U. S. AIR FORCE

PROJECT RAND

INFLUENCE OF RESOURCE AND POLICY CHANGES
ON AIRCRAFT CAPABILITIES

Chauncey F. Bell

R-382

March 1, 1961

MANUSCRIPT COPY NO._____

Assigned to_____

This research is sponsored by the United States Air Force under contract No. AF 49(638)-700 monitored by the Directorate of Development Planning, Deputy Chief of Staff, Development, Hq USAF.

This is a working paper. It may be expanded, modified, or withdrawn at any time. The views, conclusions, and recommendations expressed herein do not necessarily reflect the official views or policies of the United States Air Force.

The RAND Corporation
1700 MAIN ST. • SANTA MONICA • CALIFORNIA

SUMMARY

The capabilities of manned-aircraft weapon systems are extremely sensitive to operational and support policies and resource allocations at base level. For this reason RAND has conducted studies of the interactions between maintenance and operations over the past several years, seeking to further the understanding of the tradeoffs among policies and resources and to apply this knowledge to specific support problems of concern to the Air Force.

This Research Memorandum presents the methods and principles that have evolved from our research to date. They have a wide applicability and should be of value to operations and support personnel engaged in planning organizational capability and resource requirements, or modifications thereto, regardless of weapon system, and also to management personnel at base level who are operating and supporting manned aircraft. The general presentation should also be useful in educating new personnel.

The principal method employed to examine the effects of changes in policies and resources has been a machine-simulation technique developed in the course of our research. The outputs of the simulation have been checked frequently against Air Force experience to insure that they are reasonably pertinent and accurate. In this Research Memorandum, a hypothetical squadron of aircraft is used as the vehicle for studying the effects of different policies and resources on operational capability. At first, operational policy changes and their effect on capability are systematically examined. A similar examination then follows, dealing with maintenance policies and changes in numbers of aircraft in an organization, numbers of direct maintenance personnel in the squadron, quantities of aerospace ground equipment, and spare parts.

The maintenance personnel are considered in terms of work priority, skill levels and cross training. Maintenance-management responsiveness is also discussed.

Following the point-by-point examination of the effects of individual policies and resources on operational capability, the study takes up the problem of selecting particular policies and resources in the light of cost and manpower limitations as well as strategic and tactical matters. Finally it deals with problems of new weapon systems phasing in, and those phasing out.

This comprehensive review, both by item and as a whole, establishes a number of principles which are particularly important in planning for and managing aircraft weapon systems. These are summarized below:

(1) Operational readiness is strongly influenced by the flying program. Flying which is unnecessary for sustaining aircrew proficiency or meeting alert requirements degrades readiness substantially.

(2) The relationship between the flight schedule, which generates demands for maintenance, and availability of maintenance personnel, is an important one which should receive careful consideration in establishing both flight and maintenance workshift schedules.

(3) With normal or heavy flying activity, a multiple workshift policy for maintenance personnel is one of the most effective ways of maintaining high operationally ready rates.

(4) The number of aircraft in a first-line squadron or wing should be determined primarily by strategic and tactical operational requirements, rather than by logistics considerations.

(5) In determining maintenance-manning requirements, the priority of workload requirements must first be defined. Work necessary to make aircraft

operationally ready or alert should have precedence over the repair of parts which are to be returned to stock. Ordinarily it will be found that when manpower requirements are established for the first-priority work, sufficient man-hours will be left over to perform lower-priority work.

(6) The degree of management responsiveness in the use of resources has a great influence on the quantities of resources needed to support an operational program. Even more important is its effect on the speed with which the weapon system is returned to readiness. No other area offers so powerful an approach toward maximizing operational capability.

(7) Weapon systems phasing into the inventory have problems so different from those of mature first-line weapons that they warrant separate planning factors.

(8) Weapon systems passing from first-line to phase-out status have cost characteristics which warrant changes in the resource allocations.

CONTENTS

SUMMARY iii

Section
I. INTRODUCTION 1

II. METHOD OF ANALYSIS: MACHINE SIMULATION VERSUS SERVICE TESTS .. 3
Machine Simulation 3
Service Tests 9
Future Weapon Systems 11

III. EFFECTS OF CHANGES IN POLICIES AND RESOURCES 13
Operational Policies 14
Changing the Flying Program 14
Number of Sorties 14
Length of Sorties 17
Scheduling of Sorties 17
Changing the Ground Alert Requirement 21
Maintenance Policies 24
Changing the Workshift Policies and Times of Work 24
Changing the Scheduled Workload Requirement 28
Improving the Weapon 28
Resources 30
Changing the Number of Aircraft in the Organization 31
Changing the Manning Tables 35
Priority of Work 37
The Specialty Mix 38
Degree of Skill and Cross-Training 39
Changing Quantities of Aerospace Ground Equipment (AGE) and Spare Parts 41
Management Responsiveness in the Use of Resources 42
Cumulative Effects 44

IV. OPTIMIZING UNDER CONSTRAINTS 47
The Tradeoffs 47
The Constraints 52

V. RESOURCES MIX AND WEAPON-SYSTEM MATURITY 53
First-Line Aircraft 53
Future Aircraft and Those Phasing In 55
Aircraft Being Phased Out 56

VI. CONCLUSIONS 59

REFERENCES 63

FIGURES

1. Flow of Aircraft Through Maintenance in Simulation Model 5
2. Effect of Sortie Activity on Operationally Ready Rate 15
3. Effect of Sortie Length on Operationally Ready Rate 18
4. Effect of Flying Schedule on Operationally Ready Rate 20
5. Effect of Alert Requirement on Operationally Ready Rate 23
6. Effect of Workshift Policy on Operationally Ready Rate 26
7. Effect of Workload on Operationally Ready Rate 29
8. Effect of Squadron Size on Sortie Rate and Number of Aircraft Operationally Ready: 26 vs 25 Aircraft Squadron 33
9. Effect of Squadron Size on Sortie Rate and Number of Aircraft Operationally Ready: 75 vs 25 Aircraft Squadron 36
10. Effect of Quantity of Maintenance Personnel on Operationally Ready Rate 40
11. Effect of Supply or AGE Shortages on Operationally Ready Rate 43
12. Effect of Flying Program on Aircraft Status 45
13. Effect of Direct Maintenance Personnel Changes on Sortie Activity and Operationally Ready Rate: 25-Aircraft Squadron 48
14. Sortie Capability and Cost Versus Direct Maintenance and Manpower: 25-Aircraft Squadrons 50
15. Sortie Capability and Cost Versus Direct Maintenance Manpower for Several Squadron Sizes 51
16. Hypothetical Threat-Intensities for Fighter Bases Along U. S. Periphery 54

I. INTRODUCTION

For several years The RAND Corporation has been studying the effects of base-level maintenance policies and resources on the operations of manned aircraft, as well as the effects of operational requirements and policies on base maintenance. A number of previous Research Memoranda* have described specific aspects of this work; the object of this Research Memorandum is to present the methods and principles that have emerged, in such fashion that they may be of general value in connection with policy, planning, and procedural decisions in today's environment, and for educational purposes. A hypothetical organization and a general schematic approach are used for this purpose. The generalized approach is based on the specific findings of a great deal of empirical work.

Section II describes the method of research analysis and the place such a method may have in establishing policies and procedures as compared to more conventional service testing. Section III studies the effects of changes in the operational and materiel policies and resources which have been examined in the research, looking at each change systematically, one at a time. Section IV deals with the problem of selecting preferred combinations of policies and resources, recognizing that there may be constraints on money and manpower availability. Section V considers the effect of weapon-system maturity on the mix of resources as the final step in determining preferred organizations and postures.

---

*See "References," p. 63.

II. METHOD OF ANALYSIS: MACHINE SIMULATION VERSUS SERVICE TESTS

MACHINE SIMULATION

The principal method of analysis used in this research is the simulation, on paper and with an electronic computer, of the activities of an aircraft squadron or wing. In a very real sense we have conducted tests of both current and future weapon systems, in order to study the effects of changes in operational and materiel policies and resources. To do this, it has of course been necessary to measure, or estimate, the relevant characteristics of the type of aircraft being tested, and to introduce into the simulation the operational environment, the operational and maintenance policies, and the materiel resources which are a part of the organization to be tested.

To help explain this method, and to illustrate the methods and principles which will be discussed, we will use a hypothetical base which operates a squadron of 25 interceptor aircraft, the latest version of a first-line aircraft. During a time of uneasy peace, the squadron is required to maintain a small number of these aircraft, together with standby maintenance crews and aircrews, on very short alert notice, and to maintain an additional number of aircraft on backup alert. From time to time the alert aircraft are "scrambled" to inspect unknown aircraft or to perform exercises of one kind or another. The backup aircraft must then move into their places to continue the alert protection. Still other aircraft must be flown each day to provide the flight training needed to maintain aircrew proficiency at a high level, since ready aircraft are useless without ready aircrews. All of this operational activity generates demands for logistic support. On landing from a flight, aircraft will need servicing to ready them for their next flight. Frequently pilots will report, or after-flight inspection will reveal,

discrepancies or malfunctions in some of the many complex systems of the aircraft. To return the aircraft to in-commission or operationally-ready status will require combinations of spare parts, test or handling equipment, and maintenance personnel of particular skills and skill levels. On occasions, the records will show that it is time to conduct a major, or periodic inspection; to replace a component which is still operating satisfactorily but may be worn and hence less reliable than a new or reconditioned part; or to incorporate a modification.

Figure 1 presents a schematic view of what one might see going on at the base at any point in time. Some aircraft are awaiting service or being serviced. Others are available for flight, including those assigned to alert or backup alert.

One may be at the end of the runway, about to attempt to fly. Not all attempts to fly are successful; occasionally there is a ground abort, due to some malfunctioning system which must be corrected. Other aircraft may be flying, either for training or because of a "scramble" order.

When an aircraft lands after a flight, it can enter one of three categories. If it has no malfunctions, it needs only servicing to be available again for flight. If it requires scheduled maintenance, it may have to wait for dock space, may again have to wait for the proper mechanic, piece of equipment, or spare part, and will be further out of commission during actual repairs. Servicing will then make it available for flight. Or thirdly, the aircraft may require unscheduled maintenance to correct maladjustments or malfunctions. Again, there may be a delay while it waits for the proper mechanic, equipment, or spare part, and more out-of-commission time during repairs, before servicing can make it available for flight.

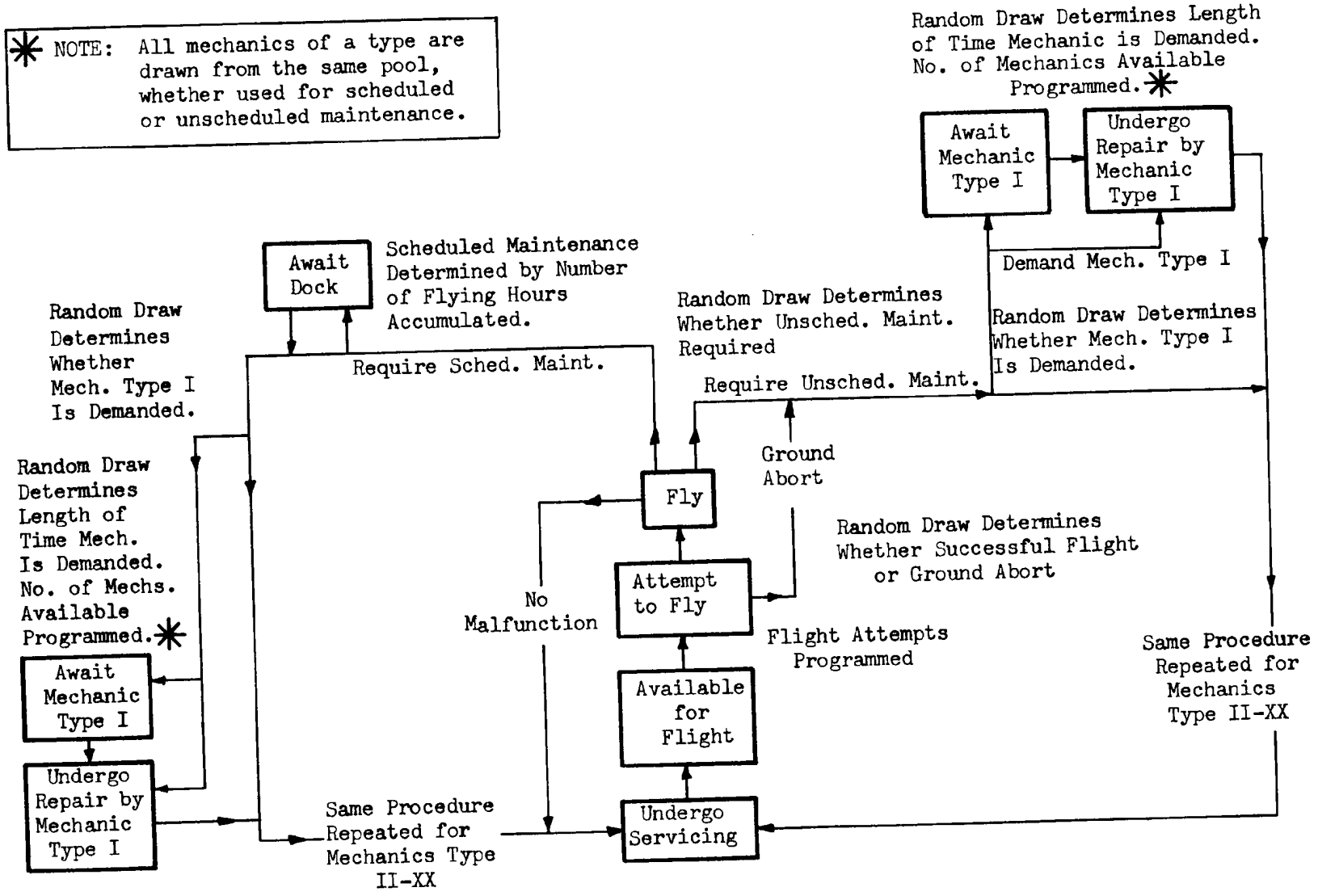


Fig. 1—Flow of aircraft through maintenance in simulation model

We simulate these activities and conditions. To do so realistically requires certain information. First we need to know something about the aircraft itself. A Piper Cub will go through this maze faster than a B-36 will, and the hypothetical interceptor has its own particular features. Fortunately, we can simulate the aircraft characteristics realistically if we have knowledge of just two types of characteristics, broadly defined as reliability and maintainability, established by systems or subsystems. Analysis of malfunction data can give this knowledge. Reliability is expressed as a probability of malfunction per sortie or per flying-hour, aggregated according to the skill-type of the maintenance personnel required for correction, and/or the ground support equipment necessary. Maintainability is expressed in terms of the net elapsed time necessary for the proper personnel and equipment to make repairs or replacements, and the team size involved. For any particular aircraft type, then, and for any particular flying program, we can compute the number of demands for maintenance and, if the necessary resources are available, the elapsed times for repair. We can also analyze the flying program to determine when scheduled maintenance is required; and since our maintainability data include elapsed times for the different scheduled-maintenance activities, we can compute how long these will keep the aircraft out of commission.

