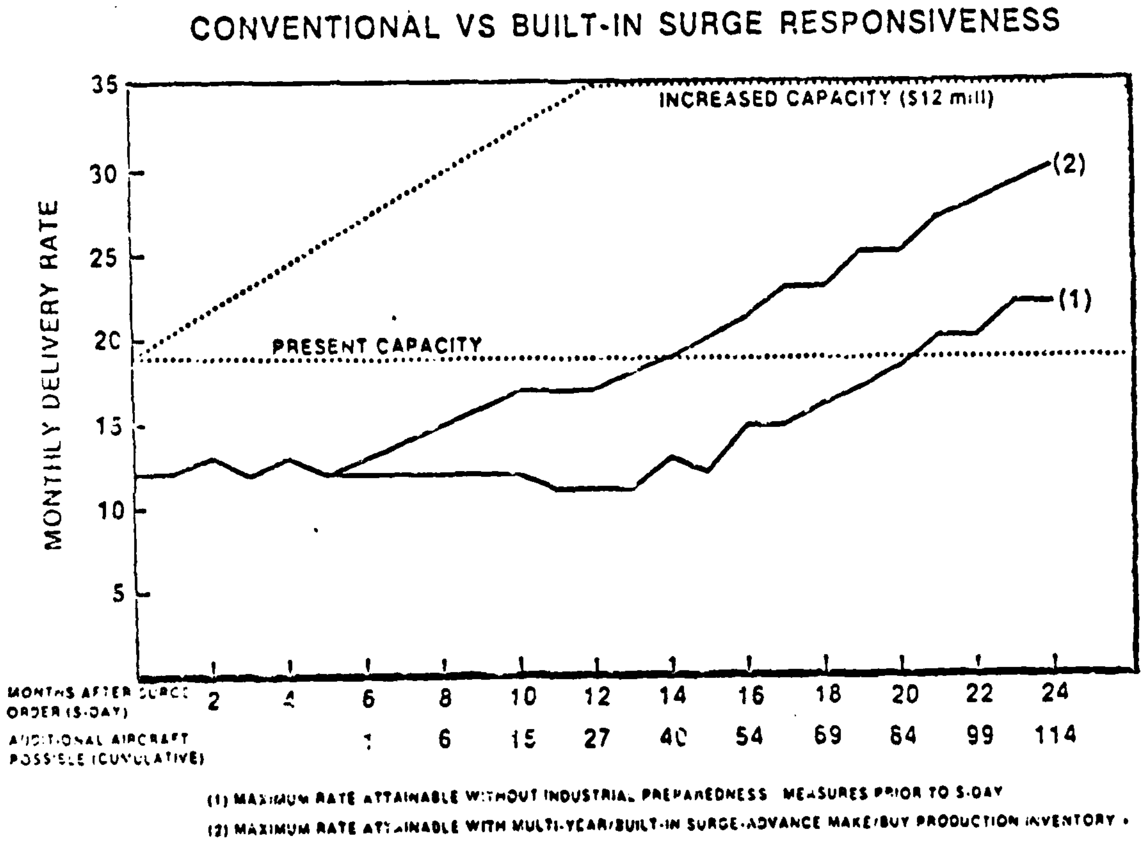


GFE



Source: General Dynamics

FIGURE 12



Source: General Dynamics

FIGURE 13

inventory would provide a 33 percent reduction in F-16 lead time. Figure 14 shows the relationship between investment required, order response time, and quantity of aircraft.

BOTTLENECKS AND CONSTRAINTS

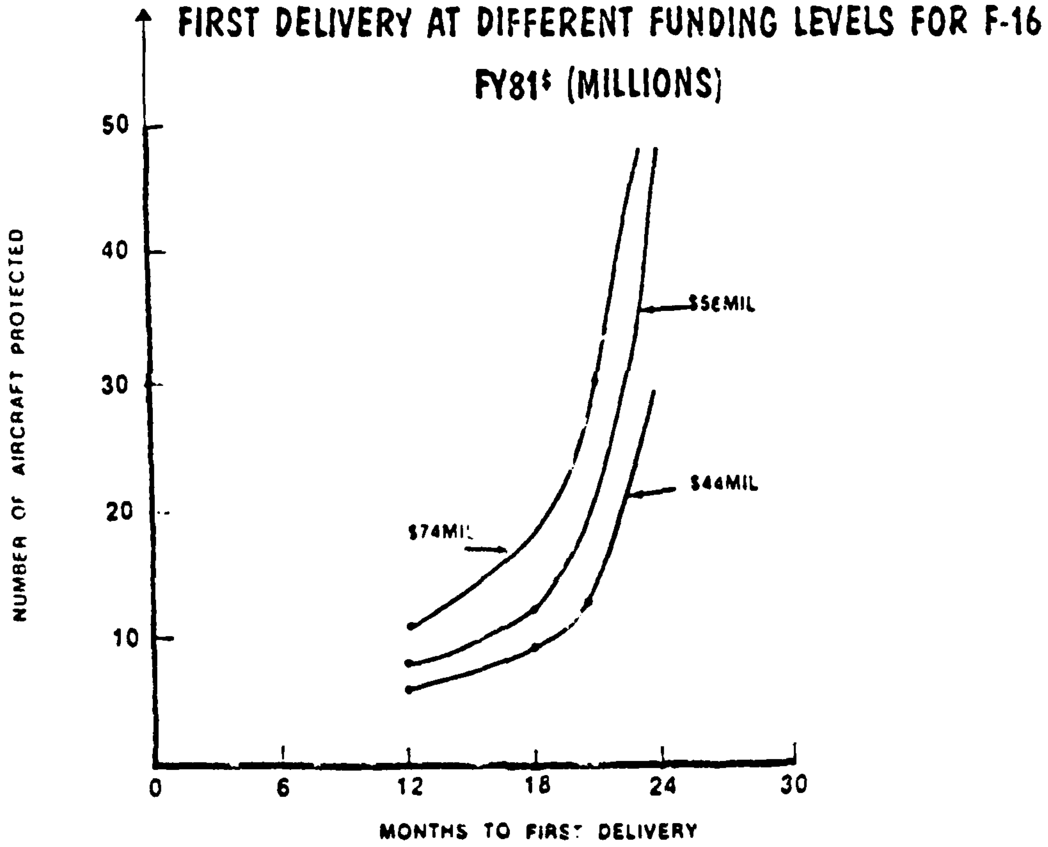
General Dynamics has the basic capability to support a 35-45 aircraft per month program on a sustained basis, assuming no surge in production of other fighter aircraft. To attain that position a substantial amount of firm, long-term orders must be funded to provide incentives for investments in capacity expansion. A few known constraints are:

- Precision Aluminum Forgings
- Heavy Aluminum Plates
- Titanium Rods and Bars

Should commercial aircraft production increase, aluminum press capacity could not support the demand on a near term basis. Increased F-16 requirements alone, however, will not provide a sufficient business base for additional industry investment in ·ress capacity.

Long term capacity problems remain with titanium also. Even with recent capacity expansion programs, a substantial backlog still remains. Figures 15 and 16 show lead times for forgings, castings, and raw materials through 1981.

NUMBER OF F-16 AIRCRAFT PROTECTED vs MONTHS



Source: General Dynamics

FIGURE 14

F-16 HARDWARE LEAD TIME (7)

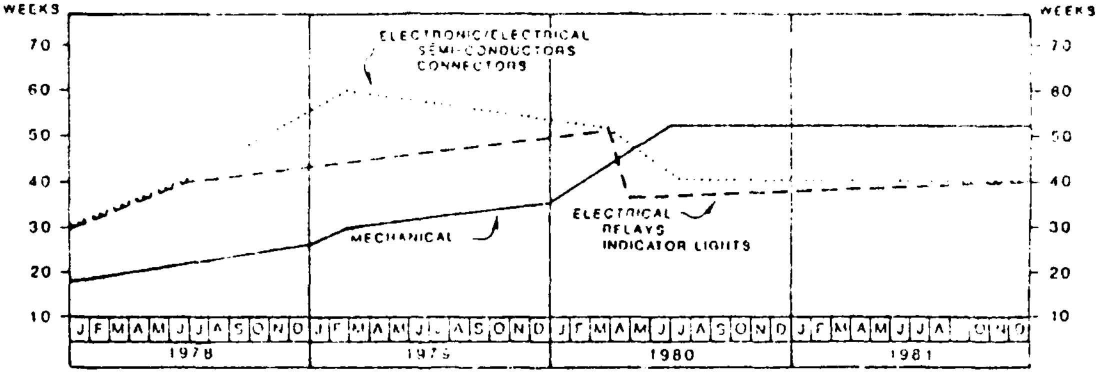


FIGURE 15

F-16 RAW MATERIAL LEAD TIMES (7)

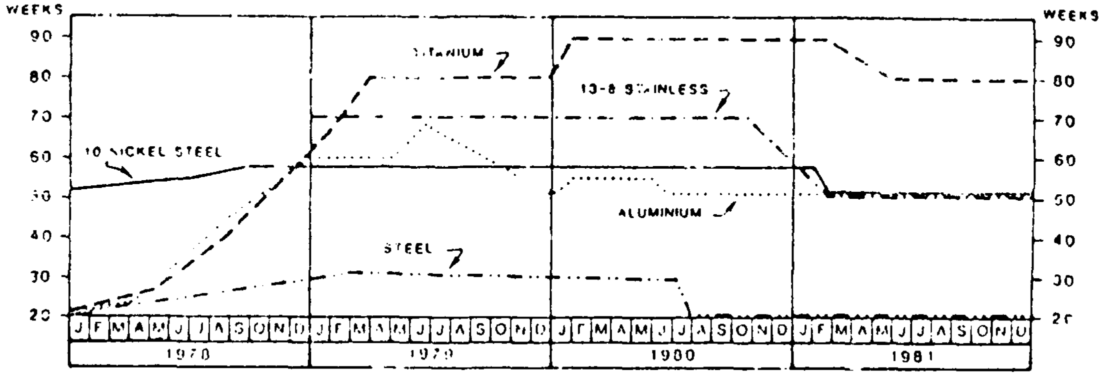


FIGURE 16

Ninety percent of the F-16 equipment items would be available to reach the 35-45 aircraft production rate in the event of a surge requirement. Thirty-six items found throughout the production process would, however, constrain surge potential. Examples include:

- Insufficient Rate Capability
    - Arkwin actuators limited to 25 ship-sets (S/S) per month.
    - J. Carter valves limited to 20 S/S per month.
    - Parker-Hannifin valves/controllers limited to 25 S/S per month.
- Producibility
    - Collins unable to sustain rate on transducers.
    - Talley has problems in manufacturing and quality on actuators, pumps, and fuel dividers.
- Material Supply
    - Sterer aluminum forging lead time is 72 weeks.
- Manpower
    - ITT/General Controls have limited personnel for assembly and calibration of vent valves.

Even with these known constraints, the production rate, on balance, can be increased to 35 aircraft per month within 24 months after go-ahead.

As noted earlier, the current F-16 production line is arranged to increase the production rate to 45 aircraft per month with only minor rearrangement and addition of tooling.

At a cost of $3 million (1981 dollars), additional tooling could be purchased to increase production to 25 aircraft per month using 2 shifts per day and a 5 day work week. Twelve months would be required to purchase and set up the tooling. A $12 million purchase of additional tooling would increase the production rate to 35 per month using 2 shifts per day and a 5 day week, and 45 aircraft per month using 3 shifts per day and a 6 day week.

Generally speaking, mobilization improvements can be achieved using a two step process. In the short term (12 months), $86 million (1981 dollars) would be required to purchase long lead material to protect a 19-20 aircraft per month rate with a 24 month delivery. In the long term (2-3 years), $280-400 million would be required to reach the 35-45 aircraft per month rate by the procurement of additional tooling, test equipment, facilities, and long lead material.

PART V

F/A-18 HORNET

DESCRIPTION

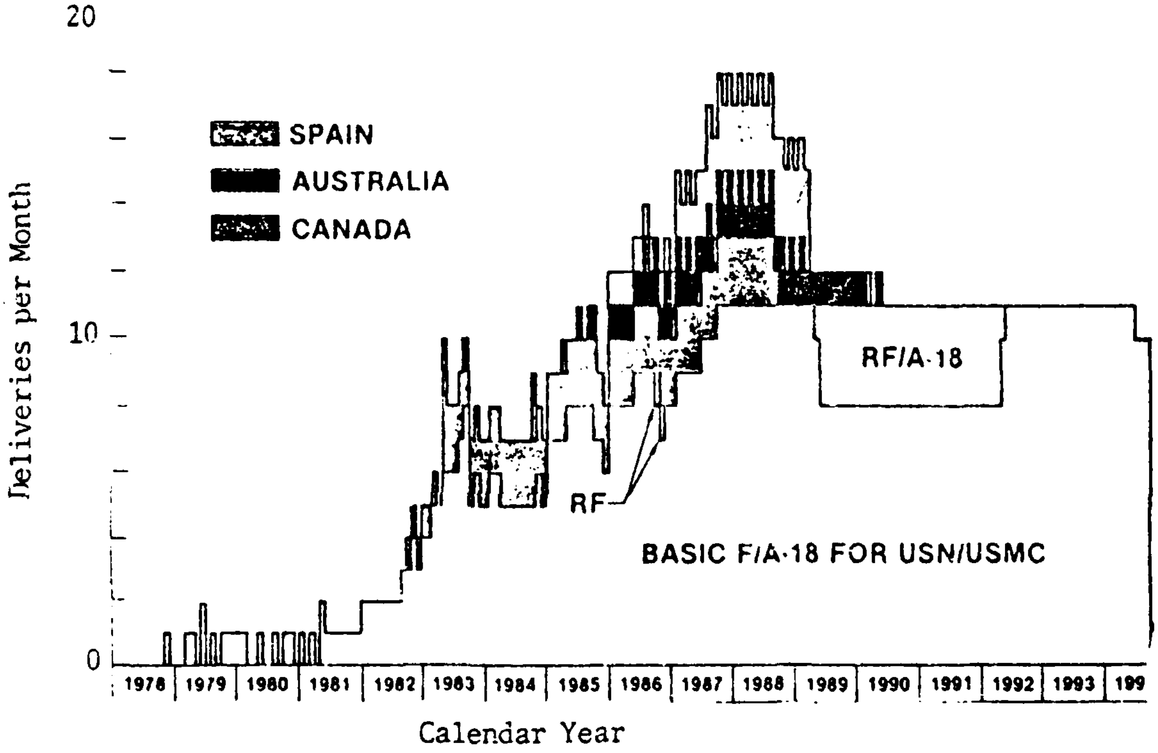
The F/A-18 Hornet Strike Fighter is a high performance, all-weather fighter and light attack aircraft built by the

McDonnell Douglas Aircraft Corporation. This multimission aircraft is powered by two General Electric F404-GE-400 turbofan engines, each capable of producing 16,000 lbs of thrust using afterburner. Capable of operating from aircraft carriers, the F/A-18 has a maximum design speed of Mach 1.7+. The F/A-18 features a variable camber mid-wing, with leading edge extensions mounted on each side of the fuselage from the wing roots to just forward of the windshield to improve high angle of attack flight, and optimize lift during maneuvering and cruise. Armament normally consists of Sparrow and Sidewinder missiles and a 20mm gun. In addition, external fuel tanks, sensor pods, and/or a wide variety of ground attack missiles/bombs may be carried. The F/A-18 is designed to replace the F-4 fighter, the A-7 attack aircraft, and augment the F-14 fighter in fleet air defense.

PRODUCTION RATES

The first F/A-18 aircraft was delivered to the U.S. Navy in 1978 for full scale development testing. The aircraft is now in production with deliveries scheduled to reach 18 per month by 1987. Eleven aircraft per month will be delivered to the U.S. Navy and Marine Corps with the remainder going to Canada, Australia, and Spain. Figure 17 shows planned deliveries through 1994. These projections are based on a U.S. buy of 1,377 aircraft, a Canadian buy of 138, an Australian buy of 75, and a Spanish buy of 84 for a total of

F/A-18 HORNET PLANNED DELIVERIES



Source: McDonnell Aircraft Company

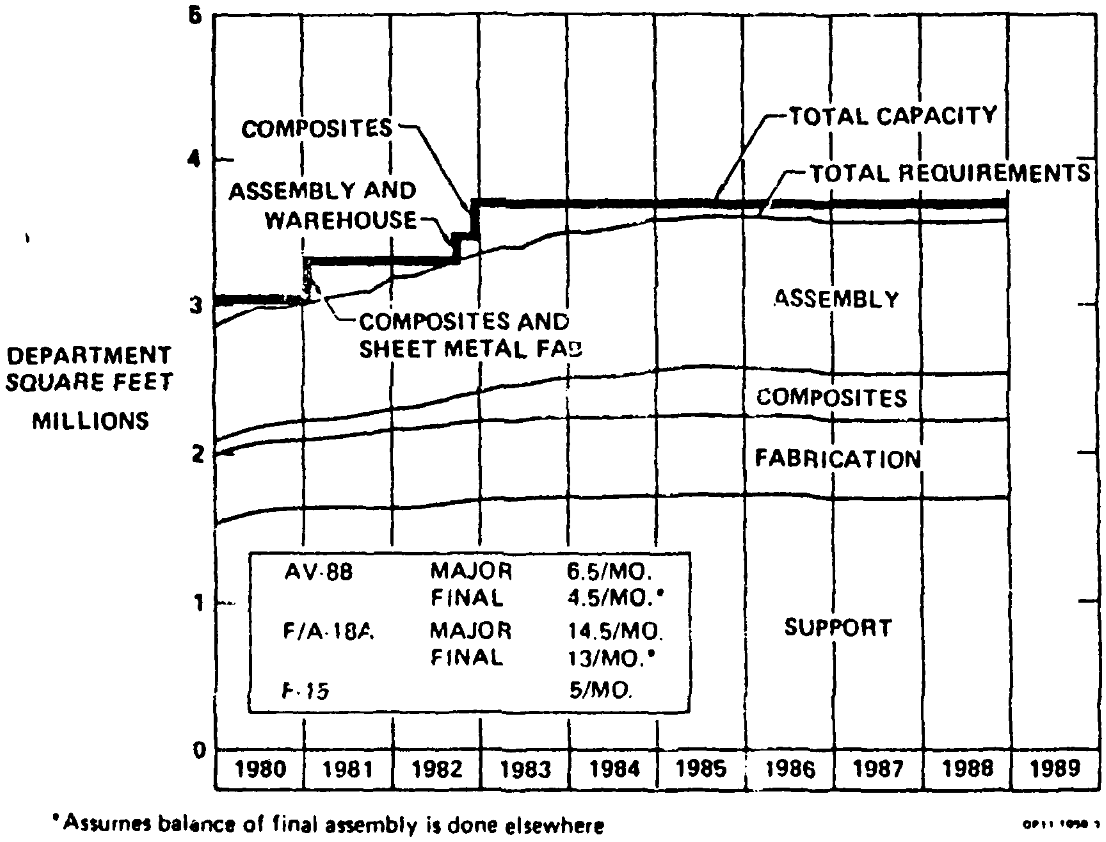
FIGURE 17

1,674 aircraft. McDonnell Douglas projects possible sales in excess of 2,500 aircraft.

