CHARACTERISTICS OF DEMAND
FOR AIRCRAFT SPARE PARTS

BERNICE B. BROWN

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PROJECT RAND

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The RAND Corporation
1700 Main St. * Santa Monica * California

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FOREWORD

The purpose of this report is to summarize the results of 2 years of RAND research on the demand for aircraft spare parts. Research on the characteristics of demand is highly important in logistics because demand has a significant influence not only on procurement, stockage, and other matériel policies, but also on the structure of the logistics system itself.

The main value of this report lies in the presentation of a consolidated picture of those demand characteristics determined from our research. The results supplement and re-enforce the impression gained by people in day-to-day dealing with individual aircraft spare parts—namely, the impression that demand is erratic and uncertain. The highly sporadic pattern of demand repeatedly found in the demand studies has significantly influenced many other parts of our logistics research, such as those concerned with inventory policies, procurement, maintenance scheduling, etc.

The presentation of the study in the form of a RAND report does not mean that we consider research into demand to be completed. We have learned something about demand, but there remains much work to be done with better data, and with the more incisive analyses which such data warrant. Still, the work has reached an intermediate stage at which more formal presentation seems justified.

First, the B-47 data, with which much of the past work has been concerned, have been exploited about as far as possible. Secondly, the study of these and related data has led to a clearing of the field—i.e., to some preliminary findings and to several practical suggestions. Thirdly, further demand studies—some of them stimulated by our experience with available data and by our preliminary findings—are under way or will be made when a larger body of satisfactory data becomes available. But some time will pass before it will be possible to say much more about demand than can be said at present.

For these reasons, a substantive, nontechnical review of the past work seems justified now.
ACKNOWLEDGMENTS

The author wishes to express her gratitude to Murray Geisler and to her colleagues at RAND who contributed so much to this study.

Special thanks are also due to the many people in the Air Force who helped us to understand this problem.
WHAT CAN THE AIR FORCE DO ABOUT UNCERTAIN DEMANDS?
(Summary and Conclusions)

Knowledge of demand for aircraft parts is needed for effective and economical procurement, distribution, and stockage decisions. The following paragraphs summarize the results of RAND research on demand and point to certain conclusions that can be drawn for the logistics system.

Low average demand rates are characteristic of a large proportion of all aircraft parts. During a year's period at the bases studied (and perhaps at all bases), as many as one-third of the available spare parts had no demand, and three-fourths had so few demands that they offer an unreliable basis for predicting future demand. Moreover, many of the parts had low unit costs. Forty-two per cent of all line items in the USAF Worldwide Stock Balance and Consumption Report for 1952-1953 had fewer than ten issues during the year and cost less than $10 each. The slow-moving, low-cost parts account for a small fraction of the total dollar value of issues, but because of their large number and, often, their essentiality to the functioning of the aircraft, they constitute a significant logistics problem.

Demand for most spare parts also tends to be erratic. Even if the demand rate for a part is known for some past period, the future demand during a similar period cannot be predicted with accuracy. To reduce the occurrence of parts shortages to a reasonably low level, it is not enough to predict (and use) average demand rates, but, rather, it is necessary to predict the probability that various demands will occur. These probabilities can then be used in calculations designed to facilitate stockage, procurement, and other important logistics decisions.

In many cases, the pronounced random element causing uncertainty in demand can be expressed by a mathematical formula. Many of the airframe parts—with sufficiently frequent demands to permit statistical analyses—show demand patterns that can be approximated by standard
probability distributions, such as the Poisson probability distribution. When such approximation is possible, logistics decisions can be computed that take into account the costs of incurring shortages as well as the costs of avoiding them. This can result in stockage, procurement, and other logistics decisions that produce greater combat capability for the resources available.

There are many causes of the unpredictability of demand for spare parts. Future program changes affecting the number of weapons to be supported or their activity rates, engineering changes in the weapons, and changes in the conditions of their use and in the nature of their support are all most difficult to predict. Also, demand can be unpredictable either for lack of quantitatively and qualitatively sufficient data applicable to the future, or for lack of a satisfactory systematization of the random element through a suitable probability distribution. This study has been concerned only with the last-mentioned cause of unpredictability and deals with the random fluctuations. Even within this narrow context, as this report shows, there is much uncertainty in demand predictions. The problem of demand prediction is made far more difficult if we also consider the other causes described. The collection of better data on demand and on the operating conditions under which demands occur will help in handling the statistical sources of unpredictability. Program and technical changes appear to be facts of life to which the logistics system must simply adjust.

Turning next to the implications of these findings for the logistics system, we find that whereas the pattern of demand is not the only factor that must be considered in determining logistics policy, it is clearly a contributing factor. Our study leads to two conclusions regarding the stockage policy for items that fail to show a clear periodicity of demand.

First, concerning low-unit-cost parts, an ample stock of such aircraft parts at all points of demand would help in meeting even extreme demands without delay. This conclusion is appropriate for low-cost items, whenever the difficulties of keeping them at the base are not prohibitive, because the costs occasioned by a shortage, including lost performance of the aircraft suffering the shortage, will usually outweigh the extra cost of ample stocks of these cheap parts. For the slow-moving, low-cost items, which are the most numerous, this means that even if there is no demand
for them in 1 year or more, they should not be regarded as excess stock and shipped back to the depot. Instead, their retention will protect against possible future demand.

Secondly, concerning high-unit-cost parts, analysis of worldwide consumption data shows that 6 per cent of the parts cost more than $100 each and account for 75 per cent of the total dollar value of issues. The stockage of high-cost parts can be differentiated on the basis of their observed demand rates. For the high-cost, fast-moving parts, enough demands are available to estimate the probability distribution of future demand. This distribution can then be used to compute the indicated stockage. For the high-cost, slow-moving parts, the estimate of future demand is much more uncertain, and so it is very difficult to determine what to stock at the bases or what to procure for the system as a whole. It may be uneconomical to stock any of these parts at the bases. Instead, it may be more satisfactory to supply the bases "as needed" by having a logistics system that is flexible and responsive, so that resupply from a storage center, or from a few centers, or possibly from the manufacturer's plant will work smoothly and effectively.

The fact remains that demand for most spare parts cannot now be predicted with confidence, and perhaps never can. This makes it necessary to consider some improvements in logistics operations to make it easier to live with demand uncertainty. Among such improvements would be a shortening of the resupply time, of the procurement lead time, and of the repair cycle for spare parts. Each of these improvements would help to reduce the time over which predictions must be made and would lessen requirements for procurement, thus reducing the risk attending prediction:

1. Shortening resupply time would generally reduce the amount of buffer stocks that must be kept at air bases. These buffer stocks are now large and costly because it is so difficult to predict demand at a base level. Even though it might cost the system more to reduce resupply time, the savings in required buffer stocks, as well as the reduction in lost performance time for aircraft suffering the shortage, might outweigh this increase in cost.

2. Reducing the procurement lead time would promise considerable economies in the procurement of spare parts. In the early stages of production, when there is little demand experience and much statistical
uncertainty, short procurement lead times, with the option of frequent reorder, would help much to economize on procurement. It is also obvious that demand prediction at all stages is hampered by many dynamic elements, such as unexpected changes in aircraft configuration, in engineering design, and in aircraft procurement schedules. A shortening of procurement lead time would reduce the impact of these elements. Such shortening might be hard to achieve because it would probably require changes in contractual and procurement techniques used by the U.S. Air Force. RAND is doing research along these lines. Very likely, reductions in procurement lead time would be accompanied by increases in unit cost, but these increases should be more than counterbalanced by reductions in the volume of parts procured.

3. A shortening of repair-cycle time, finally, could probably be accomplished only by major revisions in the present system of scheduling and doing repair. This shortening would have the same benefits as the shortening in procurement lead time. In the early stages of production, fast repair would permit the system to operate with a smaller inventory of parts; and at all stages, it would cushion the uncertainties of demand. The ability to repair quickly would require much more rapid transmission of data between bases and depots and more immediate reactions by the depots to such data. Such revisions in the repair system would undoubtedly result in higher unit repair costs, but here again the final outcome would probably be a net reduction in total cost to the system through less procurement and fewer shortages.