But now a major problem arises. While it is relatively simple to make accurate estimates of the average number of maintenance jobs and their average durations over some extended period of time, such as a month, it is impossible to predict what work will be required for any one day. Individual days or even weeks will vary widely from the average, making it difficult to arrive at a correct estimate of proper manning or equipment

quantities, or an estimate of the immediate effects of policy variations. An illustration will help clarify this point.

It would be convenient if the man-hours of hydraulic-system maintenance demanded each day as a result of the flying program were about equal to the long-range average demand. If they were, it would be easy to provide just enough man-hours to meet this average demand, and to compute the amount of time aircraft would be out of commission because of hydraulic-system malfunctions (by merely adding up the aircraft-hours consumed daily in hydraulic-system maintenance). Unfortunately, the real world seldom smooths our pathway with such convenient arithmetic. Man-hour demands in any one day may diverge widely from the average; thus, if manning were just sufficient to cover the average demand, days of heavier demand would find aircraft grounded because of a personnel shortage. In that event, total aircraft-out-of-commission time would be the sum of the aircraft-hours during which the defective systems underwent maintenance and the hours they waited for maintenance. The fact that demands on some days would be much less than average would not help; the lighter workload on these days would not enable personnel to increase in-commission time so as to counterbalance the loss on heavy demand days, since deficiencies cannot be corrected before they occur. Hence it is necessary to have substantially more manpower available than is used in the correction of aircraft malfunctions and performance of periodic maintenance.

Any estimate of necessary manning or equipping, or of the results of changes in maintenance or operations policy, must take account of the randomness of support requirements. This is done in the simulation model.[1] Programmed for the IBM 704 computer, the model uses a "random sampling" or

Monte Carlo technique which reproduces maintenance and operations events by draws of random numbers. Air Force data are used to calculate the real-world probabilities of various occurrences, and these probabilities are put into the computer. The random draw of a particular number in the computer determines a specific point in the probability distribution of one particular event. For instance, if there is a 60-per-cent probability that an aircraft will require hydraulic-system maintenance after a flight, the number 599 is put into the computer and a random number is drawn. If it falls between 000 and 599, a simulated hydraulic malfunction has occurred, while if it falls between 600 and 999, there is no malfunction. Over the long run, 60 per cent of the simulated flights will cause hydraulic malfunctions; but, as in the real world, random factors may cause the demand during any one period to rise well above the average and force aircraft into an "awaiting hydraulic maintenance" status, if not enough mechanics are available; or conversely, few demands may result in idle mechanics. Draws similar to the above determine how long a particular repair will take, whether an attempted flight will succeed or abort, etc.

In brief, then, the basis of the simulation model is a series of random-number draws which specify various malfunctions in aircraft and initiate demands upon maintenance personnel to correct them. Fixed totals of available personnel are also programmed. If a random draw imposes a demand for personnel who are available, the aircraft enters an "undergoing maintenance" status. If a series of previous draws has temporarily exhausted the number of people available in a particular specialty, the aircraft enters an "awaiting maintenance" status until mechanics are released from other jobs.

The foregoing demonstrates how it is possible to simulate the reaction of an aircraft to the activities it is subjected to, and the support

organization's ability to react to the demands imposed upon it. With the model, this kind of exercise has been performed many times with widely varying types of aircraft; actual programs have been simulated, and the results checked against actual outputs. The results were encouraging, and suggested the applicability of the method to combinations of policies and resources which have either not existed or have not been measured in the Air Force.

The cautious reader may well object that since these simulations are only paper tests, they may be inaccurate. In particular, he may take a dubious view of specific answers, while perhaps conceding the usefulness of general qualitative assertions. And of course such caution is justifiable: these exercises have not taken variant weather conditions into account, for instance, nor have they included years of experience as a factor in computing maintenance-manning requirements. It is true, then, that the results must be interpreted carefully in the light of the simulation's underlying assumptions, simplifications, and so on.*

SERVICE TESTS

On the other hand, the same cautious reader has probably long been aware that it is wise to look with equal skepticism on the results of "real world" service tests, which sometimes differ substantially from the real world in unexpected and perplexing ways. For one thing, there is the notorious "Hawthorne effect," a common psychological phenomenon: when people know they are being tested, it is difficult for them to behave normally. Consequently, the test results may not be normal, and it is hard to assess them.

---

*See Sec. III, p. 13, for a discussion of such assumptions.

Other things happen, too, sometimes unnoticed by the test managers and analysts. Not long ago, for example, an important test was conducted to determine the operational capability of a fully manned and equipped organization under normal peacetime conditions. Considerable effort was expended before the test to bring the manning into almost exact line with the appropriate manning documents, and overtime was strictly controlled. During the test, however, leaves and squadron duties were cut to a minimum. The result was that the actual availability of personnel for work rose to about 125 per cent of the normal peacetime level.(2) During another important test, intended to determine if a specific operational capability existed, training-flying was curtailed and a substantial amount of maintenance deferred.(3) And in another case, aircraft did not go into periodic maintenance at a rate appropriate for the level of flying activity being tested.(3) As a result, the organization had available an abnormal number both of aircraft for the flying program and of personnel to work on malfunction repairs. In short, all of these tests yielded erroneous results because they were based on distorted images of the real world. Furthermore, even if all discrepancies had been fully recognized, it would have been very difficult to make appropriate adjustments in the test results.

This is not to say that we should simply abandon service tests, or place total reliance on simulation and theoretical analyses--which have problems of their own. The judicious solution to the dilemma is to exert better control over tests, and conduct more frequent analytical and simulation studies as complementary efforts.

FUTURE WEAPON SYSTEMS

To study future weapon systems, of course, we have no choice between "paper" and "real world" testing. Moreover, we must estimate the reliability and maintainability parameters, rather than measure them, and so must live with greater uncertainty about the accuracy of results. Fortunately, contractors are now making some of these estimates early in the design of new weapons, in connection with identifying and meeting reliability goals, writing inspection handbooks, etc. Although it is clear that these data are only coarse estimates and there is little experience by which to judge their relative accuracy, we strongly believe that the systematic approach, which is compulsory in analytic or simulation exercises such as the ones described here, will yield more accurate estimates of attainable operationally ready rates and of manpower and equipment requirements than will gross rules of thumb or the intuitive "feel" gained through experience, however wide.

III. EFFECTS OF CHANGES IN POLICIES AND RESOURCES

The systematic examination of changes in operational policies, maintenance policies, and resources, which will be discussed in this Section, should be a part of the initial establishment of plans for a new organization. In effect, there should be an evaluation of potential changes in policies and resources at a time when only broad budgetary and personnel constraints exist. The specific problem of such over-all planning is examined in further detail in Sec. IV, "Optimizing Under Constraints," and Sec. V, "Resource Mix and Weapon-System Maturity." Additionally, conditions can be imagined under which general personnel or budget cuts would require a re-evaluation. It would be desirable to know how such cuts might affect operational capability; and if there is some latitude in choosing where and how a cut is to be made, alternatives should be explored to find which one would have the minimum adverse effect on operational capability.

For illustrative purposes, as previously explained, this Section will assume a "typical" organization in terms of number of aircraft, maintenance personnel, equipment, and supply resources. "Average" management efficiency and specific operational and maintenance policies are assumed initially. Changes from this basic posture will then be made and the effects observed.

This typical organization will be a squadron of 25 aircraft (late-model supersonic interceptors). Maintenance management has been operating on a single-shift, five-day week, with some standby personnel to support the round-the-clock alert commitment. For the past several months the squadron has been maintaining three aircraft on five-minute alert, and three more on sixty-minute alert backup. It has averaged 600 sorties a month, of about 1.5 hours each, and kept an average of 19 aircraft, or 76 per cent, operationally ready, on alert, or flying.

OPERATIONAL POLICIES

Operational policies can be aggregated into two types, both of which significantly affect logistics requirements and operationally-ready rates: first, policies which change the flying program; second, those affecting the ground-alert requirement.

Changing the Flying Program

Number of Sorties. Let us first consider changes in the number of sorties flown per month, either for aircrew training or in meeting an air-alert commitment. Many people believe that doubling the flying program will double the number of aircraft out of commission and cost twice as many man-hours a month; or that cutting the flying program in half will reduce these items by half. By this logic, if no aircraft flew at all, all 25 could be kept operationally ready. These beliefs are incorrect, of course, for several reasons.

First, current maintenance policies require aircraft to undergo certain inspections and other preventive maintenance on a calendar-time basis, independent of flying activity. Moreover, we know that certain systems will malfunction or give trouble even when they are not being used. Hydraulic oil seals, for example, are even more likely to leak if they are not operated frequently. In short, some aircraft will be out of commission even if there is no flying. A tradeoff curve of sortie activity versus operationally ready rate (Fig. 2) must therefore start with Point A below the 100-per-cent point at zero flying.

Next, since most components and systems are much more susceptible to malfunctions due to operational stresses, line AB can be drawn with a fairly steep slope, with Point E representing the squadron's experience

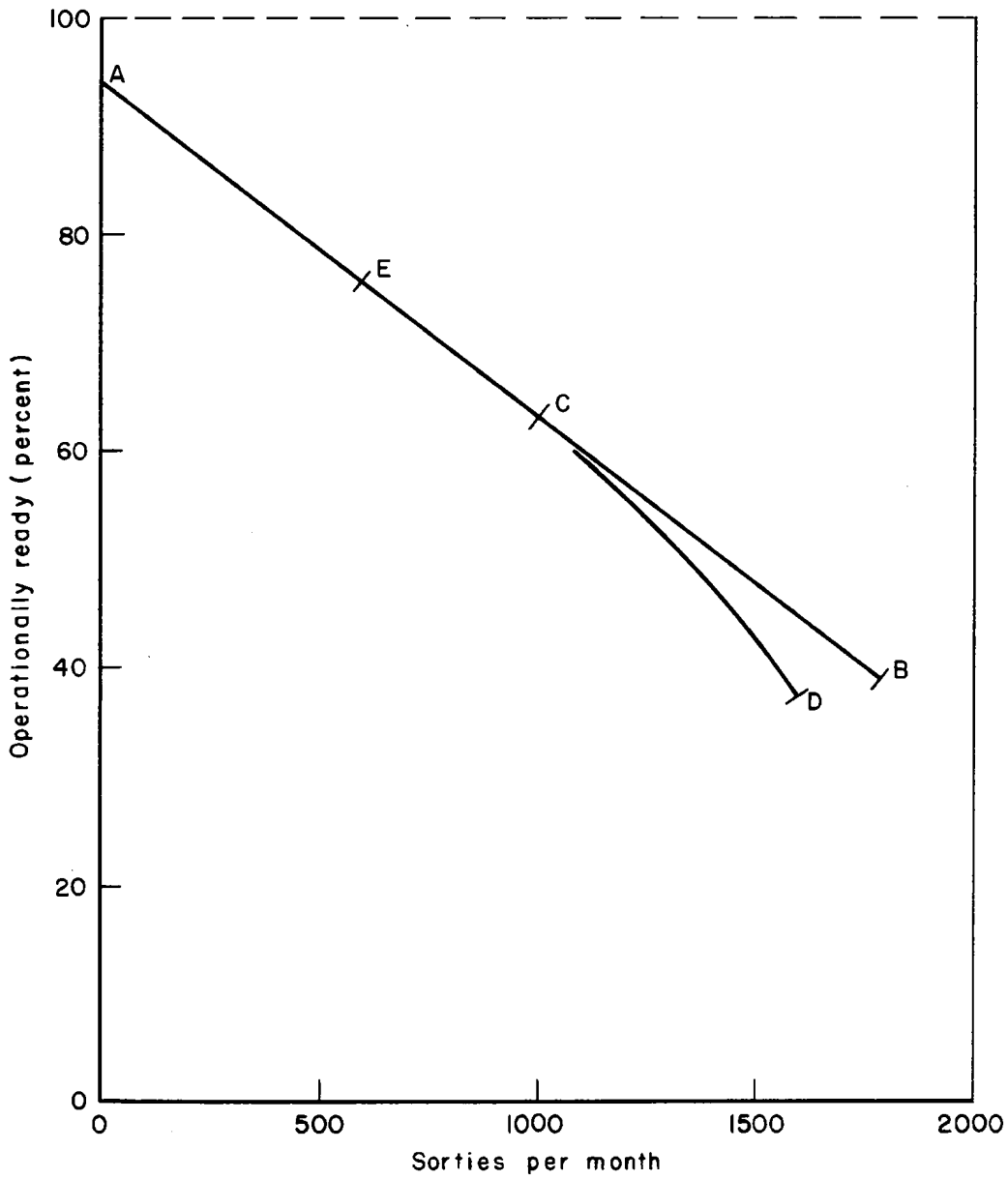


Fig. 2 — Effect of sortie activity on operationally ready rate

of being 76-per-cent operationally ready and flying 600 sorties a month for the past several months.

However, this straight-line relationship will persist only so long as there is no shortage in the proper resources (men, equipment, and spare parts) needed to perform scheduled or unscheduled maintenance, the servicing necessitated by flying activity, and the alert commitment. And even here there is an upper limit to the sortie activity, shown as Point B. Since a finite turnaround time is necessary for performing servicing and maintenance, an aircraft cannot simply land and immediately take off again, month in and month out. Point B, then, represents the situation in which Maintenance processes all the aircraft as soon as they land, and Operations flies all operational aircraft except those required for the ground-alert commitment. Since this squadron's maintenance organization has somewhat limited manpower, however, there will be times, at some point prior to Point B, when an aircraft requires maintenance but the proper personnel are unavailable because they are already working on other aircraft. In Fig. 2 we assume that this condition begins to be important when activity increases beyond that represented by Point C. Beyond this point, delays for personnel (or equipment) will become more and more significant, so the curve of capability substantially diverges from the straight line until some Point D is reached, which represents that condition in which Maintenance is processing aircraft as fast as they are able (within the same efficiency and effectiveness limitations as they were working under before) and Operations is making full use of all available aircraft.

Given this tradeoff chart, if Operations wishes to make a change in the flying program, Maintenance can report with reasonable accuracy how

the change will affect the average number of aircraft which can be kept operationally ready. Further, Maintenance can acquaint Operations with the substantial degradation in operationally ready aircraft which excessive flying (i.e., flying more than required) will cause. In one actual case, for example, the required program was overflown by 17 per cent, reducing the operationally ready rate about 9 per cent.

Length of Sorties. The flying program can also be changed by changing the average length of the sortie. Our squadron has been flying sorties averaging 1.5 hours. Let us suppose the operational requirement changes and it will be necessary in the future to have the flights average twice that, or 3.0 hours. We will need to know, of course, whether the number of sorties flown per month will remain constant, in which case twice as many hours will be flown and the periodic workload will increase, or whether the same number of hours per month will be flown, in which case the periodic workload will remain the same and the unscheduled workload will decrease, since only half as many sorties will then be flown.* Fig. 3 shows Point E, our old position, with Point F degrading the operationally-ready rate, or Point G improving it. It may be noted in passing that Point G can be held to with less resources than can either Point E or Point F; the reasons will be covered in detail below under "Resources," pp. 30 ff.

