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CONTROL SYSTEMS LABORATORY

EVALUATION OF THE ICON I

(JNS) CONTROL PROGRAM (U)

Report R-95

July, 1957

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Contract DA-36-039-SC-56695

D/A Sub-Task 3-99-06-111

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EVALUATION OF THE ICON I (JNS) CONTROL PROGRAM

Report R-95

July, 1957

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Evaluation of the ICON I (JNS) Control Program

Introduction

The original published proposal for "An Automatic Air Traffic Information and Control System" (CSL Report R-35, A. T. Nordsieck, 1953) furnished the basis from which Cornfield became a research model. The proposal described a Naval air defense system which employs automatic initiation, tracking, and track scratching, and suggested that, in such an environment, track data can be accurately produced and displayed in such quantities as to generate a need for automatic control. Consequently, it was felt that a control computer might perform many useful functions in the assignment and guidance of weapons.

In the summer of 1955, J. N. Snyder and L. D. Fosdick of this laboratory, wrote and encoded for ILLIAC* a program enabling it to function as a control computer which performs three kinds of services: threat evaluation, weapon assignment, and the generation of steering instructions for intercept vectoring, direction of strikes, rendezvous, rescue, etc. and return-to-carrier. The program is reported in detail in Report R-74 and summarized for the average reader in R-88. It became known as the JNS Control Program but has been officially re-named ICON I.

In the Cornfield model of an automatic tracking and control system, radar data is gathered at two sites and is sent to, and automatically tracked by, TASC, a special purpose drum computer. The clear picture

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* Illinois General Purpose Digital Computer, 1024 word Williams tube memory.

produced by TASC is displayed on 19-inch P-19 Charactrons and is sent in parallel to ILLIAC which, with a suitable program (such as ICON I) and by suitable input and output connections, becomes the major control function in the Cornfield complex.

When governed by ICON I, ILLIAC can control up to 128 friendly objects against hostile or unidentified objects whose number is limited only by the sorting and tracking capacity of that part of the system which feeds ILLIAC. The controlled objects may be ships, submarines, or planes, but the program is especially tailored to provide fast, frequent, and accurate control information for or against high speed aircraft; slow objects such as ships, which have more facilities for their own control, are dealt with in a less comprehensive and more leisurely way.

In the summer of 1956 experiments were begun with ILLIAC in the Cornfield system, taking the form of war games which will be described below, designed to familiarize CSL personnel with the detailed characteristics of ICON I and to furnish a basis for evaluation. Since that time sufficient information has been gathered to support the conclusions presented here and to indicate the trends which improved programs must follow. A certain insight was also gained into the general problems of evaluation itself. A more sophisticated but skeletal program, ICON II, is now underway and more advanced programs are contemplated.

A computer program for making tactical decisions in warfare is a difficult thing to evaluate. The obstacles to a satisfying, objective evaluation, while manifold, fall roughly into two classes: the difficulty in avoiding subjectivity in the judgment of tactics, and the difficulty of assessing the control quality alone from measurements taken of control system performance.

While many of the results of a prolonged interaction of intelligence, tactics, execution, and chance are sound, measurable quantities, it is quite difficult to extract from them a figure which measures the quality of the tactics employed. Yet, without such a figure, the appraisal becomes wholly qualitative and somewhat subjective.

An additional hazard lies in the choice of tests to which a control system should be subjected for the purposes of measurement or qualitative appraisal. No matter what other characteristics the evaluation will have, whether quantitative or qualitative, theoretical or experimental, it will always amount to a comparison of some sort. Sometimes the comparison may be expressly made, as when various tactical command functions are independently put to the same tests. A parallel of this is when officers or teams are separately examined in the same war game situation and their performance is compared to some function (max., min., average, etc.) of the history of performances of previous officers or teams. Such a method is theoretically possible for tactical automata but is practically unwieldy. It is needlessly empirical and requires the early design of a test which will be considered realistic and exhaustive for all similar weapon systems, past, present, and future.

A more attractive alternative is implicit comparison, where any intelligently prepared test may be applied and the observed results compared to those which, by careful analysis of the particular tests, are both preferred and theoretically achievable. Even this method, however, is not free from pitfalls and a number of cautions must be faithfully observed.

Firstly, the intelligent preparation of a test requires a certain insight into what constitutes good tactical performance for a weapon system. Yet if we knew, in detail, an excellent tactical doctrine, we could design an excellent tactical control program immediately. Instead, since we cannot immediately set down a group of tactical rules which are ideally applicable to all tactical situations, we must proceed toward that goal in iterative fashion.

A program is designed which seems, by whatever judgment processes can be applied in the design, to represent a satisfactory detailed doctrine. It is then subjected to stimuli which test its behavior in situations typical of large classes of realistic circumstances and its observed performance is compared to that which appears to be both preferred and physically possible. From inadequacies observed in the tests, further insight is gained into the necessary details of a complete doctrine, from which knowledge a new, improved program can be written.

The rate of convergence of such a cyclic evolutionary process will depend somewhat upon the skill and imagination of those responsible for the program design and the test design, application, and analysis. However, despite the fact that work in this field can rarely depend upon help from experienced tacticians, there is reason for general optimism because tactics is an application of game theory which has been practiced and studied for centuries and for which even the layman may have considerable rational aptitude.