During 1983, McDonnell will be producing F/A-18's at a maximum rate of 10 per month. The company has recently expanded its Saint Louis faciltities to the extent that it has the capacity to produce 13 F/A-18s per month. That rate can be increased to 14.5 per month if final assembly is done elsewhere. Figure 18 shows the total manufacturing area requirements to support production of the F/A-18 as well as the AV-8B and F-15 at the rates indicated, and the total capacity either planned or in place. In addition to expansion in the major and final assembly area, McDonnell Douglas has recently developed an extensive composite bonding capability, which currently exceeds their production requirements. To support their manufacturing requirements, McDonnell Douglas has also, in conjunction with their subcontractors, upgraded and modernized their machining capability. The latest in Numerical Controlled 5 axis gantries and other state-of-the-art equipment is widely used, and exceeds current requirements.

PRODUCTION FLOW

McDonnell Douglas can assemble an F/A-18 in 15 months, provided the required forgings, raw materials, and major subcomponents, particularly the landing gear and engines, McAIR TOTAL MANUFACTURING AREA REQUIREMENTS



*Assumes balance of final assembly is done elsewhere

Source: McDonnell Aircraft Company

FIGURE 18

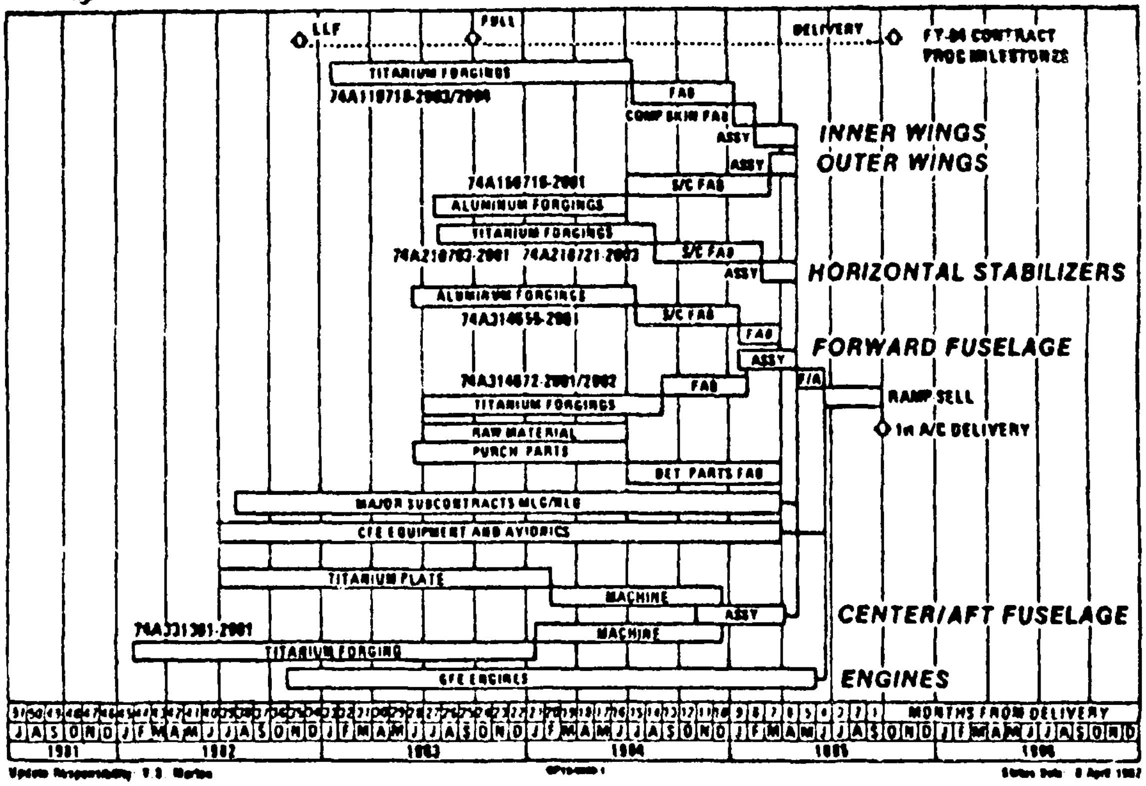
arrive when needed. Starting from the point in time where forgings must be ordered and funding made available to subcontractors, the building of an F/A-18 is a 44 month process. As shown in Figure 19, an aircraft ordered in February 1982, will be delivered in October 1985. A great deal of this time is associated with "who builds what". McDonnell Douglas manufactures few of the major components, and not all of the airframe. They do assemble most of the F/A-18, but for many of the items, McDonnell must order and wait. Such items as landing gear and servos may require lead times as long as 22 to 27 months. The lead time required to obtain major avionics such as the radar and FLIR are no better, requiring a lead time of 27 to 29 months. The General Electric F404 engine lead time is currently 26 months.

Machining of parts is another area where delays might be expected. However, McDonnell has an impressive machining capability, and has worked closely with its subcontractors to insure that they have the most modern equipment. In some cases, McDonnell has reduced lead time by doing machining for their subcontractors. For example, McDonnell accepts forgings from its landing gear manufacturer, does the major machining, and then returns the finished products to the subcontractor for assembly.

For the F/A-18, the major manufacturing steps performed

FY 84 PROCUREMENT PLAN

INCLUDES 5 MONTHS ADMINISTRATIVE AND SHIPPING TIME



Source: McDonnell Aircraft Company

FIGURE 19

by McDonnell Douglas are: machining and fabrication, major assembly, final assembly, test, and delivery. McDonnell has the capability to machine titanium, steel, and aluminum, which it does for the wings, horizontal stabilizers and forward/center fuselage. The aft fuselage and vertical tail are manufactured by Northrop and shipped to Saint Louis by rail. McDonnell does its own composite fabrication, 9% of the structural weight of the aircraft being graphite/epoxy. The wings, forward fuselage, and center fuselage are built up seperately at various assembly stations and then joined with the aft fuselage in the major assembly area. At this point, the landing gear and canopy are attached, and the aircraft is moved to another building where final assembly and ground checkouts are completed. Finally, flight test and acceptance by the government flight representative is accomplished and the aircraft is delivered.

While machining is very <u>capital</u> intensive, particularly when using the computerized, numerical controlled machines, the fabrication, production of composite components, and assembly is very <u>labor</u> intensive. Assembly stations are no more than convenient work stands which ensure proper mating of the various structures and components as they are being built up by hand.

POTENTIAL PRODUCTION RATES

Based on the formal Industrial Preparedness Planning done by McDonnell Douglas to support its FY 83 DD-1519 submissions, the company has a modest capability to expand production. Using existing production facilities and equipment, McDonnell can reach a maximum production capability of 17 F/A-18 aircraft per month by M+23 months and maintain a sustained rate of 17 per month after M+28 months. Projected sales without surge or mobilization are scheduled to reach 17.5 aircraft per month by 1988. Plant modernization and expansion are programmed to support this projected growth.

The first additional aircraft in excess of planned deliveries would be available at M+9 months. Achieving this rate would require using 2 shifts, 6 days a week. This projected increase in production is based on the following assumptions:

- F-15 and AV-8B production would also be accelerated.
- Government furnished avionics equipment would be available, as required.
- Major assemblies could be delivered to McDonnell Douglas' Tulsa facilities or leased areas.
- FY 83 procurement is in effect at M-Day with approval of 84 aircraft for the USN/USMC, 24 for Canada, and 2 for Australia, with deliveries scheduled from M+25 through M+36.
- FY 84 planning and long lead authorization is in effect at M-Day with approval for 96 aircraft for the USN/USMC, 25 for Canada, and 3 for Spain, with deliveries scheduled from M+37 through M+48.

- Priorities and allocations for critical materials and suppliers' capacity relative to current commercial aircraft orders are provided by the U.S. Government to support accelerated deliveries past M+36.

Using existing production facilities, a year's supply of long lead time items, and a 2 shift, 6 day week, McDonnell Douglas can deliver the first additional aircraft at M+8 months. The maximum surge production rate of 17 F/A-18 aircraft per month is reached by M+16 (an acceleration in production of 7 months), then maintained after M+18 (an acceleration of 10 months).

Although the F/A-18 is currently in production, if start up was required from a cold base using existing production facilities and equipment, the first aircraft would not be available until M+36, assuming production line tooling is set up concurrent with material procurement.

In addition to the formal Industrial Preparedness Planning done by McDonnell Douglas, the company has also conducted a series of studies to determine the facilities required to support F/A-18 production rates beyond those under surge or mobilization conditions. They found that the production rate could be increased to 18.5 per month, while maintaining production of the AV-8B at 4.5 per month and the F-15 at 5 per month, if additional major and final assembly areas were available. Existing composite bonding area capacity exceeds requirements. The F/A-18 production rate could be increased to 20 aircraft per month if final assembly of 1.5 aircraft per month is done elsewhere. Figure 20 shows total manufacturing area capacity and requirements. In addition to manufacturing area, McDonnell would have to increase its own or its subcontractors' machining capacity. Studies have also been completed for a scenario to simultaneously increase production of the F/A-18 to 18.5 per month and the F-15 to 12 per month while maintaining AV-8B production at 4.5 per month. These studies indicate sufficient area for composite bonding, but require additional expansion of assembly area and machining capacity.

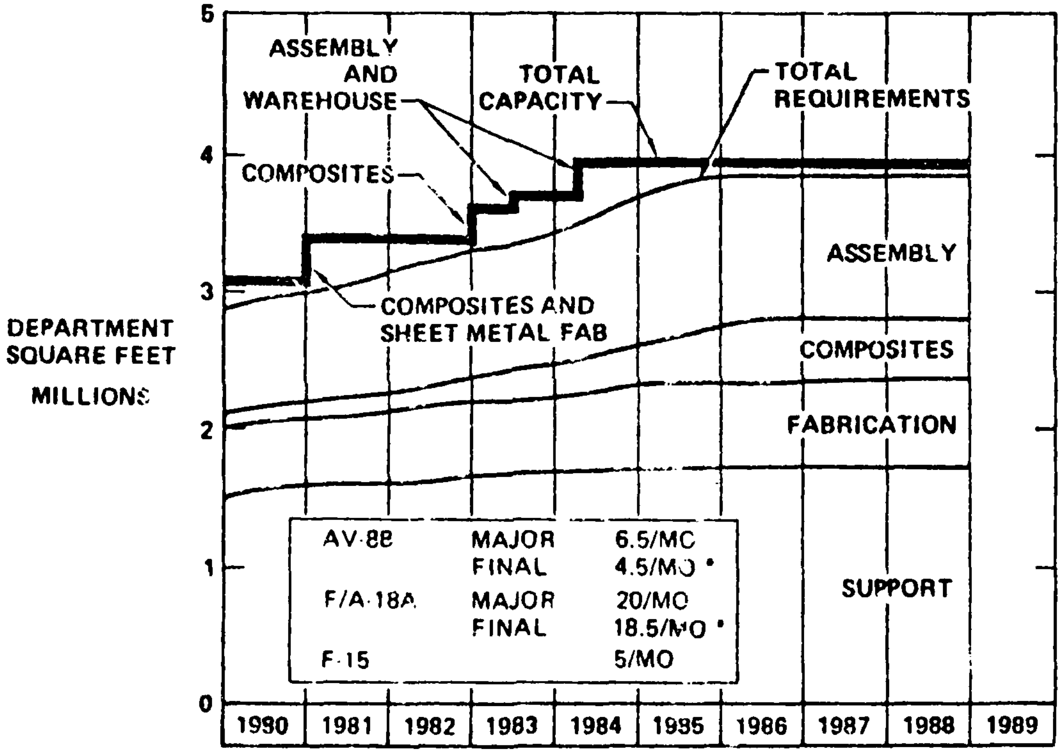
As stated by McDonnell Douglas, "There is an inherent capability to increase the rate of production of any aircraft production line. The ability to increase the rate of production is dependent on current delivery rate, quantity of aircraft on order, the capability of suppliers to accelerate production, and the availability of manpower." (4) Each of these items represents a potential bottleneck or constraint to increased production under a surge/ mobilization scenario.

BOTTLENECKS AND CONSTRAINTS

Of the factors that affect a company's ability to increase its production rate, one having a major impact is current delivery rate. As shown previously by Figure 3 on

MCAIR TOTAL MANUFACTURING AREA REQUIREMENTS

HIGH RATE STUDY-ALTERNATE



*Assumes balance of final assembly is done elsewhere

Source: McDonnell Aircraft Company

FIGURE 20

page 9, the higher the existing delivery rate, the greater the additional quantity of aircraft that can be delivered in a given period of time after M-Day. In this regard, the F/A-18 is in an enviable position; its production rate is scheduled to increase to 17.5 per month by 1988, and remain at high levels into the 1990's. If planned production rates are decreased, however, particularly before full capacity is reached , this action will place a constraint on future surge and/or mobilization of the F/A-18.

The quantity of aircraft on order has an impact similar to that of the current delivery rate; the greater the quantity of aircraft in the pipeline at M-Day, the faster the available acceleration of production rate and the greater the quantity which can be delivered in a given time after M-Day. Aircraft on order insures that long lead items are on order. If a stable procurement plan is in effect, backed by a multi-year contract, the capability for accelerated production can be enhanced by procuring an additional one year supply of long lead items and maintaining a rolling inventory. However, the quantity of F/A-18 aircraft on order continues to vary with increased cost and budget constraints. Proposed reductions in the number of aircraft procured will have an adverse affect on McDonnell Douglas' ability to place long lead items on order in sufficient quantities to ensure acceptable lead times, and establish a stockpile of long lead items.

The capability of suppliers to accelerate production is a major bottleneck in an attempted acceleration of aircraft production rates. The long lead times associated with procuring major equipment items under normal peacetime production conditions represents a major portion of the time between order and delivery of an aircraft. Table 6 shows the lead times currently associated with major equipment items of the F/A-18. In addition, numerous avionics/weapon system components used in the F/A-18 are common to other U.S. Navy tactical aircraft, and these will be in high demand during

****

Table 6. F/A-18 Fiscal Year 1984
Major Equipment Long Lead Items (5)

ITEM	SUPPLIER	MONTHS
FLIR	FORD AEROSPACE	29
RADAR	HUGHES AIRCRAFT	27
LANDING GEAR	CLEVELAND PNEUMATIC	27
JET ENGINE	GENERAL ELECTRIC	26
STABILATOR SERVO	NATIONAL WATERLIFT	25
HEAD-UP DISPLAY	KAISER	24
MULTIPURPOSE DISPLAY	KAISER	24
GUN ACCESSORY SYSTEM	GENERAL ELECTRIC	24
AILERON SERVO	HYDRAULIC RESEARCH	24
WINGFOLD MECH, DRIVE GROUP	AIRESEARCH	24
TRAILING EDGE FLAP SERVO	BERTEA	23
RUDDER SERVO	HYDRAULIC UNITS	22

SOURCE: MCAIR

****

any surge or mobilization. Critical items include the 20mm Gun System, the ECM System, the Digital Data Communications Set, the Guided Missile Launcher, the Standard Airborne Computer, and others. The ability to determine which suppliers in the subtier are the critical ones, and then provide them with the incentives to improve the capability remains the central challenge in surging or mobilizing aircraft production. The F/A-18 is similar to the F-14, F-15, or F-16 in this case.

The remaining item that may restrain increased production of the F/A-18 is the availability of manpower. This does not appear to be a problem for McDonnell Douglas in the St. Louis area. McDonnell is the only major aircraft manufacturer in the area, provides union benefits to its industrialized labor force, has an effective training program, and pays high wages. Skilled manpower is lined up outside the door!

CONCLUSION

These vertical slice studies clearly point out the recurrence of similar problems which create nearly identical bottlenecks and capacity constraints for each of these aircraft. In the next chapter problem areas will be examined by using a horizontal slice method.

CHAPTER IV

HORIZONTAL SLICE STUDY

OVERVIEW

As the preceeding chapters have shown, the ability to surge the production rates for the aircraft under study is severely constrained. The 1980 Defense Science Board assessed it this way:

> "In regard to 'surge' capability in military aircraft programs, it is virtually non-existent. Some short time increase might be possible by draining the component pipelines, but no sustained production increase should be achieved in less than 3 years. (27:13)
>
> * * * * * * * * * * * * * * *
>
> Until 1977, the production base was sized on a 1 shift, 8 hour, 5 day basis. Facilities are now sized for cost effective, peacetime production. ... Another result of the 'short war' philosophy ..." (27:22)

In this chapter the major items or factors which limit the surge capability across the entire aerospace industry will be discussed. The following list itemizes the various articles which research revealed to have a constraining effect on surge production:

- Avionics
  - Electronic Warfare System Components
  - Inertial Navigation Systems
  - Instrumentation
  - Radar and Fire Control Systems
  - Radios (Communication and Navigation)
- Canopies and Windshields
- Electrical Power System Components
- Engines
- Environmental Control Systems
- Forgings and Castings
- Fuel Gaging Systems
- Fuel-Oil Heat Exchanger
- Fuel System Valves, Pumps, and Components
- Hydraulic System Valves, Pumps, and Components
- Landing Gear
- Machine Tools (Machined Parts)
- Personnel (Skilled Labor)
- Pneumatic (Air) Valves and System Components
- Raw Materials (Strategic Materials, etc.)
- Titanium Skin
- Wheels and Brakes
- 20mm Gun

Other important factors acting to deter firms from supporting defense business include:

- Volume of paperwork
- Cost accounting standards
- Continued delays in Congressional/DoD decision making.
- Limitations on profits
- Social program requirements
- Slow pay by the government
- Small orders
- Excessive specifications (27:51)

An in-depth analysis of each of these items is beyond the scope of this paper; however, some discussion will be provided to expand upon, or to reemphasize the points considered most important.

In taking a horizontal slice through the aerospace industry at almost any level, one is struck by the fact that in many cases only one or two small companies are able or willing to produce certain components, so they are the sole suppliers for the entire industry. This situation is caused by an economic fact of life: no company can afford to maintain its production capacity at a level significantly above that required by the sales which can be made. Considering the effects of this economic factor in light of the historically small numbers of fighter aircraft produced in the United States, it is not surprising that the production base for almost every item is composed of only a few firms having very little capability to surge their production. Table 7 provides examples of cases where the

****

Table 7. Cases Where the Industrial Base is Very Thin. (27:48,49)

ITEM	# OF SUPPLIERS
ALUMINUM PLATE	2
ALUMINUM TUBING	2
TITANIUM SHEET	3
TITANIUM WING SKINS	2
TITANIUM EXTRUSIONS	1
AEROSPACE FASTENERS	24
AIR FRAME BEARINGS - SPECIAL BALL	1
NEEDLE BEARINGS	2
MIL. SPEC. QUALIFIED CONNECTORS	3
AIRCRAFT LANDING GEAR	3
RADOMES	2
IMAGE CONVERTER TUBE	1
OPTICS COATINGS	1

****

industrial base is very thin.