These improvements in logistical management, if made, would probably have valuable effects in various directions that lie outside the scope of this study. In relation to the forecasting of demand, they would tend to overcome some of the costly effects of the very limited predictability of demand for aircraft spare parts.
I. INTRODUCTION

The central problem in logistics is to get the right item to the right place at the right time—without incurring undue cost. To accomplish this, it is necessary to understand the characteristics of demand. This report presents the results of various RAND studies on the demand for aircraft spare parts.

An understanding of the pattern of demand is essential for the design of an effective and economical logistics system. For certain airplane parts, such as brakes and tires, it may be possible to establish demand rates in relation to flying activity. Demand for such “operational type” items is likely to be periodic and predictable. Other items, such as wing tips and stabilizers, do not have a discernible rate of wear in the course of the life of an airplane; they may last, or they may require replacement at any time. The demand for such “insurance type” items by an aircraft is erratic and unpredictable; it may show very little relationship to the total number of hours flown by the aircraft, or to the number of months it is in the inventory.

Clearly, a system designed to support a regular, predictable, and periodic demand will be very different from one designed to support an erratic and unpredictable demand. In the first case, there is no need for contingency stocks, and plenty of time may be taken to move shipments according to schedule from the supply point to the demand point. In the second case, however, safety levels must be used, and there is often a premium on rapid delivery when a part is needed at a location where it is not in stock.

In this report, we present what we have learned to date about the pattern of demand for aircraft spare parts, particularly for insurance-type items. We have been able to classify these patterns into four standard types, and this may be of some help in predicting demand. We have also learned a great deal about the frequency distribution of demand for certain groups of spare parts within given periods of time. We know that the demand for most aircraft spare parts is very low, and that a few
parts account for most of the demands that occur. This knowledge helps in specifying the over-all design of the logistics system and the policies for distribution and requirements that the system should follow.

There exists no single formula that could usefully be employed across the board to estimate the rate at which demands for certain parts will occur. All we have been able to do is to devise some ways by which the demand pattern can be estimated for the insurance-type items or, when even that proves impossible, to suggest certain stockage and procurement procedures that would make sense in the face of unpredictable demands.
II. NATURE OF DEMAND

DEFINITION OF DEMAND

Before entering into the discussion of the pattern of demand for aircraft spare parts and the problems of predicting demand, we shall define "demand" and enumerate some of the factors which influence it. In addition, we shall describe in this section some of the data used in the study and their limitations.

Any request for spare parts we call "demand." Demands can occur under various circumstances. One of the parts on a plane can fail during flight, making repair necessary on landing; a part can be found defective in a preflight inspection or require repair in the course of the periodic maintenance; or special instructions may be issued from higher headquarters, requiring the replacement of a particular part.

The demand for aircraft spare parts arises chiefly in the course of aircraft maintenance. Aircraft are maintained at bases and at depots. Base maintenance is performed from day to day to keep the aircraft flying; it may take the form of organizational maintenance or of field maintenance. Depot maintenance of aircraft is performed at more or less periodic intervals, usually several months apart, to take care of cumulative wear resulting from prolonged flight operations and to make directed modifications. It may take the form of IRAN,* or of such repair work on assemblies and components as the bases are not expected, or do not choose, to handle.†

Requests for spare parts may arise in any and all of these activities. As the requested parts are issued, we have what is called consumption (or issues) of parts. If the parts are not issued, because the base or depot

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*Inspection and repair (as necessary).
†Regulations specify what may or may not be repaired at a base field maintenance shop, as distinct from the depot. For some line items coded "D," the base has an option of repairing them or returning them to the depot. The activity of the base maintenance shop is much colored by the interest and capability of its personnel. An aggressive base may repair many parts that another base would return to the depot.
does not happen to have them in stock, there is, of course, no consumption. Demand as defined here, therefore, equals consumption (issue) of parts plus unsatisfied requests for parts.

The distinction between demand and consumption is of some importance for studies of the need for parts over time. True, in many instances consumption may equal demand at depot level, even at base level. But it sometimes happens that certain parts are not in stock and demands remain unsatisfied, at least for some time, or else substitutes are supplied. Such instances are too important not to be considered in a study of needs for spare parts, as would happen if needs were measured by consumption rather than by demand.

Another distinction is significant for demand studies. Demand may result from ordinary maintenance activity, or it may result from special technical orders calling for modification of the aircraft at base or depot. The maintenance facility, in other words, is not the only source of requests for parts. Now the need for parts caused by special technical orders or modification is almost impossible to foresee. It cannot be provided for by stockage decisions concerned with meeting recurrent demands or routine replacements. Special needs should ordinarily be satisfied by special kits purchased for the purpose and sent out to depots or bases in conjunction with the special orders.* Moreover, since parts requests that result from special technical orders cannot be expected to reflect flying activity—measured by flying hours, landings, aircraft-months, and the like—their inclusion in the demand data would create a prima facie reason for lack of correlation between demand and flying activity. Since we are interested in testing this correlation and its power to support predictions of demand, we prefer to use demand data that do not include parts requests resulting from special technical orders.

The various bodies of data which have been studied were not tailored equally well to the desirable definition of demand. Most satisfactory from the conceptual point of view were the data for B-47 bomber and KC-97 tanker aircraft. These data provided information on the number of units of parts requested to repair individual aircraft, including unsatisfied demand, and they were available in a form that made it possible to

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*In emergency situations, of course, stocks of parts purchased for normal replacement may be used advantageously to fill the requirements caused by special technical orders.
exclude requests resulting from special technical orders. However, the
B-47 and KC-97 data cover demand for parts at the home bases only.
This falls somewhat short of ideal requirements because demands are
excluded that may have occurred during the visits of the aircraft to other
bases and, particularly, to depots for major repair.

Data for F-86 fighters used in this study were obtained from a summary
report of demand, rather than from daily transaction cards. Therefore it
was not possible to examine the day-to-day pattern of demand for parts
on these aircraft.

Data for B-50 bombers covered consumption during a special test
exercise of these aircraft. Likewise the worldwide consumption report,
which has been analyzed, dealt with consumption of spare parts at bases
and depots. These data were not tailored to suit the measurement of
demand proper.

The nature and limitations of the data will be discussed further below,
and reference will be made to the various RAND studies based on these
data. At this point, it may suffice to say that the material offered a good
basis for analyses of demand. The results of these analyses were generally
backed up by those of consumption in the cases in which information on
demand proper was not available.

FACTORS AFFECTING DEMAND

Demand is the product of many factors. This is one reason for its
unpredictability. Wear and tear is, of course, an important cause of
demand, but the various parts of an aircraft are subject to wear at greatly
different rates depending on their engineering characteristics, the durabil-
ity of materials, the complexity of components, the susceptibility to dam-
age on the ground and under operating conditions, and the relation to
adjacent or functionally related parts. Some of our results indicate that the
frequency with which a given part is demanded also depends on the num-
ber of aircraft in the wing or squadron to which the part is applicable, and
on the scheduled maintenance practice or routine replacement policy which
is prescribed.

Besides these basic and largely objective factors, a variety of subjective
factors exercise a notable influence on demand. In a practical sense,
demand originates with the mechanics performing maintenance and repair. At times, the requests for parts may reflect the degree of skill of a mechanic, rather than the objective need for the spare part. For example, 2 units of Part No. 1AFE 15-24548-541 (the door assembly for a B-47B) were issued Friday, July 31, 1953, for a particular plane, and 1 unit of the same part was issued on Monday, August 3, for the same plane. Also, Part No. 1AFE ZP1044 (a radome for a B-47B) was issued on August 12, and again on August 14 and 18, 1953, and in each case the part was assigned to the same aircraft serial number. Since there is only one installation of each of these parts on a B-47B, it might be inferred that only one replacement of each was needed—but three units of each part were issued to accomplish the installation.