The pitfalls in the method lie chiefly in the evaluation procedures to be employed, and their avoidance requires such things as careful balancing of test completeness with test economy, quantitative analysis of the physical limitations of the weapons system followed by intelligent use of this knowledge, and recognition of those sources of perturbation which can cause many types of measured results to be a distorted reflection of the tactical command function under test. Readers interested in further pursuing a discussion of evaluation principles and procedure are invited to examine the forthcoming CSL Report R-89, on the Design and Evaluation of Tactical Automata.

One of the difficulties in the method outlined above, that of successfully extracting from overall results of a war game a clear measure of the tactical control function, may be largely sidestepped in the evaluation of the JNS (ICON I) program because its behavior is quite uncomplicated. If a program is sufficiently unsophisticated that all its decisions in a tactical exercise can be readily predicted, then the value or consequences of these decisions may also be predicted, provided certain assumptions regarding data quality and execution are allowed. Thus a paper study can substitute for an engineering study; little, if anything, further concerning the value of the control function could be gained by actually running the programmed hardware through experimental tactical exercises.

Behavior Analysis of ICON I

It was claimed in the Introduction above that all the actions of the subject program are readily predictable and may be subjected to a paper study in lieu of hardware experimentation. The confidence with which this statement can be made is significantly bolstered by the experience which has been gained from a protracted program of hardware experiments. Experience with a working model may not reveal anything which could not have been predicted but often dramatically points out characteristics which might be accidentally overlooked in a paper study. It is felt that we now have had sufficient working experience with, and have given sufficient thought to, ICON I to present at this time a just evaluation.

The medium which will be employed for some of this presentation is a running account of the predicted behavior of a reasonably typical weapon system, under the control of ICON I, as it deals with a number of selected situations. The situations have been carefully chosen to either quantitatively or qualitatively stress the control function to reveal its weaknesses without overwhelming the weapon system and obliterating whatever good qualities ICON I may possess. Let us, therefore, first set up a reasonable tactical disposition of Naval weapons and then analyze its behavior in the face of certain specific air threats.

Imagine a small fast carrier task group consisting of a central aircraft carrier accompanied by two heavy support ships and surrounded by a circular screen of AA ships disposed 30 miles apart on a 50 mile radius. Let us suppose the AA armament of the two support ships is

100-mile Talos, each ship capable of engaging two independent targets simultaneously. Let us further suppose that the AA armament (called "GUNS")* of the screening vessels is a guided missile of 20 mile range, each ship provided with installations enabling it to engage two independent targets simultaneously.

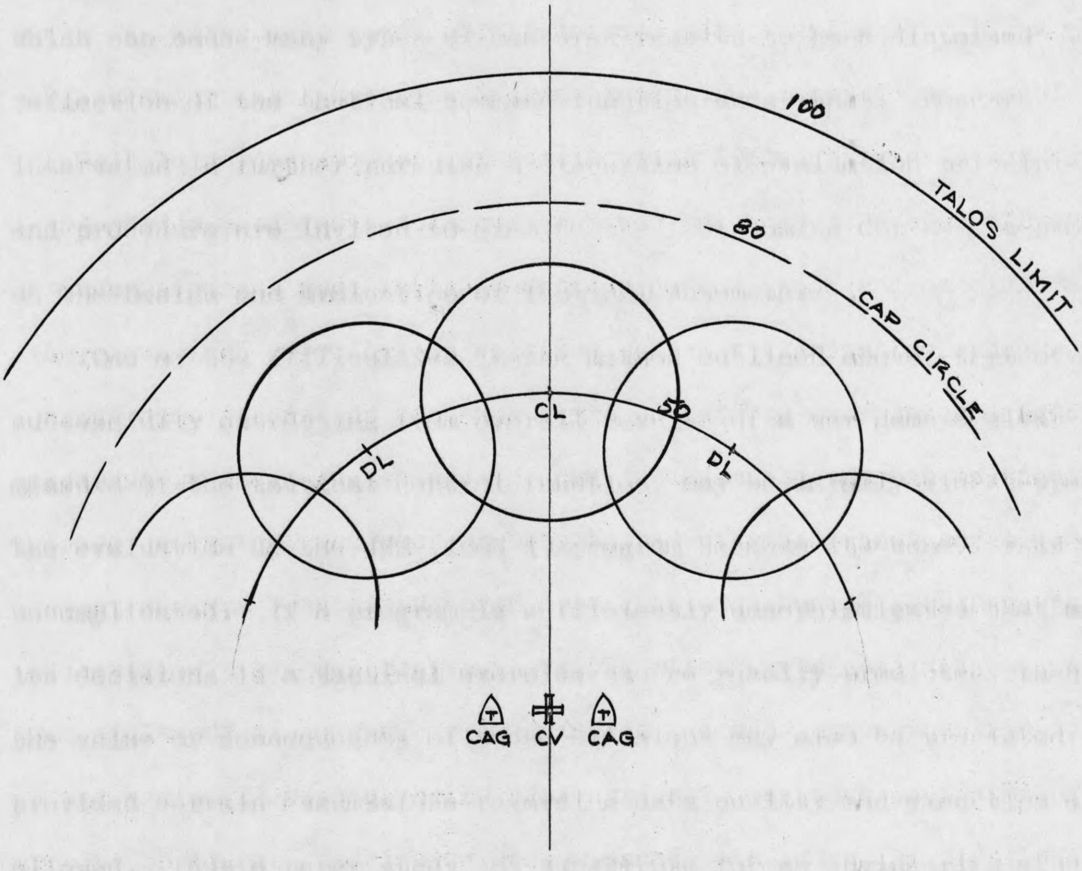

Figure 1.