Another striking factor about the industry is the large number of components provided by the subcontractor base, and the complex interrelationships which exist. There are typically over 5,000 subcontractors for each prime contractor. In turn, each major subcontractor may have a similarly large number of suppliers. As Secretary of Defense Weinberger has noted, "A detailed ... search for potential bottlenecks is not a practical possibility, as the lower tiers of the defense production process involves tens of thousands of firms ..." (33:69) It is, therefore, practically impossible to model the system so that specific limiting items can be identified. Rather, a good way to identify the existing bottlenecks and capacity constraints is to look at the lead time required to obtain an item. Those items requiring the longest lead time should then be examined to determine both the cause of the excessive lead time and the solution to the problems causing it. This paper has taken the first step of this process. We recommend that future studies focus on specific items or groups of items.

One danger of using lead time as the sole indicator of the existence of bottlenecks or capacity constraints is the possibility of overlooking items which currently have short lead times, but are being produced at a rate just slightly below capacity. These items will, of course, immediately develop a long lead time if the quantity ordered is increased. The only way to positively identify these items is to make an item-by-item survey of the supplier base. Because of the numbers of suppliers involved, however, this approach is considered to be practical for only a limited number of items. An alternative method exists in the Defense Economic Impact Modeling System (DEIMS). This system examines the major industrial suppliers to the Department of Defense and forecasts the impact of defense expenditures on industry output. By examining the output of DEIMS, one can determine those sectors of the industry which are forecast to decline, maintain status quo, or grow. From this determination, one can then assess the probability that a capacity constraint or bottleneck would exist. A detailed description of DEIMS is beyond the scope of this work; however, further data is provided in Appendix C. Next, selected long lead items and materials critical to aircraft production will be discussed.

SELECTED BOTTLENECKS AND CONSTRAINTS

Avionics

This topic includes the following items: electronic warfare system components, inertial navigation systems, instrumentation, radar and fire control systems, and communication and navigation radios. The case of the Hughes

Radar might be considered typical in this area of the aerospace industry. In 1980 Hughes

> " ... spent $1.1 billion ... buying system components and materials from some 8,400 firms ... about 85% of them small businesses employing less than 500 people.
>
> Yet, these sources, for a variety of reasons, are drying up. [Hughes Board Chairman, Allen Pucket said,] 'In 1971 we went to multiple sources with 65% of our procurement dollars. In 1980, that figure had decreased to 40%.' ... At the same time, because of the decline in that production capacity ... the lead time to deliver an airborne radar system has lengthened from 12-24 months to twice that [in 1981]. (4:27)

McDonnell Douglas stated that many producers of electronic components will simply not bid for contracts involving government business. (15) One reason is the small number of items normally ordered. An electronic chip producer who measures his normal production run of an item in the thousands may not wish to produce only several hundred chips for a fighter's radar. Add to this small-numbers problem the extensive paperwork, technical performance specifications, and inspection requirements which are a part of doing business with the government and one can see why firms will avoid these contracts. McDonnell's judgement echoes the 1980 Defense Science Boards findings:

> The military market represents only 7 to 10% of the total electronics market ... there is low investment for military products and some product lines are being dropped because of low production

rates and poor return on investment.

> The military buys are characterized by low volume, specialized designs (often very complex), extensive and costly testing, and excessive paperwork for bids and contracting. (27:11)

Another factor to be considered here is the production of specialized items such as electronic warfare systems and military communication and navigation radios. Only a very few companies are on contract to build these specialized items, and it is likely that they have all scaled their production capacity to the peacetime order rate, because, as mentioned previously, it is economically infeasible for a company to maintain a large idle production capacity over the long term.

Engines

Three of the aircraft in this study are powered by Pratt and Whitney engines. The F-15 and F-16 both use the F100 engine, while the F-14 uses the TF30. A factor to be seriously considered, therefore, is that the combined demand for engines and engine parts to supply both aircraft production and the operational forces may exceed the engine manufacturers' capability. In a 1975 study of the F100 and TF30 engines, Pratt and Whitney stated "requirements for engines and spare parts could be met," provided approximately $17 million (1975 dollars) were spent on prestocking raw materials and parts. (26:I-1) Since no prestocking funds have been allocated, the Pratt and Whitney capability is probably limited. A more recent study showed that the rate capacity for the F100 engine is approximately 50 per month. (30:4-1-13) Assuming all 50 engines go to production aircraft, for example, this rate could supply 10 F-15s and 30 F-16s per month, which is less than the surge capability of each of these prime contractors. It will therefore be necessary to overcome engine capacity constraints if the prime aircraft contractors are to surge to full capacity.

In another 1975 surge capability study, General Electric, producer of the F/A-18's F404 engine, concluded:

> - If no advanced planning and action is implemented prior to M-Day, only a small part of the required engines can be delivered at the stipulated time. This shortage is due to a combination of lead time and capacity.
>
> - The combination of USAF Industrial Preparedness requirements for spare parts and engines does result in a capacity problem in both vendor capability and in-house manufacturing capability. The shortages are due to manufacturing equipment and tooling, but not brick and mortar. (11:41)

Castings

Another serious capacity constraint exists in the foundry industry. A 1975 study showed that between 1960 and 1974 over 360 foundries closed, while only 56 new foundries opened. (22:19) The 1980 Defense Science Board report stated:

> "... castings are and will remain a serious problem. In the past decade over 400 foundries

> have gone out of business, primarily because of EPA and OSHA requirements. The demand [for foundry products] continues so the queues get longer." (27:15)

Forgings

In 1980, General Slay testified before Congress, "Currently, there are only three remaining U.S. suppliers of large forgings -- the kind we need for aircraft landing gear and components...." (29:III-16) These three suppliers are still the only sources of these forgings today:

* * *

Table 8. Sources of Large Forgings (29:III-16)

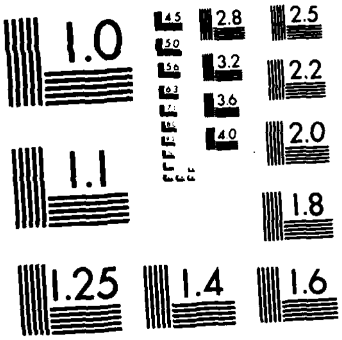
Source	Capability	Typical Aircraft Parts
Wyman Gordon	2 Presses	Bulkheads, Main Wing Ribs, Landing Gear Cylinders, etc.
Alcoa	2 Presses	Bulkheads, Wing Spars, etc.
Ladish	1 Hammer	Engine Compressor Discs, etc.

* * *

Machine Tools

As one increases the rate of production, more and more bottlenecks and capacity constraints come into play. For example, even though the current level of production for all four aircraft in this study is below even the normal

AD-A134 629 IDENTIFICATION OF BOTTLENECKS AND CAPACITY CONSTRAINTS 2/2
IN F-14 F-15 F-16 A..(U) INDUSTRIAL COLL OF THE ARMED
FORCES WASHINGTON DC J G CABUK ET AL. APR 83
UNCLASSIFIED NDU/ICAF-83/047 F/G 15/3 NL



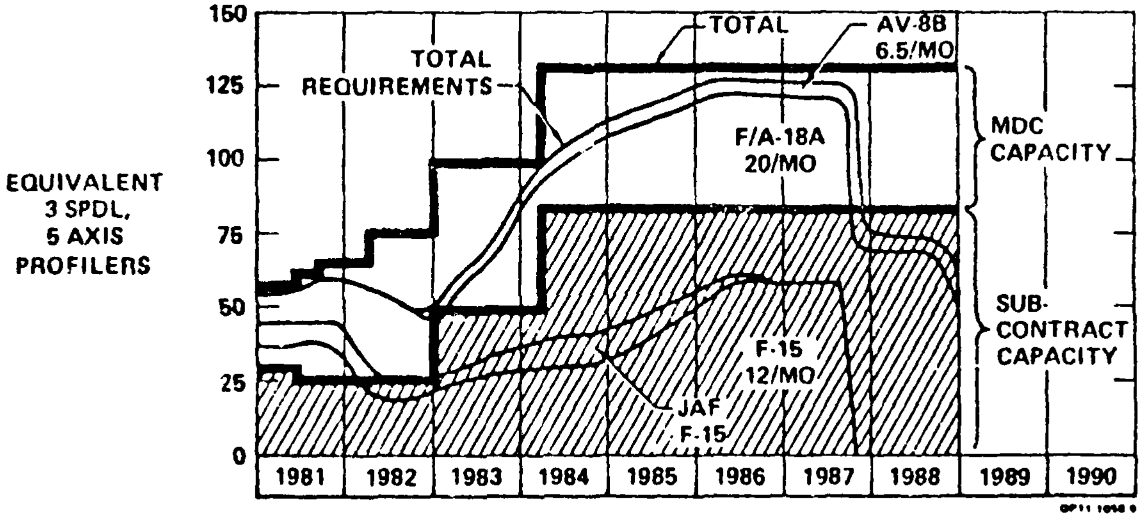
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

capacity, some machine tools are operating near full capacity because it is grossly uneconomical to allow such assets to stand idle. Therefore, if the production rate is increased, machine tool capacity must be brought on line or subcontractors found to accomplish the additional work. The 1980 Defense Science Board stated the the machine tool industry is composed of "a large number of small companies," characterized as follows:

> "Of 1,300 firms in the U.S. that make machine tools, there are only 10 firms that employ more than 1,000 people, and ... only two with 2,500 or more emplyees. ... Most of these companies have no interest in defense business and often will actually avoid it. They feel incapable of handling the red tape and the contracting paperwork.
>
> The industry has three major problems -- the growing shortage of skilled craftsmen, the difficulty of obtaining investment capital, and ... foreign competition." (27:16)

Recognizing these facts, prime contractors analyze their capabilities versus actual and potential sales. One analysis, provided by the McDonnell Douglas Company, is shown in Figure 21. The chart shows the equivalent number of 3 spindle, 5 axis numerically controlled machines required to support the simultaneous production of the F-15, F/A-18, and AV-8B at rates of 12,20, and 6.5 per month. Note that the in-house capacity (labeled "MDC Capacity") is less than half the requirement; the remainder of the work must be performed by other suppliers. Table 9 shows a McDonnell analysis of their suppliers' 5 axis numerically controlled machining

NUMERICALLY CONTROLLED 5-AXIS GANTRIES
High Rate Study



Source: McDonnell Aircraft Company

FIGURE 21

capability which was expected to be available by the end of 1982. Although the total of 67 machines compares favorably with the subcontractor capacity required through 1983 in Figure 21, McDonnell officials pointed out that these subcontractors also supply many other companies with machined parts, so it is not reasonable to expect this entire capacity to be devoted to the satisfaction of McDonnell Douglas' needs.

* * *

Table 9. McAir Suppliers -
5 Axis N/C Machining Capability (5)

COMPANY	EQUIVALENT 3 SPINDLE 5 AXIS MACHINES
ACROMIL	4
CANADAIR	4
ELLANEF	18
MONITOR BOXART	7
QUEBEC MACHINE CENTER	4
OTHERS	8
SUB-TOTAL	45
NORTHROP	22

* * *

Labor

Some insight into the status of the labor supply for the machining and forging industries is provided by General Slay:

> A special survey made by the National Tooling

> and Machining Association (NTMA) indicates that the tool industry should hire 60,000 skilled journeymen now, and will need nearly a quarter of a million skilled journeymen total by 1985. ... A survey by the Forging Industry Association shows that current shortages run as high as 20 percent of need with projections to 1990 showing that shortages run as high as 42 percent of need. ...
>
> The impact of these skills shortages is highly significant. The American Tooling and Machining Industry can't meet domestic demand in a prompt and timely manner. ...
>
> Not only does this skills shortage adversely affect the general industrial market, but it has even more impact on America's defense production capability. The NTMA study mentioned earlier also found that over 2,000 more journeymen machinists are needed now by the sector of our industry which does primarily defense type work. They are not available. Many tooling and machining firms complain of being forced to turn down defense related work while machines sit idle because of the lack of skilled workers. (29:IV-15,16)

Although the 1980 Defense Science Board report also highlighted this labor shortage, the writers are surprised by the contention that a labor shortage is a major factor in the tooling and machining industry, and that machines are sitting idle for lack of workers. Considering the World War II experience, it seems likely that labor problems could be overcome should a national emergency again require such an effort. One should bear in mind that

> In 1939 ... the entire aircraft industry employed only 63,000 workers. ... Aircraft and Parts ... provided jobs for only one out of every 167 workers in manufacturing. Four years later ... there were 21 times as many workers in the industry. ... Nearly one out of every 13 workers in the manufacturing labor force was employed in this sector. (3:2)

The Ichord panel reported, however, "Unlike World War II, when under full mobilization, thousands-upon-thousands of people ... poured into our defense factories, the current economic environment and weapons system sophistication will not support any quick fix or emergency manpower reallocation to satisfy surge requirements." (31 :15) Nonetheless, it would seem that with today's ten percent unemployment rate and generally recessionary economy, firms would be eager to find talented trainees to employ rather than allow expensive machinery to sit idle. One recently published book comments:

> A sad commentary on the current [labor] situation is that while jobs go begging for a lack of experienced, blue-collar, skilled workers, unemployment rates among youth and minorities in the areas closest to existing plants are abnormally high. In few industries is "structural" unemployment ... a persistent mismatch between job vacancies and unemployed workers -- so evident. Neither the public schools nor the vocational education systems seem to have adequately prepared the unemployed for skilled work in the industry. For whatever reasons, firms were extremely tardy in bringing the problem to national attention. (3:179)

It appears that the prime contractors are not seriously constrained by a lack of labor. The employment history of the aerospace industry seems to confirm the ability to quickly take on employees. Figure 9 on page 26 shows that several times since World War II McDonnell has been able to increase employment in a matter of months. Similar labor statistics are available for other major prime contractors. Therefore, on a macro scale at least, labor appears not to be a problem for prime contractors, although shortages in some skills may create short-term bottlenecks.

Time does not permit further discussion of this topic here; therefore, an indepth study is recommended to provide a complete understanding of the facts and the factors involved in the aerospace labor market. If, in fact, jobs are available for trained workers, this problem could be easily solved by a government program to provide training to currently unemployed workers.

Raw Materials

There are numerous problems in insuring an adequate supply of strategic materials. As the Ichord study concluded, "the U.S. is becoming increasingly dependent on foreign sources for critical raw materials." (31:1) The 1980 Defense Science Board report stated that while "Basic steel and aluminum are in reasonably good supply," specialty metals are a different matter:

> "The major basic material shortage is titanium sponge. ... During the period 1977 to 1979, the number of titanium fabricators dropped from 16 to 4, primarily because of the sponge shortage. U.S. producers are expanding capacity ... production of sponge was 20,000 tons in 1979 and is expected to reach 30,000 tons by 1985." (27:14,15)

In the interest of brevity, we will not delve further into this subject, but if the reader is interested in further information, two excellent references are: Dr. Jacques S.

Gansler's book, The Defense Industry, and the 1980 Ichord report to the House Committee on Armed Services, "The Ailing Defense Industrial Base: Unready for Crisis."

CORRECTIVE MEASURES ARE BEING TAKEN, BUT ...

As the previous pages of this report have shown, the capacity of the United States to produce large numbers of fighter aircraft on short notice is nonexistent. Even a small short term increase in production will be followed by a corresponding long term decrease until the supply pipeline can catch up with the increased demand for parts. Given the realities of the defense budget, there is no hope of bringing the industry to a state of readiness such that a simultaneous surge is possible for all the aircraft considered in this report. There is some hope for improvement in the surge capability, however, as a result of recent policy decisions within the Department of Defense. As stated in Secretary Weinberger's Annual Report to Congess for FY 1984, we have made significant strides through:

- Increased funding levels for industrial preparedness programs.

- Increases in appropriations for the Manufacturing Technology Program.

- Improvements in the management of industrial property.

- Sector analyses to review erosion of the industrial base.

- A formal program to encourage productivity improvements.

- Development of the Defense Economic Impact Modeling System. (33:115)

In addition, multiyear contracts for major weapon systems will add stability to those programs to which it is applied, resulting in firms being able to make longer range plans for investment, and, thereby, creating a better surge capability. Also, the Industrial Preparedness Program should continue efforts to buy an additional year of long lead items for critical systems, and maintain that level as a rolling inventory until needed for surge, or until the final production run. As discussed in Chapters II and III, having these additional long lead items on hand would greatly increase surge output.

Another encouraging effort is the focus on improving manufacturing technology. All of the aircraft examined in this study are practically hand built; many steps of the process are very labor intensive and time consuming. As General Slay commented,

> "By applying computer technology to manufacturing processes, we expect to be able to reduce significantly the flow time of a manufactured part. Our studies have shown that for machining, actual cutting time is only about 25 percent of the total time a part is on the machine. By automating the non-cutting operations such as parts and tool handling and numerical control tape verification, we can reduce the total amount of time it takes to process a part. Thus the lead time can be reduced." (29:VII-8)

Although no immediate breakthrough seems likely in this area, even small strides will pay big dividends through reductions in the time and labor required to fabricate an aircraft.

As this study demonstrates, anyone contemplating a surge in production of a particular aircraft would be well served to maintain a broad view of the aerospace industry as the surge is being planned. For example, before using a subcontractor's estimate of his maximum capacity to produce an item, one should also determine what other demands there will be for the item, and temper his judgement of its availability accordingly. One excellent study in this regard is the joint Air Force Systems Command and Air Force Logistics Command study titled "USAF Production Base Analysis for FY 83." This SECRET study was only in draft when we reviewed it, but we strongly recommend it to those with the appropriate security clearance and the need to know. HQ AFSC/PMOP is the point of contact. Such analyses should contribute toward overcoming the deficiencies of the existing DD-1519 system.

