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AIR DEFENSE SYSTEM (U)

FOREWORD

It is assumed that a possible enemy has sufficient atomic bombs to destroy a majority of the industry of the United States. It is a problem for the United States to insure that the minimum of these bombs are detonated and those in unimportant localities.

There are various ways by which the enemy may attempt to deliver bombs; they need not be enumerated. There are also various countermeasures, such as dispersal of industry, counterattack, and military defense. The A.D.S.E.C. is concerned with a particular phase of the military defense against the atomic bomb; a phase in which it is proposed to prevent the effective detonation of enemy bombs by destroying or deflecting all of the enemy bombing aircraft.

The Air Defense Systems Engineering Committee was invited by General Muir S. Fairchild, late Vice Chief of Staff of the Air Force, to make a fresh study of the problem of Air Defense and to make such recommendations as would lead to a marked improvement in our defense capability were this technically and economically feasible.

This paper is a summary of A.D.S.E.C. thinking about this problem to date. As such it will serve as an introduction to various hitherto private memoranda which have now so increased in number that their collection and ordering is desirable.

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THE AIR DEFENSE SYSTEM

What follows is a rationalization of various ideas on Air Defense gotten from many sources. A.D.S.E.C. did not, of course, commence its studies by inquiring "What is a system?" But its thoughts to date shall be collected here as though it had done so, because that makes a suitable frame on which to exhibit its various tentative conclusions.

It is thought moreover that this kind of discussion will resolve many of the difficulties in understanding the system which are of semantic origin. Many of the violent arguments which take place are essentially about the meanings of words; many opinions are freely expressed about the proper disposition of non-entities, which exist only as words.

Therefore, since we are reasonably certain of the meaning of the words "Air Defense" let us look into the meaning of the word "system."

The word itself is very general; Webster's gives fifteen different meanings for "system." There are, for instance: the "solar system" and the "nervous system," in which the word pertains to special arrangements of matter; there are also systems of philosophy, systems for winning with horses, and political systems; there are the isolated systems of thermodynamics, the New York Central System and various zoological systems.

The Air Defense System has points in common with many of these different kinds of systems. But it is also a member of a particular category of systems: the category of organisms. This word, still according to Webster, means "a structure composed of distinct parts so constituted that the functioning of the parts and their relation to one another is governed by their relation to the whole." The stress is not only on pattern and arrangement, but on these also as determined by function, an attribute desired in the Air Defense System.

The Air Defense System then, is an organism; and it will be worthwhile to examine some different organisms to see if there are any general principles to be induced, and possibly used.

What then are organisms? They are of three kinds: animate organisms which comprise animals and groups of animals, including men; partly animate organisms which involve animals together with inanimate devices such as is the Air Defense System; and inanimate organisms such as vending machines. All these organisms possess in common: sensory components, communication facilities, data analysing devices, centers of judgement, directors of action, and effectors, or executing agencies.

Organisms also have the power of development or growth and the possibility of decay and death. Moreover, they require to be supplied with material. Since armies are organisms, it is not surprising that these functions parallel the divisions of a general staff. Note that in an army the function of development used to be mainly that of recruiting new troops; now there are in addition laboratories whose task is to recruit the forces of nature.

Nearly all organisms can sense not only the outside world, but also their own activities. It is often the case that some of the component parts of a complicated organism are themselves complete organisms.

It is the function of an organism to interact with and alter the activities of other organisms, generally to achieve some defined purpose, but not always with any particular other organism or group of organisms.

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A large organism can be composed entirely of men -- with no machines at all. Such was Caesar's Army. Men saw and heard what was going on in battle, they were the sensory organs. Other men ran in relays back to Caesar and told him about it, they were the communication facility. Caesar's staff put all the stories together and filtered out the nonsense, they were the analysing device. Caesar himself decided what to do or what not to do, he was the center of judgement. Caesar's lieutenants gave the orders, they were the directors of action. Finally the orders were executed by the army. Perhaps sometimes Caesar not only judged but also analysed and directed; but then he had only a small job to do, and much time to do it in.

Many contemporary organisms are composed almost entirely of men with the exception of the effectors. Most manufacturing enterprises are like this. More generally, a survey of the organisms which man has put together, indicates that the relative mangitudes and degree of mechanization of their functional parts very greatly according to their purpose, and to the prejudices of their particular creators. Although there is usually but one center of judgement, such as the board of directors of a company, there can be many different kinds of sensory agents, many different analysing agencies, directors and effectors. Nor is there any fixed pattern in which all these functional parts are tied together or communicate with one another.

FUNCTIONAL COMPONENTS OF ORGANISMS

In this paper an attempt is made to examine the Air Defense System in light of human experience with other organisms of similar magnitude and complexity. Before doing this it will be necessary to investigate the kinds of functional components which are available; particularly to com-

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pare the capabilities of the various inanimate components with those of man, who is the universal component.

SENSORS

Within their physical limitations of size, pass-band, etc., the ear and eye are remarkably perfect. They each approach as near the ultimate in sensitivity as it would in any case be practical to make them, and their dynamic ranges are also remarkably great. The particular frequencies and media to which they are attuned are not particularly well adopted to the detection of high speed aircraft, but this is not their main disadvantage.

It is because all visual and aural signals must pass through very general analysing devices and centers of judgement and of direction, which may add various false or non-pertinent modifications, that their use is often unreliable. Moreover, they can only with difficulty be made to search in a methodical and exhaustive manner. A further deterrent to their use is that their data must be transmitted by voice to the remainder of the large organism, and this is too slow.

Thus many of the disadvantages of the ear and eye arise directly from the fact that they are unavoidably attached to an organism which is not the Air Defense System; and therefore their use introduces other unnecessary and unwanted brains into that organism.

In contrast, inanimate sensors such as strain gauges, speedometers, radars, microphones, photocells, etc., are rarely parts of any organism other than the main one with which they are in communication. They therefore will inevitably tell what they see, and they can be made to search methodically and exhaustively. Moreover, many of them can detect and transmit data at speeds remarkably greater than attainable by the eye or ear.

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In distinction from the case of inanimate sensors, an inanimate communication facility is often but not always part of some other organism than the one which it serves at the moment. The telephone is a case to point.

COMMUNICATION

The functional parts of an organism are connected by a communication facility such as the nervous system or the telephone system.

When the human senses are employed in an organism, the communication must pass through a human effector -- either the voice or the fingers. Neither are very rapid and both introduce errors. Men communicate rapidly by talking and making faces at one another. If the visual element is omitted the number of errors increases markedly which is a well known drawback of the telephone. But inanimate sensors can communicate without voice, by suitably varying some physical parameter as pressure, displacement, voltage, etc.

In view of these capabilities of a radar in particular, it appears too bad that so much is wasted by the addition of a further device, the PPI tube, whose only task is to interpret the data so a man can grasp it. The radar searches space methodically, and once the return signal is detected, the information is available. Furthermore, the information is in an orderly arrangement -- namely the order in which the targets were first illuminated.