Demand may be stimulated by the assignment of newly trained mechanics. For a short time these men may assume the role of "parts changers" while they are getting acquainted with the aircraft. If flying activity happens to be relatively low at the base, or is of routine character, all mechanics may devote more time to discovering replacement needs than they would under more strained conditions. Similarly, demand may be accelerated by news of a contemplated change in flying activities—causing cautious mechanics to call for a supply of extra spares to be held ready for use—and by many other highly subjective reactions.

All of these factors emphasize the difficulty of predicting demand.

DATA USED

**RAND** has published several studies describing a variety of demand data. These studies of past demand include data for the following four aircraft models: B-47, B-50, KC-97, and F-86; in addition, these studies include data on worldwide parts consumption. The data on B-47 aircraft were accumulated at two SAC bases in the Zone of Interior (March and MacDill bases), and at Fairford, England.* The data on B-50 aircraft

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were obtained from the report on Project Red Head.* The data on KC-97
tankers came from the same bases as the B-47 data—i.e., from March and
MacDill bases, and from Fairford, England. The F-86 data were obtained
from Perrin Air Force Base, using the same reporting system as was
employed with the B-47 data.† The analyses of the worldwide consump-
tion data of aircraft spare parts, finally, used data for all kinds of aircraft
from the USAF Worldwide Stock Balance and Consumption Report for
1952–1953.‡

The demand data for the B-47, KC-97, B-50, and F-86 aircraft included
the following information for each part number:

1. Date that each demand occurred,
2. Quantity of each demand,
3. Aircraft serial number generating demand (not always).

The worldwide data were obtained from the Air Materiel Command
and included the following information for each line item: unit cost,
quantity issued worldwide from October 1, 1952, to September 30, 1953,
and on-hand and on-order inventories as of October 1, 1953.

DATA LIMITATIONS

There were some obvious limitations to the data. First, the data analyzed
by aircraft model consisted of demands generated by about 300 aircraft
at only three or four different geographic locations. We had a year’s
record on 90 B-47’s at MacDill base, 6 months’ data for 90 B-47’s at
March base, and 3 months’ data for 45 B-47’s at the base in England.**

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*Bernice B. Brown and M. A. Geisler, Comparison of Demand for Spare Aircraft Items by B-50D Aircraft (Project Red Head) and B-47 Aircraft Deployed to English Bases, The RAND Corporation, Research Memorandum RM-1333, September 8, 1954.


‡The following studies are based on this report: M. A. Geisler, Analysis of Base Stockage Policies, The RAND Corporation, Research Memorandum RM-1431, February 17, 1955; and M. A. Geisler and A. R. Mirkovich, Analysis of Worldwide Data on Aircraft Spare Parts As to Unit Cost, Quantity and Value Issued and Inventory Value, The RAND Corporation, Research Memorandum RM-1481, May 6, 1955.

**Altogether, the B-47 material provided us with demand experience for 1300 aircraft-months, about equivalent to that of a two-wing base for a year.
For the F-86 study, we used information on 90 aircraft over a 6 months' period at a base in Texas. The B-50 data came from a special exercise held overseas for a few weeks, involving 45 aircraft. Most of the demand information derived from these records, like that on worldwide consumption, dated from the fall of 1952 through 1953. The samples were sizable enough, yet restricted in coverage.

Secondly, part of the information on demand for the B-47, B-50, KC-97, and F-86 was of limited usefulness because the record failed to identify the specific aircraft to which demand for a spare part was related. This identification is easy for parts that are used in organizational maintenance, but is not easy for parts used in field maintenance because of the bookkeeping problem. The individual components removed from an aircraft and sent to field maintenance shops must be tagged with the relevant aircraft serial number, and the repair personnel must record the parts used in the repair of each component on the tag or other appropriate form so that the parts can be associated with the serial number of the aircraft. This association is not always made by the mechanics because of the press of other duties.

Thirdly, we did not always possess the detailed knowledge of individual parts needed to extract all the meaning from the demand data. Thus, there were gaps in information for all the demand data studied on applicability of parts to aircraft, relations between parts numbers, including information on interchangeable parts, substitutable parts, parts that are components of a higher assembly, and parts that are interdependent in an operational sense. Constant design improvements mean that modifications are necessary, entailing removing some line items, rebuilding some assembly units, or installing complete new sections. All of these changes affect demand for particular parts either directly or indirectly by adding new line items in the course of time and changing the potentiality of demand for others.

Another deficiency in the data studied by aircraft model was the lack of a firm figure for the total number of all parts that might be required to maintain the aircraft. There exists no readily accessible and current source that lists all the applicable spare parts for a given aircraft model and series. Such a document would permit identification of those parts that had no demand during the period studied. This is important because,
as will be seen later, many of the parts had such low demand rates that they were treated the same in stock level and procurement decisions as items having no demand. Because of this, we had to estimate the total number of B-47 parts for that phase of the study in which we intended to point out the importance of the parts with zero demand over a fairly long period.

The B-47 data used for the detailed study of individual parts were obtained from a special reporting system set up at March and MacDill bases and monitored by Oklahoma City Air Materiel Area (OCAMA). The individual transaction cards were made available to us with the voucher number, date of the requisition, aircraft serial number, part number, number of units requisitioned, etc. There was some editing done by those administering the program to see that part numbers, dates, and quantities requisitioned and issued were correctly reported. We found few inconsistencies in the data, but inaccuracies may exist of which we have no measure. We believe, however, that the data were satisfactory for studying the underlying distribution of the demand for spare parts. The data for the other types of aircraft were less detailed and less controllable.*

*A demand data collection program for F-86H fighters, now under way at Clovis Air Force Base, promises to produce more carefully controlled and more detailed demand data for parts on this aircraft. This program is a joint undertaking of the Tactical Air Command and the Sacramento Air Materiel Area, to determine a flyaway kit, with hand advising on methods. The experience with the B-47 data contributed to the design of the methods used in this program.
III. PATTERN OF DEMAND

In this section, the characteristics of demand data are described. These are important for the subsequent discussion of prediction and of measures to overcome the difficulties of prediction.

Since entirely different logistics policies may be appropriate for fast-moving and for slow-moving parts, the first part of this section is devoted to a general description of the spare parts in terms of their frequency of demand. Similarly, since the unit price of parts is a major element in determining policies, this section also includes a description of the characteristics of spare parts in terms of their unit cost, and relates unit cost to frequency of demand for the group of spare parts studied.

Lastly, the behavior of demand over time for individual parts is considered, together with illustrations of a few different parts. These illustrations show the erratic nature of demand and lead to the final discussion, which attempts to describe some means for dealing with this irregularity. This final discussion shows, in general, that the vast majority of parts are demanded very infrequently, that the demands which occur are very erratic, and that most parts are also inexpensive.

MEANING OF PATTERN OF DEMAND

By pattern of demand, we mean, in the first place, the frequency distribution of individual aircraft spare parts according to their total demand during a given span of time—i.e., How many of the parts had low, medium, or high demand during a given number of months? We mean, in the second place, the distribution over time of individual parts—i.e., In how many weeks or months of the total period studied was there no demand for the particular part? in how many periods one demand? two demands? etc. Thus, in the first instance, we are interested in studying the pattern of demand that characterizes groups of parts; whereas, in the second case, we are interested in finding out how the demand for individual parts behaves from one time interval to the next.
In what follows, the pattern of demand will be presented first as a distribution of parts according to their total demand over the period, and, secondly, as a distribution of demand for individual parts over units of time.

**PATTERN OF B-47 DEMAND RATES**

Analysis of the described data has led us to conclude that low demand is a standard characteristic of a large proportion of all aircraft spare parts. The situation is well illustrated in Fig. 1, which shows the observed frequency of demand for B-47 parts during 1300 aircraft-months. This

![Graph showing frequency distribution of observed demand rates for B-47 spares](image)

Fig. 1—Frequency distribution of observed demand rates for B-47 spares (approximately 15,000 line items)

Note:
The data have not been extended to include demands of more than 35 units. The tail extends up to more than 10,000 units.
experience is roughly equivalent to that of a two-wing base for a year.