Another excellent effort is the cooperative planning system being established for some programs. The system is illustrated in Figure 22, and is described as follows:

> This is a simplified diagram of supply and demand interaction for a single [U.S. Air Force] weapon system. Initial production and FMS orders are traditionally placed with the prime system contractor by the system program office. ... Follow-on orders for both USAF and FMS support are traditionally placed by the Air Logistics Center

System and Support Acquisition: The Need for Cooperative Planning (22)

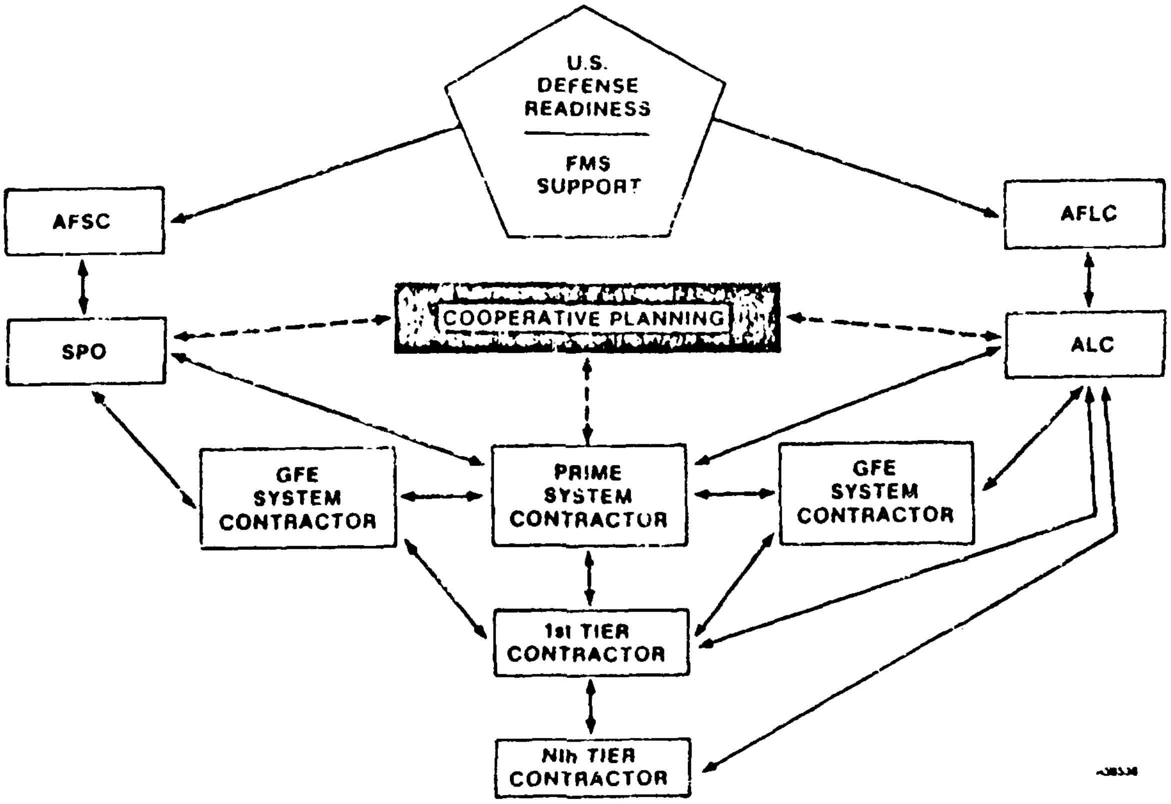


FIGURE 22

> and may be placed with either the direct source of supply or through the prime system contractor. The prime system contractor ... has the best visibility on sub-tier capacity. Cooperative planning is a key process to link demands for both initial production and support acquisition. [It] is a process that exchanges demand forecasts and capacities ... among the SPO, the prime contractor, and the Air Logistics Center. (22)

Most prime contractors attempt to avoid production difficulties by studying the supply and demand situation for items critical to their production line. For exam General Dynamics performs the following actions with subcontractors:

- In-Depth forecasting by commodity.
- Ten year procurement plan.
- Subcontractor surveys, workshops, cooperative planning sessions, and rate capability studies.
- Management controls implemented with suppliers.
- Risk and buffer stock procurement.
- Surveillance of GFAE suppliers to identify short lead time programs.
- Advanced planning for spares and support equipment. (22)

According to General Dynamics:

> The first and the last [of the above] items require close, cooperative exchange to be truely effective. ... a prime system contractor ... can develop a ten year plan and commodity forecasts. However, [in these] the emphasis is upon production installation requirements when (sic) we have the highest visibility. The greatest need for advanced planning and customer cooperation is for support requirements [which are] lead time away. ... For example, specific plans can be developed for a critical commodity such as the landing gear.

> Actions can be taken for selected long lead activities ... to reduce response time and avoid capacity constraints ... (22)

The results of a cooperative planning effort are illustrated in Figure 23. As shown, the prime contractor has forecast the capacity of the vendor system to produce various critical items. He has also forecast the demand for these items based on the production line and initial spares activity. The last column on the chart must be provided by government logistics support planners. This cooperative planning system offers great promise as a means to identify and eliminate capacity constraints.

As should be clear at this point, there appears to be no single overriding bottleneck or capacity constraint. Rather, there exists a myriad of challenges presented by the truly monumental task of producing modern fighter aircraft. On both the DoD and the contractor staffs the key people are, first, aware of the problems pointed out in this paper, and, second, working to solve those which can be solved with existing resources. There is a widely held belief that the relatively pessimistic estimates of surge production capability can be greatly exceeded if the government declares an emergency and deletes many of the administrative "business as usual" rules and procedures which are used for day-to-day production. The degree to which response time could be reduced and production capacity increased by such emergency

Capacity Planning (22)

VENDOR SYSTEM	MONTHLY RATE CAPACITY	INSTALLATION AND INITIAL SPARES ANTICIPATED MAX RATE	GOVERNMENT DIRECT SPARES & REPAIRS
ISA	35	25	
LANDING GEAR	30	25	
ESS	35	25	
LEFD	42	25	
EPU	35	25	
FLT CONTROL COMPUTER	54	25	
INS	27	25	
HUD	45	25	
SPEED BRAKE ACTUATOR	35	25	
FCC	35	25	
RADAR	25	25	
LG DOOR ACTUATOR	25	25	
A CANOPY ACTUATOR	*20/20*	*25*	
B CANOPY ACTUATOR	12/12	8	
PUMP	120	25	
PUMPS	100	25	
VALVE	40	25	
LIGHTS	50	25	
ECS VALVE	30	25	
LEF VALVE	45	25	
HYD RESERVOIR	30	25	
POWER SUPPLY CIU	35	25	
VALVE, TAIL HOOK	25	25	
VALVE	100	25	
HUD PUMP	40	25	
EXT TANK VENT VALVE	35	25	
CAUTION PANELS	30/50	25	
CARD ASSEMBLY CIU	40	25	
PTO SHAFT	35	25	
MISSILE LAUNCHER	110	25	
HYD VALVES	30	25	

FIGURE 23

actions has not been quantified, however.

Dr. William Perry, Under Secretary of Defense for Research and Engineering, said in 1980, "If we wanted to double the production rate of F-16's, in three months or six months, there is no way we can do it. I define that as a surge capability, and we don't have it." (31:12) To obtain a surge capability on the scale envisioned by Dr. Perry would undoubtedly require massive increases in federal defense spending. To the extent that such spending increases are unlikely, then having a surge capability, by Dr. Perry's definition, is unlikely. However, based on the evidence presented in this paper, it appears that significant benefits can be obtained from more modest expenditures. By selecting only a few aircraft to attempt to surge, and then buying an additional year of long lead items for these aircraft, short term surge capability would be greatly improved for a relatively small price. Even so, unfortunately, there is no magic key which can positively identify all the bottlenecks and constraints, and certainly none which will solve them all.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

There are many bottlenecks and capacity constraint affecting our ability to surge the production of F-14, F-15, F-16, and F/A-18 aircraft. From the time a surge is ordered, a nominal six months would elapse before the first additional aircraft rolled off the production line, and it would be approximately 3 years before sustained production rates increased significantly. Two major factors creating this time delay are:

- The time required to fabricate and deliver an airplane is approximately one year.
- The reorder lead time for many aircraft parts exceeds two years.

These predicted response times and quantities may be significantly improved if the government directs a "business not as usual" approach, but the degree to which such a declaration would improve the response is unknown. Comparing the results of the 1967 F-4 production surge to the current surge predictions indicates that current estimates may be conservative.

Critical long lead parts can be categorized as follows:

- Avionics
    - Electronic Warfare System Components
    - Inertial Navigation Systems
    - Instrumentation
    - Radar and Fire Control Systems
    - Radios (Communication and Navigation)
- Canopies and Windshields
- Electrical Power System Components
- Engines
- Environmental Control Systems
- Forgings and Castings
- Fuel Gaging Systems
- Fuel-Oil Heat Exchanger
- Fuel System Valves, Pumps, and Components
- Hydraulic System Valves, Pumps, and Components
- Landing Gear
- Machine Tools (Machined Parts)
- Pneumatic (Air) Valves and System Component
- Titanium Skin
- Wheels and Brakes
- 20mm Gun

The critical parts listed above are in short supply because the demand for them is extremely low due to the low level of aircraft procurement. It is an economic fact of life that companies cannot afford to maintain idle productive capacity, so the production base is bound to size itself to the existing level of production. One way around this problem is for the government to pay for keeping some excess productive capacity available, but current resources limit the use of this option. Realizing this fact, both the contractors and the Department of Defense are making a concerted effort to keep both production efficiency and surge production capability at the best level possible within existing resources.

In addition to the critical parts mentioned above, shortages of skilled labor may create bottlenecks and capacity constraints. There is a need to examine the aerospace industry labor market to determine why skilled labor is in short supply despite the current high unemployment rate.

Current studies of the raw materials situation seem to adequately define this problem area. However, efforts to obtain funding to correct or alleviate even the most critical of these shortages have not been successful. Therefore, numerous critical raw materials are likely to be in short supply during a production surge, thereby creating bottlenecks.

RECOMMENDATIONS

- The Industrial Preparedness Program efforts to obtain funding for an additional year of long lead items should be strongly supported because it can significantly increase the surge capability.

- Efforts should be made to place these aircraft, and other aircraft for which a production surge is contemplated, on multiyear contracts.

- Aircraft procurement programs should be funded at a level that will allow production near the most economically efficient rate for a one-shift, 40-hour week work force.

- Manufacturing technology improvements should be applied as rapidly as possible.

- An indepth study of the F-4 surge production experience should be made to preserve the lessons learned.

- The aerospace labor market should be studied, and, if necessary, a program to train workers in critical skills should be established within the Industrial Preparedness Program or in conjunction with other federal "jobs programs."

- Further horizontal slice studies should be made of various subcontractor sectors to determine the approximate total capacity to produce the critical items identified in this paper. These findings should then be compared to the total prime contractor surge demand, thereby determining where the potential demand exceeds the potential supply. A balanced corrective program should then be prepared and presented to Congress for funding.

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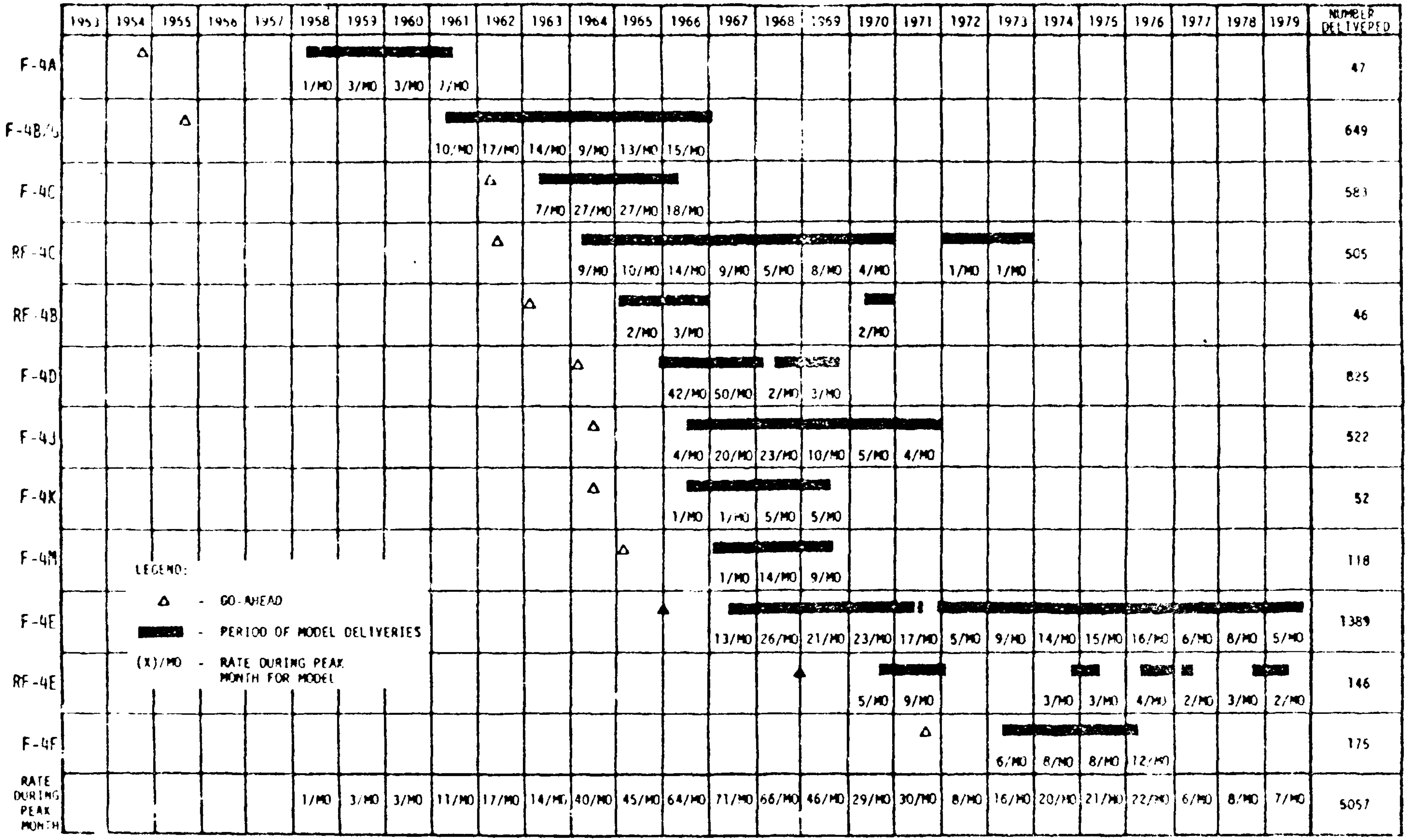
APPENDIX A

THE F-4 PHANTOM II SURGE EXPERIENCE

These tables provide further information on the F-4 production surge discussed in Chapter III.

PHANTOM II DELIVERIES



ACTUAL DELIVERY SPANS INCLUDE U.S. AND FMS DELIVERIES

PREPARED BY D.013/MFG

02 FEBRUARY 1983

DATE 11 Jun 63
REVISED 5 Dec 73
REVISED

MCDONNELL
ST. LOUIS, MISSOURI

PAGE 1 of 6
REPORT 3.0
MODEL Phantom II

F-4 SCHEDULED DELIVERIES VS. ACTUALS

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X
	U.S. NAVY								U.S. AIR FORCE												F-4 SUMMARY			
	F-4B				RF-4B								F-4C				RF-4C				[illegible]			
	SCHEDULE		ACCEPTANCE		SCHEDULE		ACCEPTANCE		SCHEDULE		ACCEPTANCE		SCHEDULE		ACCEPTANCE		SCHEDULE		ACCEPTANCE		SCHEDULE		ACCEPTANCE	
DATE	UNIT	CUM	UNIT	CUM	UNIT	CUM	UNIT	CUM	UNIT	CUM	UNIT	CUM	UNIT	CUM	UNIT	CUM	UNIT	CUM	UNIT	CUM	UNIT	CUM	UNIT	CUM
May 1958	1	1	1	1																	1	1	1	1
Jun	0	1	0	1																	0	1	0	1
Jul	0	1	0	1																	0	1	0	1
Aug	0	1	0	1																	0	1	0	1
Sep	1	2	1	2																	1	2	1	2
Oct	0	2	0	2																	0	2	0	2
Nov	1	3	1	3																	1	3	1	3
Dec	0	3	0	3																	0	3	0	3
Jan 1959	1	4	1	4																	1	4	1	4
Feb	0	4	0	4																	0	4	0	4
Mar	1	5	1	5																	1	5	1	5
Apr	0	5	0	5																	0	5	0	5
May	1	6	1	6																	1	6	1	6
Jun	2	8	2	8																	2	8	2	8
Jul	1	9	1	9																	1	9	1	9
Aug	1	10	1	10																	1	10	1	10
Sep	2	12	2	12																	2	12	2	12
Oct	3	15	3	15																	3	15	3	15
Nov	3	18	3	18																	3	18	3	18
Dec	0	18	0	18																	0	18	0	18
Jan 1960	0	18	0	18																	0	18	0	18
Feb	0	18	0	18																	0	18	0	18
Mar	0	18	0	18																	0	18	0	18
Apr	1	19	0	18																	1	19	0	18
May	2	21	3	21																	2	21	3	21
Jun	2	23	3	24																	2	23	3	24
Jul	3	26	1	25																	3	26	1	25
Aug	0	26	0	25																	0	26	0	25
Sep	3	29	0	25																	3	29	0	25
Oct	3	32	0	25																	3	32	0	25
Nov	4	36	2	27																	4	36	2	27
Dec	5	41	1	28																	5	41	1	28
Jan 1961	6	47	1	29																	6	47	1	29
Feb	0	47	2	31																	0	47	2	31
Mar	0	47	7	38																	0	47	7	38
Apr	0	47	5	43																	0	47	5	43
May	0	47	11	54																	0	47	11	54
Jun	0	47	11	65																	0	47	11	65
Jul	7	54	10	75																	7	54	10	75
Aug	10	64	10	85																	10	64	10	85
Sep	10	74	10	95																	10	74	10	95
Oct	10	84	6	101																	10	84	6	101
Nov	11	95	6	107																	11	95	6	107
Dec	12	107	6	113																	12	107	6	113