All this advantage of speed and orderliness is lost by the use of the PPI tube. For now a man scans the tube in his usual non-orderly fashion and so misses some of the data; the rest he succeeds in transmitting in some random order at a low speed to the remainder of the organism. Now since all the data was in the radar receiver originally in the form of

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electrical impulses, one may well ask why go through all the trouble of using cathode ray tubes and radar operators so as to put the data on telephone lines, again in the form of electrical impulses -- especially when most of the data is lost and mixed up in the process. It is scarcely conceivable that any amount of training, or the use of any number of men will ever succeed in getting the data onto the lines in as accurate a form as it originally was in the radar receiver.

DATA ANALYSERS

The raw data transmitted by the communication facility from the sensory devices must be analysed or predigested before it can be utilized in the making of judgements. The ear hears Chinese as easily as English but unless the listener can interpret Chinese to himself he cannot form any judgement or take any action on the basis of what he hears. In a commercial establishment the raw data may consist of bills, orders, checks received and so on. From this mass of material the directors would be unable to form any judgements useful for guiding the business. Therefore, they employ bookkeepers and accountants to digest or summarize all these papers.

In the Air Defense System this function is called "data filtering." It consists of plotting aircraft tracks, determining aircraft courses and velocities, identification of aircraft and deletion of now pertinent data such as noise and friendly aircraft.

In general a survey of other systems shows that although men are extensively used for data analysis, a great deal of semi-automatic or completely automatic machinery is also in use. The familiar punched card accounting machinery is an example of this.

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JUDGEMENT

Judgements are formed as reactions to the incoming analysed data. Judgements are usually formed in accordance with certain rules; thus the directors of a company usually refer to the standard operating practices of the enterprise, and to the statute law before rendering their decision. Judgement is almost invariably carried out with reference to past history which implies that a center of judgement contains within it a memory.

Except for trivial things like the switch in a coin operated machine which fails to close if a slug is detected, judgement is performed by men or groups of men. Usually of course they are equipped with books and other mechanical aids to memory.

In the Air Defense System this function takes place in the "Area Control Center." The function itself is called "threat evaluation" and also is part of the function of command.

In response to the incoming data, judgement decides (1) should any action be taken; (2) what action should be taken; (3) what agency should undertake this action. Thus if sales of a particular item are falling off, the board of directors must first decide whether to do anything about it; having decided this in the affirmative, they must decide whether to increase advertising, get more salesmen, lower the price or admit defeat and stop manufacturing that item. Obviously they do this in the light of past experience. Presumably if they decide not to take any action, they disregard further data concerning that item for the time being. It is not clear that this principle is at present effectively carried out in the Air Defense System.

It is currently proposed by some that complicated judgements can be

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made by digital computing machines. Whether this is a desirable innovation for the Air Defense System depends on the results of maneuveres intelligently carried out and whether there is a need for the increased speed of the machine and on whether the limitations of machine judgements are compatable with the flexibility of enemy operations.

DIRECTORS

In a business these are the managers, foremen, etc., who accept judgements and work out the detailed operations which the executing agency must perform in order to take the required action. Thus an advertising agency will plan the increased advertising, the sales manager will hire and instruct new salesmen, the production men will decide how the price can be lowered and so on. Much of this work can be done by computing machines; indeed in gun-laying it is completely automatic. At present in the Air Defense System it is accomplished by a man, called the ground controller. It is to be noted that often directors are complete and complex organisms themselves.

EFFECTORS

The effectors of an animal are its muscles. In addition man employs a huge variety of tools. Since the advent of servo-mechanisms we have had mechanical effectors which can be controlled without the direction of men. Often of course men are used as effectors in the form of manual workers. The Air Defense System employs fighter aircraft each of which is itself a complex organism; it may also employ anti-aircraft artillery guided missiles and electronic countermeasures.

It should be held clearly in mind that, while effectors are vitally important parts of the organism, they are not all of it. It will be evident that, in analogy with a man, A.D.S.E.C. considers the contemporary

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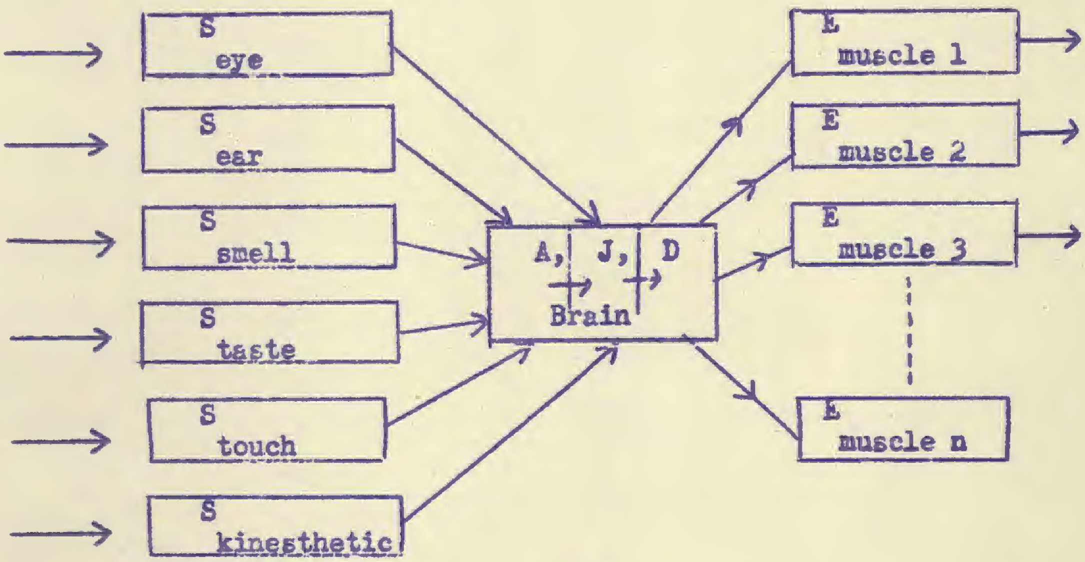
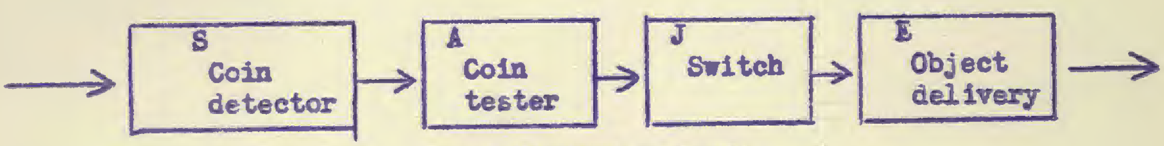
Air Defense System to be lame, purblind, and idiot-like. Of these comparatives, idiotic is the strongest. It makes little sense for us to strengthen the muscles if there is no brain; and given a brain, it needs good eyesight.

THE ORGANIZATION OF ORGANISMS

In the following block diagrams each functional component will be indicated by a box, except for the communication link, which is indicated by a line. Sensors, analysers, judgement, directors, and effectors will be denoted by their respective initials.