Scheduling of Sorties. The third type of operational policy change to be examined involves the times at which flights are scheduled. First recall that our squadron--now back to the old 1.5-hour sortie length--has its maintenance personnel working a one-shift, five-day week. Their hours

*It has been clearly shown, most recently by SAC (Head Start II Materiel Evaluation Final Report (S)), that most malfunctions are more closely related to number of sorties than to number of flying-hours.

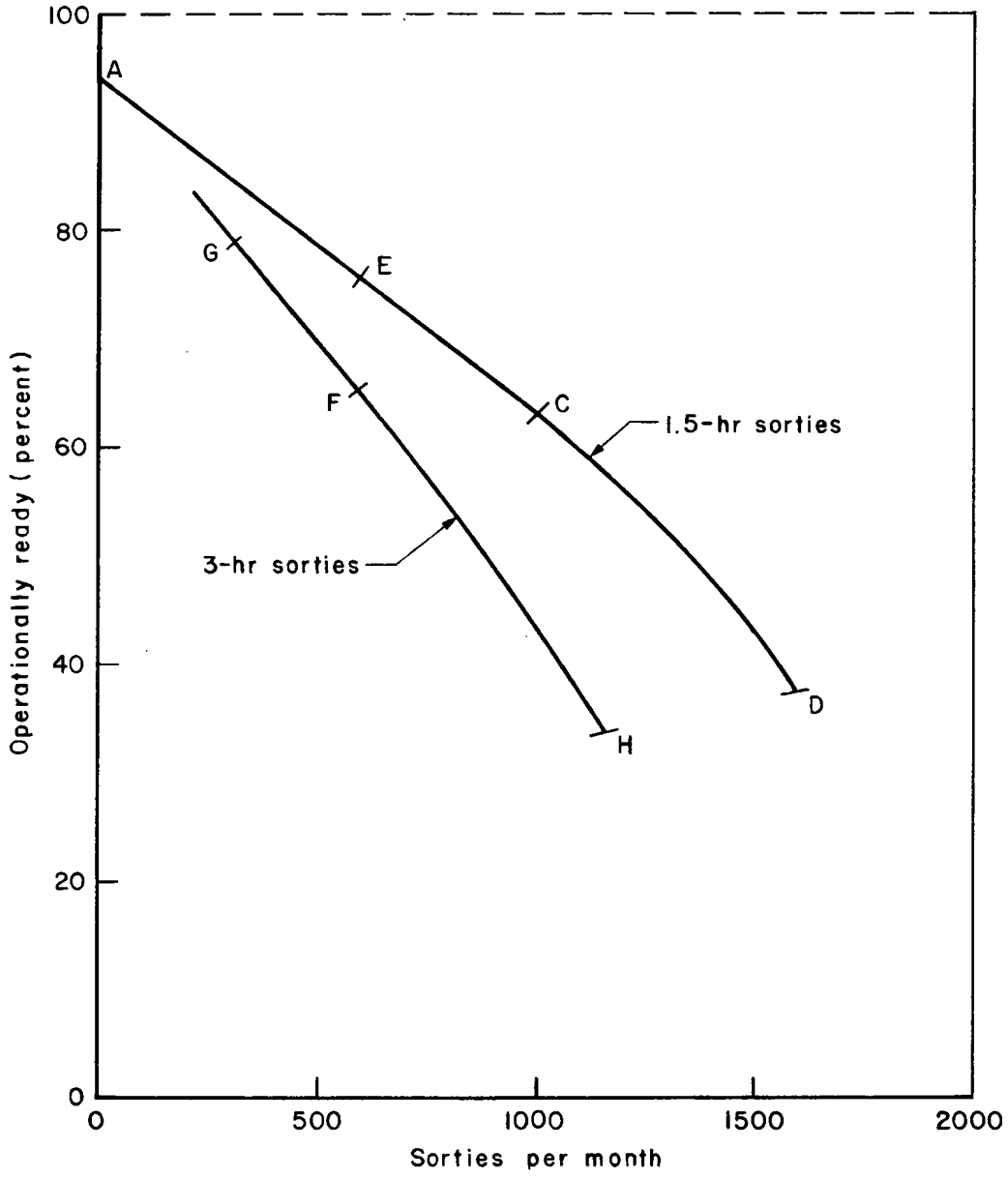


Fig. 3 — Effect of sortie length on operationally ready rate

are from 0700 to 1600--40 hours for the five days. Overtime is frowned on, since the squadron has a full complement of personnel according to the manning tables. Such occasional overtime as is sanctioned draws compensatory time off within the next week. Under these circumstances, the worst kind of schedule the Operations Officer could contrive would be to fly all operational aircraft (not on ground alert) en masse each afternoon, so that they landed just at quitting time. This schedule would almost guarantee that most of them would be out of commission and not being worked on for 16 hours each weekday, plus being idle for 64 hours over the weekend. Conversely, the best thing he could do, if he were going to fly en masse, would be to schedule the flights to end just as the maintenance personnel came to work. This "worst" and "best" are far apart. Let us make a few simplifying assumptions and then perform some illustrative arithmetic. Assume that the squadron keeps a total of six aircraft on alert or back-up alert at all times. Assume that all flights generate some kind of maintenance requirement, that all these maintenance requirements can be worked off in one shift or less, and that there are no periodics. Also assume that there is no overtime; i.e., work is performed only during working shifts, eight hours a day, five days a week. The squadron flies 19 sorties each workday (all aircraft not on alert)--412 sorties in an average month, the maximum that can be flown under this "worst" schedule. Figure 4 illustrates the operationally ready rate for the two policies as a function of the time it takes to perform the maintenance during the workday. While this is certainly a hypothetical example, it shows a spread of nearly 60 percentage points in the average operationally ready rate, an amount large enough to dramatize the importance of good scheduling of flight activity.

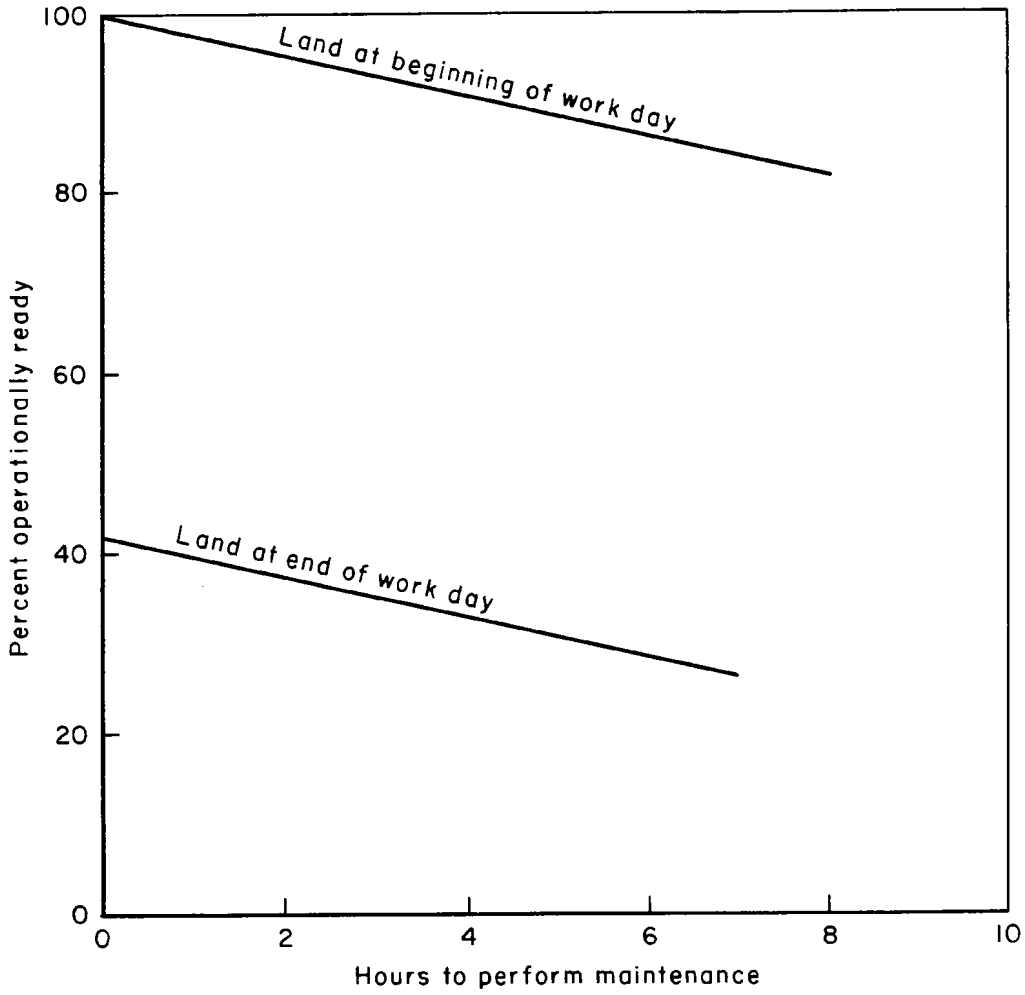


Fig. 4—Effect of flying schedule on operationally ready rate

Obviously, either Operations or Maintenance can, to some degree, cause or cure the particular trouble illustrated in the above example. If Maintenance has been working from 0700 to 1600, and Operations has been landing at 1600, either Operations can change its schedule to land at 0700, or Maintenance can change its start time to 1600, or they can reach some compromise that puts the resources at the right place at the right time.

Of course the hypothetical example is unrealistic in at least two ways. First, it assumed that all flying was done en masse, and second, an "average operationally ready rate" was given. Realistically, flying is spread out to some degree, although interceptor squadrons usually do most of their training flying during the daylight hours. And realistically we should be interested in a high operationally ready rate at any time, not merely an average. In one actual case in which there was a two-shift maintenance policy (better than the one-shift policy postulated here), it was found that the mix of maintenance and operational policies gave an average over-all operationally ready rate of 65 per cent; but during the working day, when aircrews were readily available, the average rate was only 59 per cent, and during offshift periods, when neither aircrews nor maintenance personnel were readily available, it was 75. This experience reveals the hazards of placing too much reliance on "average" figures, and points up the importance of carefully planned sortie scheduling.

Changing the Ground Alert Requirement

So much for operational policies which affect the flying program. Now let us look at policies affecting the ground-alert commitment. Suppose that a new directive changes the present requirement of 6 aircraft on ground alert or back-up alert to a total of 12 aircraft--double what our

squadron has been doing. At first glance it would appear that the increased requirement can be absorbed with no effect whatever. After all, the squadron has been averaging a 76-per-cent operationally ready rate, with about 5 per cent of this flying, 24 per cent on alert, and the remaining 47 per cent "in commission," on the average. Presumably, all that is needed is to fuel and arm about half of this excess and all is well. In fact, since this is so easy, why not put all in-commission aircraft on alert and have no "in commission only" aircraft? As might be suspected, there are a number of reasons that things do not work out this way. In the first place, the base may not have facilities, runways, and ground support equipment to care for or use this number of alert aircraft. Secondly, there may not be enough aircrews to man this number for any extended time period, and if the aircrew complement is increased so as to meet this problem, then flying must be increased for training purposes, and the operationally ready rate will decrease accordingly. Thirdly, added alert aircraft would cost the maintenance program something in terms of the personnel who must stand by with the aircraft, even though they may have no work to do there. This means that fewer personnel would be left available for scheduled or unscheduled maintenance if and when it arose. In addition, and most important, a much larger percentage of the squadron's aircraft would be left in the "pool" to care for the inevitable variations in the flying program, malfunction rates, and repair times. Thus, a curve showing the effect of sorties flown per month on the operationally ready rate will depart from its straight-line relationship at a lower activity-level than before, say at point J instead of point C (Fig. 5). It will be recalled that point C represented an activity level beyond which aircraft would have to wait more and more frequently

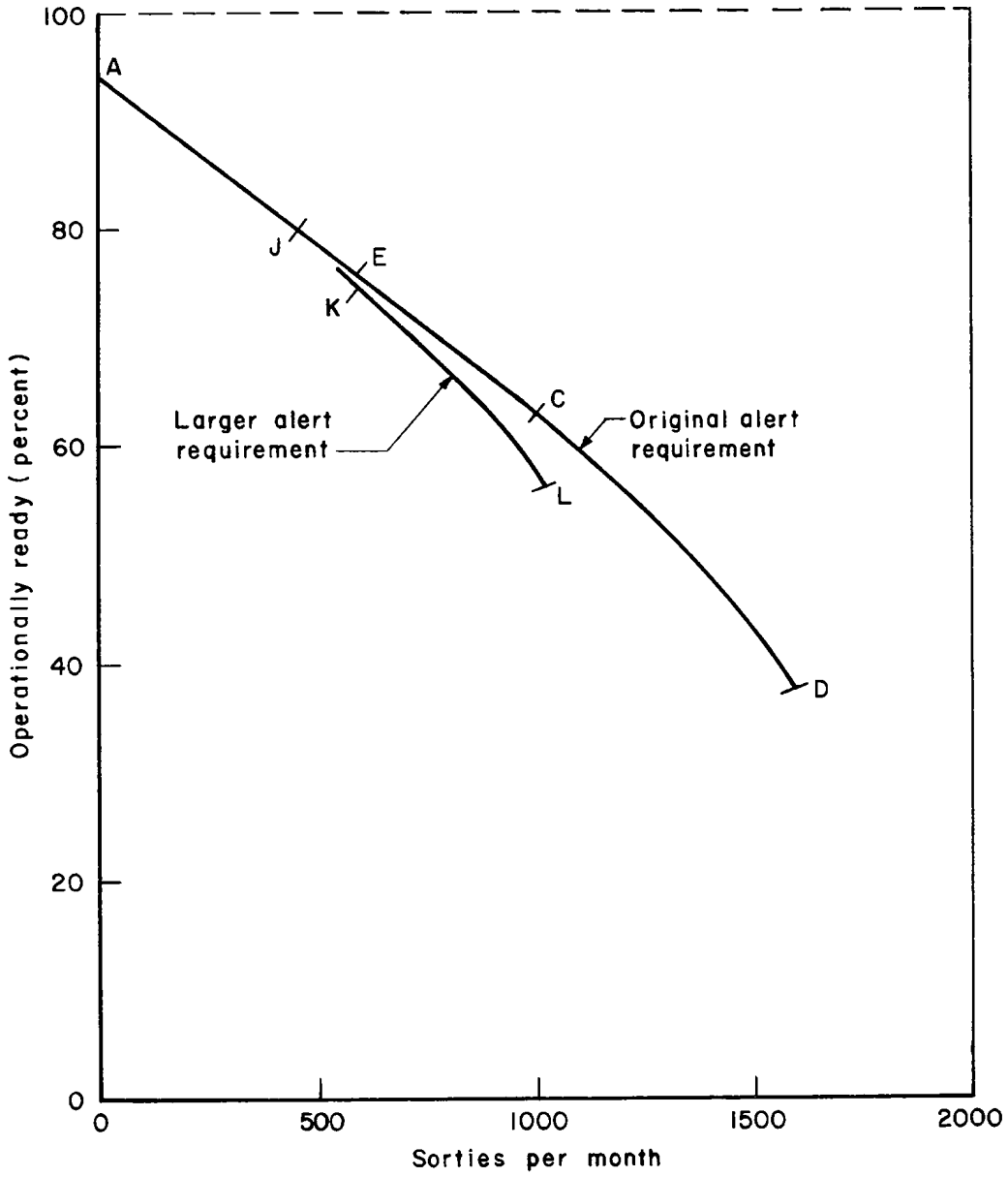


Fig. 5— Effect of alert requirement on operationally ready rate

for personnel. In the example as drawn, point J is to the left of our original operational point E, so there is some adverse effect on the operationally ready rate, although there would not be at lower sortie levels. The larger number of aircraft now needed for alert would also sharply limit sortie capability (point L versus point D). Finally, as previously pointed out, these curves represent average rates, although the squadron is trying to hold to an absolute and unvarying number of aircraft on alert. If in the past they have been missing their 6-aircraft goal, say 3 per cent of the time, they will miss the more stringent 12-aircraft commitment even more often--say 10 per cent of the time--because of the random fluctuations in workload.