The total number of B-47 part numbers applicable to aircraft on base during the period was estimated as 15,000. These are the parts for which some demand could have arisen. About 25 per cent of the parts were not demanded at all in the 1300 aircraft-months. An additional 20 per cent of the parts had a demand of only 1 unit during the period, and another 10 per cent had a demand of only 2 units. The data of Fig. 1 have not been extended to include items with demands of more than 35 units. One part had a demand of over 10,000 units, which gives some indication of the length of the "tail" of this distribution. Figure 1 shows the tendency of the demands to occur in rounded units, such as multiples of five or multiples of a dozen.

Interestingly, while the parts shown in Fig. 1 (with demands of 35 units or fewer during the period) accounted for approximately 85 per cent of the estimated total of B-47 spares, they accounted for only about a fourth of the number of units demanded. In other words, most spare parts have very low demand, but the few parts that have high demand account for most of the units demanded.

The low-demand parts are very important, not only because of their large number, but also because of their role in the occurrence of parts shortages. Examination of AOCP's (aircraft out of commission for parts) occurring at March and MacDill bases during the 2 months following the period covered by the demand data indicated that the parts covered in Fig. 1 were responsible for nine out of ten AOCP's. Also, it was found that about half of the parts causing these AOCP's had had zero demand during the previous year. This typical pattern of demand has important implications for the logistics system, which are discussed in Section IV.

PATTERN OF DEMAND RATES FOR OTHER AIRCRAFT

Studies of the demand characteristics of parts for a conventional bomber (the B-50), the tanker-transport KC-97, and the F-86D fighter, have brought out demand patterns very similar to the pattern for the B-47.

DEMAND FOR AIRCRAFT SPARE PARTS

Table 1 shows the percentage distribution by quantity demanded of the number of line items (with at least one demand) for each of the four types of aircraft. While the periods during which demands were recorded varied from 3 months to 1 year, the aircraft-months from 135 to 1500, and the number of line items from 499 to 11,000, and although the nature

<table>
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<tr>
<th>Quantity Demanded Per Line Item</th>
<th>B-47(^a) All Property Classes (11,000 Items, 1300 Aircraft-months)</th>
<th>F-86D(^a) All Property Classes (5061 Items, 585 Aircraft-months)</th>
<th>B-50D(^b) Airframe (569 Items, 135 Aircraft-months)</th>
<th>KC-97 Airframe (499 Items, 1160 Aircraft-months)</th>
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<td>1.6</td>
</tr>
<tr>
<td>14</td>
<td>1.0</td>
<td>0.6</td>
<td>0.7</td>
<td>0.6</td>
</tr>
<tr>
<td>15</td>
<td>0.8</td>
<td>1.3</td>
<td>2.1</td>
<td>0.2</td>
</tr>
<tr>
<td>16</td>
<td>0.8</td>
<td>0.9</td>
<td>2.3</td>
<td>1.4</td>
</tr>
<tr>
<td>17</td>
<td>0.6</td>
<td>0.5</td>
<td>0.7</td>
<td>0.8</td>
</tr>
<tr>
<td>18</td>
<td>0.8</td>
<td>0.6</td>
<td>0.2</td>
<td>1.0</td>
</tr>
<tr>
<td>19</td>
<td>0.4</td>
<td>0.3</td>
<td>0.5</td>
<td>0.4</td>
</tr>
<tr>
<td>20</td>
<td>1.3</td>
<td>1.6</td>
<td>1.1</td>
<td>1.4</td>
</tr>
<tr>
<td>Above 20</td>
<td>33.1</td>
<td>31.5</td>
<td>24.2</td>
<td>12.0</td>
</tr>
<tr>
<td>Total</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
</tr>
</tbody>
</table>


\(^b\)See Bernice B. Brown and M. A. Geisler, *Comparison of Demand for Spare Aircraft Items by B-50D Aircraft (Project Red Head) and B-47 Aircraft Deployed to English Bases*, The RAND Corporation, RM-1333, September 8, 1954.
of flying activity, the type of aircraft, the age of aircraft, and the location of the bases differed greatly, the percentage distributions show a surprising similarity. The same general pattern was found to hold for the worldwide consumption data, with 60 per cent of the line items showing issues of fewer than 10 units during the year studied. Thus, all patterns were consistent with only minor differences in the level of demand.

PATTERN OF UNIT COSTS

In studying the pattern of demand, it is important to consider the unit cost of the parts, because one way of combating demand uncertainty is to carry sufficient inventories to meet very large demands. For low-cost items, such a practice is not expensive, but for high-cost items, it may be. In the following paragraphs, we show how parts are distributed according to unit cost, and the relation between demand rates and unit cost.

In addition to having low demand, most aircraft spare parts are also characteristically low in unit cost, so that the dollar value of issues of most parts is correspondingly low during, say, a year's time. Thus, of the estimated 15,000 B-47 spare parts, about 60 per cent had unit costs of less than $10; 24 per cent had unit costs between $10 and $100; and 16 per cent had unit costs of more than $100. The demands for the 60 per cent of the parts having unit cost of less than $10 (accounting for more than 70 per cent of the total number of units demanded) represented only 1 or 2 per cent of the total dollar value of issues. Thus, the demand per line item for these numerous inexpensive items is so low that the value of their issues is quite insignificant, despite the fact that they account for most of the issues.

If we rank the B-47 parts in descending order according to the dollar value of issues for each, we find that the highest 2 per cent of the parts accounts for 60 per cent of the total dollar value of issues. These few parts, chiefly electronic equipment, are both expensive and frequently demanded. Because of their high demand activity, these are not the parts that usually cause much difficulty in prediction, since fairly short histories

*See M. A. Geisler and A. R. Mirkovich, Analysis of Worldwide Data on Aircraft Spare Parts As to Unit Cost, Quantity and Value Issued, and Inventory Value. The RAND Corporation, Research Memorandum RM-1481, May 6, 1955.
of past demand throw much light on future requirements for such parts. This satisfactory condition applies to a very small fraction of the spare parts only; but from the point of view of dollars and cents, this small fraction is quite important.

The study of the aggregated worldwide data led to broadly similar results.* These data showed that 73 per cent of the items cost less than $10 per unit, 21 per cent cost between $10 and $100 per unit, and 6 per cent cost more than $100 per unit. The concentration of items in the low-unit-cost bracket is of some significance for living with the unpredictability of demand for most of those parts. Stockage of large quantities of low-cost items, ample to fill any conceivable need, is an economical way to combat the unpredictability of demand.

**RELATIONSHIP BETWEEN ISSUE RATES AND UNIT COST**

The close association of low demand and low unit costs for the majority of aircraft parts is brought out by the three-dimensional frequency distribution in Fig. 2. Based on the worldwide consumption data, Fig. 2 shows the spare parts grouped by unit cost and quantity of units issued. The X-axis classifies the line items by unit cost, the Y-axis classifies them by the number of units issued, and the Z-axis gives the number of line items falling in each unit-cost and number-of-units-issued category. Figure 2 may be read in the following way: Of the line items (part numbers) which had fewer than 10 issues annually worldwide, 60,000 cost less than $1; 100,000 cost between $1 and $10; 56,000 cost between $10 and $100; 13,000 cost between $100 and $1000; 2700 cost between $1000 and $10,000; etc. The salient feature of Fig. 2 is the large concentration of line items at low issue and low-unit-cost values, which was noted earlier. One hundred and sixty thousand, or 42 per cent, of all line items studied had fewer than 10 issues worldwide, during the year, and cost less than $10 each.

Similarly, the B-47 data show that about 45 per cent of the items had 0 unit or only 1 unit demanded during 1300 aircraft-months, and cost less

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Note:
Aircraft property classes (worldwide) for year ending September 30, 1953, include airframe (O), engine (O2), accessories (O3), armament (O4), and electronics (O6).