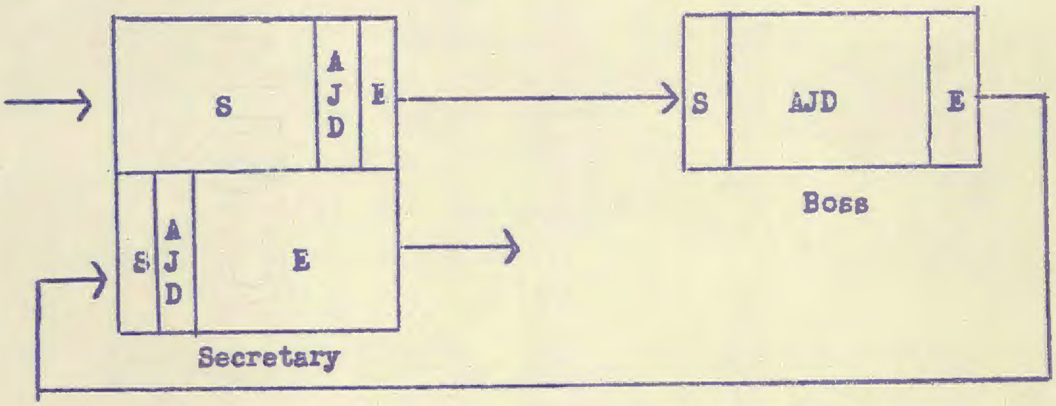
ANIMAL



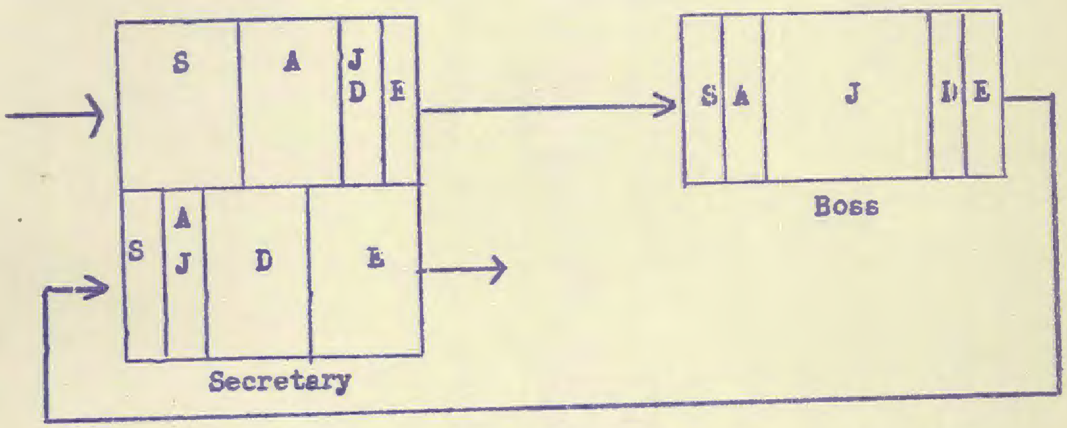
COIN VENDING MACHINE

The effector can only operate in one way so that no explicit director is needed.

When we consider organisms made up of a number of men we must realize that the man who is director attempts to control the muscles of the effector directly, but actually must give orders through the effector's senses and brain. Thus all of the man is always in use regardless of his function, but to varying degree. In the following men will be indicated by boxes divided unequally into parts according to which of his capabilities is dominant in his assigned function.



BOSS AND SECRETARY (LOW PRICED)



BOSS AND SECRETARY (HIGH PRICED)

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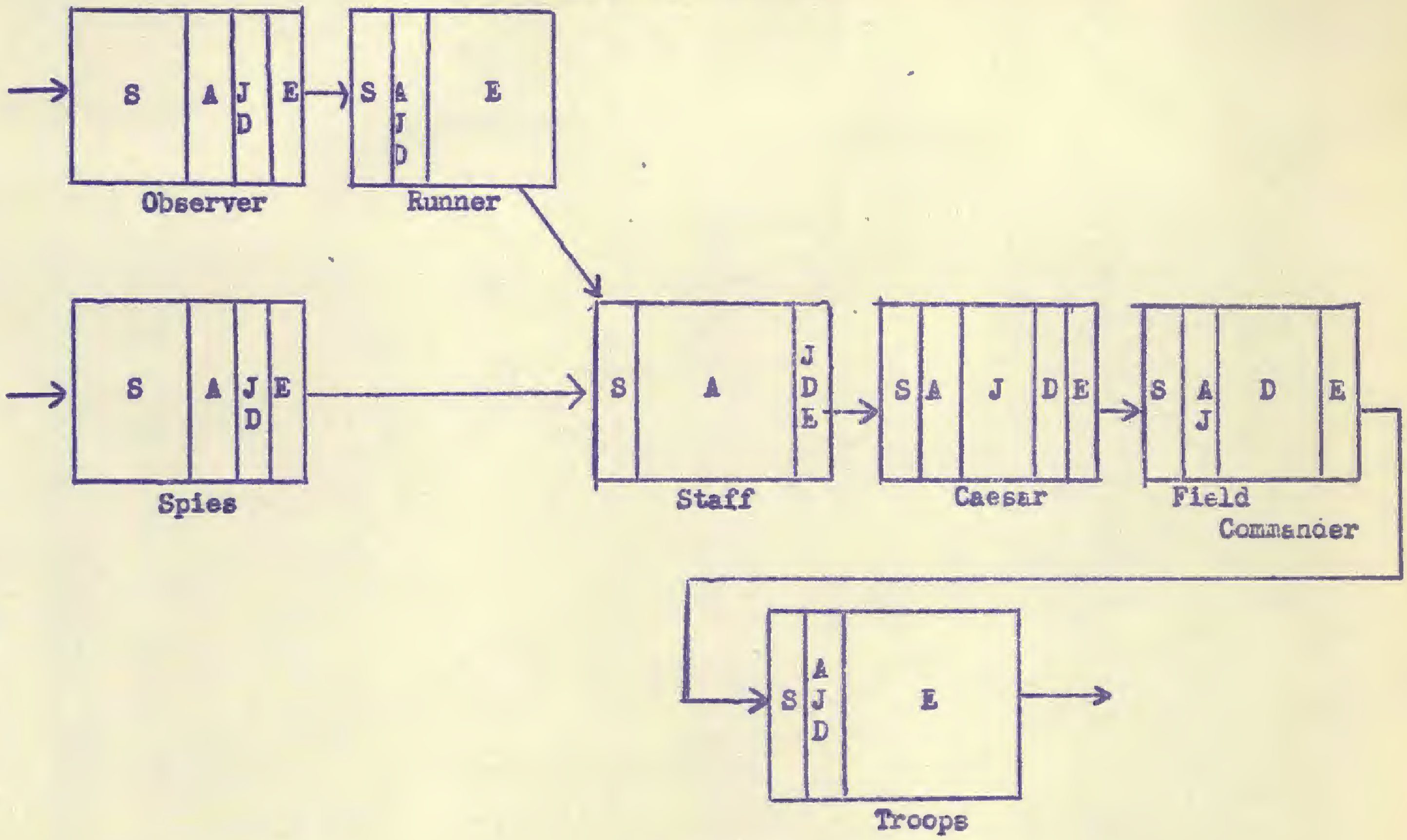
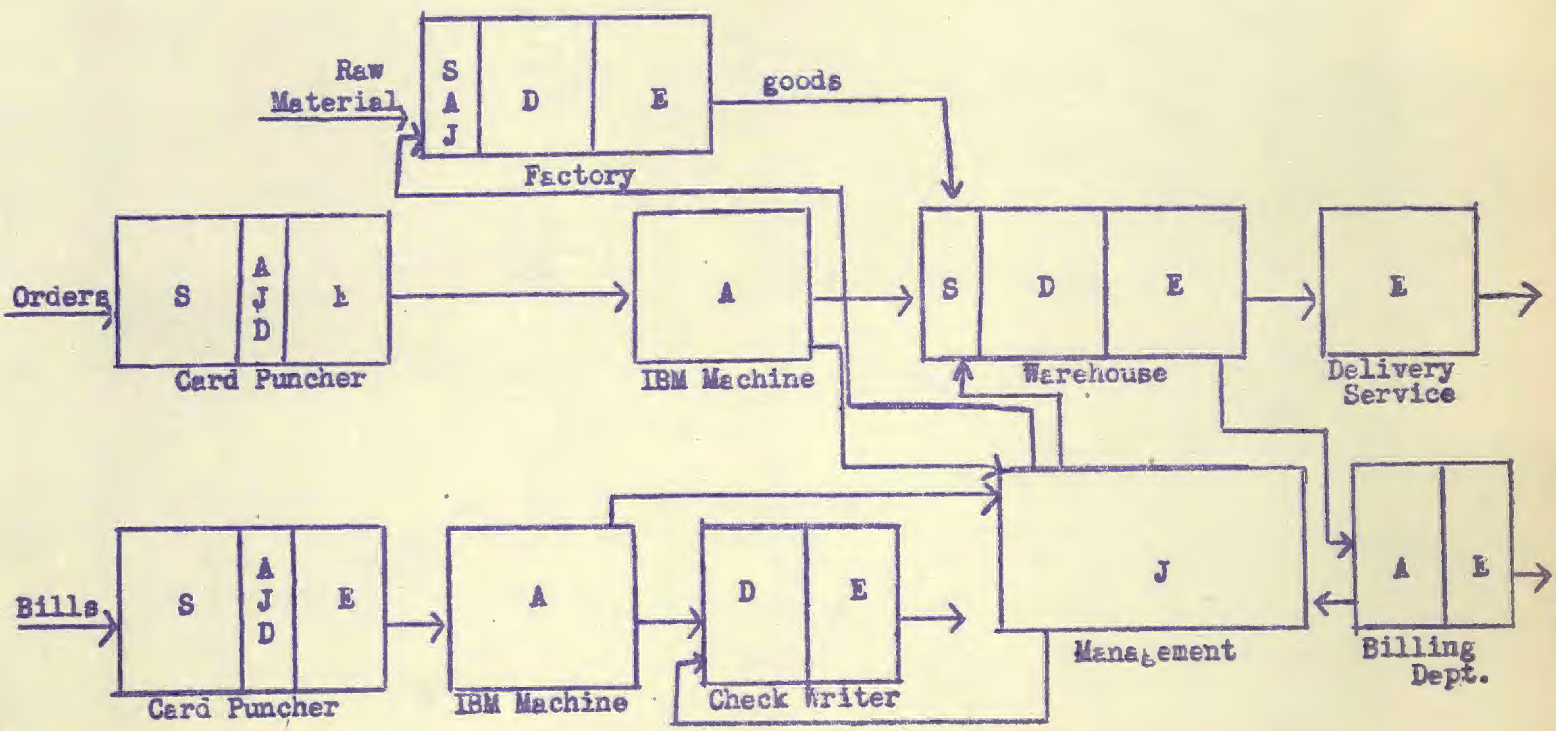