MAINTENANCE POLICIES

Now let us return to the original operational requirement, and look at the effect of changes in maintenance policies on operationally ready rates and operational capability.

Changing the Workshift Policies and Times of Work

First let us dispose of one change already discussed under "Operational Policies": the starting time of the workshift. Figure 4 depicted the effect of the flying schedule on operationally ready rates, given a specific maintenance workshift time. The difference between a "best" and "worst" match of flying schedule to maintenance workshift schedule was found to be very large--nearly 60 percentage points in the example given. It was pointed out that matching the schedules was a two-way problem, in that Operations could tailor its flying program to best match the work schedule of Maintenance, or Maintenance could match its work period to meet the Operations plan, or some compromise could be worked out. The whole point was

that availability of resources and potential demand for resources should be matched as closely as possible, since mismatch can be very costly in weapon downtime. Thus the maintenance policy on work periods significantly affects operational capability.

Next let us broaden our view, and instead of trying to adjust the work times of only one shift to best match the demands for work, consider how we might profitably distribute the same number of direct-maintenance personnel over more than one shift a day and more than five days a week. These shifts would not all be the same size; the size of the shift should be matched as well as possible to the size of the workload we expect for it. For example, the distribution might be 40 per cent on the first shift, 30 per cent on the second, 20 per cent on the third, and the remaining 10 per cent distributed around the clock on weekends. This kind of distribution is beneficial, because with the present one-shift policy, personnel are often available for direct maintenance work but temporarily have none to perform; yet some direct work always needs to be done on the second and third shifts, when no personnel are present to do it. Operational readiness can clearly be improved by moving some of the personnel over to a shift where we know they can be used, from a shift where we know that part of the time they will not be used.

Figure 6 illustrates the benefits of multiple shifts as compared to our hypothetical squadron's present one-shift capability. It is clearly very undesirable to allow aircraft to stand idle, while they await personnel resources, for more than two-thirds of the time during which they may need these resources. Of course, we cannot consider workshift policy without knowing what the operational program is, any more than we were previously able to ignore the workshift policy when we were discussing the operational

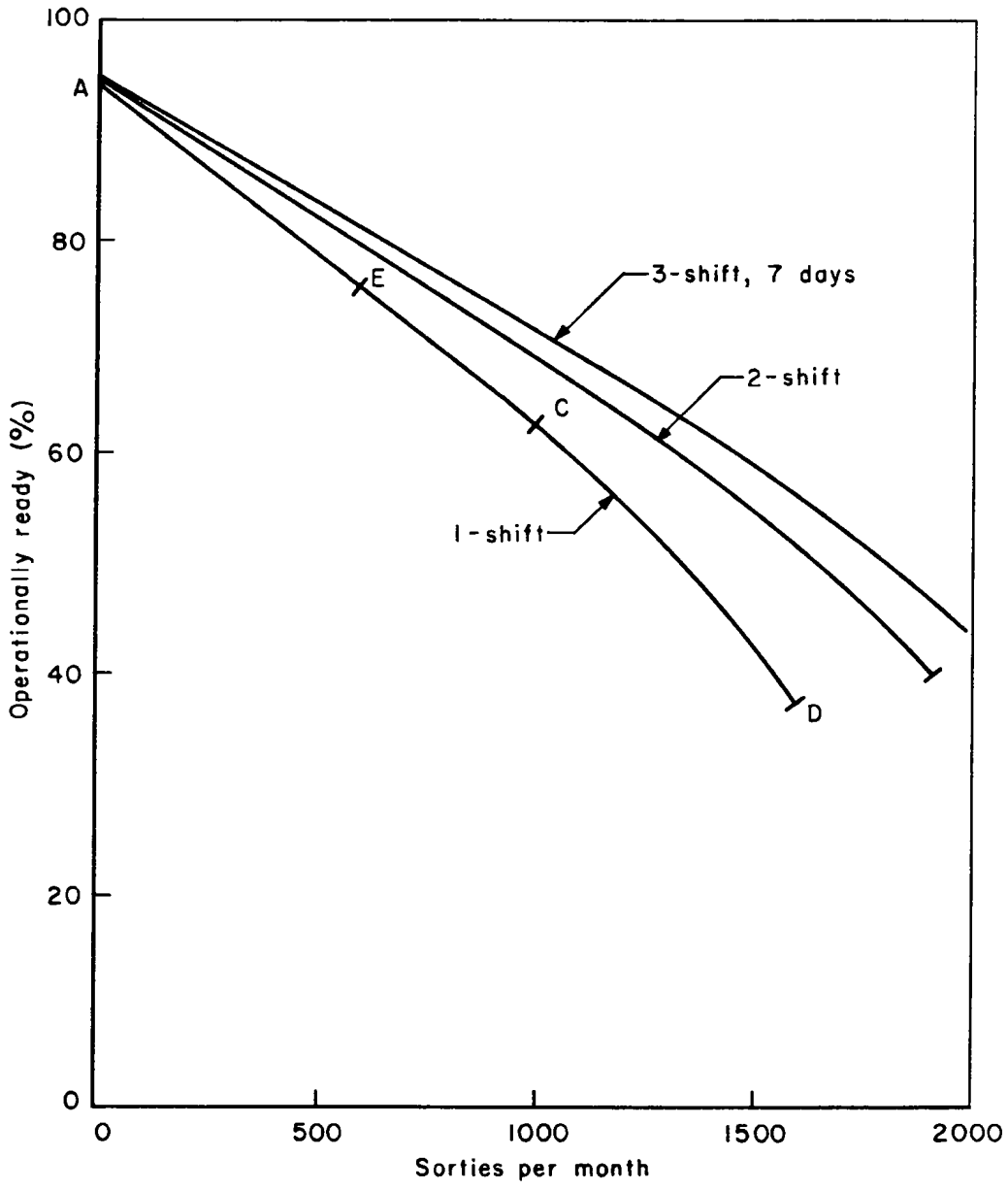


Fig. 6— Effect of workshift policy on operationally ready rate

program. The particular tradeoffs in Fig. 6 have the indicated values because the maintenance policies were varied as indicated, but around a specific operational policy. The one-shift capability would have been higher if more flying had been done before the start of that shift, or if the shift had worked different hours. The improvement indicated when we go from one shift to two shifts is partly due to this mismatch of the one-shift work period to the operational program. The improvement is also a function of the average elapsed time it takes to perform maintenance jobs. If most jobs were short, the first shift could clean up most of them; there would be less need for a second shift and almost no need for a third shift. If most jobs were long, a second and third shift would be more valuable. Furthermore, the amount of spreading that can be done with resulting benefit to the operationally ready rate will depend on the number of personnel available. For instance, one should not consider three shifts for a category of specialists if the organization has only one or two such specialists to begin with. But generally speaking, it has been our observation that most squadrons and wings are so manned that multi-shift operations can substantially improve their operationally ready rates.

It is by no means contended, however, that these improvements can be made without cost or difficulty--they usually cannot. A multi-shift operation will encounter added costs and difficulties because of the need for more supervisors and additional administrative/support services, such as messing provisions, supply support, and the like, and because of the problems of coordinating incomplete work among more workers. However, if additional operationally effective weapons are desired, we believe the Air Force can get them far more cheaply by incurring the added costs and difficulties just described, rather than by adding more squadrons or wings.

Changing the Scheduled Workload Requirement

Another important way to change operational capability is to change the scheduled-maintenance workload. This is usually done by changing the lists of items to be inspected, and changing the intervals between inspections and/or time-significant removals. Historically, such changes have reduced the number of items to be inspected, and increased the time intervals between inspections or replacements. These changes reduced the over-all workload because the original policies were over-conservative, calling for too-frequent checks or changes rather than too-seldom. In some cases, moreover, the early policies may actually have defeated the safety goal under which they were established; certainly, they defeated the goals of preventive maintenance, in that they caused unnecessary man-hours and decreased operationally ready rates resulted, rather than the reverse.

Let us consider the effects of changes in these policies. Suppose our squadron increases the time between periodics from 100 to 200 hours, without worsening system-failure rates, since the 100-hour interval was in fact conservative. The maintenance workload is thus reduced, and the operationally ready rate can be raised from our old point E to a new point M (Fig. 7), because fewer aircraft are now out of commission for periodics. (In one actual case, this interval was doubled, and could have increased the operationally rate 5 percentage points had no other changes been made.) An alternative to increasing the ready rate, of course, is to fly more sorties while maintaining the old ready rate, perhaps to sharpen the aircrews to a higher degree of proficiency (point N).

Improving the Weapon

Another way of lightening the maintenance workload in order to raise operational capability or reduce cost is to improve the weapon (product

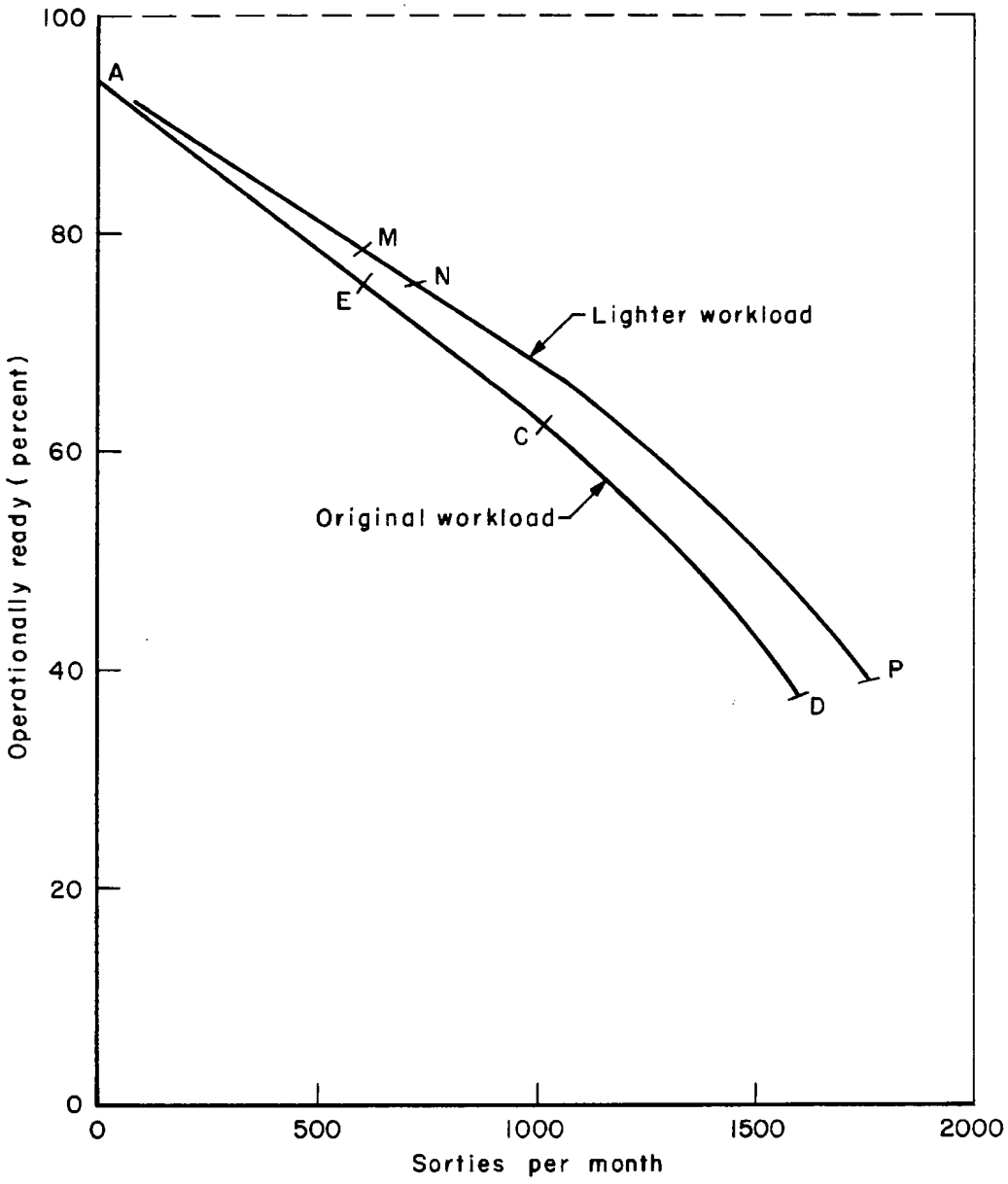


Fig. 7 — Effect of workload on operationally ready rate

improvement). This may mean increasing reliability. The more reliable the systems, the less often they demand repair or replacement. In other words, our squadron can move from point E to point M or point N (Fig. 7) after incorporating modifications which reduce failure rates and hence the unscheduled-maintenance workload, rather than by changing the periodic interval to reduce the scheduled-maintenance workload. Improving maintainability by reducing repair times is another way of improving the product and lightening the workload. Better training can also lead to reduced repair times. These product improvements or improved-training routes are especially important during weapon phase-in, both because the potential direct payoff at that time is great, and because of two important subsidiary effects: First, in addition to the direct improvement in operational capability resulting from the changes, further improvement may be achieved by reducing the frequency of inspection, etc., on these more reliable systems more than would otherwise be possible. Second, the aircraft now have a higher probability of successfully completing their missions because of lower ground- or airborne-abort rates and airborne-malfunction rates. As a weapon system matures, it naturally becomes more difficult to improve the product further.

RESOURCES

We have been considering the effects of changes in policies, either operational or maintenance, on the operational capabilities of an organization. Thus far we have assumed no changes in the resources the hypothetical squadron possessed when we began the policy changes, other than recognizing the probable need for more supervisory and administrative support when maintenance was put on a multi-shift basis.

Now we will hold policies constant (although we may look at several basic sets) and observe how changes in the squadron's resources may affect capabilities. As defined here, resources include the aircraft themselves, direct maintenance personnel, ground support equipment, facilities, and spare parts. (It is recognized that changes may be needed in administrative and housekeeping types of support in connection with certain changes in direct resources or policies, but these will not be examined in this Memorandum.)