Fig. 2—Frequency distribution of line items classified by number of units issued and unit cost.
than $10. The worldwide data and the B-47 data both show that 15 per cent of the items cost between $10 and $100 each, and had demands of fewer than 10 units during the year. The wide range of unit costs from a few cents to many thousands of dollars, and the large spread of the number of units issued from zero to hundreds of thousands per year, emphasize that there exists no "average" spare part. It follows that logistics policies governing procurement and distribution of aircraft spare parts should take into account the asymmetrical pattern of unit cost and issue rates among the parts.

**PATTERN OF DEMAND OVER TIME**

**Data Studied**

Turning now to the demand pattern over time, we shall examine the behavior of the demand for individual spare parts from one period to the next. For this purpose, data showing demand by time periods had to be used. Demands for individual airframe parts at MacDill base were tabulated by weekly intervals during a 15-month period ranging from October, 1952, through December, 1953.* About 85 per cent of the tabulated airframe items showed fewer than ten daily transaction entries during the period—i.e., too few to provide data for a statistical study. It should be noted that the number of transactions, rather than the amount of the demand, had to be used as a criterion because high demands observed on few occasions offer as unsatisfactory a base for prediction as low demands.†

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*The tabulation included only parts for which there was at least one demand during the period. For these parts, the tabulation indicated the day or days on which the demand occurred, but did not state positively the weeks during which no demand occurred. Those weeks had to be estimated by subtracting the weeks in which demand occurred from the total number of weeks. This approach tends to overstate the number of weeks of zero demand, because the total number of weeks may well include periods during which demands for the part could not possibly have occurred—i.e., during absences of aircraft from the base—or because certain parts may not be applicable to all aircraft on the base. This approach, however, was the best available.

†To illustrate the difference between high-demand and fast-moving parts, Part No. 1AFE 3-47504 (a washer) showed a total demand of 90 units, and Part No. 1AFE 3-51633 (a seal) showed a total demand of 92 units. In the case of the washer, there were six transactions,
Examples of Individual Parts

Out of a total of more than 1800 B-47 airframe parts for which there was demand at MacDill base, there were only 258 parts for which ten or more transactions were reported, thus meeting our minimum requirement. These parts constituted approximately one-seventh of the total number of airframe line items demanded, and about two-thirds of the total number of transaction entries, as well as two-thirds of the total quantity of demand. We used 100 of these parts (about 40 per cent) for case studies of the demand distribution by weeks.

Some examples may serve to illustrate the weekly pattern of demand for the items in the sample. Part No. 1AFE 15-24377-27 (a boost assembly —elevator control), the unit cost of which was about $800, showed a total demand of 60 units over the period. Since this part replaced Part No. 1AFE 15-24377-20 and was, in turn, replaced by Part No. 1AFE 15-24377-504, we also took account of a demand for 1 unit of the former and 24 units of the latter.* The total demand for 85 units for the three interchangeable parts was distributed over the 65 weeks in the manner illustrated by Fig. 3. The listing on page 21 shows the number of weeks in which 0, 1, 2, 3, 4, and 5 units of the part were demanded.† This part is one that appears to be demanded in single units, and only 1 unit was

each requesting 15 units, with two transactions occurring on each of 3 days. The demand information is that 30 units were required on March 31, 1952; 30 units on July 29, 1953; and 30 units on August 21, 1953. Four months elapsed between the first and second demands, and three weeks between the second and third.

In the case of the seal, the 92 units demanded involved 59 transactions. Two transactions occurred on each of 7 days, so that there were 52 days in which a demand for the seal occurred. There were 48 different aircraft that were designated as the users of these parts. In general, the demand was for only 1 unit for an aircraft on a given date. The seal is regarded as a faster-moving part than the washer, although the demand is for an equivalent number of units.

*The effect of interchangeability and substitutability in the demand for spare parts is graphically illustrated by this part. Obviously very good information on interchangeability and substitutability must be available in order to obtain valid demand rates for parts.

†We did not know the number of weeks for which the true demand for this part was zero. We estimated that number by counting the weeks in which no demand was reported, although aircraft to which the part was applicable were on the base, and demands for other parts were being reported.
Fig. 3—Distribution of demand for selected spare parts over a 65-week period (MacDill Air Force Base, October, 1952–December, 1953)
demanded in any 1 day for a particular aircraft.* The mean demand at the two-wing base was about 1.3 units per week. During 23 of the 65 weeks studied, the demand was above the mean, i.e., 2 units or more.

Figure 3 shows the observed weekly demand distribution of five airframe parts, some of them fairly expensive. Three of these parts (the first, second, and third) had average weekly demands of about 1 unit; two of these parts (the fourth and fifth) had average weekly demands of about 2 units. But the pattern of weekly demands differed greatly. Item 1 was demanded rarely, in many weeks not at all; but in the week before the last, it was in extraordinarily heavy demand. Item 2 was demanded at a less uneven rate, yet still quite irregularly; item 3 was perhaps the least irregular of the lot. Item 4 had most of its fairly high demand (1.7 units per week) concentrated in a few weeks, or sequences of weeks, while item 5 was demanded in most weeks of the period.

Undoubtedly these fluctuations reflect many causes of more or less random nature. It was not possible, and not essential, for us to track down these causes. The essential point is that demand for these parts does not appear as a smooth and even flow over time. Instead, it fluctuates widely from week to week. The function of the logistics system is to contend with these demands so that total effectiveness of the system is made as great as possible within the budget limitations.

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*There are parts that are usually demanded in multiples (say, 6 units) because of multiple installations on an aircraft. The demand for parts showing such a pattern may have to be studied in multiple units (say, with 6 units being counted as one demand).

*On December 23, as many as 50 units were requested for a single aircraft.
IV. PREDICTING DEMAND

An important reason for collecting demand data is to use past experience to help us to predict future demand. Prediction is an essential part of an efficient logistics system because it takes time to order, produce, and deliver material. The U.S. Air Force must make a prediction of what the demand for a part will be every time it places an order for that part. The longer the pipeline periods, the longer the period over which the prediction must be made.

The accuracy of the prediction influences the cost of supply to the system. If the prediction considerably overstates future demand, and as a result little of the quantity ordered is ever used, then the cost is raised through unnecessary stockage, obsolescence, etc. On the other hand, if the prediction considerably understates future demand, and as a result the stock is too small to satisfy the demand, then the cost to the system is raised by the loss of utility of the aircraft for which the stock was procured: it may be out of commission for parts. In either case, inaccurate prediction of demand means higher system costs.

PROBABILITY CHARACTERISTICS OF DEMAND

The demand data shown in this report testify to the variability of demands from week to week, which makes prediction so difficult. Since this variability seems to be characteristic of the demand for aircraft parts, it should be considered in the calculations of requirements, distribution, procurement, repair of spare parts, etc.

The variability of demands can sometimes be characterized by a probability distribution. We cannot say that the demand next April will be for 3 units of Part x; but we may be able to say that there is a 15 per cent chance that the demand will be zero, a 15 per cent chance that it will be 1 unit, a 20 per cent chance that it will be 2 units, a 25 per cent chance that it will be 3 units, a 15 per cent chance that it will be 4 units, and a 10 per cent chance that it will be 5 units. This kind of statement
represents a probability distribution. It recognizes that one cannot say exactly what the demand will be, but it is useful in estimating future demand.

The statistical study of how to predict future demand involves, first, deciding what the form of the probability distribution should be, and, secondly, finding the value of the parameters* that define the specific distribution to be used. The study of the form of the distribution involves taking past historical data on individual parts and trying to fit known statistical probability distributions to them. Later, we describe how we go about fitting such distributions and the results of some fits.

Of course, we require a reasonably large number of observations in order to fit curves, and if demand in most of the weeks is zero, it is not possible to fit a curve. This situation applies to most aircraft spare parts, as we have already said. Fortunately, it is much less important to have the exact form of the probability distribution for low-demand parts. But in the cases in which curves can and should be fitted, it is necessary that the observations be not only numerous, but generated under uniform circumstances. That is to say, the data should be homogeneous.