CAESAR'S ARMY



A RUDIMENTARY MAIL ORDER BUSINESS

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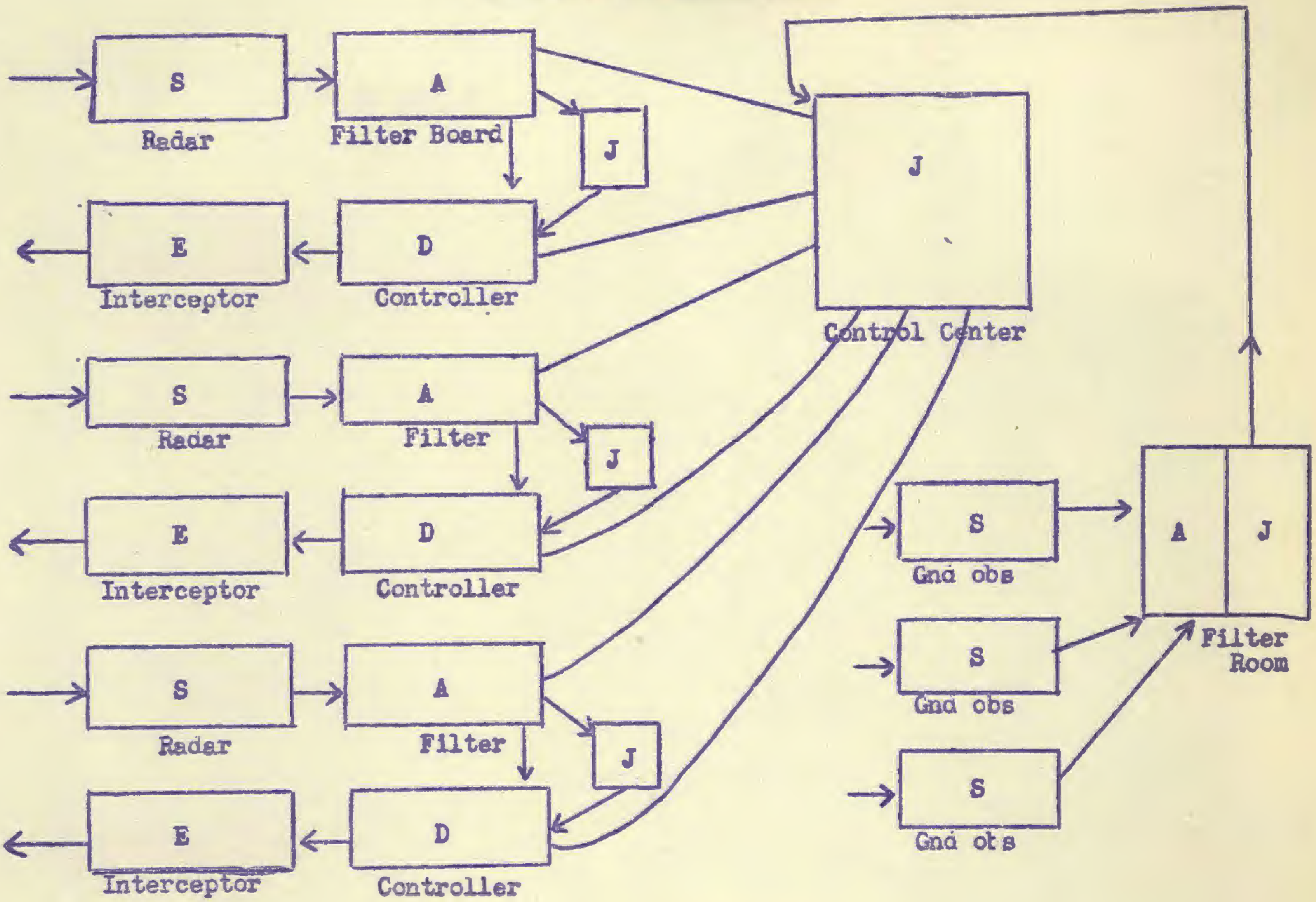

PRESENT AIR DEFENSE SYSTEM

The multiplicity of data analysers and directors, each connected to only one sensor can be regarded as uneconomical. The profusion of centers of judgement is far worse since it leads to confusion and poor judgements; "many cooks spoil the broth."