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* Snyder provided for recognition of 4 AA weapon types: TALOS, GUNS, CAP and decked Carrier Planes. Since the characteristics of each weapon are chosen and preset by control personnel in ILLIAC it is possible to give, say Guns, the characteristics of a medium range missile, thereby enabling the category called Guns to actually represent such missiles rather than rifle projectiles.

The major interest in the behavior of the control program is to see how it acts to prevent penetration of the screening circle; what it does against any bogeys which successfully achieve this primary goal is of secondary importance and, for the time being, may be ignored. It furthermore appears reasonable to assume that the Threat Evaluation parameters will be set to cause weapon assignment to take place on any bogey within 200 miles of the carrier if the bogey is closing.

Before we can test this setup against some imaginary intruders, it remains to specify still more parameters, for the action of ICON I is heavily dependent upon the control parameters chosen. In R-88 it was shown that the known weapon characteristics, such as speed, and range, and the limitations on the position and velocity data employed in weapon assignment, combine to limit severely the intelligent choice of weapon assignment parameters. Each of the weapon types recognized by ICON I has characteristics which make its optimum employment more or less unqiue. Decked carrier planes have the longest maximum range but are slower than any missile and are guaranteed to have a greater altitude disadvantage than any airborne CAP. They would therefore not be considered to compete for assignments which are equally close to any available Talos or CAP. Range-weapon priorities* should be adjusted

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* CSL Reports R-74 and R-88 describe the design and action of the JNS (ICON I) Control Program. For description of weapon assignment and an explanation of how Range-weapon priorities may be set up using weapon preference weighting functions, α_i, see R-74 pp. 111-128, R-88 p. 33 and especially R-88 Appendix II. In the process of assigning a weapon to a bogey, ILLIAC searches through every available weapon. At the end of the search it has stored four weapons, each the "best" of its type (CAP, Carrier Plane, Talos, or Gun). The final choice of one from the four "best" weapons is made on the basis of the Figure of Merit assigned to each of the four. The Figure of Merit is of the form $a_i R_{ci}$, (Footnote continued bottom of following page)

in such a way that a CAP or Talos which can complete an interception at a greater distance from the screen will have priority over a carrier plane. In no case, however, should a carrier (or CAP) plane be allowed to attempt an interception at such a range as to interfere with the action of the AA missile screen. If a bogey ever reaches the screen, it should not be while some earlier intercept assignment is still in progress, thereby preventing assignment to the missiles, for the probability of knocking him down with missiles in a well-deployed screen is much greater than a single interception can provide.

The above suggestions amount to saying that decked carrier planes will be used for assignments to bogeys between 140 and 200 miles only if available CAP are too far away or if there are no CAP available at all, and that no other automatic assignments will occur to decked planes.

On a 200-mile bogey (directed at Carrier) a carrier plane is a poor substitute for an airborne CAP with an 80-mile head start. Assuming equal speeds for all aircraft, the CAP, if directly in the bogey's path, would complete his interception at 140 miles (from Carrier) while the carrier plane interception would occur later, at 100 miles. A glance at the construction below (Figure 2) will show that a CAP can be considerably to one side of the bogey track and still be considered as at least an equally good choice as a carrier plane. If he is on an 80-mile station circle and 183 miles from a bogey who is on the 200-mile circle, he can, with no speed advantage, intercept the bogey at the 100-mile circle if the bogey flies a radial path. Actually since he has altitude and

(continuation of Footnote from 95-10)

* where α_i is a pre-set weighting constant for use with weapon type i and R_{ci} is a certain function of the range from the weapon to the bogey.