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MODEL Phantom II

F-4 SCHEDULED DELIVERIES VS. ACTUALS

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X
	U. S. NAVY								U. S. AIR FORCE												F-4 SUMMARY			
	F-4B				RF-4B								F-4C				RF-4C							
	SCHEDULE		ACCEPTANCE		SCHEDULE		ACCEPTANCE		SCHEDULE		ACCEPTANCE		SCHEDULE		ACCEPTANCE		SCHEDULE		ACCEPTANCE		SCHEDULE		[illegible]	
DATE	UNIT	CUM	UNIT	CUM	UNIT	CUM	UNIT	CUM	UNIT	CUM	UNIT	CUM	UNIT	CUM	UNIT	CUM	UNIT	CUM	UNIT	CUM	UNIT	CUM	UNIT	CUM
Jan 1962	12	119	9	122																	12	119	9	[illegible]
Feb	12	131	11	133																	12	131	11	133
Mar	12	143	13	146																	12	143	13	[illegible]
Apr	12	155	14	160																	12	155	14	[illegible]
May	12	167	7	167																	12	167	7	[illegible]
Jun	13	180	17	184																	13	[illegible]	17	[illegible]
Jul	10	190	10	194																	10	190	[illegible]	[illegible]
Aug	13	203	9	203																	13	203	9	[illegible]
Sep	9	212	9(1)	212																	9	212	9	212
Oct	15	227	13/2	227																	15	227	15	227
Nov	15	242	15	242																	15	242	15	[illegible]
Dec	12	254	12	254																	12	254	12	[illegible]
Jan 1963	10(1)	264	10/0	264																	10	264	10	[illegible]
Feb	7/2	273	7/2	273																	9	273	9	273
Mar	7/4	284	7/4	284																	11	284	11	[illegible]
Apr	7/4	295	7/4	295																	11	295	11	[illegible]
May	6/5	306	6/5	306											1	1					11	306	12	[illegible]
Jun	7/5	319	6/6	318											0	1					13	319	12	[illegible]
Jul	7/5	332	8/6	332									1	1	0	1					14	[illegible]	[illegible]	[illegible]
Aug	6/2	340	11	343									0	1	1	2	1 YRF	1	1	1	9	342	13	[illegible]
Sep	8	348	8	351									0	1	0	2	0	1	0	1	8	350	8	[illegible]
Oct	8	356	8	359									1	2	1	3	1 YRF	2	1	2	10	[illegible]	10	[illegible]
Nov	8	364	8	367									5	7	5	8			0	2	13	373	13	[illegible]
Dec	8	372	5	372									8	15	7	15			0	2	16	389	12	[illegible]
Jan 1964	8	380	8	380									11	26	11	26			0	2	19	[illegible]	19	[illegible]
Feb	8	388	8	388									14	40	14	40			0	2	22	430	22	[illegible]
Mar	8	396	8	396									17	57	17	57			0	2	25	455	25	[illegible]
Apr	8	404	9	405									20	77	20	77			1	3	28	483	30	[illegible]
May	8	412	8	413									23	100	27	104			1	4	31	514	36	[illegible]
Jun	8	420	9	422									23	123	25	129	1	3	0	4	32	[illegible]	[illegible]	[illegible]
Jul	8	428	9	431									23	146	25	154	2	5	1	5	33	579	[illegible]	[illegible]
Aug	8	436	8	439									23	169	25	179	3	8	3	8	34	613	[illegible]	[illegible]
Sep	8	444	8	447									23	192	23	202	4	12	4	12	35	648	[illegible]	[illegible]
Oct	8	452	8	455									23	215	15	217	4	16	4	16	35	683	27	[illegible]
Nov	8	460	5	460									23	238	21	238	5	21	2	18	36	719	[illegible]	[illegible]
Dec	8	468	8	468									23	261	23	261	5	26	9	27	36	755	40	[illegible]
Jan 1965	9	477	10	478									23	284	23	284	5	31	4	31	37	792	37	[illegible]
Feb	9	486	11	489	1	1	1	1					23	307	26	310	5	36	7	38	38	830	45	[illegible]
Mar	10	496	9	498	0	1	0	1					23	330	23(2)	333	5	41	6	44	38	868	48	[illegible]
Apr	10	506	13	511	0	1	0	1					23	353	27	360	5	46	5	49	38	906	45	[illegible]
May	10	516	10	521	1	2	1	2					23	376	25	385	5	51	5	54	39	945	41	[illegible]
Jun	10	525	10	531	1	3	1	3					23	399	24	409	6	57	6	60	40	985	41	[illegible]

(1) Includes 29 F-4B aircraft delivered to the U. S. Air Force.
(2) Includes F-4C #67 which was stricken and terminated.

MAC 231W (REV 8-1-61)

NOTE: REVISED 5 DEC 73 TO AGREE WITH PROVISIONAL ACCEPTANCE FOR LANDING GEAR MODIFICATION (F[illegible]).

PREPARED BY [illegible]

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F-4 SCHEDULED DELIVERIES VS ACTUALS

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	BB
	U.S. NAVY																UNITED KINGDOM											
	F-4B				F-4J				RF-4B				RF-4J				F-4M (R.A.F.)				F-4K (ROYAL NAVY)				SUB-TOTAL			
	SCHEDULE		ACCEPTANCE		SCHEDULE		ACCEPTANCE		SCHEDULE		ACCEPTANCE		SCHEDULE		ACCEPTANCE		SCHEDULE		ACCEPTANCE		SCHEDULE		ACCEPTANCE		SCHEDULE		ACCEPTANCE	
DATE	UNIT	CUM.	UNIT	CUM.	UNIT	CUM.	UNIT	CUM.	UNIT	CUM.	UNIT	CUM.	UNIT	CUM.	UNIT	CUM.	UNIT	CUM.	UNIT	CUM.	UNIT	CUM.	UNIT	CUM.	UNIT	CUM.	UNIT	CUM.
J 1965	10	536	10	541					1	4	1	4													11	540	11	545
A	10	546	11	552					1	5	1	5													11	551	12	557
S	10	556	10	562					1	6	1	6													11	562	11	568
O	10	566	10	572					1	7	1	7													11	573	11	579
N	10	576	4	576					1	8	1	8													11	584	5	584
D	10	586	9	585					1	9	2	10													11	595	11	595
J 1966	10	596	9	594					2	11	2	12													12	607	11	606
F	10	606	11	605					2	13	2	14													12	619	13	619
M	10	616	10	615					2	15	1	15													12	631	11	630
A	10	626	12	627					3	18	3	18													13	644	15	645
M	10	636	15	642					2	20	2	20													12	656	17	662
J	10	646	13	655	1	1	1	1	2	22	2	22									1	1	1**	1	14	670	17	679
J	10	656	9	664	0	1	0	1	2	24	2	24									0	1	0	1	12	682	11	690
A	10	666	9	673	0	1	0	1	2	26	3	27									1	2	1**	2	13	695	13	703
S	9	675	5	678	1	2	1	2	3	29	2	29									0	2	0	2	13	708	8	711
O	8	683	6	684	3	5	3	5	2	31	2	31									1	3	1	3	14	722	12	723
N	8	691	7	691	4	9	4	9	2	33	2	33									0	3	0	3	14	736	13	736
D	3	694	3	694	4	13	4	13	3	36	3	36									0	3	0	3	10	746	10	746
J 1967	2	696	2	696	4	17	4	17													0	3	0	3	6	752	6	752
F					4	21	4	21											1	1	0	3	0	3	4	756	5	757
M					5	26	6	27											0	1	1	4	1	4	6	762	7	764
A					6	32	6	33											0	1	0	4	0	4	6	768	6	770
M					10	42	10	43									1	1*	1	2	0	4	0	4	11	779	11	781
J					12	54	12	55									0	1	0	2	0	4	0	4	12	791	12	793
J					16	70	20	75									1	2	0	2	0	4	0	4	17	808	20	813
A					17	87	16	91									0	2	0	2	0	4	0	4	17	825	15	829
S					13	100	13	104									0	2	0	2	0	4	0	4	13	838	13	842
O					13	113	14	118									0	2	0	2	0	4	0	4	13	851	14	856
N					16	129	14	132									0	2	0	2	0	4	0	4	16	867	14	870
D					20	149	17	149									0	2	0	2	1	5	1	5	21	888	18	888
J 1968					22	171	20	169									0	2	0	2	0	5	0	5	22	910	20	908
F					16	187	19	188									0	2	0	2	0	5	0	5	16	926	19	927
M					22	209	22	210									0	2	0	2	0	5	0	5	22	948	22	949
A					17	226	20***	230									0	2	0	2	3	8	3	8	20	968	23	972
M					21	247	17	247									1	3	0	2	3	11	2	10	25	993	19	991
J					20	261	20	267									3	6	2	4	3	14	2	12	26	1019	24	1015

* - TM

** - YF-4K

*** Includes F-4J S/N 224 terminated prior to delivery

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F-4 SCHEDULED DELIVERIES VS ACTUALS

	CC	DD	EE	FF	GG	HH	II	JJ	KK	LL	MM	NN	OO	PP	QQ	RR	SS	TT	UU	VV
	U.S. AIR FORCE																			
	F-4C				F-4D				F-4E				RF-4C				F-4 SUMMARY TOTAL			
	SCHEDULE		ACCEPTANCE		SCHEDULE		ACCEPTANCE		SCHEDULE		ACCEPTANCE		SCHEDULE		ACCEPTANCE		SCHEDULE		ACCEPTANCE	
DATE	UNIT	CUM.	UNIT	CUM.	UNIT	CUM.	UNIT	CUM.	UNIT	CUM.	UNIT	CUM.	UNIT	CUM.	UNIT	CUM.	UNIT	CUM.	UNIT	CUM.
J 1965	23	422	22	431									7	64	6	66	41	1026	39	1042
A	23	445	24	455									9	73	9	75	43	1069	45	1087
S	23	468	23	478									9	82	10	85	43	1112	44	1131
O	23	491	23	501									10	92	10	95	44	1156	44	1175
N	23	514	16	517									11	103	8	103	45	1201	29	1204
D	22	536	17	534			1	1					12	115	9	112	45	1246	38	1242
J 1966	20	556	18	552			0	1					11	126	11	123	43	1289	40	1282
F	18	574	15	567			0	1					11	137	9	132	41	1330	37	1319
M	7	583	14	581	8	8	7	8					11	148	14	146	40	1370	46	1365
A			2	583	16	24	16	24					11	159	12	158	40	1410	45	1410
M					20	44	20	44					11	170	12	170	43	1453	49	1459
J					24	68	24	68					11	181	14	184	49	1502	55	1514
J					28	96	28	96					11	192	11	195	51	1553	50	1564
A					32	128	32	128					11	203	11	206	56	1609	56	1620
S					37	165	37	165					10	213	8	214	60	1669	53	1673
O					39	204	39	204					10	223	10	224	63	1732	61	1734
N					41	245	41	245					10	233	10	234	65	1797	64	1798
D					42	287	42	287					10	243	10	244	62	1859	62	1860
J 1967					49	336	50	337					8	251	8	252	63	1922	64	1924
F					50	386	50	387					8	259	8	260	62	1984	63	1987
M					50	436	50	437					8	267	9	269	64	2048	66	2053
A					50	486	50	487					8	275	9	278	64	2112	65	2118
M					50	536	50	537					8	283	8	286	69	2181	69	2187
J					50	586	50	587			1	1	8	291	8	294	70	2251	71	2258
J					42	628	43	630			0	1	8	299	8	302	67	2318	71	2329
A					44	672	44	674	1	1	0	1	8	307	8	310	70	2388	68	2397
S					34	706	34	708	4	5	4	5	8	315	6	316	59	2447	57	2454
O					29	735	28	736	7	12	7	12	8	323	7	323	57	2504	56	2510
N					22	757	21	757	11	23	11	23	8	331	8	331	57	2561	54	2564
D					16	773	16	773	13	36	13	36	8	339	8	339	58	2619	55	2619
J 1968					15	788	13	786	13	49	13	49	3	342	3	342	53	2672	49	2668
F					5	793	7	793	13	62	13	62	4	346	4	346	38	2710	43	2711
M									12	74	13	75	2	348	2	348	36	2746	37	2748
A									22	96	23	98	5	353	5	353	47	2793	51	2799
M									24	120	24	122	5	358	5	358	54	2847	48	2847
J									23	143	24	146	4	362	4	362	53	2900	52	2899

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DATE 10 July 1969
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SCHEDULED VS. ACTUAL DELIVERIES

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	BB
	U. S. NAVY								REPUBLIC OF IRAN								UNITED KINGDOM								SUB TOTAL			
	F-4J				RF-4B				F-4E/IR				F-4D/IR				F-4M (R.A.F.)				F-4K (ROYAL NAVY)							
	SCHEDULE		ACCEPTANCE		SCHEDULE		ACCEPTANCE		SCHEDULE		ACCEPTANCE		SCHEDULE		ACCEPTANCE		SCHEDULE		ACCEPTANCE		SCHEDULE		ACCEPTANCE		SCHEDULE		ACCEPTANCE	
DATE	UNIT	CUM	UNIT	CUM	UNIT	CUM	UNIT	CUM	UNIT	CUM	UNIT	CUM	UNIT	CUM	UNIT	CUM	UNIT	CUM	UNIT	CUM	UNIT	CUM	UNIT	CUM	UNIT	CUM	UNIT	CUM
J 1968	18	285	19	286									2	2	2	2	6	12	8	12	4	18	4	16	30	1049	33	1048
A	12	297	11	297									2	4	2	4	9	21	9	21	3	21	5	21	26	1075	27	1075
S	10	307	10	307									2	6	2	6	11	32	6	27	2	23	2	23	25	1100	20	1095
O	20	327	23	330									2	8	2	8	10	42	12	39	2	25	2	25	34	1134	39	1134
N	19	346	19	349									2	10	2	10	11	53	11	50	2	27	2	27	33	1167	34	1168
D	15	361	18	367									2	12	2	12	11	64	14	64	2	29	2	29	31	1198	36	1204
J 1969	14	375	8	375									2	14	2	14	5	69	5	69	4	33	4	33	25	1223	19	1223
F	6	381	6	381									2	16	2	16	2	71	5	74	1	34	1	34	11	1234	14	1237
M	5	386	7	388									0	16	0	16	5	76	7	81	4	38	5	39	14	1248	19	1256
A	6	392	4	392									2	18	2	18	10	86	9	90	4	42	5	44	22	1270	20	1276
M	6	398	10	402									2	20	2	20	10	96	9	99	4	46	2	46	22	1292	23	1299
J	6	404	4	406									2	22	2	22	10	106	8	107	4	50	4	50	22	1314	18	1317
J	7	411	7	413									2	24	2	24	7	113	6	113	2	52	2	52	18	1332	17	1334
A	7	418	6	419									3	27	3	27	5	118	5	118					15	1347	14	1348
S	7	425	6	425									3	30	3	30									10	1357	9	1357
O	5	430	7	432									2	32	2	32									7	1364	9	1366
N	5	435	3	435																					5	1369	3	1369
D	5	440	7	442																					5	1374	7	1376
J 1970	4	444	3	445																					4	1378	3	1379
F	4	448	4	449																					4	1382	4	1383
M	4	452	4	453																					4	1386	4	1387
A	3	455	2	455																					3	1389	2	1389
M	0	455	1	456	1	37	1	37																	1	1390	2	1391
J	2	457	3	459	1	38	1	38																	3	1393	4	1395
J	4	461	4	463	1	39	1	39																	5	1398	5	[illegible]
A	4	465	4	467	1	40	1	40																	5	1403	5	1405
S	4	469	4	471	1	41	1	41																	5	1408	5	1410
O	5	474	3	474	1	42	1	42																	6	1414	4	1414
N	5	479	5	479	2	44	2	44																	7	1421	7	1421
D	5	484	5	484	2	46	2	46																	7	1428	7	[illegible]
J 1971	4	488	4	488																					4	1432	4	[illegible]
F	4	492	4	492																					4	1436	4	[illegible]
M	4	496	4	496																					4	1440	4	1440
A	4	500	4	500					4	4	4	4													4	1448	8	[illegible]
M	3	503	3	503					4	8	4	8													7	1455	7	[illegible]
J	3	506	3	506					4	12	4	12													7	1462	7	[illegible]
J	3	509	3	509					4	16	4	16													7	1469	7	[illegible]
A	3	512	3	512					4	20	4	20													7	1475	7	[illegible]
S	3	515	3	515					4	24	4	24													7	1483	7	[illegible]
O	3	518	3	518					4	28	4	28													7	1490	7	[illegible]
N	2	520	2	520					4	32	4	32													6	1496	6	[illegible]
D	2	522	2	522																					[illegible]	[illegible]	[illegible]	[illegible]

* P.77: INCLUDES 6/6 F-4Bs AND 36 RF-4Bs FROM REPORT 3.0.

PREPARED BY [illegible]

DATE 10 July 1968
REVISED 12 May 1970
REVISED 5 Nov 1970

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SCHEDULED VS. ACTUAL DELIVERIES

	CC	DD	EE	FF	GG	HH	II	JJ	KK	LL	MM	NN	OO	PP	QQ	RR	SS	TT	UU	VV
	U. S. AIR FORCE								FEDERAL REPUBLIC OF GERMANY				JAPAN				F-4 SUMMARY			
	F-4E				RF-4C				(GY)RF-4E				(JA)F-4F				TOTAL			
	SCHEDULE		ACCEPTANCE		SCHEDULE		ACCEPTANCE		SCHEDULE		ACCEPTANCE		SCHEDULE		ACCEPTANCE		SCHEDULE		ACCEPTANCE	
DATE	UNIT	CUM	UNIT	CUM	UNIT	CUM	UNIT	CUM	UNIT	CUM	UNIT	CUM	UNIT	CUM	UNIT	CUM	UNIT	CUM	UNIT	CUM
J 1968	23	166	25	171	4	366	4	366									[illegible]	2957	62	[illegible]
A	23	189	23	194	3	369	3	369									5	3009	53	3024
S	25	214	23	217	3	372	3	372									[illegible]	3062	46	[illegible]
O	25	239	24	241	3	375	3	375									[illegible]	3124	66	[illegible]
N	26	265	26	267	3	378	3	378									[illegible]	3156	63	[illegible]
D	25	290	25	292	3	381	4	382									[illegible]	3245	65	[illegible]
J 1969	23	313	21	313	3	384	2	384									[illegible]	3296	42	[illegible]
F	10	323	11	324	2	386	2	386									[illegible]	3319	27	[illegible]
M	9	332	15	339	2	388	3	389									[illegible]	3344	37	[illegible]
A	15	347	20	359	5	393	6	395									[illegible]	3386	45	3406
M	18	365	18	377	5	398	5	400									[illegible]	3431	46	[illegible]
J	18	383	11	388	6	404	6	406									[illegible]	3477	35	[illegible]
J	18	401	18	406	7	411	5	411									[illegible]	3510	43	[illegible]
A	20	421	20	426	8	419	8	419									[illegible]	3563	42	[illegible]
S	20	441	20	446	8	427	8	427									[illegible]	3601	37	[illegible]
O	15	456	17	463	6	433	7	434										[illegible]	33	[illegible]
N	15	471	14	477	6	439	5	439									[illegible]	3655	[illegible]	[illegible]
D	15	486	19	496	6	445	6	445									[illegible]	3691	31	[illegible]
J 1970	20	506	15	511	3	448	3	448									[illegible]	3708	21	3714
F	20	526	18	529	3	451	3	451									[illegible]	3735	25	[illegible]
M	20	546	17	546	3	454	3	454									[illegible]	3762	26	[illegible]
A	18	564	23	569	3	457	3	457									[illegible]	3756	28	[illegible]
M	4	568	4	573	3	460	3	460										[illegible]	9	[illegible]
J	10	578	14	587	3	463	4	464									[illegible]	3810	22	[illegible]
J	17	595	15	602	3	466	3	467									[illegible]	3835	23	[illegible]
A	19	614	15	617	3	469	3	470									[illegible]	[illegible]	23	[illegible]
S	19	633	21	638	3	472	2	472			1	1					[illegible]	[illegible]	[illegible]	[illegible]
O	18	651	16	654	3	475	3	475			1	2					[illegible]	3916	24	[illegible]
N	14	665	14	668	3	478	3	478	3	3	1	3					[illegible]	3943	25	[illegible]
D	12	677	14	682	3	481	3	481	5	8	5	8					[illegible]	[illegible]	29	[illegible]
J 1971	14	691	14	696	2*	483	2*	483	7	15	7	15					[illegible]	[illegible]	27	[illegible]
F	14	705	17	713	2*	485	2*	485	7	22	7	22					[illegible]	4024	30	[illegible]
M	14	719	16	729	2*	487	2*	487	7	29	7	29					[illegible]	4051	29	[illegible]
A	12	731	8	737					7	36	7	36					[illegible]	4078	23	[illegible]
M	11	742	5	742					7	43	7	43					[illegible]	4103	19	[illegible]
J									7	50	7	50					[illegible]	[illegible]	14	[illegible]
J									7	57	7	57	2	2	2	2	[illegible]	[illegible]	15	[illegible]
A									7	64	7	64					[illegible]	[illegible]	14	[illegible]
S									7	71	7	71					[illegible]	[illegible]	[illegible]	[illegible]
O									7	78	7	78					[illegible]	[illegible]	14	[illegible]
N									7	85	7	85					[illegible]	[illegible]	13	[illegible]
D	2	744	2	744	4 ⓑ	4	2	2	3	88	3	88					[illegible]	[illegible]	9	[illegible]

* [illegible]

[illegible] AND 713 F-4Ds FROM REPORT 3.1. ⓑ (IR)RF-4E.