These diagrams are useful to give us confidence. If a two-bit mail order house organization looks so complicated and works, and if the Air Defense System is simple and doesn't work, then the obvious assumption is that the Air Defense System must be very complicated indeed in order to work; but then see what a simple diagram can be drawn for the animal. Consequently we need not expect to have to make an organisati

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of great complexity.

One thing obvious is that the best organizations have only one center of judgement; perhaps this is something to be copied.

CRITICISM OF THE PRESENT AIR DEFENSE SYSTEM

SENSORS

The main sensory elements employed are large ground based radar sets. (We shall not discuss at this point the supplementary ground observer system). The radars suffer from the following inherent limitations: (1) They are intended to be used for detection of aircraft at maximum ranges of about 150 miles but their range against low flying aircraft is limited to about 30 miles by the earth's curvature; (2) They cannot detect interceptors beyond about 75 miles at any altitude; (3) Their facilities for finding target altitude are even more limited in effective range, are slow and inaccurate; (4) They are unreliable due to faulty maintenance; (5) The installations are costly and require large staffs; (6) Pulse radars require additional MTI equipment to remove ground clutter.

COMMUNICATION

Voice communication is employed exclusively. This requires a special transducer to be added to the radar, the PPI tube, the use of which enormously deteriorates the data. Much telephone plant is available but its physical capability is largely wasted by the use of voice. The message rate is about 100 times too low to handle the necessary traffic due to human limitations. Tests show that one man can continuously transmit the necessary data pertaining to only 2 aircraft. Tests run by Cambridge Research Laboratories under A.D.S.E.C. auspices indicate that the ultimate traffic capacity of a normal telephone line is (   ) aircraft positions.

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The ground to air communication link can be jammed. In sharp distinction to the ground to ground communications, it has ample speed and traffic capability.

The use of voice is chiefly objectionable because the pilot is often distracted and doesn't listen well. The ground transmitters are underpowered to a degree. A code system based on modern ideas would also alleviate these difficulties, all of which, while of themselves serious, are relatively minor compared to the troubles on the ground.

ANALYSERS

The present filter boards suffer greatly due to poor communications. In addition their traffic capacity is also limited because of the speed limitations of the men who do the plotting. They are also inaccurate and unprecise. No numerical means is available to compute velocities and bearings rapidly. The plotters work under physically and mentally exhausting conditions. Although these men are used as machines, they must constantly make many minor judgements as they locate coordinates, etc. Thus mistakes are made. Coordinates are transposed from ρ, θ to X, Y systems graphically in the crudest fashion.

A considerable number of judgements are now made by these boards because of the limited communications with the center of judgement. Consequently no one knows who is doing what.

CENTER OF JUDGEMENT

The Area Control Center is now merely a filter board made large. Cartesian coordinates from several radars are plotted on this board. The judgement is made by men looking at the board. Since no such board ever gets good data from the present filter boards, it cannot be said definitely that the required judgements cannot in principle be made speedily and

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accurately enough by men; however, such judgements cannot in fact be made now. The judgements are: should the aircraft be attacked?; from which air base should interceptors be sent and how many? The present Control Centers function more as inspectors than commanders. At the present time it is not clear that they really function at all; consequently it can be questioned whether there really is an Air Defense System or whether what we have now is a collection of uncoordinated radars and fighter squadrons.

DIRECTOR

This is another man sitting at a PPI tube. It has been amply demonstrated in the anti-aircraft business that all of this function can be mechanized. Actually the ground controllers at present have no mechanical aids to computation at all. Moreover, there are far too few ground controllers in the system to handle its expected traffic by about 100 times.

EFFECTORS

We shall discuss only effectors belonging to the Air Force, i.e. interceptors. These are very complex organisms in their own right. They have the following inherent limitations: (1) They are ineffective at low altitude; (2) They are excessively expensive; (3) They have enormous quantities of delicate, hard to maintain sensory analysing and directing mechanisms; (4) They have to land on runways.

The blind landing problem is exceedingly difficult to solve; it is far more difficult in principle than the interception problem. In effect a complete sensory, communications, judgement, and directional organism must be set up along side the AC/W system for this purpose. Present indications are that this blind landing system must be nearly as complicated and as expensive as the AC/W system. Moreover, there is no

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landing system which has been proven even for slow rigidly scheduled civil transport aircraft, whereas here we have fast aircraft flying almost randomly with minimum fuel. The importance of doing away with the necessity for this additional extraordinarily complex and costly system can not be overestimated. Almost any solution should be accepted in place of electronically controlled blind approach and landing for interceptors.

ORGANIZATION

Because it appears that the eyes of the organism are half blind, the nervous system and brain almost non existant and the muscles weak, it would appear that the organizational pattern by which these are connected is scarcely worth while criticising. Some tentative remarks can nevertheless be made.

First it may be more economical to organize the system like an animal. That is one might centralize the analysis, judgement and direction functions. This would necessitate vastly improved communication methods. At present each radar is equipped with a data analyser and a director, each of which should ideally be capable of handling a maximal raid. But by definition of maximal raid can occur in the neighborhood of but one station at a time; therefore, the analysers and directors of the other stations are mostly idle. While some extras are needed for emergency, it is improbable that we need 10,000 per cent spares.

One operational difficiency of dispersed analysers is that hostile plane flying successively in the outer range of adjacent radars may appear in each of their scopes for insufficient time to be plotted and recognized; he could then penetrate the system although detected. A centralized analyser would militate against this.

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OPERATIONS

Although the separate components of the organism are basically inadequate, they are at present far from achieving even their limited ultimate efficiency. The maintenance of equipment is poor and the operational procedures are unsystematized.

In addition the civilian authorities apparently do not take the effort seriously. One evidence of this is the fact that aircraft of foreign origin are allowed to approach New York directly and must be identified close to New York. New York is thereby rendered indefendable. The interceptors must fly in assigned corridors and must under certain circumstances get CAA approval. Navy aircraft fly in from carriers with out? flight plans. We must realize that a tight Air Defense System cannot be achieved unless only the air defense aircraft have complete freedom of flight; there will inevitably be hindrances to other aircraft. This is one of the prices of air defense.

SUMMARY

The present system is inadequate even for "broadcast control."

WHAT CAN BE DONE NOW

SENSORS

In order to get low altitude information we must employ not less than one radar per 4,000 square miles and preferably twice that number. This would increase the capital investment in radars by from 10 to 30 times what it is now and would require from 5 to 15 times as many AC/W personnel. Further it is predicated on the use of digital analysers which have not been proven. This improvement is therefore not for "now." All that can be done is to make the present radars more reliable by the injection of some common sense into the system.