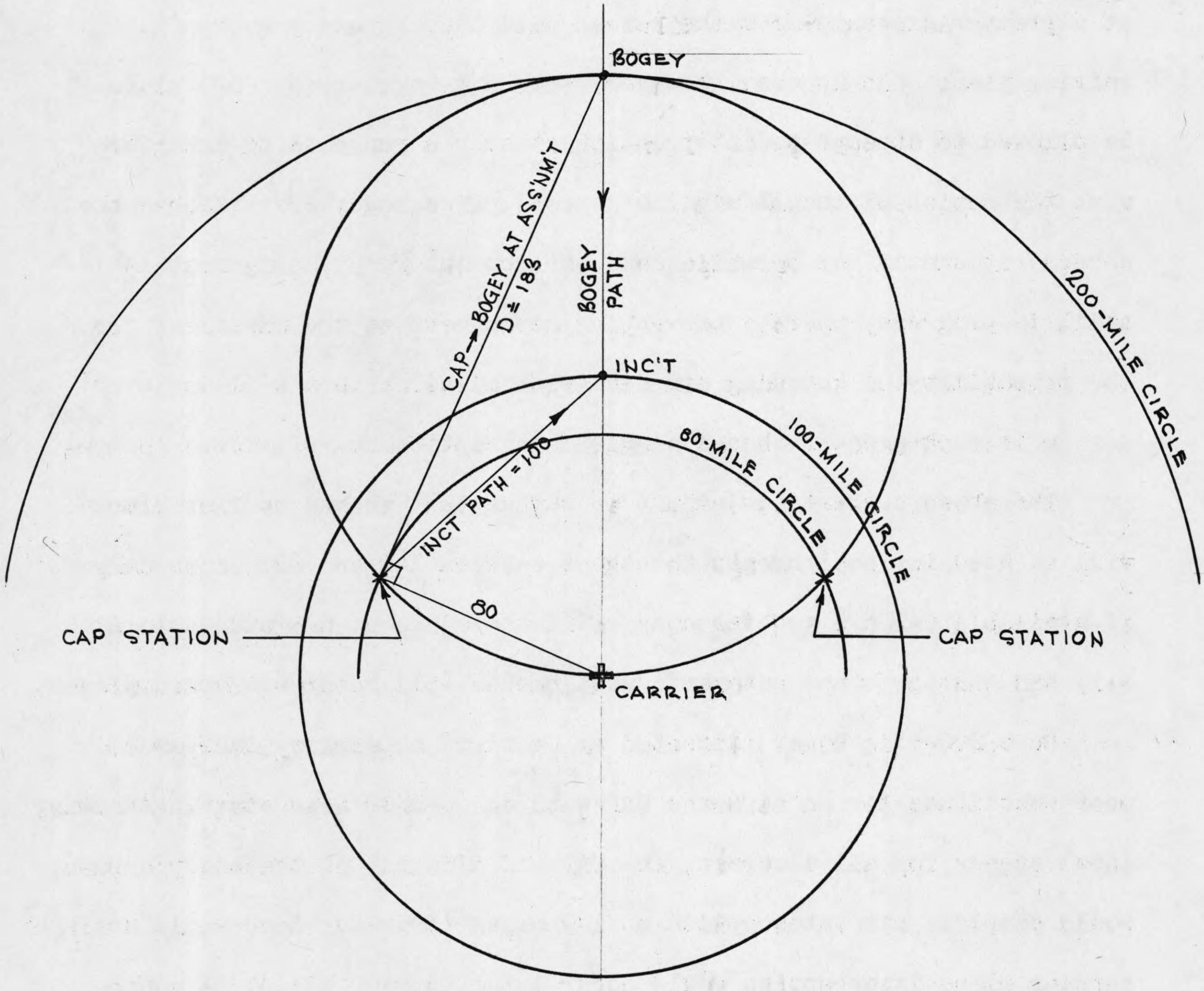

BOGEY
BOGEY PATH
CAP → BOGEY AT ASS'NM'T
D ≐ 183
200-MILE CIRCLE
INC'T
100-MILE CIRCLE
80-MILE CIRCLE
INCT PATH = 100
80
CAP STATION
CAP STATION
CARRIER

Figure 2

therefore probably speed advantage over a carrier plane, he could probably do as well from 210 miles (from Bogey) as any carrier plane could do from 200 even though the carrier plane has the great advantage of being on the bogey path. Therefore, when we choose our weapon assignment priority α's we shall do so in such a way that a 210-mile CAP ($R_{P \rightarrow B}$ = 210) has equal priority with a 200-mile carrier (plane), the 27-mile difference between 183 and 210 more or less balancing the tracking delay and altitude disadvantage at the carrier.

So far we have discussed some special advantages and disadvantages of CAP and carrier planes on deck and how they interact to limit the intelligent choice of assignment priorities of bogeys located on range circles of 140-200 miles. It remains to discuss Talos and its priority relations to both CAP and carrier planes and to allow for weapon assignments to bogeys in the 70-140 mile ranges. Clearly, any interception which can be completed before the bogey reaches 100 miles is outside the capability of Talos if its maximum range is 100 miles. However, since Talos has a considerable speed advantage over 600-knot aircraft and since we have specified that the Talos ship will be moderately close to the carrier, it has a clear superiority over carrier planes within its range. It is one of the misfortunes of coding economy, however, that the JNS program cannot use, in the Weapon Assignment sorting, the calculated range to the interception point. Not knowing when (or even <u>if</u>) a bogey will cross the 100-mile range circle, ILLIAC cannot safely assign bogeys to Talos if they are very much outside. To be safe, let us make the maximum Talos assignment range 130 miles, then, with a speed advantage of 2:1, Talos will be able to complete its intercept at not