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	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	BB
	U. S. AIR FORCE								REPUBLIC OF IRAN				FEDERAL REPUBLIC OF GERMANY				FOREIGN MILITARY SALES				GREECE				F-4 SUMMARY			
	F-4E				RF-4C				(IR)F-4E				F-4F				F-4E				F-4E				TOTAL			
	SCHEDULE		ACCEPTANCE		SCHEDULE		ACCEPTANCE		SCHEDULE		ACCEPTANCE		SCHEDULE		ACCEPTANCE		SCHEDULE		ACCEPTANCE		SCHEDULE		ACCEPTANCE		SCHEDULE		ACCEPTANCE	
DATE	UNIT	CUM	UNIT	CUM	UNIT	CUM	UNIT	CUM	UNIT	CUM	UNIT	CUM	UNIT	CUM	UNIT	CUM	UNIT	CUM	UNIT	CUM	UNIT	CUM	UNIT	CUM	UNIT	CUM	UNIT	CUM
J 1972	5	749	5	749	1	488 ⓐ	1	488			2ⓑ	4													6	4205	8	[illegible]
F	5	754	5	754	1	489	1	489																	6	4211	6	421
M	5	759	5	759	1	490	1	490																	6	4217	6	[illegible]
A	5	764	5	764	1	491	1	491																	6	4223	6	[illegible]
M	5	769	5	769	1	492	1	492																	6	4229	6	[illegible]
J	5	774	5	774	1	493	1	493																	6	4235	6	[illegible]
J	5	779	5	779	1	494	1	494																	6	4241	6	4241
A	5	784	5	784	1	495	1	495																	6	4247	6	[illegible]
S	5	789	5	789	1	496	1	496																	6	4253	6	[illegible]
O	4	793	4	793	1	497	1	497																	5	4258	5	[illegible]
N	5	798	5	798	1	498	1	498																	6	4264	6	[illegible]
D	4	802	4	802	1	499	1	499																	5	4269	5	[illegible]
J 1973	5	807	5	807	1	500	1	500																	6	4275	6	[illegible]
F	5	812	5	812	1	501	1	501																	6	4281	6	[illegible]
M	5	817	6	818	1	502	1	502									1	1	1	1					7	4288	8	[illegible]
A	5	822	5	823	1	503	1	503	1	33	1	33					2	3	2	3					9	4297	9	[illegible]
M	5	827	5	828	1	504	1	504	1	34	1	34			1	1	3	6	3	6					10	4307	11	[illegible]
J	4	831	4	832	1	505	1	505	2	36	2	36	1	1	1	2	3	9	3	9					11	4318	11	[illegible]
J	2	833	1	833	1	506	1	506	5	41	5	41	1	2	1	3	2	11	2	11					11	[illegible]	10	[illegible]
A	1	834	1	834	1	507	1	507	5	46	5	46	2	4	2	5	2	13	2	13					11	4340	11	[illegible]
S	1	835	1	835	1	508	1	508	5	51	5	51	3	7	2	7	3	16	3	16					13	4353	12	[illegible]
O	1	836	2	837	1	509	1	509	5	56	5	56	5	12	6	13	2	18	2	18					14	4367	14	[illegible]
N	2	838	1	838	1	510	1	510	6	62	6	62	6	18	5	18									15	4382	13	[illegible]
D	1	839	1	839	1	511	1	511	6	68	6	68	6	24	6	24									14	4396	14	[illegible]
J 1974	4	843	4	843					5	73	5	73	6	30	6	30									15	4411	15	4411
F	4	847	4	847					4	77	4	77	6	36	6	36									14	4425	14	4425
M	4	851	4	851					2	79	2	79	6	42	6	42					4	4	4	4	16	4441	16	4441
A	2	853	2	853					2	81	2	81	6	48	6	48					4	8	4	8	14	4455	14	4455
M	2	855	2	855					3	84	3	84	6	54	6	54					4	12	4	12	15	4470	15	4470
J	2	857	2	857					3	87	3	87	6	60	6	87					4	16	4	16	15	4485	15	4485

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NOTES: ⓐ INCLUDES SIX (6) (IS)RF-4E. ⓑ (IR)RF-4E

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SCHEDULED VS. ACTUAL DELIVERIES

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	BB
	U. S. AIR FORCE				REPUBLIC OF IRAN				FEDERAL REPUBLIC OF GERMANY				GREECE				TURKEY				JAPAN				F-4 SUMMARY			
	F-4E				(IR)F-4E				F-4F				F-4E				F-4E				RF-4E				TOTAL			
	SCHEDULE		ACCEPTANCE		SCHEDULE		ACCEPTANCE		SCHEDULE		ACCEPTANCE		SCHEDULE		ACCEPTANCE		SCHEDULE		ACCEPTANCE		SCHEDULE		ACCEPTANCE		SCHEDULE		ACCEPTANCE	
DATE	UNIT	CUM	UNIT	CUM	UNIT	CUM	UNIT	CUM	UNIT	CUM	UNIT	CUM	UNIT	CUM	UNIT	CUM	UNIT	CUM	UNIT	CUM	UNIT	CUM	UNIT	CUM	UNIT	CUM	UNIT	CUM
J 1974	2	859	2	859	2	89	2	89	6	66	6	66	4	20	4	20									14	4499	14	4499
A	2	861	2	861	2	91	2	91	6	72	6	72	6	26	6	26	2	2	2	2					18	4517	18	4517
S	1	862	1	862	3	94	3	94	6	78	6	78	8	34	8	34	2	4	2	4					20	4537	20	4537
O	1	863	1	863	3	97	3	97	6	84	7	85	2	36	2	36	2	6	2	6					14	4551	15	4552
N	0	863	0	863	4	101	4	101	6	90	8	93					2	8	2	8	2	2	2	2	14	4565	16	4568
D	1	864	1	864	4	105	4	105	6	96	3	96					4	12	4	12	3	5	3	5	18	4583	15	4583
J 1975	1	865	1	865	4	109	4	109	6	102	8	104					4	16	4	16	3	8	3	8	18	4601	20	4603
F	1	866	1	866	3	112	3	112	6	108	4	108					4	20	4	20	1	9	1	9	15	4616	13	4616
M	1	867	1	867	4	116	4	116	6	114	8	116					4	24	4	24	2	11	2	11	17	4633	19	4635
A	3	870	3	870	2	118	2	118	6	120	4	120					3	27	3	27	2	13	2	13	16	4649	14	4649
M	0	870	0	870	3	121	3	121	1	121	1	121					1	28	1	28	1	14	1	14	6	4655	6	4655
J	1	871	1	871	1	122	2	123	2	123	3	124					1	29	1	29					5	4660	7	4662
J	2	873	2	873	2	124	2	125	1	124	3	127					2	31	2	31					7	4667	9	4671
A	4	877	4	877	2	126	2	127	3	127	4	131					2	33	3	34					11	4678	13	4684
S	4	881	5	882	4	130	3	130	7	134	3	134					3	36	2	36					18	4696	13	4697
O	5	886	6	888	3	133	5	135	6	140	6	140					4	40	4	40					18	4714	21	4718
N	6	892	4	892	4	137	4	139	4	144	7	147													14	4728	15	4733
D	6	898	6	898	3	140	2	141	5	149	4	151													14	4742	12	4745
																	FOREIGN MILITARY SALES				REPUBLIC OF IRAN							
																	F-4E *				RF-4E							
J 1976	8	906	9	907	1	141	0	141	7	156	5	156													16	4758	14	4759
F	9	915	10	917					7	163	7	163													16	4774	17	4776
M	10	925	10	927					7	170	12	175													17	4791	22	4798
A	9	934	10	937					5	175															14	4805	10	4808
M	11	945	10	947									1	37	1	37	2	20	2	20			1	5	14	4819	14	4822
J	13	958	13	960									1	38	1	38	2	22	2	22			0	5	16	4835	16	4838
J	12	970	12	972													1	23	1	23			0	5	13	4848	13	4851
A	8	978	10	982													3	26	3	26	2	6	2	7	13	4861	15	4866
S	6	984	3	985													5	31	6	32	2	8	1	8	13	4874	10	4876
O	4	988	3	988													7	38	6	38	2	10	2	10	13	4887	11	4887
N	3	991	3	991	4	145	4	145									4	42	4	42	2	12	2	12	13	4900	13	4900
D	2	993	2	993	6	151	6	151													4	16	4	16	12	4912	12	4912

* PEACE ICON
** Ten (10) F-4Es Identical to, and Numbered Sequentially with USAF F-4E Aircraft

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MODEL PHANTOM II

SCHEDULED VS. ACTUAL DELIVERIES

	A	B	C	D	E	F	G	H	I	J	K	L
	REPUBLIC OF IRAN (IR) F-4E				FEDERAL REPUBLIC OF GERMANY (GY) F-4E				REPUBLIC OF KOREA (KS) F-4E			
	SCHEDULE		ACCEPTANCE		SCHEDULE		ACCEPTANCE		SCHEDULE		ACCEPTANCE	
	UNIT	CUM	UNIT	CUM	UNIT	CUM	UNIT	CUM	UNIT	CUM	UNIT	CUM
J - 1977	4	155	4	155								
F	4	159	4	159								
M	4	163	4	163								
A	4	167	4	167								
M	2	169	2	169	2	995**	2	995				
J	3	172	3	172	3	998	3	998				
J	3	175	3	175	3	1001	3	1001				
A	2	177	2	177	2	1003	2	1003				
S									4	4	4	4
O									4	8	6	10
N									4	12	4	14
D									4	16	2	16
J - 1978									3	19	3	19
F												
M												
A												
M												
J												
J	GREECE (GR) RF-4E				TURKEY (TK) RF-4E							
A												
S												
O	1	1	1	1	1	1	1	1				
N	1	2	1	2	2	3	2	3				
D	1	3	1	3	2	5	1	4				
J - 1979	1	4	0	3	2	7	1	5	2	21	0	19
F	2	6	1	4	1	8	1	6	2	23	2	21
M	2	8	2	5			0	6	3	26	5	26
A			0	6			2	8	3	29	3	29
M			1	7					3	32	3	32
J			1	8					3	35	2	34
J									2	37	1	35
A											1	36
S											0	36
O											1	37
N												
D												

	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	BB
	GREECE (GR) F-4E				TURKEY (TK) F-4E				FOREIGN MILITARY SALES (FMS) RF-4E*				SUB-TOTAL			
	SCHEDULE		ACCEPTANCE		SCHEDULE		ACCEPTANCE		SCHEDULE		ACCEPTANCE		SCHEDULE		ACCEPTANCE	
	UNIT	CUM	UNIT	CUM	UNIT	CUM	UNIT	CUM	UNIT	CUM	UNIT	CUM	UNIT	CUM	UNIT	CUM
J - 1977													4	4916	4	4916
F													4	4920	4	[illegible]
M									2	8	2	8	6	4926	6	[illegible]
A									2	10	2	10	6	4932	6	[illegible]
M									2	12	2	12	6	4938	6	[illegible]
J													6	4944	6	[illegible]
J													6	4950	6	[illegible]
A													4	4954	4	[illegible]
S													4	4958	4	[illegible]
O													4	4962	6	[illegible]
N													4	4966	4	[illegible]
D													4	4970	2	[illegible]
J - 1978					1	41	1	41					4	4974	4	4974
F					***0	41	0	41					0	4974	0	4974
M					***2	43	4	45					2	4976	4	4975
A	2	40	2	40	***7	50	5	50					9	4985	7	[illegible]
M	2	42	2	42	***4	54	6	56					6	4991	8	[illegible]
J	2	44	2	44	4	58	4	60					6	4997	6	[illegible]
J	2	46	2	46	4	62	3	63					6	5003	5	[illegible]
A	2	48	2	48	3	65	3	66					5	5008	5	[illegible]
S	2	50	2	50	3	68	2	68					5	5013	4	[illegible]
O	2	52	2	52	3	71	3	71					7	5020	7	[illegible]
N	2	54	2	54	1	72	1	72					6	5026	6	[illegible]
D	2	56	2	56									5	5031	4	[illegible]
J - 1979													5	5036	1	[illegible]
F													5	5041	4	[illegible]
M													5	5046	7	[illegible]
A													3	5049	5	[illegible]
M													3	5052	4	[illegible]
J													3	5055	1	[illegible]
J													2	5057	1	5055
A															1	5056
S															0	5056
O															1	5057
N																
D																

* PEACE ECHO
** TIN (GY) F-4Es Identical To and Numbered Sequentially with USAF F-4E Aircraft
*** (TK) F-4E SCHEDULE REVISED DUE TO LATE DELIVERIES ON LITTON INERTIAL NAVIGATION SETS (INS)
\# JAN AND FEB 1979 DELIVERIES ARE BEHIND SCHEDULE DUE TO INCLEMENT WEATHER

Prepared by D.013,FM

APPENDIX B

SELECTED VENDORS OF LONG LEAD TIME ITEMS

The following tables provide an alphabetical listing of some of the firms which manufacture long lead items for the four aircraft in this study. The list is not complete, as time did not permit an exhaustive pursuit of all the data needed; however, the list does provide a feel for the extent to which critical items are available from only a few sources.

COMPANY	ITEM	F-14	F-15	F-16	F/A-18
ABEX Corp	Elec Gen	X	X		
Oxnard, Ca	Hyd Pump		X		X
Airesearch Mfg	Cabin Press Reg Valve	X	X		X
Torrance, Ca	Cabin Safety Valve		X		X
Alcoa	Alum & Titanium	X	X		
Cleveland, Oh	Forgings				
Bendix	Wheel & Brake Assy	X			X
S. Bend, In					
Canadair, LTD	Machined Parts		X		
Montreal, Que					
Clark-Aiken Co	Machined Parts		X		
Arlington, Tx					
Clark&Wheeler	Machining				X
Cerritos, Ca					
Cleveland Pnuem	Main&Nose Lndg Gear		X		X
Cleveland, Oh	Machined Parts		X		
Cont Forge Co	Forgings				X
Duke Mfg	Machined Parts		X		
Tulsa, Ok					
Eldec Corp	Transformer Rect		X		X
Lynnwood, Wa					
Ellanef Mfg Corp	Machined Parts	X	X		
Corona, NY					

COMPANY	ITEM	F-14	F-15	F-16	F/A-18
Garrett Phoenix, Az	Jet Fuel Starter		X		
GE West Lynn, Ma	Engine				X F404
GE Burlington, Vt	20mm Gun	X	X	X	X
Goodyear Akron, Oh	Gear Wheels&Brakes	X	X		
Honeywell Inc St Louis Park, Mn	Antenna&Avionics	X	X		X
Hughes Aircraft Culver City, Ca	Radar Wpns Cont Sys	X	X		X
Hydro-Mill Chatswoth, Ca	Machined Parts		X		
J.C. Carter Costa Mesa, Ca	Fuel Valves & Couplings		X		X
Kelsey Hayes Co Lake Orion, Mi	Hyd & Pneu Valves	X	X		X
Ladish Co Cudahy, Wi	Steel Forgings	X	X		
Ladish Pacific Los Angeles, Ca	Titanium Forgings		X		X
Litton Woodland Hills, Ca	Inert Nav Sys	X	X		X
Martin Marietta Torrance, Ca	Forgings		X		
Midland-Ross Corp Plymouth, Ct	Hyd Valves	X			X

COMPANY	ITEM	F-14	F-15	F-16	F/A-18
Midland-Ross Corp Columbus, Oh	ECS Components	X			X
Murdock Mach&Eng Irving, Tx	Machined Parts		X		
National Waterlift Kalamazoo, Mi	Hyd Actuators	X	X	X	X
Parker-Hannifin Irvine, Tx	Fuel, Air, Hyd Valves & Sys Components	X	X	X	X
Pneudraulics Inc Montclair, Ca	Valves	X			X
Pratt & Whitney East Hartford, Ct	Engines	X TF30	X F100	X F100	
Precision Mach Inc Wellington, Ks	Machining				X
RMI Co Niles, Oh	Wing Skins & Stiffeners	X	X		X
Rckwell, Collins Cedar Rapids, Ia	TACAN, VOR/ILS	X	X	X	X
SCI Sys Inc Huntsville, Al	Communications Equip		X	X	X
Sargent Ind Burbank, Ca	Bearings	X	X		
Simmonds Precision Vergennes, Vt	Fuel Qty Gaging Sys		X		X
Sperry Phoenix, Az	Avionics	X	X		X
Sundstrand Corp Rockford, Il	Air&Fuel Valves,Pumps	X	X		X
Swedlow Inc Garden Grove, Ca	Canopy, Windshield	X	X		X

COMPANY	ITEM	F-14	F-15	F-16	F/A-18
Textron Inc Valencia, Ca	Hyd Sys Parts	X	X		X
Titanium Met Corp Toronto, Oh	Titanium Skin	X	X		X
Tool Craft Mach St Charles, Mo	Machining				X
Triangle Mach Hurst, Tx	Machined Parts		X		X
TRW Inc Cleveland, Oh	Fuel Boost Pump		X		
United A/C Prod Dayton, Oh	Fuel/Oil Heat Exch		X	X	X
Universal Prod Arlington, Tx	Machined Parts		X		
Whittaker Cont N Hollywood, Ca	Fuel,Air,Hyd Valves	X		X	X
Wilson Spec Mfg Fort Worth, Tx	Machining				X
Wyman Gordon Co Worchester, Ma	Forgings	X	X		X

APPENDIX C

THE DEFENSE ECONOMIC IMPACT MODELING SYSTEM

This appendix contains an explanation of the Defense Economic Impact Modeling System. The explanation comes from a draft paper prepared by Dr. David Blond, and has been edited for the purposes of this paper. Also included in this appendix are extracts taken from the output of the modeling system. These extracts have been marked to indicate the areas of interest for this study.