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COMMUNICATIONS

On the ground, voice communications can be made more effective by training, better job assignment and general management improvement. Air to ground communications could be improved by the application of the Davis System and higher power transmitters.

ANALYSIS

A number of devices are available to make manual tracking and human filtering more efficient. The TPI photographically projected filter board is one. The Navy is another. These should be experimented with and if useable, got into production quickly. Besides being quick and dirty, they are invaluable training and operational analysis tools. Target acquisition and tracking should be separate jobs. Many more operators and PPI tubes can be installed. In this way broadcast control may be made feasible.

JUDGEMENT

Essentially trivial reorganization could be tried. Most importantly maneuvers should be run and suitably recorded for study so that there will be some experience for the making of judgements. It may be possible thus to strengthen this function.

DIRECTORS

Many more controllers should be employed. They should be given Craig Computers or the like. They should be supervised by a chief controller.

EFFECTORS

The interceptors are in better relative shape than any other part of the system. There is little that can be done to them on a short term basis. Since broadcast control is probably most effective with the present system, and there is no blind landing equipment, a great excess of fighters is needed. [redacted]

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OPERATION

Even when so improved, the present system will hardly overcome the vast distances involved in the United States as compared to Britain, to achieve World War II kill rates of around 10%. Close control with this system would hardly be practicable against more than 10 bombers per radar. Broadcast control should therefore be studied exhaustively for operation on the present system. The system so improved will not counter a blitz raid; it may be suitable for a war of attrition.

WHAT MIGHT BE HAD IN A FEW YEARS (1954)

(This is based on gadgets known to work on an experimental basis now.)

SENSORS

It is doubtful if any improvement can be gotten by the use of any new pulsed radar; it would be better to improve by modification the present FPS-34 CPS-6 to get superior high altitude coverage. Beacons should be installed in all interceptors.

COMMUNICATIONS

The digital radar relay device could be used to take TPI plots to the ADCC and thus render it a real command post.

ANALYSIS

Analogue track-while-scan units could be used for the use of SAGCI as well as TPI-DRR for judgement centers. This puts two analysers in parallel and could result in confusion.

JUDGEMENT

Some kind of crude electro-mechanical situation board may be feasible; or the DRR data may be displayed on a large multi-gun cathode ray tube.

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Essentially not much can be done. There is no sense in making calculators to evaluate threats for this 1954 system.

DIRECTOR

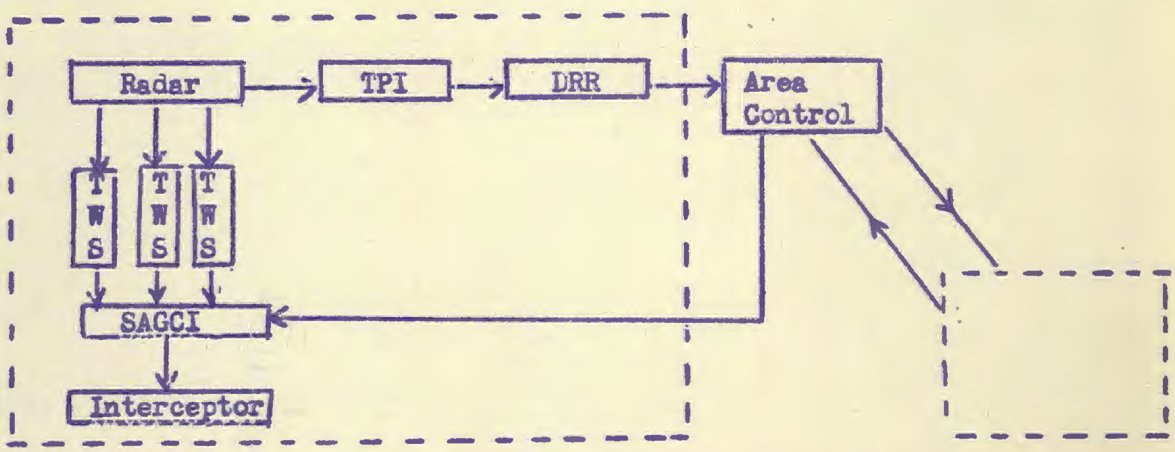
The SAGCI could be used for "modified broadcast control, i.e. groups of fighters are directed at groups of bombers.

EFFECTOR

Some sort of navigation system should be installed for broadcast control.

ORGANIZATION

The separate analysers for judgement and direction as well as the manual target acquisition are weak points.



There is still no solution to the interceptor landing problem or to the low altitude problem. Its effectiveness against a small raid might be fairly high, but it would saturate easily and because of the poor organization, might make gross errors even worse than the present system. It has the merit of using the gadgets now developed and if the A.D.S.E.C. sponsored experiments fail, will probably be adopted. It should be studied by Rand.

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WHAT MIGHT OPERATE BY 1956

There follows now a discussion of how the following characteristics might be obtained: (1) The ability to make close-controlled interceptions on raids of all sizes, limited not by technical deficiencies but by the amount of money assigned to the task; note that no amount of money could do this for the 1951 and 1954 systems; (2) Low altitude bombers could be attacked.

It should be noted that whereas manned interceptors can be used successfully in either broadcast or close control, ground to air missiles must be close controlled.

The discussion which follows discusses new ways of achieving the different functions of the organism from two points of view: economics and operational efficiency. The cheapest system is sought with the maximum traffic capacity.

RADARS

Economics of Capital Investment:

The economics of small radars vs large ones can be estimated in the following way. Divide the radar into its basic components: transmitter, receiver, scanner, terminal equipment, and PPI tubes; then see how the cost of these components varies with the size of the radar.

But first, what is meant by a big radar -- obviously one which has a long range; however, the problem with which we are faced is the defense of an area. Therefore we should speak of the area swept by the radar, rather than of its range. Suitably recasting the radar equation we have $A \simeq W^{2/3} P^{1/2}$ where A is the area covered, W is the weight of the scanner (taken proportional to the 2/3 power of the dish area) and P the transmitter power. Now the cost of machinery is usually at least proportional

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to its weight, and there is some empirical evidence that the cost of transmitting equipment is proportional to the square root of the power. Consequently if we increase the area covered by increasing the power of the radar, we break even. If we increase the range by increasing the antenna size, we definitely lose; indeed for an eight-fold increase in antenna cost we get at most a four-fold increase in area covered. This indicates that very large radars in which the scanner represents the major item of expense are likely to be uneconomical unless their size buys us something more than range (such as narrow beams which wouldn't be needed if the range were not so great.) If the problem of continuous height finding is added, this picture is even more in favor of small radars.

If we similarly investigate the cost versus area covered of PPI tubes we again obviously break even. On the cost of receivers we lose, but usually the receiver is a negligible fraction of the total cost.

If, however, we consider the cost of special necessary equipment, especially of MTI, but also of equipment which would be needed to relay data without the use of human observers, such as L.R.R., then the advantage is very definitely in favor of the long range radar, since this can be a major expense which is independent of the area covered by the radar.