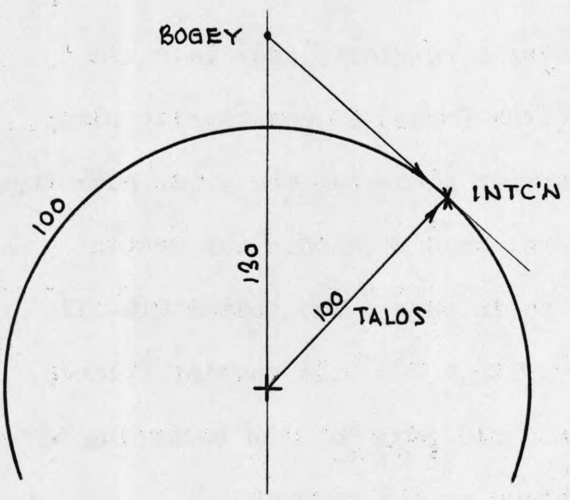
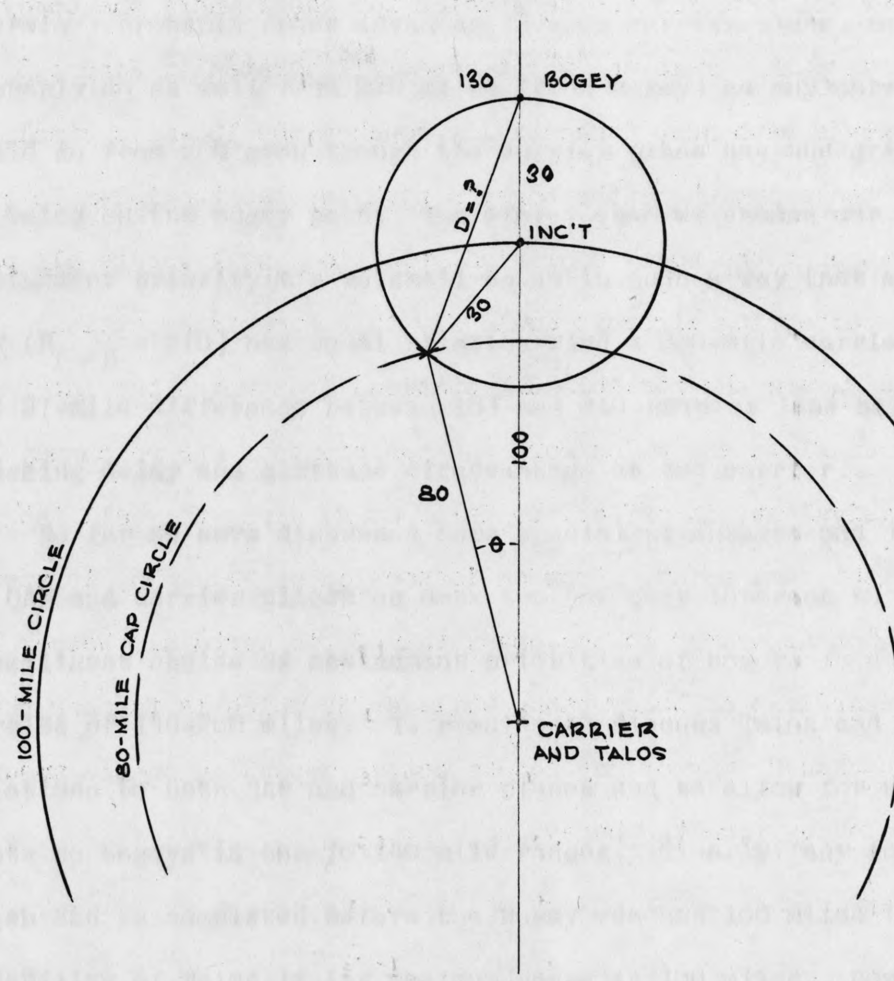


Figure 3

more than 100 miles on any 130-mile bogey whose path intersects the 100-mile circle. The worst case of such a bogey is illustrated in the adjacent diagram.

To find how the Talos assignment priority should be adjusted relative to that of CAP, consider the following situation illustrated in Figure 4. Suppose a bogey is located 130 miles from the carrier (and the Talos ship), and is flying a course directed at the carrier. Talos could intercept him at 100 miles if the relative speeds were 2:1 in favor of Talos. On the other hand, a CAP plane stationed on the 80-mile circel could intercept him earlier if his station is near the bogey's projected track. If he is off to one side so far that his present position to the bogey is about 56 miles, he can still intercept him at 100 miles. Such a CAP, at 56 miles, may therefore be considered equivalent to a Talos at 130 miles. If the CAP is still further off to one side of the bogey track ($R_{P\to B} = 56$), the Talos will be a better assignment.



To find θ:

$$(30)^2 = (80)^2 + (100)^2 - 2(80)(100)\cos\theta$$

$$\theta = \cos^{-1}\frac{155}{160} \doteq \cos^{-1} .97$$

To find D:

$$D^2 = (80)^2 + (130)^2 - 2(80)(130)\cos\theta$$

$$D = 55.9 \text{ miles}$$

Figure 4

A similar construction can be studied for cases where the bogey is not on a radial path. Take the worst case, illustrated in Figure 5 below, where the bogey's path just tangentially touches the 100-mile circle. A circle drawn around the point where the bogey's path touches the 100-mile circle, and passing through the bogey's original position, will locate all points from which intercepting aircraft could fly this same interception. The two points C_1 and C_2 are the possible CAP stations from which the interceptions could have been flown and which mark the positions of CAP which may be considered equivalent, in effect, to Talos at P, since they all intercept the bogey at the same point. From an inspection of Figure 5, it appears that a CAP which is nearer to the bogey than C_1 is certainly better than Talos at P regardless of bogey path, while a CAP which is further than C_1 and nearer than C_2 may or may not be better depending on the amount of closing velocity from the bogey.