ASSESSING THE IMPACT OF NATIONAL DEFENSE EXPENDITURES ON THE UNITED STATES ECONOMY: The Defense Economic Impact Modeling System (DIEMS)*

A Short History of the Project

The Defense Economic Impact Modeling System (DEIMS) is a direct outgrowth of analysis performed by the Office of the Assistant Secretary of Defense, Program Analysis and Evaluation, on the effects of higher levels of defense expenditures on the United States economy. Previous efforts to measure these effects have relied upon large scale macroeconomic models. It became clear from these experiments that these models, while adequate for identifying large macroeconomic impacts, do not provide sufficient industry detail to permit an examination of interindustry flows so potential industrial bottleneck areas can be identified. Moreover, the lack of an up-to-date share matrix with which to distribute projected levels of defense outlays meant that effects on key supplying industries highlighted in these models, might not be valid since the spending by industry reflected the defense final demand pattern apparent in 1967, not in 1980.

Coincidental with the preparation of these simulations, an analysis was conducted on the availability of primary heat treated aluminum plate for non-aircraft defense programs. Shortages had led to a lengthened lead-time in supply of these types of materials and prices had increased dramatically. It became clear that with the limits on industrial capacity and assuming larger than usual increases in final demand, further bottlenecks and increasing pressure on prices of intermediate goods and labor, could be expected. To avoid production bottlenecks in the private sector and to limit excessive price increases caused by shortages of industrial capacity, additional facilities would have to be built by industry. The aluminum industry was, however, reluctant to commit additional investment funds to new facilities without Department of Defense assurance that there would be a continuing defense need for the output of these modernized and enlarged facilities. When this question was under discussion, no valid methodology was available for readily translating the Department's demands, arrayed by budget categories, into DoD requirements for aluminum or for any other industrial raw material. Today such a methodology exists and this type of information can be made available to industry, as well as used for inhouse analysis.

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* This draft, dated December 4, 1980, was prepared by Dr. David Blond, Senior Economist - OASD(Program Analysis and Evaluation).

The Five Year Defense Plan (FYDP) As A Starting Point

The standard source of information on what the Department of Defense plans to spend in the future is the Five Year Defense Plan (the FYDP). The distribution of this document is limited to a relatively small group of DoD offices. Even if the FYDP were released to contractors, it would not provide the type of economic information that industry needs to plan future productive capacity. The format for the FYDP that is of some value to industry is the translation of the five year plan from TOA (total obligation authority, planning type information) to defense outlays by year (national income accounts type data). The outlays version of the current five year plan (including outlays associated with past authorizations) is the only acceptable document for use in conducting an analysis of the possible demand induced effects of a particular defense program.

Even this document which contains considerable program detail, would be of limited use to industry planners. A methodology is needed to translate outlays by appropriation categories into final demand by commodity. A defense industrial share matrix has been developed to allow this translation to be made. The rows of this matrix represent the individual industries producing the detailed commodities whose combined output equals U.S gross national product. The columns in the matrix are the 10 primary budget categories (each column sums to unity). This matrix constitutes an approximation of expenditures by commodity showing the pattern apparent in 1980 with some information garnered from the FYDP back-up and related to future programs. For example, the distribution of spending by types of procurement (Air Force aircraft, Navy ships) was calculated based on TOA for the full program and not the TOA expected only for the budget year -- thus it represents some future pattern of spending, not simply the pattern for the budget year.

When the defense output to commodity matrix is used in conjunction with projected outlays by appropriation categories (constant dollar weights), the result is a single defense final demand vector presenting the expected expenditures in each industrial commodity category for a single year. This is translated into a share vector by dividing each row by the total outlays for that year.

By applying projected yearly outlays (in constant $s) to the defense output to commodity sector, an estimate of the appropriate pattern representing defense final demands by industrial commodity for any future year may be developed. The weights change over time so industry shares also change. This share vector is the starting point for our analysis of the inter-industry pattern of DoD programs. It is only the beginning step in our translation of classified, in-house planning information, into more useful, economically-oriented outputs by commodity that is to be made available to the American business community in the near future.

The information is presented with respect to derived demand from DoD purchases and that resulting from non-DoD purchases. DoD derived final demand represents direct purchases from suppliers of goods and services. DoD derived plus intermediate demand is the sum of all purchases plus all intermediate sales associated with these direct purchases (first order effects, i.e., sales of aircraft engine manufacturers to aircraft assemblers). DoD derived gross output measures the full pass through effects resulting from DoD final demand purchases.

To illustrate the gross output concept we can trace some of the transactions (using relationships included in the 1972 input-output table) associated with a $1 million direct DoD purchase of aircraft. Tracing through we see that to produce the aircraft, the aircraft industry has to purchase $8,222 from the screw machine and products stamping industry. It in turn must purchase $755 from the primary iron and steel manufacturing industry. That industry, in order to produce the steel for the preceding order, needs to buy $9.60 from the maintenance and repair construction industry. The maintenance and repair industry then purchase $.30 worth of fuel from the petroleum refining and related industry. Gross output is the summation of all of these interrelated transactions summed across the full defense program (or the full non-defense program). The gross output for any industry in an input-output model is determined by solving the model for a pattern and amount of final demand, for example, that defined by the DoD specific mix of requirements.

Each commodity summary table presents results obtained from the macroeconomic model showing the effect on industry sales from non-defense derived final demand (other government, private consumption, investment, and exports) as well as defense demand. Also shown is an estimate of the price index for each commodity group that may result from these transactions, and the likely employment generated. An estimate of the amount of this gross output that may have to be imported from abroad for the defense and non-defense portions of total final demand is also presented.*

The next phase of the analysis is to be used primarily for in-house studies. Gross flows from defense derived demand are used to measure employment effects. These employment effects can be translated for each industry into employment by skill level. A separate model developed by the Bureau of Labor Statistics and available as part of the Defense Economic Impact Modeling System can be used to distribute employment by industry into more than 200 separate employment skill categories. This information should prove valuable for future government work in this area. A summary report format with skills divided into 36 aggregate categories is available

The second additional capability uses total gross output associated with defense final demand. derived from the input-output model, and relates it to physical quantities of strategic materials likely to be consumed (by the industry making the sale). Thus, aluminum, titanium, or cobalt demand, measured in pounds, can be determined roughly for any sized defense program

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* This last estimate measures only the imports using the average import relationship included in the input-output model itself and does not reflect any special information available to the Department of Defense.

The Defense Economic Impact Modeling System

The Defense Economic Impact Modeling System includes five separate, but interrelated, computerized models (the Defense Final Demand Translator, the DRI Interindustry and Employment Model, the Skill-Area Distribution Model, the Strategic Materials Requirements Model, and the Interservice Male High School Graduate Recruitment Model). The first model, takes constant dollar outlay information and breaks the data into 403 categories of final demand purchases appropriate for the Data Resource's Interindustry and Employment Model (400 commodity sectors plus government wages and salaries).* This output is then turned into a single share vector by dividing through by the total spending projected for that period. A unique defense share vector is thus produced for each year for which outlay projections are available (presently 1980-86).

The second modeling system takes the yearly defense share vector and integrates it into the structure of the Data Resources Macroeconomic and Interindustry Forecasting Model System (see Chart 1). Only the share vector is released to the public so that the actual forecast for DoD outlays to be spent in each of the five planning years remains classified. By applying outlay totals for defense within the context of the macroeconomic model, and by feeding these results directly into the input-output model, estimates for industry gross output resulting from a specific defense program are derived. The DRI Interindustry model is a dynamic input-output model with its coefficients adjusting over time as material input requirements change. The DRI model is commodity based, rather than industry based,** so it conforms to the commodity specific final demand breakdown by the DoD FYDP translator model.

Results are displayed in final set of summary tables (see Table 1)--one table for each included commodity group (there are 400 commodities identified in the DRI model In each summary table is presented projections for the period 1980-1986 for the following variables:

- o Final demand in 72$ billions (direct demand);
- o Direct plus intermediate demand in 72$ billions (direct plus first order indirect)
- o Gross output in 72$ billions (direct plus all indirect);
- o Employment in thousands
- o Prices (1972s = 1.0)
- o Imports in 72$ billions

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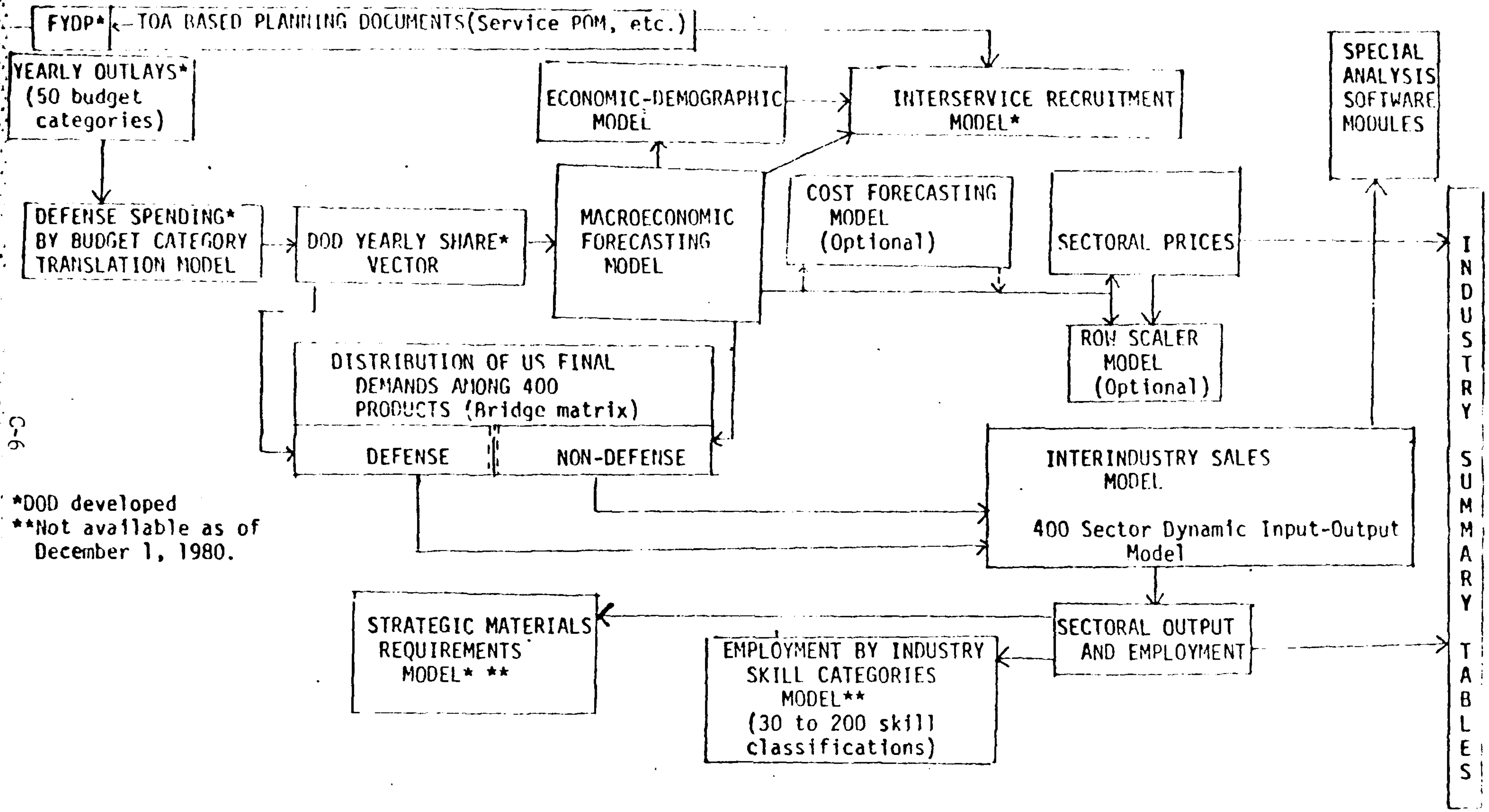
* The share matrix is in terms of 1972 prices for defense purchases with the price adjustment carried out using specific BEA deflators. The outlays used as weights are in 1972 dollar equivalents (deflated using OSD developed price deflators. The resultant share vector is thus priced in 1972 $s, the base year used in the DRI Interindustry Model.

** The standard BEA table is industry based with each reporting firm classified in the industry associated with the major product it markets. A commodity based system is better as most industrial concerns produce many different products.

CHART 1

DEFENSE ECONOMIC IMPACT MODELING SYSTEM: INTERACTION WITH DRI MODELS AND SOFTWEAR



*DOD developed
**Not available as of December 1, 1980.

TABLE 1

SAMPLE TABLE FOR AN INDUSTRY GROUP'S OUTPUT

300 Electronic Computing Equipment SIC 3573		ACTUAL		FORECAST						GROWTH CAR
		1979	1980	1981	1982	1983	1984	1985	1986	79-86
Output - 1972 Dollars										
Defense										
Direct	- level	-	-	-	-	-	-	-	-	NC
	- growth	-	-	-	-	-	-	-	-	NC
	- share	-	-	-	-	-	-	-	-	NC
Direct & 1st order indirect	- level	-	-	-	-	-	-	-	-	NC
	- growth	-	-	-	-	-	-	-	-	NC
	- share	-	-	-	-	-	-	-	-	NC
Direct & all indirect	- level	-	-	-	-	-	-	-	-	NC
	- growth	-	-	-	-	-	-	-	-	NC
	- share	-	-	-	-	-	-	-	-	NC
Nondefense										
Direct & 1st order indirect	- level	-	-	-	-	-	-	-	-	NC
	- growth	-	-	-	-	-	-	-	-	NC
	- share	-	-	-	-	-	-	-	-	NC
Direct & all indirect	- level	-	-	-	-	-	-	-	-	NC
	- growth	-	-	-	-	-	-	-	-	NC
	- share	-	-	-	-	-	-	-	-	NC
Total	- level	-	-	-	-	-	-	-	-	NC
	- growth	-	-	-	-	-	-	-	-	NC
Employment - thousands										
Defense - direct & all indirect	- level	-	-	-	-	-	-	-	-	NC
	- growth	-	-	-	-	-	-	-	-	NC
Total	- level	-	-	-	-	-	-	-	-	NC
	- growth	-	-	-	-	-	-	-	-	NC
Prices										
Index	- level	-	-	-	-	-	-	-	-	NC
	- growth	-	-	-	-	-	-	-	-	NC
Imports - 1972 dollars										
Defense - direct & all indirect	- level	-	-	-	-	-	-	-	-	NC
Nondefense - direct & all indirect	- level	-	-	-	-	-	-	-	-	NC
Defense import share domestic use	- ratio	-	-	-	-	-	-	-	-	NC

In Summary, the purpose of this system as to prepare industry

The primary purpose of this system is to provide better quality information to industry as a prerequisite for asking industry to respond to our requests for additional industrial capacity. The aim is to focus attention directly on areas of potential bottlenecks. Through information feedbacks from industry we expect the Department of Defense can help industry to overcome problems due to overtaxed production facilities before they occur. Information derived from the skill matrix breakdown of defense final demand may be used in-house as well as made available to other Federal and State governmental users. For example, the Departments of Education and Labor may find these estimates useful for their work. It is our hope that job training and basic educational programs can be adjusted to concentrate in areas of the greatest critical need.

In short, the intent of the Defense Economic Impact Modeling System is to provide the Office of the Secretary of Defense with a highly automated capability to assess how a pattern and amount of expenditure on national defense will affect industry output, employment, skill requirements, prices, and the adequacy of raw material stocks. By providing of this information on likely long-term impacts of actual or contemplated budgeting decisions, we may help American firms meet our needs without disruption of private sector product flows. The effectiveness of this new system of information depends upon the reactions of industry to the data we provide. The system described is therefore but a first step in the process of establishing a meaningful dialogue between government and industry on DoD plans and proposed industry responses.

DEFENSE ECONOMIC IMPACT MODELING SYSTEM
MAJOR INDUSTRIAL SUPPLIERS TO DEPARTMENT OF DEFENSE
RANKED BY DEFENSE SHARE OF PRODUCTION
(MILLIONS OF 1980 DOLLARS EXCEPT AS NOTED)