<u>Economics of Personnel Required:</u>

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Economics of Small Radars:

The basic, unalterable properties of radio waves indicate that over land we cannot achieve low altitude coverage with radar ranges of greater than thirty miles because of earth's curvature. We are therefore forced to employ small radars. But the economics indicate that as the power and antenna size decreases, we should also decrease the terminal equipment required. Put another way, while very large pulse radars are uneconomical, very small ones are also, and the smallest economical size is too large to give low altitude coverage. This we do not know how to do with pulsed radar.

However, these ground radars are interested only in detecting moving targets. The present pulse radars do this at short ranges by the addition of a Doppler-effect sensitive device of considerable complexity and delicacy — the MTI. But it is possible to construct radars which are ab initio sensitive only to moving targets alone — the so called CW radars. These would require no MTI and would give vastly superior ground clutter rejection. Moreover the equipment required to relay their data appears to be appreciably simpler than the pulse radar DRR equipment. By the use of CW radar, therefore, it may be possible to achieve both high and low altitude coverage at a comparable cost per square mile in men and money as we now get only at high altitude with pulse radar.

It is primarily to investigate the technical practicability of this economically attractive possibility that A.D.S.E.C. has advised the developement of experimental CW short range radars. These radars may have other advantages as well, but low initial cost and minimum of personnel necessary for maintenance and operation are the dominant ones.

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TARGET TRACKING

Case of the Large Pulsed Radar

Manual Tracking

Suppose that there is in view a large number n of targets, and the scan period of the radar is T. Suppose also that the time required for a man to read off the range and azimuth of one target is t where obviously t must be less than the scan period T or else data is being lost. Then the maximum number of targets which can be tracked by one man is T/t and the minimum staff required is $\frac{n\,t}{T}$. Then if n = 100 targets, if the scan period is 12 seconds and if it requires 3 seconds to read off coordinates of a particular target, we require 25 trackers.

Actually this is far too optimistic, for a rather involved reason having to do with making certain that each man tracks the correct target.

First of all it is obvious that each of these men cannot choose for himself echoes to track, for then some echoes would be tracked by several men and others by no men at all. Therefore echoes must be assigned to these men. This implies one other man whose job is to assign trackers. But this man requires time to do his work in, and if each tracker is given the whole PPI picture to begin tracking on, then by the time the assignor gets to the 25th man the picture will have so changed that he may not be sure just which echoes the first men are tracking.

The remedy for this is simple in principle. One merely divides the PPI picture into radial and angularly defined regions, and sets each tracker to begin tracking targets which appear in a given region. But this means that all of a given tracker's echoes now appear in a restricted azimuth region, so that he has not the scan time T in which to work, but a time T/k where k is the number of azimuth regions in which the PPI is

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divided. Consequently he can handle fewer than T/t targets, and no more than $n\,t/T$ men are required. In this way we can easily conclude that fifty trackers should be used on such a radar as AN/FPS-3; actually on the similar AN/CPS-5 but two are currently used. (The large number (19) tubes furnished with AN/CPS-6 are not accompanied by any organizational facility to guarantee their utility.)

Thus we see that there is a fantastically narrow bottleneck in communications traffic capacity right at the sense organ of the organism.

It is clear then that: First, we must employ more men as trackers; second, we must employ a target assignor. But if we employ a target assignor he must get his information from somewhere and thus implies still other men whose job it is not to track targets but simply to detect new ones.

Now if these target detecting men or target acquirers are only required to detect targets coming in from maximum range, they can each be given sector scopes of range say between 125 and 150 miles and covering say 45° of azimuth. Their information must then be collected and presented to the assignor. It would then appear that we could use also several assignors each restricted to a particular region; or even perhaps use the acquirers themselves as assignors.

But the situation is complicated considerably when we recognize that interceptors must also take off and first appear on the scope at close ranges. It then becomes mandatory to have some method whereby each echo has a distinguishing mark attached to it at least to indicate that it is already being tracked if such is the case. It would be best if this mark could also identify fighters from other aircraft of course.

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Thus we come to a system which also has about 100 independent range and azimuth mark generators, besides upwards of forty cathode ray tube indicators. It also requires about 50 operators as it stands.

But the number of operators could perhaps be halved if instead of reading off the target position, each man were given a cursor with which he could spot the target. But this involves about 100 independent cursors and their individual data transmission devices.

What has been described thus far is essentially the tracking part of the British Admiralty Comprehensive Display System. A.D.S.E.C. believes that this part of the system alone comprises enough vacuum tubes to make a digital computer to do the job with only the aid of a technician; and that in all likelihood one man of technician's calibre could be picked from a group suitably intelligent to run the C.D.S. The capability of a digital computer to do this particular job is expected to be experimentally demonstrated by 1 February 1951, as a part of the A.D.S.E.C. experimental program. Furthermore the time required to set up the C.D.S. system would not be appreciably shorter than that required to set up a many target digital tracking system.

<u>Machine Tracking</u>

There are approximately ~~15~~ 10 "track-while-scan" machines currently under development. All of those which have been demonstrated to work with actual radar signals can track but a single target at a time. Most of them are analogue devices. All of them require to be set on target manually (actually this is more due to the poor clutter rejection of pulse radars than to inherent limitations of these devices).

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Broadly speaking all these devices operate on the same principle. By means of range and azimuth "gate" signals a small area is defined and this area is initially set manually to include a target echo. At the moment the echo appears its exact position is recorded in the device; the small defined area is initially made large enough so that a second echo from the moving target will also be recorded. These two sets of data are used to form a target velocity estimate, whereupon the defined area starts to move at this velocity and also to become smaller, finally reaching a minimum size dependent on the reliability of the prediction. Provision is also made to continue the operation with a more open mesh if the target echo is lost for a few scans.

It is seen that this device also performs part of the function of the data analyser, i.e. it computes course and velocity.

It should be abundantly clear from the discussion of manual tracking that this line of development is an important one.

Although there are many devices of this sort under development, lack of suitable facilities has prevented any investigation as to what the optimum mode of operation of these devices should be. Thus, should the velocity be computed on the basis of 2, 3, 4 - - or n points; should the data be smoothed and if so how; how should the data be corrected; should concentric boxes be used to handle the case of two diverging aircraft? Now it is very likely either that there is only one right way of designing these gadgets, or that there are several different circumstances each of which requires a different adjustment. The previously mentioned A.D.S.E.C. digital computer experiments will attempt to answer these questions, and the results should be equally applicable to either

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analogue or digital machines.

It is believed, however, that analogue machines are not the most economical means of doing the job when hundreds of targets must be handled simultaneously. One digital computer, according to this view, could do the jobs of many separate analogue devices. This point will also be tested.

COMMAND CENTER

While questions of economy entered into the discussions of ideal radars and data analysers as well as the dominant question of operational capability, only the latter can be considered under this heading. Our discussion of other organisms shows that important decisions are only made at central headquarters in the light of the big picture. If we believe, as we do, that we should design the Air Defense System on lines proven successful in many other fields, then certainly this important function must be centralized. This can only be done if the communications system is effective and if the data analysis is thorough and fool proof.

All important operational decisions must be made at the A.D.C.C.