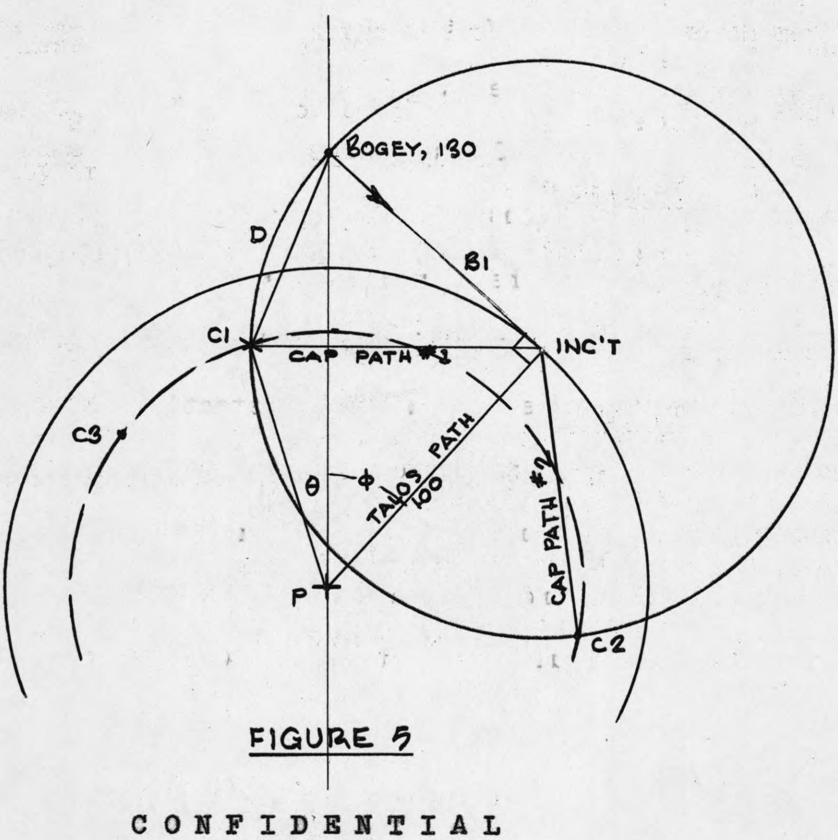


FIGURE 5

Because of this indeterminacy we shall use the CAP distance C_1B as the basis for comparing CAP with Talos at 130 miles. This distance turns out to be about 56 miles, just as in the case of the radial bogey, and indicates that, for our particular parameters, any CAP as near as 56 miles to a bogey is at least as good a weapon choice as a Talos at 130 miles.

Figure 6 is a graph illustrating the weapon assignment priorities for the situation we are about to test and will be consulted to perform many of the predictions about to be presented. The reader may consult CSL Report R-88, Appendix II, for a discussion of the use and properties of such a graph. In so doing, he will note that Figure 6 differs from the "preferred" arrangement shown in R-88. The writer feels that the present selection represents an improvement.

Having posted our ships, selected a CAP station range, and assigned weapon priorities, it now remains for us to actually station the CAP and run in some test bogeys.

Since this is a small task group, it seems reasonable to suggest keeping only two sections of CAP in the air if the expected attack is almost certainly from the forward hemisphere. These we shall station about 100 miles apart, straddling the forward centerline. See Figure 7. Hopefully, we will have some means of detecting incoming aircraft at ranges of more than 200 miles from the carrier. If so, a single test bogey, flown in along path A, will have its threat number reach assignment threshold at about 200 miles, and will be assigned by ILLIAC to CAP section # 2. The interception should occur at about 140 miles from the carrier. If