Changing the Number of Aircraft in the Organization

First let us consider the number of aircraft in the squadron—the UE (unit equipment). Many people seem to feel there is an "ideal" UE from a logistics point of view. They argue that a fighter squadron, for instance, should have only 18 aircraft instead of 25. Others argue for 30. Either may be correct, if there is a mismatch of accompanying resources, related policies, and operational requirements, since there is a "best mix" of resources for any given set of policies and requirements. In fact, only if there is a set of policies and requirements can there be a best mix of resources, including a specific UE. Of course, from the point of resource economy alone, the larger the UE and other associated resources in a squadron, the better. For example, if the choice is between one organization of 25 aircraft, 500 people, and $2 million in spares and ground support equipment, and another organization with 50 aircraft, 1000 people, and $4 million in parts and support equipment, the larger organization is better. Its greater flexibility will enable it to keep more than twice as many aircraft operationally ready for a given sortie rate per aircraft-month, or mount more than twice the average number of sorties for a given

operationally ready rate, than can the smaller organization. In theory, this argument will hold true for successive increases in organiz tion size until the entire force of the particular weapon is on one base.

Considerations apart from resources, however, will dictate a maximum desirable size. For instance, management span-of-control problems, the result of human limitations, will require breaking the organizations down into independent sub-units which may operate just as well on separate bases as on one huge field. Limited runway facilities may impede the takeoffs of the large number of ready aircraft. The real constraints on size are probably strategic and tactical, however. Vulnerability considerations prohibit putting all our weapons on one base. Furthermore, it would be unwise to put all our hypothetical interceptors on a super-base in Kansas, for example, since they could not intercept an enemy threat as fast from there as they could if spread around our periphery, even though we would be able to put a larger number in the air from Kansas per dollar invested in the system.

Two conclusions follow from this reasoning. First, from the point of view of resource economy, the larger the organization the better. Second, rather than being mere constraints, strategic and tactical factors probably should be the basic determinants of squadron UE size, upon which is built a "best" over-all organization.

But for the moment, let us get back to the specific problem of a squadron with its "typical" support, in terms of resources. The question is, how are maintenance and operations affected if one aircraft is added to the organization? Figure 8 illustrates the now-familiar tradeoff between operationally ready rate and sortie activity, but gives the ready rate not in percentages, but in numbers of aircraft operationally ready. This is

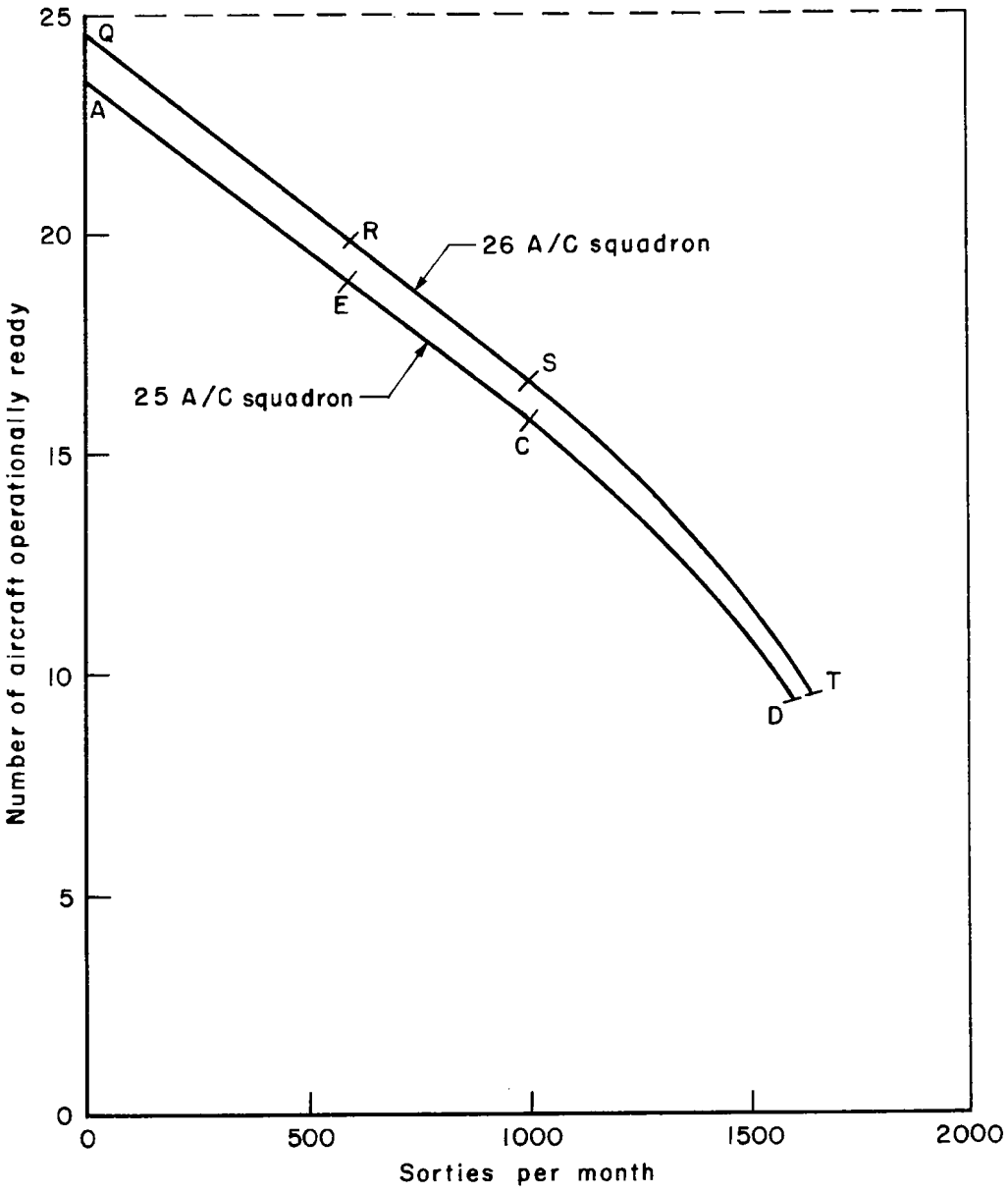


Fig. 8—Effect of squadron size on sortie rate and number of aircraft operationally ready: 26 vs 25 aircraft squadron

really the proper way to talk about capability, since it is numbers of aircraft, not percentages, that fight or deter the enemy. Point E represents the posture the squadron has been maintaining, point C the activity level beyond which resource shortages begin to be a real problem, and point D the maximum activity level the organization can sustain. The upper curve shows the result of adding one plane to this organization. At zero sorties, the previously small workload generated by ground malfunctions and time-significant changes or inspections is increased by the 4-per-cent increase in squadron size. As the level of sortie activity increases, this 4 per cent of the zero-sortie-rate workload becomes an even smaller percentage of the total workload, and so will not become a significant problem until point S has been passed. Beyond point S, any added work requirement becomes more and more burdensome, to the extent that, at the sortie level of point D, the one extra aircraft yields about a half-aircraft advantage. In this particular case, the added aircraft benefits the squadron regardless of whether its mission is to maximize the number of operationally ready aircraft at sortie level (E to R), or to maximize sortie production (D to T). The word "benefit" should not be interpreted as meaning that this larger squadron is <u>better</u>, however, since cost has not been considered.

It does not follow, furthermore, that additional aircraft will always benefit a squadron which is trying to maintain a fixed flying-program and a maximum number of operationally ready aircraft. Let us take an extreme example to illustrate this clearly, and instead of adding only one plane or a few planes to the squadron, add 50. Overnight, the UE has become 75, with no increases in other resources. These planes must be flown in order for them to be useful and to be considered part of the squadron. Just as

we did when only one aircraft was added, we again spread the flying as equally as possible among the total available aircraft. If the squadron is to continue to fly 600 sorties per month (and we will shortly check to see if it can), then each of the 75 aircraft will fly one-third as many sorties per month as did each of 25 aircraft previously. A look at the trade-off curves (Fig. 9) will reveal, however, that the new squadron cannot maintain the old flying program. The 200-per-cent increase in workload generated by ground malfunctions and calendar-time policies, the lowered efficiency of resource utilization resulting from the more complex planning required, and the increased delays due to facility overcrowding, combine to send the operationally ready curve into an early plunge downward. It would be necessary to cocoon some of the aircraft in order to maintain the flying program (let alone the alert requirement), for all practical purposes removing them from the squadron. If, however, the squadron were in some way able to reduce its peacetime flying requirements (by using a Link Trainer, for instance) to, say, 400 sorties per month, it could then maintain a much larger number of aircraft operationally ready than before. Again, however, this combination might not be desirable from a cost standpoint.

Changing the Manning Tables

Now let us consider changes in direct maintenance personnel as specified in the manning tables, and observe the effect on operational capability. A number of simplifying assumptions were made in this connection, and should be identified before proceeding. Frequently, more than one man--i.e., a team--performs maintenance work. We have not tampered with team size. When several maintenance jobs are to be performed on an aircraft, this work

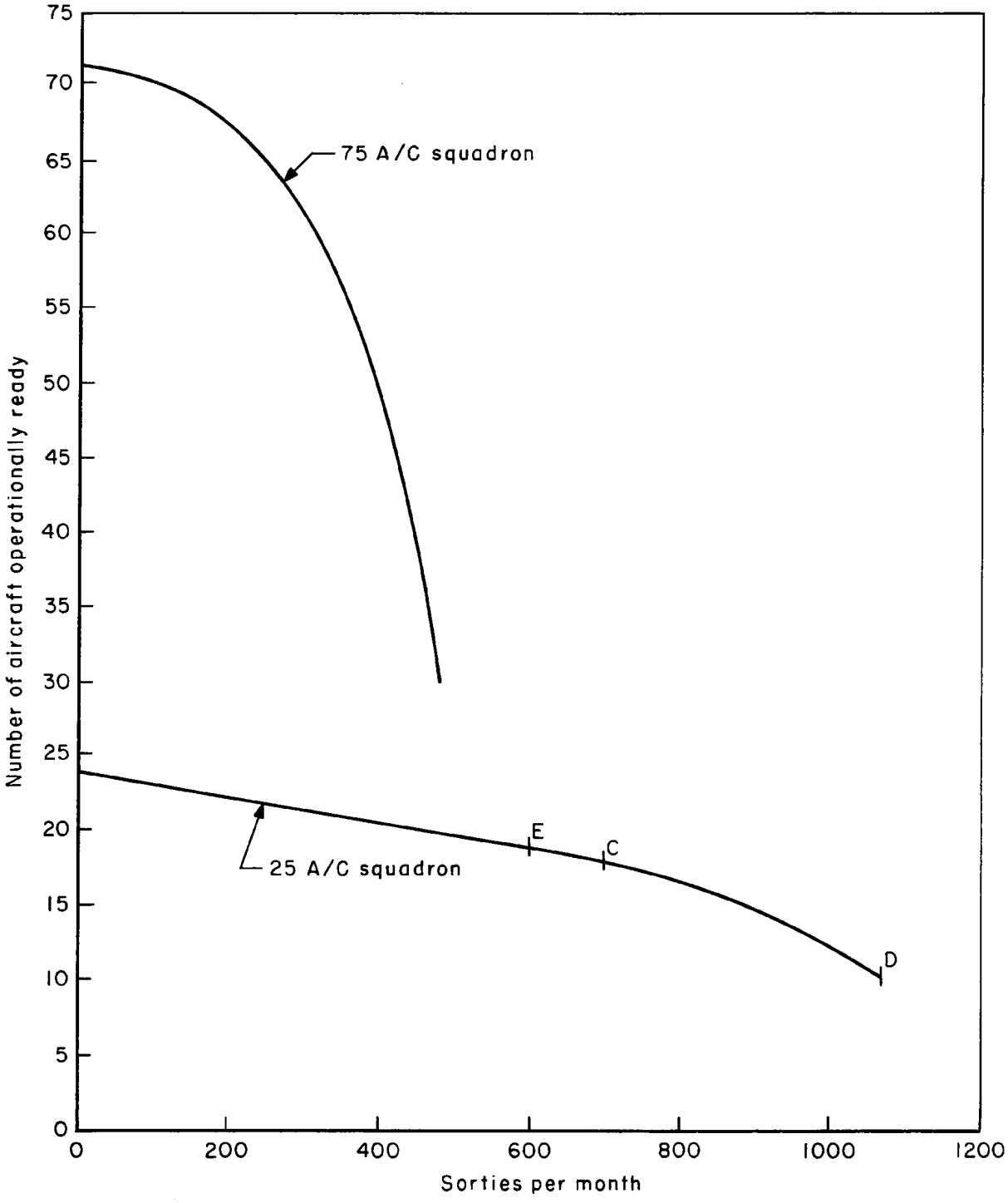


Fig. 9—Effect of squadron size on sortie rate and number of aircraft operationally ready: 75 vs 25 aircraft squadron

is scheduled; sometimes several jobs are done concurrently, while others are not (perhaps because of electrical power requirements). We have not altered the relationship between concurrent and non-concurrent work. We have used the actual times taken to perform work, as reported, rather than "standard" times. We have kept the relative proportions of skilled, semi-skilled and unskilled personnel in the same ratio as in actual organizations when making changes in manpower. Customary availability-for-work factors have been used, which account for illness, leave, squadron duties, etc. We have no permitted overtime during peacetime operations.

Priority of Work. To examine how changes in direct maintenance personnel affect operational capability, the matter of work priority must be established. It can be demonstrated that in determining what personnel should be in the organization, the most important question concerns the demands of the aircraft for these people. In other words, first priority should be assigned to the servicing or repair work necessary to make the aircraft operationally ready, as well as to meet alert standby requirements. Second priority can then be assigned to direct work connected with the repair or overhaul of parts to be put into stock; and still lesser priorities can be assigned to other direct or indirect work which may be performed at a base by direct maintenance personnel. There is no sharp line of demarcation between the skill-types and levels required to do first-priority and lower-priority work. On the contrary, they are substantially free to cross back and forth. Moreover, Air Force records indicate, and our research analyses confirm, that proper manning entails relatively low personnel utilization for first-priority work, leaving enough man-hours to do the lower-priority jobs as well. This is not to say that certain personnel with special skill-qualifications may not be needed only for Priority Two or lower work, nor that the Air Force should not hire them; the idea is merely that when they

are exceptions to the rule, ways should be sought to increase the flexibility of other personnel so that the same people can do both high- and low-priority work. In some cases, perhaps this means selecting skills and levels on the basis of their ability to perform lower-priority work only so long as they can also do high-priority work, and determining quantities on the basis of the latter. To simplify our present analysis, however, we have chosen to consider only the needs for personnel to do first-priority work directly connected with the aircraft, and assume they will have both the skills and the available time to repair parts for stock and do other necessary maintenance work of lesser priority.