RANK		INDUSTRY NAME	DEFENSE SHARE(%)			DEFENSE FINAL DEMAND			DEFENSE PRODUCTION			NONDEFENSE PRODUCTION
			1981	1987	%GROWTH 81 TO 87	1981	1987	%GROWTH 81 TO 87	1981	1987	%GROWTH 81 TO 87	%GROWTH 81 TO 87
1	40.	NEW MILITARY FAC.	100.00	100.00	0.00	644	1,231	11.39	644	1,231	11.39	NC
2	46.	AMMUNITION,EX SMALL ARMS,NEC	82.31	90.58	1.61	1,824	4,043	14.19	1,945	4,296	14.12	1.13
3	50.	OTHER ORDNANCE & ACCESSORIES	79.60	87.40	1.57	1,431	2,775	11.67	1,433	2,782	11.69	1.47
4	47.	TANKS & TANK COMPONENT	72.11	84.51	2.68	569	1,235	13.78	755	1,654	13.97	0.64
5	338.	SHIPBUILDING & REPAIRING	56.33	63.30	1.96	6,726	10,272	7.31	6,320	9,690	7.38	2.30
6	49.	SMALL ARMS AMMUNITION	52.53	69.52	4.78	377	886	15.32	375	888	15.46	2.34
7	45.	COMPLETE GUIDED MISSILES	48.73	61.94	4.08	3,610	6,944	11.52	3,665	7,082	11.60	2.03
8	322.	RADIO&TV COMMUNICATION EQUIP	45.32	59.17	4.55	11,518	23,789	12.85	12,705	26,503	13.04	2.98
9	336.	AIRCRAFT ENGINES&ENGINE PARTS	42.72	59.57	5.70	3,493	6,911	12.05	4,718	9,142	11.66	0.32
10	337.	AIRCRAFT PARTS & EQUIP,NEC	39.23	55.98	6.10	2,980	5,553	10.93	4,743	8,748	10.74	1.09
11	167.	EXPLOSIVES	36.83	48.49	4.69	297	637	13.57	372	802	13.68	4.95
12	335.	AIRCRAFT	29.60	45.13	7.29	7,050	15,991	14.63	6,753	15,497	14.85	2.69
13	315.	ENGINEERING & SCIENTIFIC INST	29.50	37.57	4.11	1,030	1,908	10.83	1,104	2,073	11.07	4.54
14	346.	MEASURING & CONTROL INSTR	27.86	35.51	4.12	3,076	5,996	11.76	3,178	6,211	11.81	5.40
15	235.	NONFER FORGINGS	23.13	33.53	6.38	0	0	NC	187	352	11.09	1.93
16	325.	ELECTRONIC COMPONENTS,NEC	20.02	27.78	5.61	174	342	11.88	2,654	6,263	15.39	7.42
17	270.	INDUST TRUCKS & TRACTORS	15.98	23.87	6.92	509	1,107	13.83	487	1,072	14.05	4.33
18	324.	SEMICONDUCTORS	14.70	21.01	6.14	98	195	12.16	1,422	4,161	19.59	11.24
19	260.	STEAM ENGINES & TURBINES	14.54	22.35	7.43	339	649	11.46	386	716	10.84	1.54
20	253.	PLATING & POLISHING	14.40	20.90	6.40	2	3	14.38	391	823	13.20	5.00
21	234.	NONFER CASTINGS,NEC	14.18	20.11	6.00	0	0	NC	104	176	9.19	1.79
22	351.	OPTICAL INSTRS & LENSES	12.37	15.18	3.47	266	501	11.16	260	525	12.43	8.08
23	221.	PRIMARY METAL PROD,NEC	12.24	18.54	7.17	18	29	8.52	145	292	12.44	3.62
24	291.	ELECTRONIC COMPUTING EQUIP	10.47	13.46	4.28	2,171	4,570	13.21	2,820	6,852	15.95	10.56
25	232.	ALUMINUM CASTINGS	10.02	14.99	6.95	1	1	12.43	349	682	11.83	3.58
26	323.	ELECTRON TUBES	9.99	16.16	8.35	74	180	15.99	210	436	12.95	3.01
27	191.	FOOTWEAR CUT STOCK	9.54	12.77	4.98	47	69	6.54	49	73	6.67	0.99
28	48.	SMALL ARMS	9.53	16.72	9.82	92	219	15.46	86	213	16.42	4.55
29	212.	NONMETALLIC MINERAL PROD,NEC	9.52	14.10	6.77	10	16	8.82	53	107	12.35	4.32
30	230.	NONFER ROLLING & DRAWING,NEC	9.31	14.32	7.44	44	73	8.91	546	1,184	13.78	4.90
31	301.	ELECTRIC MEASURING INSTR	9.16	13.41	6.55	122	245	12.26	415	873	13.20	5.40
32	308.	ELEC IND APPARATUS,NEC	8.83	10.91	3.59	93	139	6.87	113	188	8.91	4.74
33	271.	MACH TOOLS,METAL CUTTING	8.79	14.06	8.14	606	1,368	14.52	635	1,432	14.50	4.83
34	220.	METAL HEAT TREATING	8.72	13.15	7.09	12	20	9.02	136	258	11.33	3.10
35	233.	BRASS,BRONZE,& COPPER CASTINGS	8.67	12.33	6.04	8	14	8.23	75	144	11.37	4.31
36	290.	MISC MACHINERY	8.65	13.16	7.26	38	81	13.63	1,339	2,659	12.11	3.65
37	247.	SCREW MACHINE PRODUCTS	8.44	12.49	6.75	51	81	8.18	543	945	9.68	1.97
38	227.	SECONDARY NONFER METALS	7.75	12.11	7.73	0	0	NC	25	48	11.42	2.59
39	273.	SPECIAL DIES,TOOLS,ACCESSORIES	7.61	11.42	6.99	193	426	14.05	828	1,652	12.21	4.15

RANK		INDUSTRY NAME	DEFENSE SHARE(%) 1981	1987	%GROWTH 81 TO 87	DE[illegible] FINAL DEMAND 1981	1987	%GROWTH 81 TO 87	DEFENSE PRODUCTION 1981	1987	%GROWTH 81 TO 87	NONDEFENSE PRODUCTION %GROWTH 81 TO 87
40	125	WOODEN CONTAINERS	7.60	12.55	8.73	1	2	13.51	52	104	12.21	2.25
41	254	METAL COATING & ALLIED SERV	7.52	11.66	7.57	1	2	14.52	149	313	13.13	4.37
42	350	WATCHES & CLOCKS	7.52	10.35	5.46	4	65	6.76	146	239	8.49	2.34
43	229.	ALUMINUM ROLLING & DRAWING	7.43	11.60	7.70	0	1	12.30	834	1,761	13.26	4.36
44	286	INDUSTRIAL PATTERNS	7.36	10.72	6.47	3	4	4.85	32	54	9.36	2.08
45	219	IRON & STEEL FORGINGS	7.18	[illegible]	7.05	0	0	NC	430	805	11.01	3.01
46	15	COPPER ORE MINING	7.17	[illegible]	7.35	0	0	NC	192	372	11.65	3.28
47	225.	PRIMARY ALUMINUM	7.02	10.91	7.63	9	14	8.37	846	1,699	12.32	3.61
48	276	METALWORKING MACH,NEC	6.82	10.45	7.37	[illegible]	181	14.82	94	211	14.46	5.90
49	348	SURGICAL APPLIANCES & SUPPLIES	6.80	8.34	3.47	[illegible]	363	7.98	287	483	9.07	5.12
50	228	COPPER ROLLING & DRAWING	6.76	10.56	7.72	[illegible]	1	12.30	376	742	11.98	3.24
51	224	PRIMARY ZINC	6.61	9.39	7.12	7	14	12.58	51	88	9.52	1.61
52	222	PRIMARY COPPER	6.55	9.88	7.10	60	88	6.56	448	845	11.16	3.17
53	366.	WATER TRANS & RELATED SERV	6.39	7.60	2.93	1,0[illegible]4	1,389	4.70	1,484	1,958	4.72	1.51
54	318	WIRING DEVICES	6.32	10.01	7.96	5	13	16.39	316	652	12.85	3.84
55	287	POWER TRANSMISSION EQUIP	6.30	9.21	6.55	8	68	10.06	272	477	9.78	2.49
56	223	PRIMARY LEAD	6.28	9.77	7.64	[illegible]	2	-14.60	64	115	10.26	1.79
57	226	PRIMARY NONFER METALS,NEC	6.23	9.61	7.40	1	-2	-19.95	273	534	11.91	3.39
58	284	BALL & ROLLER BEARINGS	6.20	9.47	7.31	37	76	12.81	229	420	10.68	2.54
59	305.	INDUSTRIAL CONTROLS	6.08	9.41	7.56	25	62	16.38	232	478	12.81	4.26
60	209	MINERALS, GROUND OR TREATED	6.04	7.34	3.30	[illegible]7	113	6.54	122	195	8.12	4.42
61	259.	FAB METAL PROD,NEC	5.81	8.49	6.53	[illegible]	63	8.14	358	687	11.46	4.12
62	214.	ELECTROMETALLURGICAL PROD	5.78	8.70	7.04	0	0	11.85	77	131	9.18	1.46
63	161.	INORGANIC & ORGANIC CHEM	5.67	8.02	5.96	2,201	3,597	8.53	4,402	7,753	9.89	3.28
64	213.	BLAST FURNACES & STEEL MILLS	5.61	8.33	6.81	174	325	11.00	3,593	6,316	9.86	2.35
65	382.	HOTELS & LODGING PLACES	5.58	8.04	6.29	763	1,156	7.16	1,186	1,982	8.93	2.04
66	14.	IRON & FERROALLOY ORES MINING	5.54	8.20	6.76	-4	-8	-12.84	189	303	8.15	0.82
67	16.	METAL ORES MINING,NEC	5.47	8.47	7.58	0	0	NC	155	252	8.46	0.28
68	217.	STEEL PIPE & TUBES	5.44	8.49	7.68	0	0	NC	6	10	10.64	2.19
69	272	MACH TOOLS,METAL FORMING	5.43	9.01	8.80	106	255	15.65	126	289	14.89	4.92
70	307.	CARBON & GRAPHITE PROD	5.34	8.76	8.59	4	9	16.40	49	95	11.79	2.32
71	304.	MOTORS & GENERATORS	5.12	8.20	8.19	138	303	14.03	416	803	11.57	2.56
72	155	MANIFOLD BUSINESS FORMS	5.05	7.79	7.51	53	91	9.26	246	475	11.56	3.27
73	111	FAB. TEXTILE PRODUCTS,NEC	5.01	5.94	2.89	184	233	3.95	258	372	6.31	3.16
74	240.	HEATING EQUIP, EX ELEC	4.99	7.32	6.57	58	100	9.49	88	155	9.81	2.61
75	122.	WOOD PALLETS & SKIDS	4.96	7.97	8.25	12	28	15.87	46	92	12.33	3.21
76	369	TRANSPORTATION SERV,NEC	4.93	6.45	4.56	100	156	7.65	185	288	7.61	2.65
77	239.	PLUMBING FITTINGS & TRIM	4.91	6.08	3.62	56	82	6.54	77	119	7.31	3.35
78	306	WELDING APPARATUS	4.89	6.31	4.35	5	11	15.86	76	131	9.66	4.82
79	128.	WOOD TV & RADIO CABINETS	4.84	7.48	7.53	0	0	NC	24	51	13.58	5.13
80	367.	AIR CARRIERS & RELATED SERV	4.75	6.34	4.93	1,534	2,186	6.08	2,324	3,816	8.62	3.23
81	216.	COLD FINISHING,STEEL SHAPES	4.75	7.25	7.32	0	0	NC	7	13	10.45	2.46
82	385	MISC. BUSINESS SERV	4.73	6.91	6.50	2,202	3,777	9.41	6,473	12,836	12.09	4.84
83	231.	NONFER WIRE DRAWING&INSULATIN	4.64	7.41	8.13	6	10	8.52	461	954	12.88	3.88

RANK		INDUSTRY NAME	DEFENSE SHARE(%)			DEFENSE FINAL DEMAND			DEFENSE PRODUCTION			NONDEFENSE PRODUCTION
			1981	1987	%GROWTH 81 TO 87	1981	1987	%GROWTH 81 TO 87	1981	1987	%GROWTH 81 TO 87	%GROWTH 81 TO 87
84	218.	IRON & STEEL FOUNDRIES	4.56	7.12	7.72	3	6	12.54	557	945	9.22	0.93
85	397.	SOCIAL SERV,NEC	4.49	5.36	3.00	255	355	5.68	272	389	6.13	2.88
86	285.	BLOWERS & FANS	4.49	6.15	5.39	10	25	15.24	97	158	8.55	2.70
87	243.	FAB PLATE WORK(BOILERSHOP)	4.47	6.57	6.64	398	723	10.47	562	1,010	10.28	3.03
88	274.	POWER DRIVEN HAND TOOLS	4.29	7.05	8.65	58	135	15.19	67	150	14.38	4.77
89	255.	MISC FAB WIRE PROD	4.26	6.73	7.91	6	15	16.61	238	469	12.02	3.35
90	269.	HOISTS,CRANES & MONORAILS	4.24	7.00	8.73	31	82	17.34	61	129	13.34	1.74
91	204.	LIME	4.19	6.38	7.26	0	0	NC	27	49	10.19	2.34
92	365.	MOTOR FREIGHT	4.18	5.41	4.36	1,906	2,618	5.43	3,539	5,701	8.27	3.53
93	248.	METAL STAMPINGS	4.14	6.58	8.02	1	1	14.32	726	1,563	13.63	4.74
94	133.	METAL OFFICE FURNITURE	4.13	4.87	2.78	64	97	7.27	99	152	7.35	4.31
95	207.	ABRASIVE PROD	4.08	6.33	7.59	0	0	11.85	101	199	11.99	3.68
96	187.	FAB. RUBBER PROD,NEC	4.06	6.14	7.13	58	98	9.18	219	407	10.92	3.16
97	245.	ARCHITECTURAL METAL WORK	3.95	5.87	6.83	0	0	NC	55	103	10.90	3.45
98	142	ENVELOPES	3.94	5.57	5.93	28	41	6.40	61	103	9.04	2.64
99	171.	PLASTIC MATLS & RESINS	3.93	5.88	6.95	51	78	7.37	917	2,008	13.96	6.19
100	170.	CHEM PREPARATIONS,NEC	3.82	5.73	7.02	54	91	8.93	229	440	11.49	3.83
101	368	PIPELINES, EX N. GAS	3.77	5.72	7.21	49	74	7.02	191	273	6.14	1.33
102	100.	NARROW FABRIC MILLS	3.76	4.78	4.10	13	16	3.77	33	49	6.80	2.41
103	18.	CRUDE PET & NAT GAS	3.76	5.86	7.70	0	0	NC	4,625	7,422	8.20	0.09
104	181.	PET. REFINING & RELATED PROD	3.71	5.76	7.59	4,410	6,409	6.43	8,577	12,861	6.99	0.92
105	180.	PAINTS & ALLIED PROD	3.67	5.34	6.44	5	8	7.07	278	491	9.91	2.97
106	237.	METAL BARRELS,DRUMS & PAILS	3.67	5.56	7.18	1	3	14.47	48	81	9.15	1.50
107	44.	MAINTENANCE & REPAIR,OTHER	3.59	5.45	7.20	1,246	2,106	9.14	2,552	4,456	9.74	2.03
108	241.	FAB STRUCTURAL METAL	3.58	5.65	7.89	43	65	7.35	272	489	10.28	1.85
109	261.	INTERNAL COMBUS. ENGINES,NEC	3.57	5.23	6.57	85	174	12.68	407	751	10.74	3.61
110	251.	HAND SAWS & SAW BLADES	3.51	5.14	6.57	0	0	NC	19	36	11.10	3.96
111	289.	GEN IND MACHINERY,NEC	3.45	5.14	6.87	107	237	14.26	149	323	13.69	6.07
112	329.	ENGINE ELEC EQUIP	3.44	5.33	7.55	23	50	13.99	129	258	12.23	4.01
113	327.	PRIMARY BATTERIES,DRY & WET	3.41	6.16	10.36	22	48	13.49	22	44	11.95	0.95
114	321.	TELEPHONE & TELEGRAPH EQUIP	3.38	4.52	4.93	263	567	13.66	405	920	14.64	3.04
115	302.	TRANSFORMERS	3.35	5.43	8.40	22	54	16.51	94	177	11.16	2.17
116	250.	HAND & EDGE TOOLS,NEC	3.33	4.50	5.13	68	103	7.24	107	183	9.38	3.83
117	196.	GLASS & PROD EX CONTAINERS	3.31	5.32	8.23	9	24	18.15	224	461	12.76	3.82
118	347.	SURGICAL & MEDICAL INSTRS	3.29	5.06	7.44	116	248	13.55	114	241	13.23	5.06
119	283.	PUMPS & COMPRESSORS	3.25	4.80	6.75	72	135	11.15	312	573	10.68	3.40
120	188.	MISC PLASTIC PROD.	3.21	4.98	7.61	63	98	7.60	1,216	2,814	15.01	5.54
121	267.	ELEVATORS & MOVING STAIRWAYS	3.19	5.13	8.21	3	5	12.58	25	47	10.97	2.21
122	363.	RAILROADS & RAIL-RELATED SERV	3.18	4.38	5.49	476	697	6.57	1,214	2,065	9.26	3.36
123	244.	SHEET METAL WORK	3.11	4.83	7.63	0	1	13.32	190	374	11.94	3.70
124	198.	CEMENT,HYDRAULIC	3.10	4.13	4.89	84	124	6.54	127	210	8.83	3.57
125	153	MISC PUBLISHING	3.09	4.50	6.46	29	45	7.34	56	95	9.13	2.25
126	252.	HARDWARE,NEC	3.05	4.6C	7.11	27	42	7.67	215	432	12.30	4.56
127	268.	CONVEYORS & CONVEYING EQUIP	2.97	4.04	5.27	64	117	10.37	77	140	10.43	4.71

RANK		INDUSTRY NAME	DEFENSE SHARE(%) 1981	DEFENSE SHARE(%) 1987	DEFENSE SHARE(%) %GROWTH 81 TO 87	DEFENSE FINAL DEMAND 1981	DEFENSE FINAL DEMAND 1987	DEFENSE FINAL DEMAND %GROWTH 81 TO 87	DEFENSE PRODUCTION 1981	DEFENSE PRODUCTION 1987	DEFENSE PRODUCTION %GROWTH 81 TO 87	NONDEFENSE PRODUCTION %GROWTH 81 TO 87
128	208	ASBESTOS PROD & SEAL. DEVICES	2.91	4.51	7.57	4	11	18.07	109	209	11.43	3.30
129	130	METAL HH FURNITURE	2.91	3.50	3.14	17	26	7.49	48	70	6.77	3.42
130	387.	MISC PROFESSIONAL SERV	2.90	4.63	8.12	543	1,033	11.32	2,725	5,619	12.82	4.04
131	303.	SWITCHGEAR & SWITCHBOARD	2.75	4.43	8.27	28	61	13.80	150	296	11.96	3.10
132	17.	COAL MINING	2.69	4.14	7.43	9	18	11.12	484	958	12.05	4.04
133	186.	RECLAIMED RUBBER	2.68	4.34	8.37	0	0	NC	2	3	7.76	-0.85
134	396.	NONPROF ORGS & MISC PROF SERV	2.66	3.94	6.72	890	1,544	9.60	1,139	2,026	10.08	2.92
135	352.	OPHTHALMIC GOODS	2.65	3.44	4.44	27	40	7.22	33	52	7.72	3.00
136	199	STRUCTURAL CLAY PRODUCTS	2.61	3.65	5.73	23	37	8.34	47	84	9.98	3.83
137	395	EDUCATIONAL SERV	2.60	3.63	5.72	649	1,025	7.90	680	1,082	8.04	2.01
138	169	CARBON BLACK	2.60	4.15	8.14	0	0	NC	20	38	10.91	2.29
139	242	METAL DOORS, SASH & TRIMS	2.54	3.99	7.80	23	67	19.76	93	197	13.31	4.85
140	105	TIRE CORD & FABRIC	2.51	4.16	8.81	0	0	NC	26	49	11.17	1.88
141	360.	OFFICE & ARTISTS' MATLS	2.51	3.49	5.71	22	27	3.94	61	105	9.47	3.39
142	168.	PRINTING INK	2.49	4.07	8.50	10	23	15.28	37	77	12.68	3.57
143	257.	PIPE, VALVES & PIPE FITTINGS	2.49	3.63	6.46	78	138	9.89	324	630	11.71	4.73
144	20.	CHEM & FERT MINERAL MINING	2.49	3.63	6.54	0	0	NC	81	130	8.22	1.38
145	372.	ELECTRIC UTILITIES	2.49	3.85	7.59	940	1,541	8.59	3,364	5,989	10.09	2.08
146	172.	SYNTHETIC RUBBER	2.48	3.91	7.89	1	1	12.43	86	156	10.56	2.22
147	370.	COMMUNICATIONS, EX RADIO & TV	2.46	3.25	4.75	914	1,448	7.97	1,927	3,818	12.07	6.84
148	12	FORESTRY & FISHERY PROD	2.46	3.14	4.20	83	98	2.72	155	243	7.79	3.32
149	43.	MAINTENANCE & REPAIR, RESIDENT.	2.43	3.41	5.81	578	918	8.01	764	1,244	8.46	2.33
150	282.	SPECIAL INDUSTRY MACH, NEC	2.42	3.74	7.53	97	212	13.98	140	289	12.79	4.65

RANKED ON 1981 DOLLAR VALUES
REAGAN0282