We envisage the data coming in from the analyser to consist of three categories: interceptors, identified aircraft, unidentified aircraft. We believe that one of the rules for making judgements will be: "All unidentified aircraft will be presumed hostile and will be intercepted".

In the initial operations of this system and possibly always, these judgements will be formed by men. A possible situation board would present, as has been suggested before, a three dimensional picture in which the three categories of aircraft are given different colors. This should be fairly easy to contrive, given digital computer signals to work with instead of radar signals. From this board all judgements affecting large

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groups of aircraft can certainly be made.

There is another type of judgement, however, which is best made by machine and is properly incorporated in the director. This includes the arranging of fighter paths to avoid collision, the decision as to whether a particular fighter should attack a second target, etc.

Eventually one could do practically all the work of the A.D.C.C. by machine according to the chess-playing machine ideas of Shannon. One could then have the results of maneuveres tabulated as alternative strategic programs for a universal digital computer which would essentially play out the game according to the best move possible based both on the immediate tactical situation and on what has been learned in maneuveres. There is much to be said for this method if it can be achieved; principally that it insures that the experience gained from painstaking studies of maneuveres will actually be applied to the war. A.D.S.E.C. does not propose that this idea be tried immediately, however.

DIRECTOR

The function of the director is to do the actual close-controlling of the individual fighter-bomber duels. This function is technically similar to that of a gun director. The chief difference is that a gun director concerns itself with only one target at a time whereas this director must compute on hundreds of targets simultaneously. This computer problem is more straight forward than that of the data analyser computer but the individual computations are more complex. The traffic handling capacity of the computer can be estimated as follows: let T be the maximum allowable interval between successive orders which must be sent to the fighter; let t be the time required by the machine to compute a new set of orders for one aircraft. Then T/t is the number of

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aircraft which can be controlled. There is, of course, no reason why several directors could not be paralleled for increased capacity.

If this were all that was required, this could most economically be a fixed-program computer. However, if low order judgements are required of it as outlined in the preceding section, then it must have at least several alternative programs and may end up being a univeral computer such as is the Whirlwind Computer.

There is, of course, no reason in principle why one computer only should not do the three jobs of analysis, game playing, and direction. However, it is our guess that computers may not have the required capacity to do all three functions for the tremendous numbers of aircraft involved in the time period under consideration. This point must be emphasized and reemphasized. We must be able to control precisely the individual fighters in huge numbers, and no computing device which can control only a few aircraft at a time should be considered for the long term solution.

WEAPONS

Given a good system, it should direct the operations of any useful weapon. Some possible weapons are manned fighters, anti-aircraft artillery, guided missiles and electronic countermeasures. We shall not discuss anti-aircraft artillery or short range ground to air missiles since these are not under Air Force cognizance. There should be little difficulty in integrating these weapons into the system if they are furnished with individual fire-control systems.

MANNED INTERCEPTORS

The MX-1179 Interceptor is estimated to weigh about 15 tons and to have a 50% kill probability. Its control and guidance equipment exclusive

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of armament will weight about half a ton and consume about 10 kilowatts of power. Its cost will be well over a million dollars.

If the enemy can mount an attack of 500 bombers (based on a total force of 1000 bombers) it appears to us that three MX-1179 should be assigned to each bomber. If the combat radius is 300 miles, the defended area is 600 miles deep and the defended perimeter is 3000 miles, we see that five sets of 1500 fighters each are required or 7500 fighters representing a capital investment of over $7,500,000,000. This would give a maximum attrition of 87.5% or 438 bombers. If 100 only of the original 500 bombers carry A-bombs, then the number of A-bombs which could still be dropped ranges from zero to 62 depending on the ingenuity and success of the enemy in using its surplus aircraft to shield the bomb carriers. Obviously we must study and apply counter tactics so that the attrition on bomb-carriers approaches that for all bombers together.

Alternatively we must attach each bomber with aircraft of higher kill efficiency or with more aircraft. On this basis it would require four times as many aircraft (30,000) to absolutely insure that only 15 of the original 100 bombs were dropped. This is, of course, very pessimistic since if 485 of the original bombers are shot down it would be unlikely that the remaining crews would be sufficiently clear-headed to hit their targets.

Obviously all of this assumes the worst possible case. It is not the business of A.D.S.E.C. to do staff planning or to calculate risks. A.D.S.E.C. in all technical problems takes the most pessimistic estimate for two reasons: (1) It is the only estimate for which the basic data are available and which can be made rigourously at this time; (2) We doubt that

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the most pessimistically estimate situation can be overcome by the defense, but that by aiming at overcoming it, we can come close to the countering whatever is calculated to be the most probable attack.

LONG RANGE GROUND TO AIR MISSILES

A great advantage would obviously be gained if we could get a kill probability of 50% at a cost of say $100,000 per missile. We could then more readily afford huge numbers of weapons. Such weapons make mandatory a close control capability on the part of the ground system, however, and A.D.S.E.C. believes that neither the present system nor the 1953 system as sketched in this paper can ever achieve this requirement. Therefore, there is no use in having these missiles until the ground system has the high traffic capacity needed.

There are additional advantages: (1) Since the machine fires no guns or rockets or MX-904 missiles it need compute no lead angles; therefore it need not measure the range from itself to the bomber; therefore (a) it can home on jamming signals; (b) it can use a simple CW type A-1 radar capable of working at any altitude; (2) Since it need not land or take off from an airport it has the great economic advantage of not requiring airports and extensive blind approach and blind landing systems which we don't know how to make, and the great operational advantage of flexibility of launching-site location.

THE MANNED RAMMER

Preliminary calculations show that a 9000 lb. all steel delta-wing airplane with a range of 600 miles could be made which could collide with a bomber without injuring the pilot. This device could be recovered by means of parachute landing and special recovery trucks. It has every

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advantage of the long range guided missile with the additional features of recovery and most important of all it can be used with the present ground system and for broadcast control with any system.

This is regarded in some quarters as bizarre; one may, as far as technical principles are concerned, make the same remark about the guided missiles. The moral question we leave to others to discuss, contenting ourselves with pointing out that there is not much safety in landing a jet fighter on a dark and stormy night with two minutes of reserve fuel.

In Table I we show the relative advantages of the three types of weapons.

TABLE I

Capabilities	Orthodox Manned Fighter	Manned Rammer	Long-range G-A Missile
Broadcast control	Yes	Yes	No
Close-control	Yes	Yes	Yes
Home on Jamming Signal	No	Yes	Yes
Use low altitude CW homing head	No	Yes	Yes
Low cost	No	Yes	Yes
Needs no airport	No	Yes	Yes
No blind landing problem	No	Yes	Yes
Use with present system	Yes	Yes	No

CONCLUSION

A.D.S.E.C. does not know if such a system can be made. It will not attempt on the basis of any paper studies to estimate its effectiveness even if it can be made. The reasons stated in this paper indicate the direction to go to make an optimum system. Whether it can be made and what it will do

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can only be answered by experiment and A.D.S.E.C. encourages all who propose to carry out pertinent experiments. These ideas were not dreamed up over night, nor without consultation with many other interested groups; they are not regarded as fixed for all time; they will be altered in the light of continuing experiment.

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