The Specialty Mix. Let us consider the problem of an improper mix or distribution among the several specialty categories which has created one or more bottlenecks or shortages. We will not change the total number of direct-maintenance personnel assigned to our squadron; instead, we will try to "balance" by taking personnel away from specialist shops where the pace is leisurely, and adding them to the harder-pressed shops afflicted with delays in meeting commitments. The effect of such a change depends on a number of things. If there is only one serious bottleneck, for instance, relieving it not only enables the affected shop to process its work faster, but allows the others to stop "marking time," as it were, yet keep up with the resultant increased pace. On the other hand, if some other shop has no surplus capacity, relieving one bottleneck may do no more than create another one and improve the squadron's operational capability very little. But whether the improvement is large or small, the object should be to "balance" the skill shortages or the skill surpluses among the several specialist shops, so that airplanes are not kept out of commission for lack of any one kind of specialist more than they are for any other type. (In one study where this balancing procedure was simulated, a

40-per-cent increase in maximum sorties per month was gained with no loss in ready rate.)*

An important factor to be considered, however, is the operational plan for which this balance should be attempted. Peacetime activity and wartime activity may demand substantially different ratios of specialist quantities. In wartime, for instance, more armament specialists will certainly be needed. Moreover, wartime conditions will demand more total activity. Since personnel will be expected to work as needed, rather than on an eight-hour five-day week, more man-hours will be available. In short, it is difficult to determine the best mix among skill categories for a given total number of maintenance personnel.

We can also consider the effects of changing the total numbers of maintenance personnel assigned to an organization. If we add or take away in a skill area where a serious shortage already exists, changes in capability will be large. If we do so in less critical areas, the changes may be negligible unless we have made substantial cuts. But what if we start with a balanced organization, and add or subtract in such a way as to keep it balanced in the sense we have been using? This time the answer depends on the flying program. Adding or taking away personnel from the maintenance organization will not significantly affect the operationally ready rate unless the sortie level is high enough to cause significant waiting for personnel. (See Fig. 10.) In one case studied, for instance, it appeared that manning could be reduced 30 per cent with only a 4-percentage-point reduction in the operationally ready rate, at the specified flying level.

Degree of Skill and Cross-Training. Another maintenance-personnel factor subject to change is the degree of skill and experience the men possess.

*The "balance," of course, must consider the cost of the specialist; if radar men cost ten times as much as engine men, we would want the aircraft out of commission more often for the radar men.

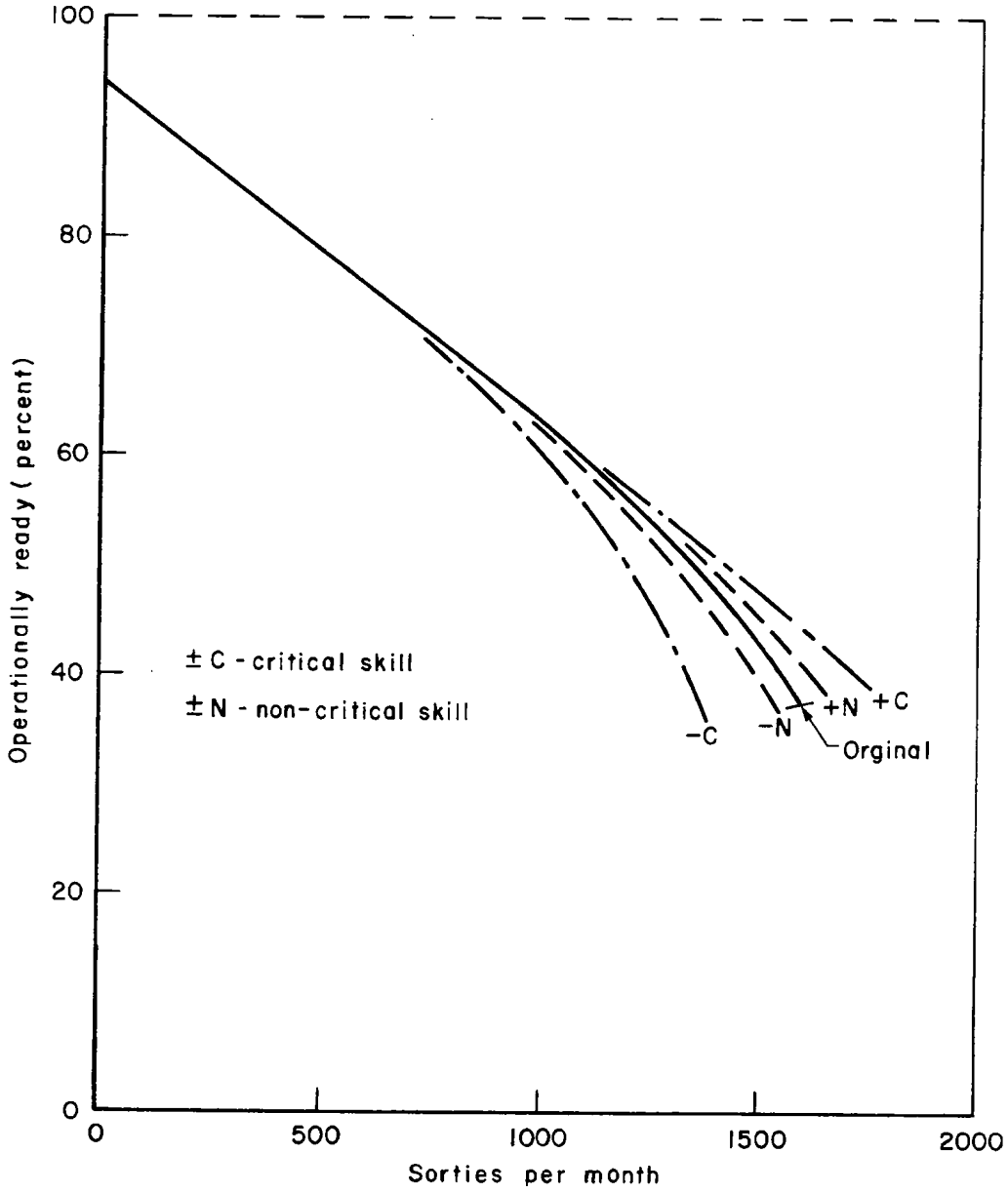


Fig. 10—— Effect of quantity of maintenance personnel on operationally ready rate

Skilled and experienced personnel diagnose and perform corrective work faster than unskilled personnel, and cause fewer malfunctions in the process. Thus unskilled personnel can be said to increase the maintenance workload, by increasing both the malfunction rate and the repair time. The effect on operational capability is the same as though the workload were altered in some other way (see Fig. 7).

The merits of cross-training are frequently discussed--that is, training a man in a variety of skills. For a given number of people in the maintenance organization, the benefits of cross-training depend on the size of the workload in particular specialties, regardless of whether the workload is caused by the reliability/maintainability characteristics of the weapon system or by the ratio of personnel to weapon quantities. If the workload in some specialties is so heavy that backlogs accumulate, large benefits can accrue from cross-training, because men can cross over the line from their normal specialties to help out. If the workload is more evenly distributed, such versatility has less effect. If the workload is small to begin with, however, cross-training can reduce the total number of personnel required at a base, without appreciable loss of operational capability. This reduction can result in substantial savings, especially if the force is widely dispersed.

Changing Quantities of Aerospace Ground Equipment (AGE) and Spare Parts

AGE and spare parts are logistics resources, just as maintenance personnel are, and have similar effects on operational capability. As discussed above under "The Specialty Mix," an excess quantity of one type--or of one part number, in this instance--does not necessarily offset the shortage of another. Relieving only one of several bottlenecks or shortages

merely transfers the "responsibility" for downtime to the others. The composition of spare parts bears some analogy to cross-training for personnel, in that next-higher assemblies can substitute when a specific component is not available. As activity increases, a given spare-parts and AGE inventory which is inadequate will have more and more impact on operational capability (Fig. 11), just as was the case with manpower. As with manpower, where temporary increases in activity can be combatted by overtime, making more man-hours available, AGE can be used more shifts to some degree. Spare parts, however, cannot be worked overtime, and for this reason reserve stocks are a necessary part of logistics resources.

Management Responsiveness in the Use of Resources

Management responsiveness is closely linked to such items as workshift policies, scheduled workload requirements, and product improvement programs (discussed under "Maintenance Policies" earlier in this Section). It is also linked directly to personnel, AGE, and supply resources in that a tradeoff exists between "average" management of certain quantities of these resources, and "better" management, which can get the same job done with less resources. By management responsiveness, then, we mean the rapidity with which decisions are made and action is taken after a demand occurs. A more responsive management can not only do the same job with less resources by using them better, but can often do the job faster, irrespective of the quantity of resources. That is to say, responsiveness can be traded off to some degree with resources, but also can be traded against time, regardless of resources. Since time-out-of-commission is what is saved and added to operationally ready time, management responsiveness is often far more valuable than savings in manpower or support equipment

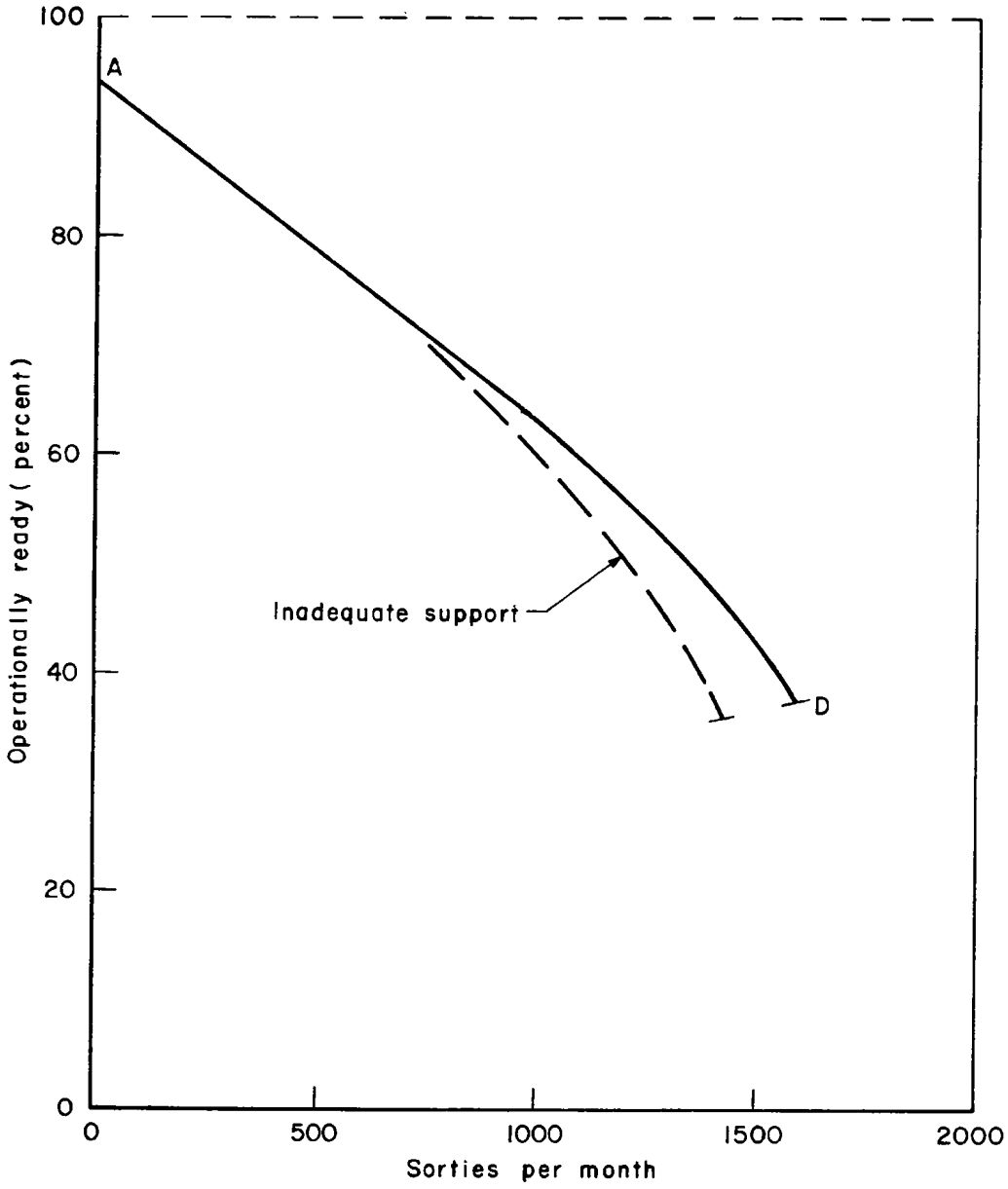


Fig.11 —— Effect of supply or AGE shortages on operationally ready rate

alone. RAND analysis of substantial quantities of data indicates that a very substantial part of total out-of-commission time attaches to aircraft not being worked on because of delays associated with management responsiveness, workshift policies, and facility layout. We therefore believe these areas warrant special consideration.

CUMULATIVE EFFECTS

We have been discussing how changes in operational policies, maintenance policies, resources, and use of resources affect operational and maintenance capabilities. It may be useful to examine the cumulative effects of some of these changes; Fig. 12 depicts them schematically. The flying program increases from left to right. The bar at the top of the figure marks the average number of aircraft being worked on to correct ground-generated malfunctions, and undergoing calendar-time inspections or change requirements, all of which are independent of flight activity. The areas immediately below depict unscheduled work associated with flight activity and inspections or changes related to flight activity. Also shown are the average number of aircraft out of commission but not being worked on--that is, delayed--because of shift policies (no one at work), facility layout (takes time to get from maintenance shop or supply warehouse to aircraft), management responsiveness (how soon management acts after a demand occurs), and resource shortages (AOCP, all specialists otherwise occupied, etc.). The average number of aircraft flying and required on alert, for a given level of sortie activity, rises from the bottom of the chart to complete the picture. Maximum, or less than maximum, conditions can be determined. For instance, with six aircraft required, about 1600 sorties a month is the maximum average flying rate. Or, if only 1000 sorties are required, about two aircraft are