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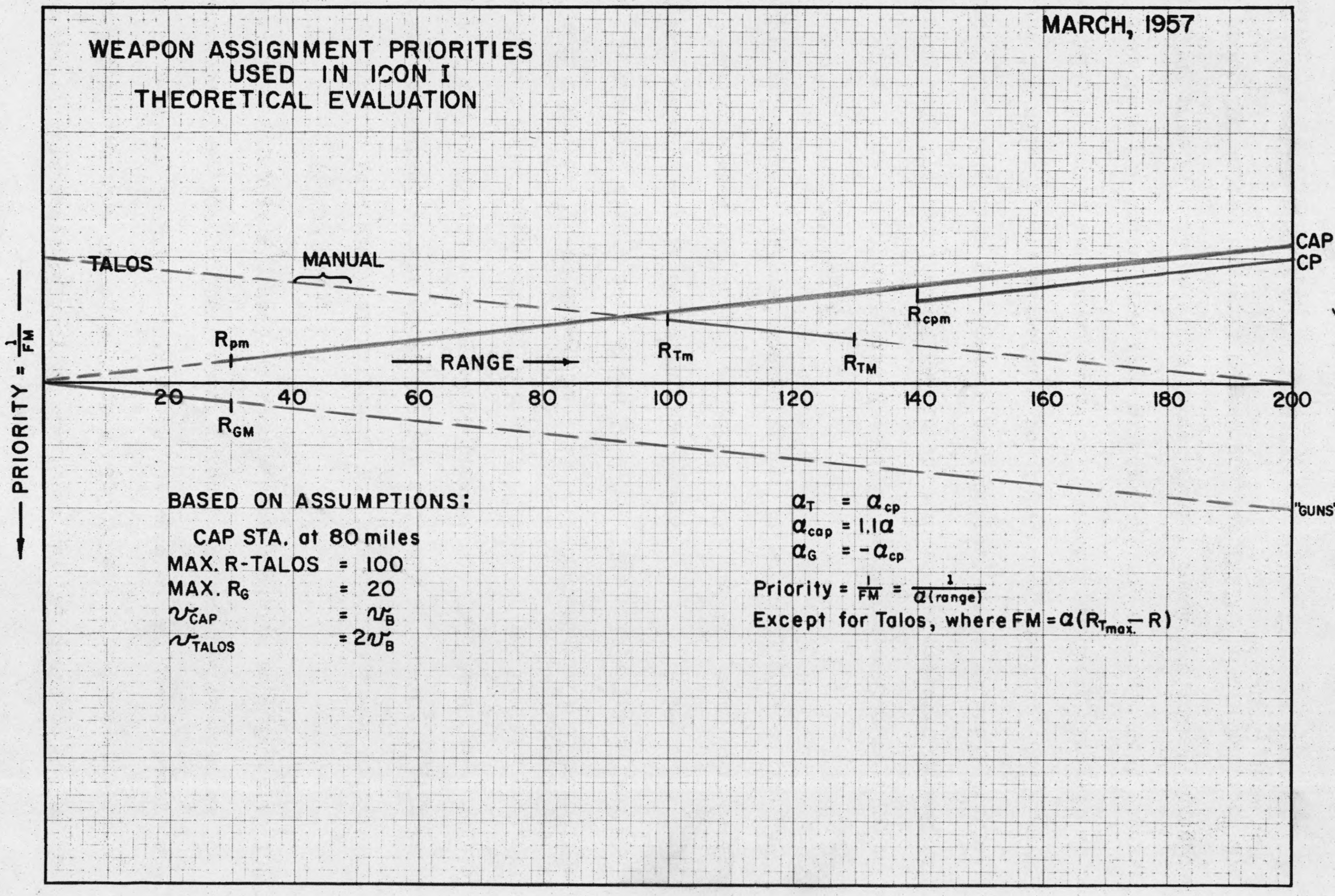

Figure 6

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the interception misses, control personnel will be so informed by CAP # 2 and will

1. Change mission of CAP# 2 from INTERCEPT → CAP
2. Give bogey a threat# = assignment threshold, causing ILLIAC to perform another weapon assignment on the bogey and considering CAP# 2 in its choice.