Now this condition is never fully realized, and the parameters estimated from the data, such as the average demand to be expected, are therefore likely to reflect changes in the quality of the part, in the mechanics' ability to repair it if it needs adjustment, or in the level or kind of activity in which it has been used. One of the reasons that we express demand predictions as probability distributions is to absorb some of the uncertainties about these factors in the future; but where possible, the accuracy of our predictions and the consequent validity of the supply decisions should be increased by the anticipation or identification of changes in the parameters. Among the indexes that are often used to predict changes in parameters are flying hours, aircraft-months, etc. As is described below, we have made limited progress in finding relationships that may help to predict such parameters. However, much remains to be done, and it is fair to

* A 'parameter' is a number used in the mathematical expression of a probability distribution to identify a specific distribution. The mean is an example of a parameter that occurs in many different kinds of probability distributions. This—in our case average demand—must be assigned a definite numerical value before the probability that the demand will be 0, 1, 2, etc., can be computed for the part.
say that the determinants of change in the demand parameters are largely unknown at this time.

USE OF POISSON DISTRIBUTION TO CHARACTERIZE DEMAND

One of the well-known forms of a probability distribution, called the Poisson distribution, has been used for many years, particularly in failure-data work.* This distribution has been found to fit well the data for times-to-failure of electron tubes in electronic equipment and the frequency of breakdowns of industrial machines. In an earlier study we found that the Poisson distribution also fits reasonably well the demand pattern over time for a number of individual B-47 airframe spare parts.† Later in this report, we shall give results of further fittings of the distribution to B-47 airframe data.

We shall now illustrate the use of the Poisson distribution in predicting demand and guiding stockage decisions. Figure 1 (page 12) depicted the frequency distribution of B-47 parts according to the number of demands. In this figure there were, for instance, 46 line items, each of which was demanded 29 times during 1300 aircraft-months. This is equivalent to an average demand rate of 1.0 unit per month, by a single wing.

If each of these 46 parts had a demand distribution of the Poisson type, it would look like the distribution shown in the second column of Table 2, which is the Poisson distribution with an average demand of 1 unit per wing-month. As can be seen, an item with an average demand of 1 unit per wing-month is subject to some variability. There are months when the part is not demanded, when 1 unit is demanded, or when 2 units are demanded, etc. The probabilities with which these monthly demands occur are shown in the second column. These probabilities may be interpreted as relative frequencies—i.e., in 368 out of 1000 wing-months,


Demand for Aircraft Spare Parts

Table 2
Demand Distribution of Spares with an Average Demand of 1 Unit per Wing-Month and Expected Supply Results Under Three Stockage Policies

<table>
<thead>
<tr>
<th>Number of Units Demanded</th>
<th>Probability of Demand</th>
<th>Number of Units Stocked</th>
<th>Expected Supply Results</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Surplus</td>
</tr>
<tr>
<td>0</td>
<td>.368</td>
<td>None</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>.368</td>
<td>One each line item(^b)</td>
<td>17</td>
</tr>
<tr>
<td>2</td>
<td>.184</td>
<td>Two each line item(^c)</td>
<td>51</td>
</tr>
<tr>
<td>3</td>
<td>.061</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>.015</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>.003</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>.001</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^a\) An average demand of 1 unit per wing-month is equivalent to 29 units demanded in 1300 aircraft-months. There were 46 line items in Fig. 1 which experienced that demand.  
\(^b\) 1 month's supply.  
\(^c\) 2 months' supply.

The demand for the part will be zero; in the same number of months, 1 unit; in 184 months, 2 units; etc. The probabilities shown are for a single item, but each of the 46 different spare parts is subject to the same probability distribution.

The right-hand part of the table shows the effects of this demand pattern upon expected supply results in a given month under three stockage policies, namely, (1) stock none, (2) stock 1 unit, and (3) stock 2 units of each line item. Under a stock-none policy, the expected number of shortages will be 46. This does not mean that each spare part will have a shortage of 1 unit, because some parts will not be demanded at all and others will be required in quantities of 2, 3, 4, or more units, as is to be expected from the probability distribution. It is the sum of the shortages over the 46 parts which will total 46 units.

If 1 unit of each of the 46 parts were stocked, Table 2 indicates that 29 units would be consumed, 17 units of demand remain unsatisfied, and 17 units would be surplus, on the average. The expected shortages in this instance total 37 per cent \(17\frac{1}{4}\%\), which is fairly high. Thus, stocking the average monthly demand (1 unit) results in shortages of some parts and surpluses of others.
Since the demand for one of these parts during a month can differ from average demand, it may seem desirable to stock 2 units of each part in order to reduce the number of shortages. If 2 units of each part were stocked, there would be only 5 shortages, on the average, or less than one-third of the previous amount. Fifty-one units, however, would now be surplus, which is three times the number of surpluses found when 1 unit was stocked. This is an inevitable result, and, in deciding how much to stock, we presumably weighed the cost of greater stocks against the value of reduced shortages.

The distribution given in Table 2 was the hypothetical Poisson distribution for a situation in which the mean demand is 1 unit per wing-month. In Table 3 we show probability distributions fitted to the actual demand experience of three of the parts that were described in Fig. 3. These parts have demand distributions that seem to agree with the Poisson distribution. We show the theoretical Poisson distribution alongside the observed demand frequencies, to indicate the goodness of fit. In the next section we shall discuss how the suitability of the Poisson formula for an observed distribution can be determined and how many of the parts tested were well fitted by such a distribution.

FITTING THE POISSON DISTRIBUTION TO OBSERVED DATA

The way we determine whether a particular demand pattern has a Poisson distribution is to take the observed number of demands over time (e.g., so many weeks), and prepare a frequency distribution giving the number of weeks with zero demands, the number of weeks with one demand, etc. This frequency distribution is then compared with a Poisson distribution which has the same average number of demands per week. If the two distributions agree closely, then we can say that the mathematical formula for the Poisson distribution fits the observed data well. Other probability distributions can be fitted in the same way.

This technique has been applied to the demand experience for the 100 selected B-47 airframe parts for which we had sufficient experience to permit testing for the probability distribution that might describe their pattern of demand. As a result of this study, we found that the demand
### Table 3

**OBSERVED FREQUENCIES OF DEMAND COMPARED WITH DERIVED POISSON DISTRIBUTIONS**

Three B-47 Airframe Parts, MacDill Air Force Base
(65 weeks)

<table>
<thead>
<tr>
<th>Item</th>
<th>Units Demanded Per Week</th>
<th>Number of Weeks Observed</th>
<th>Poisson</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seal: $3 each (1AFE 15-24548-501)</td>
<td>0</td>
<td>48</td>
<td>46</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>12</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>2</td>
<td>3(^b)</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>2</td>
<td>..</td>
</tr>
<tr>
<td></td>
<td>50(^c)</td>
<td>1</td>
<td>..</td>
</tr>
</tbody>
</table>

**MEAN DEMAND PER WEEK:**

- **0.3\(^c\)**

<table>
<thead>
<tr>
<th>Dome assembly: $610 each (1AFE 4-2608-826)</th>
<th>Units Demanded Per Week</th>
<th>Number of Weeks Observed</th>
<th>Poisson</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>33</td>
<td>26</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>17</td>
<td>24</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>7</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>5</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>1(^d)</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>..</td>
<td></td>
</tr>
</tbody>
</table>

**MEAN DEMAND PER WEEK:**

- **0.9**

<table>
<thead>
<tr>
<th>Boost assembly—elevator control: $800 each (1AFE 15-24377-27, and substitutes -20, -304)</th>
<th>Units Demanded Per Week</th>
<th>Number of Weeks Observed</th>
<th>Poisson</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>20</td>
<td>17</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>22</td>
<td>23</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>13</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>5</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>3</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>2</td>
<td>1(^e)</td>
<td></td>
</tr>
</tbody>
</table>

**MEAN DEMAND PER WEEK:**

- **1.3**

---

\(^a\) Computed by assuming that the observed mean demand per week is the mean of the Poisson distribution.