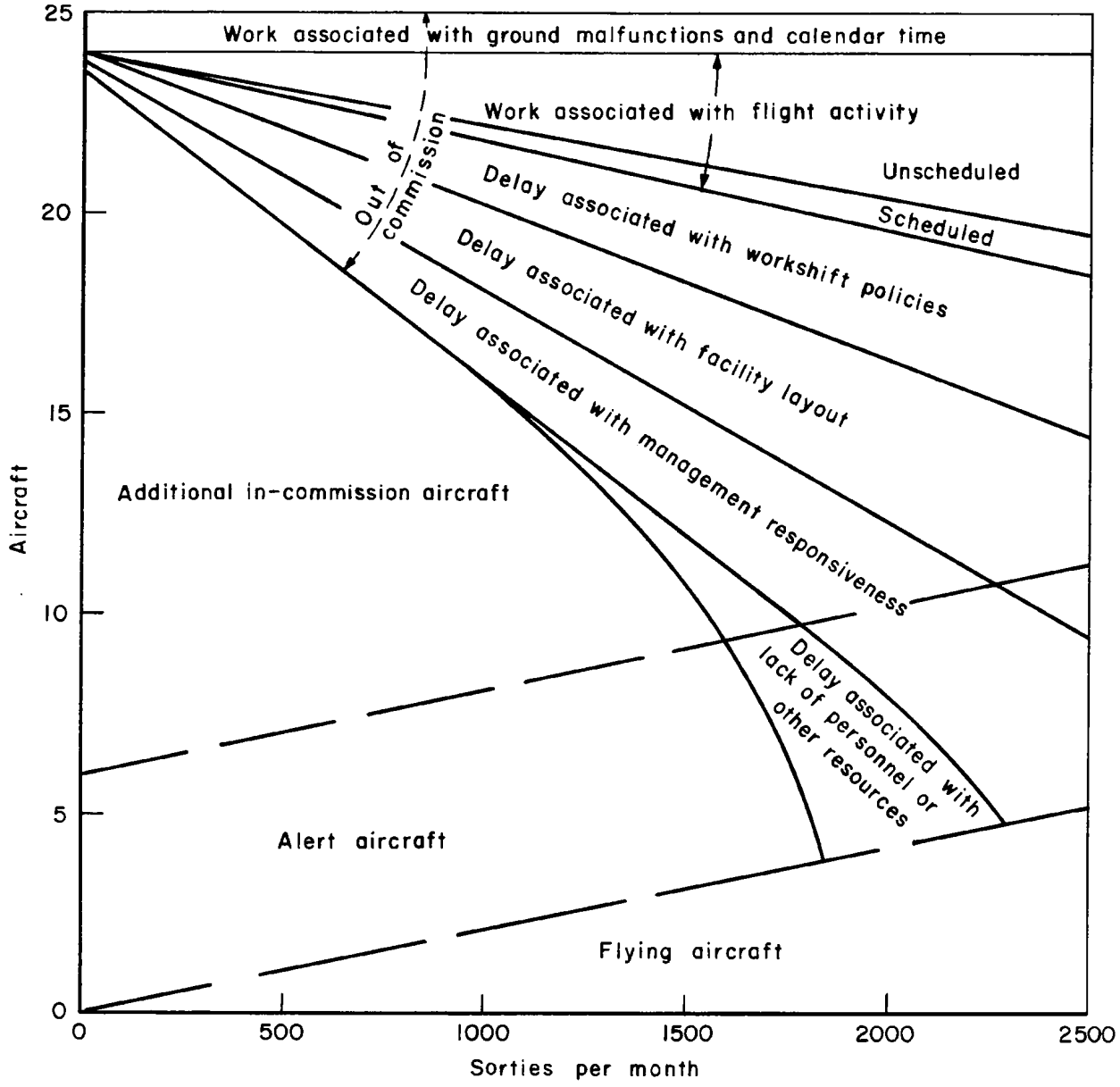


Fig.12 —— Effect of flying program on aircraft status

flying, six are on alert, eight are in commission, six are out of commission but not being worked on for various reasons, and three are being worked on, on the average. The relative effects of changes in any item can be estimated to see whether special efforts may be worthwhile.

IV. OPTIMIZING UNDER CONSTRAINTS

Section III discussed the effects on operational capabilities of changes in the flying and ground-alert programs, maitenance policies, and resources available at the base. Each type of change was treated separately, and each started from the same basis, a "typical" organization. Aircraft were shown to be out of commission because of flight-generated malfunctions, ground malfunctions, and periodic or other scheduled inspections. Work-shift policies, base facility layout, management responsiveness, and resource shortages were shown to delay the return to operational readiness. This Section examines the changes and their effect on readiness, with a view toward selecting some combination which is "best" under certain conditions.

THE TRADEOFFS

The difficulty of specifying objectives properly will not be analyzed here; rather, certain assumptions will be made so that we may proceed to illustrate the task of optimizing. We assume our original squadron's flight-crew assignments and peacetime sortie rate are adequate to maintain proficiency of the crews. We further assume that the best way to accomplish the wartime mission is to mount the maximum number of sorties during the first hour of the war, without regard for second-strike capability, and that we want to do so at a minimum over-all cost per sortie mounted. Let us begin with the original UE--25 aircraft—and vary the number of direct maintenance personnel and their associated support. Figure 13 does so for squadron manning levels of 500, 400, 300 and 200 personnel, using the squadron's 600-sortie requirement as a point of reference. In each case we assume a "best mix" among skills. A drop from 500 to 400 personnel would cost almost nothing in capability but would of course save money, so the

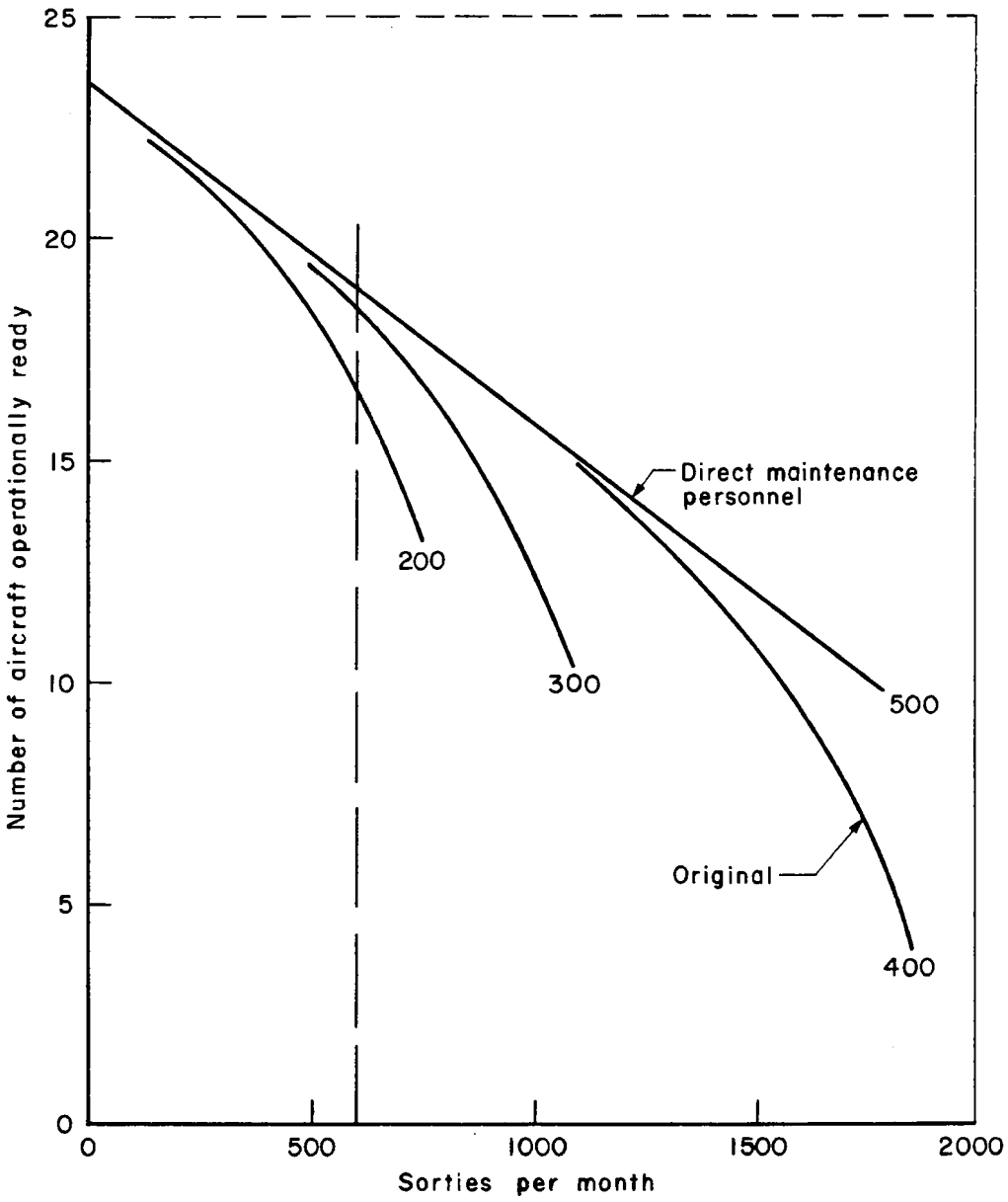


Fig. 13 — Effect of direct maintenance personnel changes on sortie activity and operationally ready rate: 25-aircraft squadron

cost per sortie would be less. A cut from 400 to 300 would also save money, but lose some combat capability; the cut from 300 to 200 seems very costly in "lost" aircraft. If appropriate cost-values are applied to the aircraft and associated AGE and facilities, and to personnel and associated services, we can compute an "average cost per sortie," assuming that only operationally ready aircraft (less a fraction for aborts) will contribute sorties, and capability and cost per sortie can be shown for the manning levels. It may be seen from Fig. 14 that we could minimize the cost per wartime sortie with an organization of 300 men, although added manpower would, in fact, increase the number of sorties. It would cost less, however, to have more squadrons of 25 aircraft and 300 men if more total sorties are required, than to load this squadron up with more manpower.

Next let us look at a number of different squadron-UE sizes. In Fig. 15, a number of curves representing first-hour sorties are plotted against the average cost per sortie for UE's of 25, 19, 14, and 12 aircraft, and an envelope curve of "least cost" is added. Clearly, if the objective is to mount the maximum number of sorties, the larger the UE the better, but not the more personnel the better, unless cost is no object. On the other hand, if some particular number of sorties is desired at this particular base, and aircrews are available only for this number, then larger UE's and the added aircraft procurement past the proper point are also costly. The problem is even further complicated. Assume, for instance, a requirement for about five sorties. This could be met at cost D by a 25-aircraft squadron with less than 200 men. The best organization, however, would comprise 14 aircraft and 150 men--point B. Notice that point B is not the lowest cost-per-sortie point for a 14-aircraft squadron; point A is.

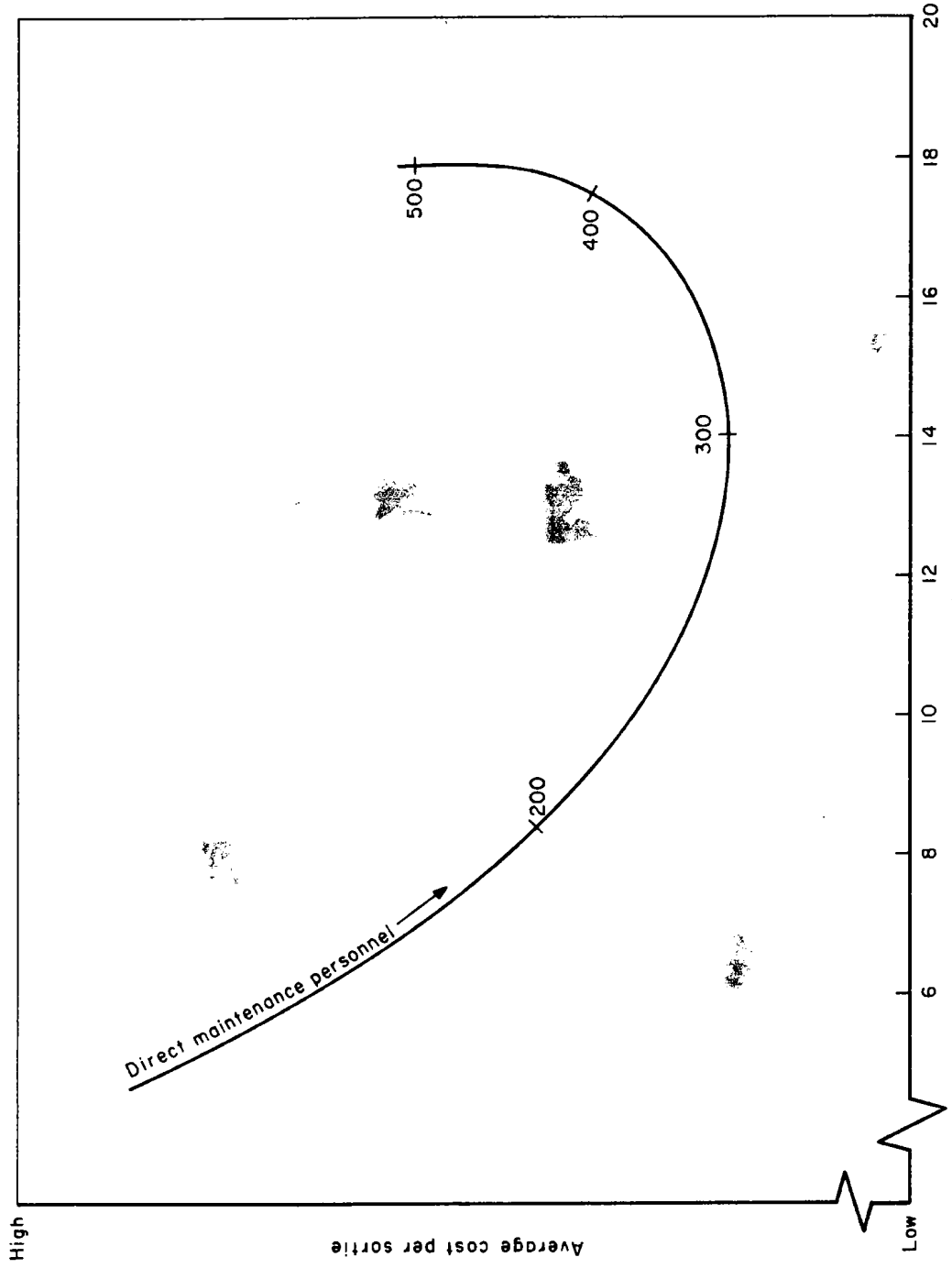


Fig. 14—Sortie capability and cost versus direct maintenance and manpower: 25-aircraft squadrons