\(^b\) 2 units or more.

\(^c\) A demand of 50 units by a single aircraft was recorded on December 23, 1953. The mean used to fit the Poisson distribution (0.3) was obtained omitting this demand.

\(^d\) 4 units or more.

\(^e\) 5 units or more.
patterns for these 100 parts might be classified into the following four groups:

1. **Group A** comprised parts that seemed to be demanded in single units. From available engineering data, these seemed to be parts for which there was only one installation on the aircraft. Further, only 1 unit of such parts was demanded in any one day for a particular aircraft. We fitted the Poisson distribution to the observed data for these parts, using the mean demand per week as calculated from the sample, and found that the fit was satisfactory.* About 70 of the 100 selected parts of the airframe class appeared to belong to this group. Part No. 1AFE 15-24377-27, -20, -504, a boost assembly—elevator control described on page 19 and in Fig. 3, is illustrative of parts in Group A.

2. **Group B** consisted of parts for which the demand occurred in multiple units per aircraft. Frequently the multiple unit was 6. Investigation of some of these parts revealed that they were used in multiple installations on the aircraft. For example, some parts had 18 installations, others had 24.† Part No. 1AFE 3-40666, a washer, illustrates this type of part. There are 18 installations per aircraft; and since the demands for the washer occurred in multiples of 6 units per aircraft, it was inferred that the maintenance procedure at the bases studied was to replace 6 units at a time. If we think of 6 units as constituting a demand of 1 unit, 12 units a demand of 2 units, etc., the Poisson distribution will fit the observed frequency distribution. About 9 of the 100 airframe parts investigated had this demand characteristic.

3. The parts in **Group C** have a demand characteristic that might have been generated by a scheduled maintenance policy. Demands seemed to occur in clusters and more or less periodically. The Poisson distribution did not fit the data well. For these parts, however, it should be relatively easy to anticipate demand. Each has been treated in its own characteristic cyclical pattern. The gasket, Part No. 1AFE 3-40509-1 (shown in Fig. 3),

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*Tests for independence of demand over time were not made with these parts; but earlier studies of similar parts indicated that they were not serially correlated. (See Bernice B. Brown and M. A. Geisler, *Analysis of the Demand Patterns for B-47 Airframe Parts at Air Base Level*, The RAND Corporation, Research Memorandum RM-1297, July 27, 1954.)

†We observed that in a particular aircraft series, the number of installations of some of the parts was changed as production of the aircraft proceeded. This indicates another complication encountered in analyzing demand data.
may be characteristic of the demand pattern found for this group of parts. Altogether, 5 of the 100 parts showed this kind of pattern.

4. **Group D** (like Group C) consisted of parts for which the Poisson distribution did not fit—in this case because of the long tail on the right-hand side. This means that in certain weeks unusually large demands occurred for the parts, more than could be accounted for by the Poisson distribution. For some of these parts, we found that the variance* was eight or ten times as much as the mean demand. Some other probability distribution, permitting a significant difference between mean and variance, would have to be used to describe this pattern. About 16 of the parts studied appeared to belong to this group. The canopy, Part No. 1AFE 4-1850-561 or -601, had a demand pattern characteristic of the one found for the parts in Group D. (This is shown in Fig. 3.)

To summarize the results of our study of B-47 airframe parts: About 85 per cent of the more than 1800 parts for which there was demand at MacDill had such low demands that it was impossible to judge their probability distribution. But the exact form of the probability distribution does not affect appreciably stockage policy for these parts.

Of the remaining 15 per cent of the parts, the majority (in the case study, 79 out of 100—i.e., Groups A and B) seemed to have demand patterns over time that can be described by the Poisson distribution. For these parts, statistical demand analysis has something to contribute to stockage policy. It aids in setting stockage policy by determining the probability of shortages for alternative stockage levels.

For the smaller part of the 15 per cent (i.e., Groups C and D of the case study), demand prediction would have to rely on probability distributions other than the Poisson—perhaps on the empirical distributions observed in the past, or, in some cases, on information regarding scheduled maintenance work.

The more than 1800 airframe parts for which there was demand at MacDill had a total value of issues of $5.0 million over 29 months. The 258 fast-moving parts—by no means all high-cost items—had $3.1

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*The "variance" is a measure of the variation of the individual observations about the mean. In the Poisson distribution, the mean and the variance are equal.

* The negative binomial distribution appears to be suitable.
million of issues, and the 100 parts singled out had $2.1 million of issues. Group A—i.e., the parts for which demand could be fitted by a Poisson distribution—accounted for about 90 per cent of the last figure. It appears that a substantial fraction of the dollar value of issues of airframe parts pertain to items for which the demand can be estimated with the help of Poisson distributions.

Painstaking demand analysis is, of course, especially needed where high-cost items are involved. Attempts to fit probability distributions to demand data are most likely to be of interest in the U.S. Air Force "Hi-Valu" Requirements Program that is aimed at these items. Our study cannot say that most of the high-cost items are likely to have demands that follow the Poisson pattern. But it indicates that many do, at least in the airframe class.

DEMAND AND FLYING ACTIVITY

The management of aircraft spare parts makes prediction of demand necessary, be it for the purpose of setting distribution levels (reorder points and stock control levels), computing requirements (procurement and repair), or estimating future aggregate workloads, such as for transportation scheduling or requisitioning.

In making demand predictions, programmed flying hours or aircraft-months are commonly used as guides. The statistical data available permit us to appraise the validity of this procedure for distribution and aggregate-workload calculations, but they do not permit an appraisal of the procedure for requirements calculations. The sample of data is really too small to permit very broad conclusions to be drawn, but the results are of interest.

Our data give the experience of 291 B-47 aircraft over the period from September 1, 1954, to September 30, 1955. Not all aircraft were in the report over the entire 13 months of this period. For each aircraft, we have the total number of months it appeared in the report, the number of flying hours it accomplished during this time, and its total demand for each line item in the B-47 airframe property subclass.

In order to provide enough numerical values with which to analyze the correlation between demand and flying activity, our study is confined
to those 193 line items (out of the more than 1700 B-47 airframe parts in the report) that were requested by at least ten different aircraft. Even so, the demands for almost all of these 193 parts by each aircraft was quite low, seldom ranging above 10 to 15 units for a given line item. The aircraft themselves ranged in flying hours from fewer than 10 hr to more than 500 hr during the report period.

As one might expect, we found a strong correlation between the number of months each aircraft was in the report and the number of flying hours reported for it, with correlation coefficients ranging from 0.85 to 0.95. This means that any finding concerning the relation between demand and flying hours among the aircraft also applies to demand and number of months.

We correlated the total demand by each aircraft for a given line item with the total hours it flew during the reported period. For the 193 parts studied, the data did not reveal a perceptible linear relationship between demand and flying hours or aircraft-months. This result means that for the range in hours flown per aircraft over the period (up to approximately 500 hr), aircraft with a longer history of flying hours do not tend to have higher demands for a particular part than aircraft with shorter histories. The same negative result was found in correlating demand with the number of months that the aircraft was observed. On the other hand, the variability in demand that can occur under a Poisson distribution is so large, particularly for the low demands involved for the airframe parts studied, that it may mask whatever underlying relationship may be present. In other words, these data do not permit us to say with assurance whether or not a relationship exists. These remarks apply only to so-called distribution or stockage policies, because the history-length of the data on which these results are based is at most 13 months, and because we were studying demand at only one base.

Very often, the stockage problem is to decide whether 0 unit or 1 unit of a given low-demand item should be stocked. In these cases, it makes little difference in the final result whether or not flying hours or aircraft-months are used to predict demand. However, for the few medium- or high-demand items, it may make a big difference in the resulting stock level or reorder point whether or not flying hours or aircraft-months are
used to predict demand. In such instances, judgment and experience will have to be used to decide to what extent flying hours and aircraft-months should influence the demand prediction.

We also correlated the hours flown by each B-47 aircraft in the reporting period with the total number of airframe parts demanded by that aircraft. We found a correlation coefficient of 0.6, which is a significant correlation. This would indicate that the more hours flown by an aircraft over time (and equivalently the more months the aircraft is in the inventory), the greater will be its demand for airframe parts as a whole. This implies that the aggregate demand per aircraft per flying hour or per month tends to be uniform, and this may be a useful index for projecting transportation or requisitioning workloads.

To summarize, flying hours do not appear to offer a useful guide for projecting demand per aircraft for distribution purposes. They offer some guidance for transportation or requisition workload scheduling. The data available for this analysis were limited in scope and offer no more than a basis for tentative conclusions; but since these questions are of much interest in logistics planning, it seemed appropriate to include the findings in this report.

DEMAND EXPERIENCE AND PROVISIONING OF SPARE PARTS

A significant fraction of the initial provisioning of an aircraft model occurs before it goes into production. Obviously, there exists no operational experience with the aircraft at such a time, so that demand estimates can only be based on guesses, possibly guided by past experience with similar parts on earlier aircraft. This difficulty results directly from the early provisioning procedure and cannot be avoided if spare parts are to be delivered concurrently with the aircraft from the very start.

There are ways, however, of alleviating the difficulty. It should be possible to gather some demand data from the experience gained in testing engines, other components, and prototypes of the new aircraft. It should also be possible to gain data from the early experience of the first squadron in operation. Such data would in all probability be insufficient to predict future demand with any degree of confidence. Yet they might
permit a tentative sorting-out of parts into broad demand categories—fast moving and slow moving. The collection of early-experience data, therefore, might help not only in guiding further provisioning but also in developing a basis for fuller studies of demand.

As aircraft are delivered and assigned to the operating units, demand experience begins to accumulate. This demand experience can be used to make predictions of future needs. For most parts, a large amount of experience is required to estimate demand with reasonable precision. Consequently, it takes time to gain sufficient experience, and, meanwhile, further provisioning, or follow-on procurement, may have to be undertaken in the face of great uncertainty regarding future demand. The mere length of the data-gathering time, moreover, is not the only factor that counts. The experience reflected in the data must be homogeneous. If it is not—e.g., because of changes in parts or changes in operating procedures—it cannot be cumulated for the purpose of obtaining a good basis for prediction.

The statistical uncertainty we are discussing is, of course, only one of the problems that complicate procurement. Uncertainties as to program changes, such as changes in number and types of aircraft in the system, engineering features, etc., add to the difficulty of making demand predictions that can be useful for procurement decisions.

**EFFECT OF DISPERsal ON DEMAND PREDICTION**

The vulnerability of fixed air bases to atomic attack creates a need for dispersing aircraft. The dispersal can have a significant effect upon the problems of predicting future demand for spare parts at the scattered locations, if each location has its own logistical support. The low demands typical of most parts may become even lower if fewer aircraft are to be supported at each of the dispersed sites than were supported at the original single site.

The prevailing patterns of demand clearly indicate that it is necessary to use a long period of homogeneous experience in order to predict future demand with any accuracy. If we have the experience needed to make predictions, the relevance of the predictions will depend on the organization of the supply system. In the present section we shall discuss how
predictions that may be relatively safe for large logistical support units serving a certain number of aircraft can become unsafe if applied mechanically to small logistical support units serving the same number of aircraft dispersed over several locations.

Since we have no actual demand data from dispersed locations, we have created a synthetic illustration of what might happen, using three assumptions: (1) that the demand for parts is homogeneous for aircraft at the differing locations; (2) that the demand distribution can be described by the Poisson formula; (3) that the Poisson parameter is proportional to the number of aircraft being supported. If the squadrons of a wing, along with their logistical support, are dispersed to three locations, and the aircraft of the squadrons (again with the necessary logistics support) are in turn dispersed to nine locations, greater stockage will generally be required to provide the same degree of assurance against shortages at each location.

Suppose a B-47 wing is located at one base, and demands are reported by each squadron separately. Squadron 1 reported that it used 11 units of a certain part in a 6-month period; Squadron 2 used 13 units; and Squadron 3, 12 units. Added together, the demand for this part was 36 per wing in 6 months. Let us assume that the demand for the part is homogeneous for the three squadrons, that the Poisson distribution describes the demand pattern, and that we need consider only chance variations and the caprices of sampling.

If we now predict that the mean demand for the next 6 months will be 36 units, as observed in the previous 6 months, and stock an amount equal to this mean demand, we can expect two shortages at the one base.* If we are more conservative and stock 45 units, the expected number of shortages will be less than ½ unit.

Now suppose the three squadrons of the wing are dispersed to three locations. Demand experience remains the same. Each squadron has its own logistical support, and the wing's stock is distributed equally among

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*The expected number of shortages is computed by summing the products of two components: (1) the number of units short if \( x \) is demanded and \( s \) is stocked, and (2) the probability of the occurrence of a demand for \( x \) units. These products are summed for all \( x \) greater than \( s \).
the three locations. If we stock 36 units (12 at each location), we can expect four shortages. Even if we stock 45 units, we can expect one shortage.

If, finally, we let each of the three squadrons be dispersed and have nine locations that share equally in the wing's stock of parts, we may expect seven shortages of the part if we stock 36 units over-all (3 at each location), four shortages if we stock 45 units, and two shortages if we stock 54 units, as shown in Table 4.

<table>
<thead>
<tr>
<th>Location of Logistical Support</th>
<th>Expected Number of Shortages for the Wing as a Whole</th>
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<tbody>
<tr>
<td>At 1 location (no dispersal)</td>
<td>Stock 36</td>
</tr>
<tr>
<td>At 3 locations (wing dispersed)</td>
<td>2</td>
</tr>
<tr>
<td>At 9 locations (squadrons dispersed)</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>7</td>
</tr>
</tbody>
</table>

The same experience can be expressed in this way: Suppose that for a single location we felt safe enough stocking 45 units of the part; then we would have to distribute a total stock of 54 units over three locations, or 72 units over nine locations, to achieve the same degree of safety in each case. Dispersal of logistics support in conjunction with the dispersal of aircraft thus imposes a definite handicap on demand prediction and correlated stockage policy.

A further complication arises from dispersal that is not evident from the illustrative problem. In the illustration, we assumed in effect that a mechanism existed for pooling the demands for the separate locations in determining the stockage for each of them. Such pooling requires a communications and data-processing system that can transmit and compute the data. Substantial work on such a system has been conducted both in the U.S. Air Force and at RAND.* As long as no efficient system is in use,

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capable of pooling demand information in a timely way, each of the locations must function as separate entities, using its own demand experience in determining its stockage. This means that each location must have an even larger stock to achieve the same protection described in the illustration above. In addition, the absence of adequate communications and data processing will hamper whatever sharing of stock may be possible among the separate locations.
V. CONCLUDING REMARKS

This report has been concerned with the difficulty of predicting demand. The data presented have been more accurate than most data available, and the situations discussed have been much more stable than those often encountered. Despite the numerous difficulties, there is much that can be done to combat the uncertainty of demand or, at least, to overcome its effects.

In the Summary and Conclusions at the beginning of this report, we described a number of things that could be done to combat this uncertainty of demand. Since most of the parts are low in demand and unit cost, adequate stocking of these parts at sites of possible demand would do much to reduce the risk of shortages for such parts. This action would not involve a particularly large additional investment in spare parts and would not require a long time to accomplish.

Additional ways of overcoming difficulties of predicting demand involve making the logistics system more responsive. These ways would include shortening the resupply time, reducing the time cycle for repair of components, and reducing the procurement lead time. Such measures might require major changes in logistics structure and policy; consequently, they would take time to effect. But they do affect the items that dominate the U.S. Air Force investment in spare parts.