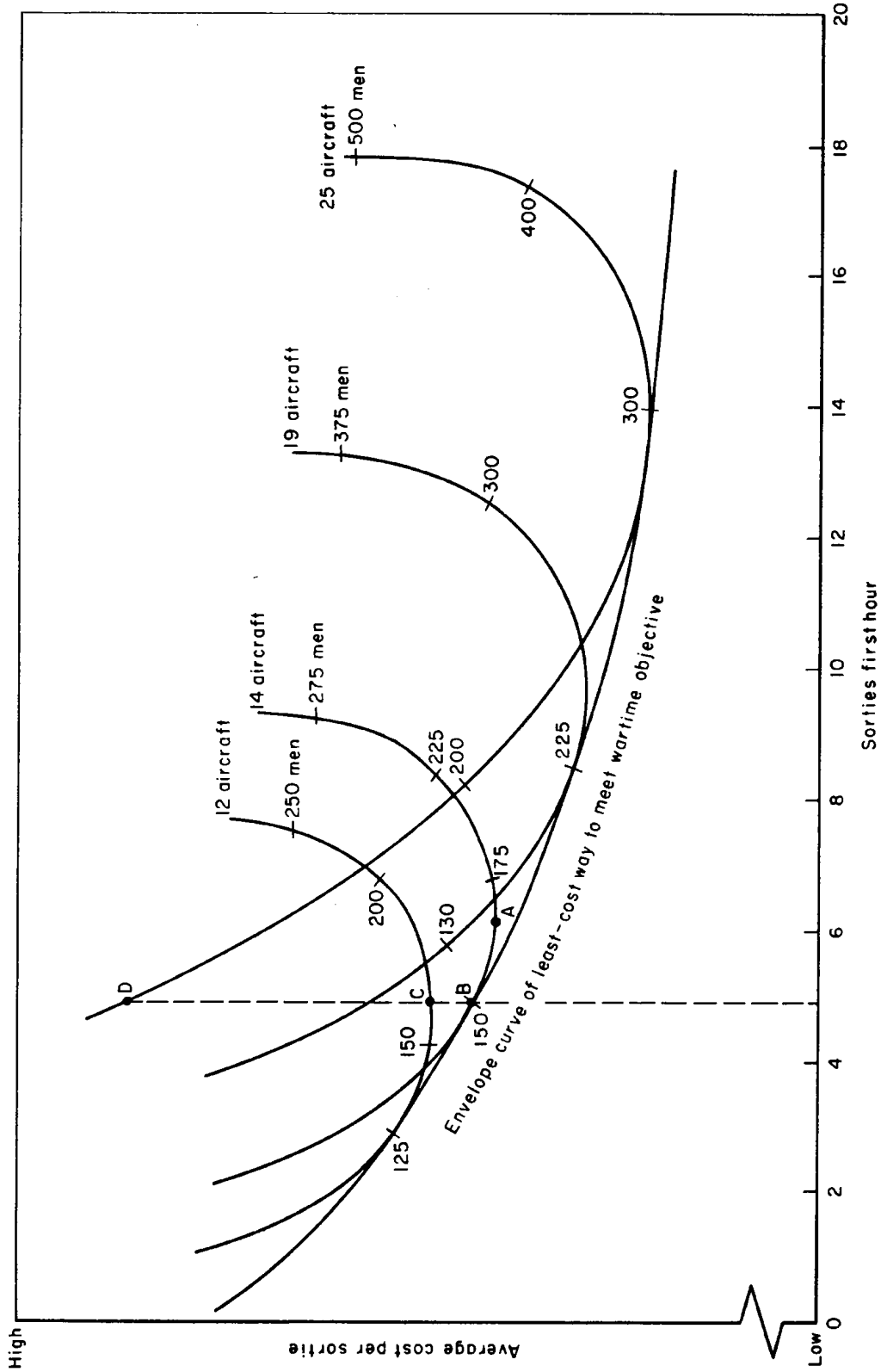


Fig. 15—Sortie capability and cost versus direct maintenance manpower for several squadron sizes

And if we had asked the wrong question and obtained minimum-cost-per-sortie points for various UE's, point C would have been selected. The objectives, then, must be clearly defined before we proceed to determine the best organization.

THE CONSTRAINTS

There are usually at least two constraints: money and manpower. Often these are coupled with vulnerability and other strategic considerations. Given limited money and manpower, the force should be placed at as few sites as possible, if we may ignore strategic considerations; if we may not, we are forced into dispersal, which is costly either in dollars or in operational readiness. Clearly these issues must be resolved if preferred organizations are to result.

Manpower ceilings may dictate uneconomical mixes of weapons and personnel. For instance, to meet an operational objective of 8 sorties (Fig. 15) it might be necessary to have squadrons with 200 men and 25 aircraft, even though it would be cheaper to have 225 men and 19 aircraft, simply because the extra men may not be available but the procurement dollars for the aircraft are.

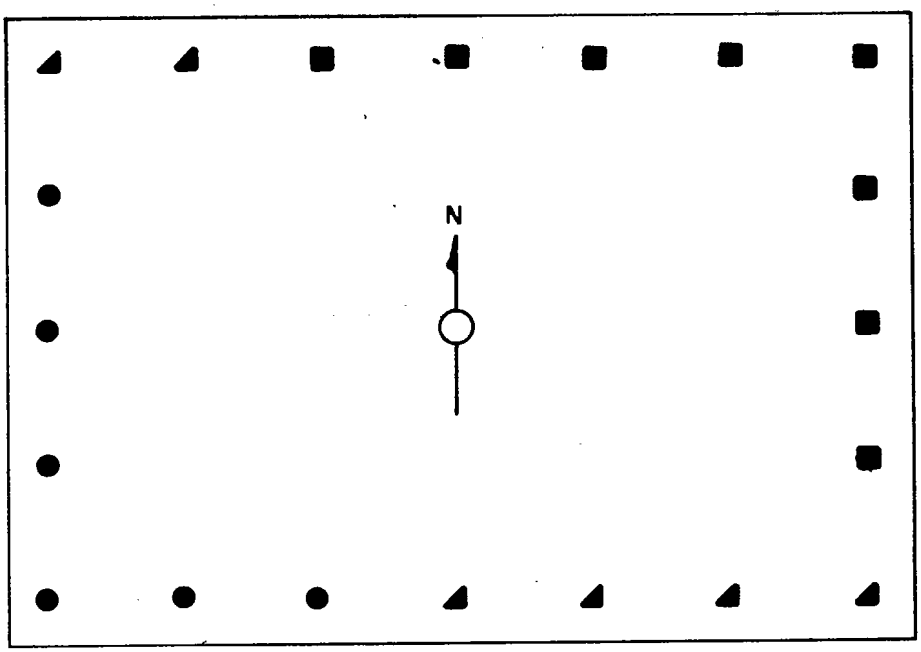
V. RESOURCES MIX AND WEAPON-SYSTEM MATURITY

The proper mix of resources depends on the point in time at which we find ourselves in the life cycle of the aircraft system. Perhaps we can divide this cycle into three parts: future aircraft or those just now phasing in; first-line mature aircraft; and second-line aircraft now phasing out of the inventory. We want to plan primarily for the first-line mature weapon system, and then make adjustments as desirable and necessary at the beginning and end of the life cycle.

FIRST-LINE AIRCRAFT

Let us imagine we are Headquarters planners, and go back several years to the time when the aircraft we have been talking about was a future weapon system, and we were developing plans, capabilities, and costs. We have received the best possible estimates of range, speed, and other operational parameters, cost quotations for aircraft, spare parts, and ground support equipment in varying quantities, and estimates of reliability and maintainability characteristics.

First, considering range, speed and other pertinent performance characteristics, as well as vulnerability considerations, we decide to place units at 20 bases around the periphery of our imaginary country to protect its boundaries (Fig. 16). Next we consider the possible threat to each base, in terms of possible intensity or in terms of the number of sorties we would hope to mount in the first hour. Perhaps we decide that the greatest threat is from the southwest and the least from the northeast, and we accordingly assign an intensity of 10 to each of 6 southwestern bases, an intensity of 3 to 8 northern and eastern bases, and 5 to the remaining 6 bases. The total threat would then be 114. For the moment, therefore, let us say we are asking for



Threat intensity	X	Bases	=	Total
● 10		6	=	60
◢ 5		6	=	30
■ 3		8	=	24
		20		114

Fig. 16—Threat-intensities for fighter bases on the periphery of a hypothetical country

114 sorties the first hour.

To arrive at our first force-budget cut, we move across the bottom scale of Fig. 15 to the point designating 10 sorties the first hour, note the cost per sortie and multiply it by the 10 sorties to get the total base cost, and then multiply the result by the 6 bases of this size. The exercise is repeated for the 5-sortie bases and the 3-sortie bases to arrive at the total cost for the 20 bases. If this amount is either more or less than we are prepared to spend, we must modify our demand for sorties. Assume, for instance, that we can spend only about half this amount. We might decide to cut all sortie requirements in half, rather than re-evaluate each location, and would then re-enter the curves at 5, 2.5, and 1.5 sorties

the first hour, multiply the costs per sortie by the number of sorties per base and the number of bases, and so recompute force cost; and we could adjust a third or fourth time if necessary until we achieved a cost approximately in line with what we are prepared to spend, or better, until we achieve a reasonable compromise between the sorties the force will be expected to mount to meet the threat, and the money we are prepared to spend to counter this threat.

Squadron sizes, then, are selected in terms of UE and manning tables to provide the required sorties at minimum cost. For instance, if the requirement is 5 sorties for one base, the squadron should have 14 aircraft and 150 direct maintenance personnel. We hope at this point, of course, that our estimates of aircraft capabilities and demands for resources are reasonably accurate, and then proceed to write UMD's (Unit Manning Documents) and TTE's (Tentative Tables of Equipment). These should be reviewed and modified shortly before the first squadrons are ready for activation, using the best contractor or Air Force data then available.

FUTURE AIRCRAFT AND THOSE PHASING IN

Now let us turn to the phase-in of the first several squadrons. Several peculiarities exist. First, the aircraft are not thoroughly broken in; they still need the benefit of an intensive product-improvement program with its attendant requirements for technical order inspection and kit installation. Secondly, your personnel, veterans though they may be, are not yet familiar with the peculiarities of this weapon. In short, it would be pleasant to have some extra maintenance personnel for a while. But let us work this backwards: instead of assigning more people to the squadron during phase-in, let us activate the squadron with less than its

normal complement of aircraft, say 2/3 or 3/4. This amounts to increasing the maintenance manning by 1/3 or 1/2, and has the special advantages of enabling us to activate more bases at an early period, train more technical, administrative, and command teams, and get a broader base of experience. After all bases are activated, then let us use production to build the UE up to assigned numbers. Meanwhile, of course, experience, reflected in carefully collected and analyzed data, may show that some changes are desirable in the manning and equipping tables, and these changes should be made.

AIRCRAFT BEING PHASED OUT

Lastly, we have phase-out. The normal procedure is to reduce the number of squadrons or bases gradually, and either scrap the now-surplus aircraft or make them available to the National Guard or friendly countries. A new and peculiar situation now exists, however. When we initially computed our "best UE" for the squadrons, the cost of the aircraft was important, and we were trading off aircraft costs and aircraft waiting-time against support costs and support-resources waiting-time. Since the aircraft were more costly than the maintenance personnel, the proper balance called for a certain amount of normally surplus personnel who would be available for peak workloads, rather than force the aircraft to remain idle. Now the story is different. The aircraft about to be scrapped or transferred are, in a manner of speaking, cost-free. If several of these aircraft were taken from each squadron being phased out, and added to the UE of the remaining squadrons, these otherwise surplus personnel at the remaining bases could be put to work keeping some of them in commission. The remaining squadrons would then have more combat-ready aircraft than they had before. Of course,

there is a limit to this kind of augmentation, as we saw earlier, but our studies indicate that an augmentation of 10 per cent or more is entirely reasonable, and more than half the added aircraft can be added to the previous number of in-commission aircraft without undue effort.

Thus we find that the preferred mix of resources varies substantially at different times in the life cycle of an aircraft system. Accordingly, it may be desirable to modify organizational plans several times.

VI. CONCLUSIONS

This Research Memorandum has schematically illustrated the influence of various resource and policy changes on aircraft capabilities at base level. It has accentuated the importance of these factors by examining their several interactions, both singly and in combinations. The knowledge thus gained can be very rewarding: it may be applied in the organization planning cycle to establish desired weapon-system capabilities with minimum cost; base management in turn can use it to maximize operational capability within their available resources; and it will insure against capability being degraded by failure to foresee the impact of policy decisions and resource allocations.

While this study does not attempt to analyze the proper specification of objectives, one of the salient points it brings out is the key importance of identifying the major objective and subordinating all others to it. There is an over-all objective for which a squadron or wing was established; it must serve as the source for the corollary objectives of operations, supply, and maintenance. Deviations from this principle can be very damaging, however plausible they may appear out of context. Even if it is successful, for example, the establishment of manpower requirements on the basis of maximum personnel utilization, when the objective should be to meet the fluctuating demands of aircraft for maintenance, can substantially degrade operational capability.

Cost factors, both direct and indirect, are found to be extremely important if maximum force effectiveness is to be gained from given budget allocations. The relative cost of temporarily idle manpower must be weighed, for instance, against the alternative cost of out-of-commission aircraft.

Moreover, substantial savings in either dollars or manpower are shown to be possible if costs are judiciously considered when weapon systems enter phase-out.

New weapon systems phasing into the inventory have problems so different from those of more mature first-line weapons that they warrant separate planning factors.

The study shows that operational capability is markedly affected by flying programs and by the relationship between flight schedules and maintenance workshift policies--much more so, in fact, than is generally recognized. Workshift policies in particular are shown to have a strong influence on operational capability; it appears that multiple-shift operations are almost mandatory if an effective force is to be maintained.

It is indicated that the number of aircraft in an organization (the UE) is and should be heavily dependent upon strategic and tactical considerations, rather than solely upon the type of organization, mission, type of aircraft, and logistics considerations.

The degree of management responsiveness in the use of resources has a great influence on the quantities of resources needed to support an operational program. Even more important is its effect on the speed with which the weapon system can be returned to readiness. No other area offers so powerful an approach toward maximizing operational capability.

These principles must be reckoned with by planning and operational personnel at headquarters levels if they are to establish the most effective preferred organizations in terms of apportioning funds and manpower among the competitors for resources. Many of the factors are also important to managers at base level, if they are to perform their assigned missions with effectiveness and dispatch.

While this Research Memorandum does not provide specific quantitative answers to the problems raised, it does clarify what the problems are and furnishes qualitative information on the effects of decisions arrived at to solve them. Such knowledge should enable management personnel at all levels to make better decisions.

REFERENCES

All the references listed are Research Memoranda published by The RAND Corporation.

1. Levine, R. A., and R. B. Rainey, The Base Maintenance-Operations Model Used in RAND Logistics Research, RM-2374 (ASTIA No. AD 220605), May 4, 1959.

2. Levine, R. A., and R. B. Rainey, F-102 Maintenance-Operations Interactions (U), RM-2437, August 18, 1959 (Secret).

3. Levine, R. A., Organizational Support of B-52 Alert (U), RM-2511, January 25, 1960 (Secret).

4. Sewell, W. P., Maintenance-Operations Interactions at Base Level (U), RM-1960 (ASTIA No. AD 133045), August 1, 1957 ( ).

5. Stoller, D. S., and R. L. Van Horn, Management Information for the Maintenance and Operation of the Strategic Missile Force, RM-2131, April 30, 1958.

6. Smith, T. C., R. B. Bristol, Jr., and R. S. Beverly, Project Full House Logistics Data, RM-2256, September 16, 1958.

7. Levine, R. A., and R. B. Rainey, A SAC Alert Concept for the Immediate (U), RM-2303, January 5, 1959 (Secret - Limited Distribution).

8. Smith, T. C., Command Management of F-102A Readiness (U), RM-2436, August 18, 1959 (Secret).

9. Bean, Eloise E., and W. H. McGlothlin, A Model for Assessing the Effect of Maintenance on Missile Launch Probability, RM-2451, September 23, 1959.

10. Firstman, S. I., and B. J. Voosen, Missile Prelaunch Confidence Checkout: Content and Equipment Design Criteria, RM-2485 (ASTIA No. AD 237091), February 22, 1960.

11. Kamins, Milton, Determining Checkout Intervals for Systems Subject to Random Failures, RM-2578, June 15, 1960.

12. Smith, T. C., Managing Strike Alert Commitments (U), RM-2599, June 24, 1960 (Secret).