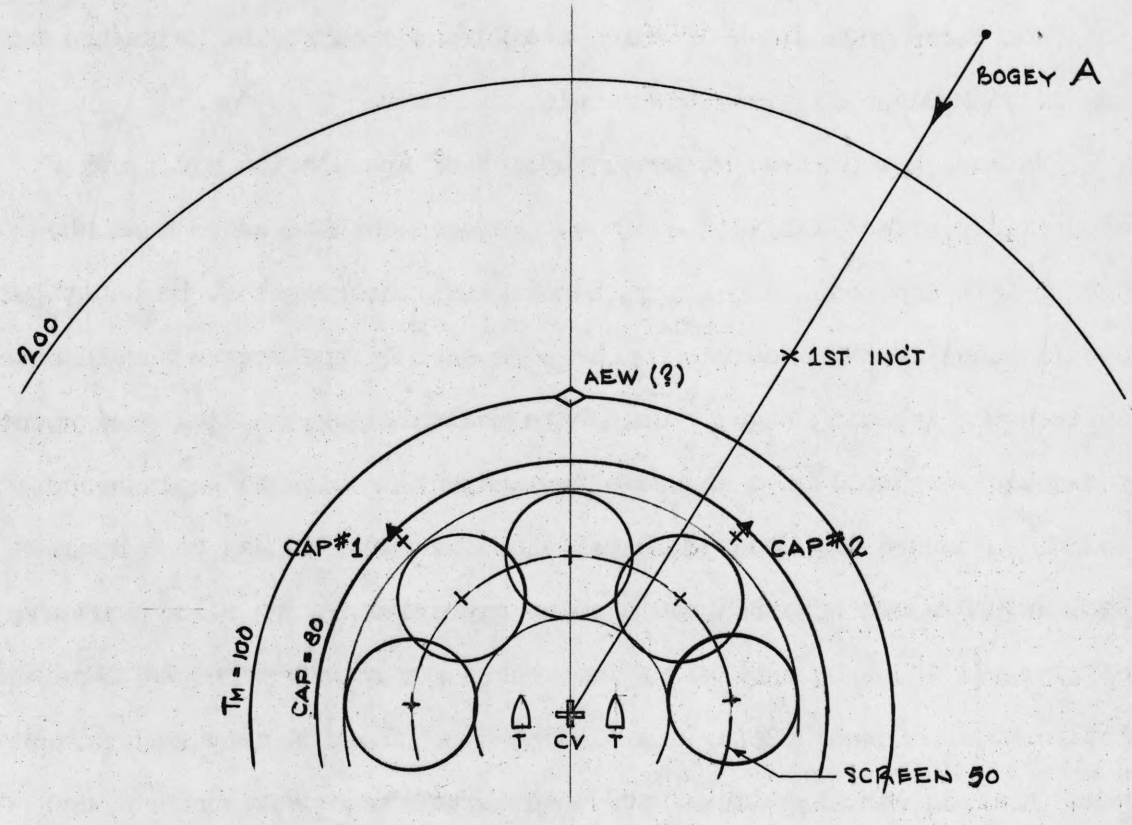

Figure 7

If the range (bogey-to-carrier) is still greater than 140 miles, the possible choices will be between CAP# 1, CAP# 2, and carrier planes. However, since CAP# 2 is most probably now behind the bogey, it will be ruled out because the bogey is not closing it. CAP# 1 and the carrier are approximately equidistant from the bogey at just over 140 miles. ILLIAC will use these distances* in choosing between them, considering a CAP whose range to the bogey is $1 \cdot 1 R_{carrier\ bogey}$ an equally good choice as a carrier plane at range $R_{carrier\ bogey}$. If CAP 1 is further from the bogey than 1·1 times the bogey's range to the carrier, a carrier plane will receive the assignment; if not, the CAP will be assigned. Since the interception will occur at roughly the same place regardless of which assignment occurs, let us assume that the carrier plane is given the mission.

We have now arrived at another point of speculation which can appreciably affect ILLIAC's actions. We have assumed above that when CAP 2 left its post to perform the original interception, no substitute was launched from the carrier. The personnel in the system should have noticed the incoming bogey, would have monitored the initial assignment, and could very well have caused a replacement section to be launched and flown toward the vacated 2 CAP station. If this had been done, the new CAP would have reached a point approximately 60 miles from the carrier and 140 - 60 = 80 miles from the bogey at the time the first interception missed. Being the closest CAP and being very much closer than (decked) carrier planes, it would certainly receive the second assignment, which it could have completed at 100 miles, allowing a possible subsequent Talos assignment. In the case where no replacement

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* Actually uses an approximation, $R \cong x + \frac{y}{2}$ (if $x > y$) whose error is a function f_1 of $\frac{y}{x}$, and $0 \leq f_1(\frac{y}{x}) \leq 11.7^{o}/o$. This approximation is called the $10^{o}/o$ R.

is launched, the carrier plane's interception would occur at 70 miles, too late for a subsequent Talos assignment.

If the critical dependency upon the repeated intervention of control personnel can be clearly and forcefully demonstrated in a very simple situation, it is felt that the reader will better understand certain statements made on pages 5 and 7 regarding obstacles to evaluation. The major difficulty to be overcome is the question of how to discount the large perturbations which can be caused by agents such as personnel which interact with the program. So far in this elementary exercise, in which an hypothetical bogey has been followed to the edge of the screen's missile range, we have encountered a minimum of six operations which are required of control personnel for effective operation of the JNS control program. Since the quality of these manual operations will greatly affect the statistically predictable overall results of the battle, it is important for us to pause a moment and notice, even at this early stage, how rapidly their number is increasing.

The most probably actions which control personnel might have taken thus far against our hypothetical bogey are listed in the following two alternative sequences:

First Possible Sequence:

1. Post CAP# 1 and CAP# 2
2. Identify and establish voice communication with CAP# 1 and CAP# 2 when they appear on Clear Picture.
3. Monitor failure of 1st interception by CAP# 2 at 140 miles and manipulate bogey's status digits to cause 2nd assignment.

4. Identify carrier plane (which receives 2nd assignment) and establish voice communication.

5. Manipulate status digits of CAP # 2 causing it to be returned to station.

6. Monitor failure of 2nd interception (at 70 miles) and manipulate bogey's status digits to cause 3rd weapon assignment.

7. Cause carrier plane to be returned to base.

or Second Possible Sequence:

1. Request CAP # 1 and CAP # 2

2. Identify and establish voice communication with CAP # 1 and CAP # 2 when they appear.

3. Monitor assignment of CAP # 2 and request replacement CAP # 2'.

4. Identify and establish communication with CAP # 2'.

5. Monitor failures of 1st interception and set bogey's status digits to cause 2nd assignment.

6. Cause CAP # 2 to return to station (or Carrier).

7. Monitor failure of 2nd interception and set bogey's status digits to cause 3rd assignment.

8. Cause CAP # 2' to return to carrier (or CAP station).

9. Monitor failure of 3rd interception and set bogey's status digits to cause 4th assignment.

Depending on which sequence of actions are taken by the control personnel, our test bogey, if not yet shot down, is now either at 70 miles on the edge of the missile screen awaiting a third weapon assignment, or is within the screen at 66 miles awaiting a fourth assignment. In either case, since the screen possesses the highest priority weapon, the next assignment by ILLIAC will be to that ship (missile battery) of the screen which is nearest to, and can engage, the bogey. In the absence of coordination control from ILLIAC (true of ICON I), the most sensible operational agreement is that this battery will assume full responsibility for the bogey for as long as he remains within firing range of the screen. It should decide what rate of fire to bring to bear and should coordinate the fire if the bogey's projected path enters an area of firepower overlap.

Even though a twenty-mile missile fired from one of the screening vessels cannot <u>hit</u> bogeys at greater range than 20, it may certainly be fired at a closing bogey long before the bogey is inside the 20-mile striking range. Dependent upon the amount of overlap provided in the firepower coverage of adjacent missile ships and upon the approximate relative speeds (bogey vs. missile), there will be a maximum assignment circle about each screening ship which is considerably greater than the maximum impact range. In the figure at the left, a missile fired at a bogey when the bogey is at B_1 will meet the bogey at E_1. In a full scale AA screen composed of several ships on a circle about a carrier, the

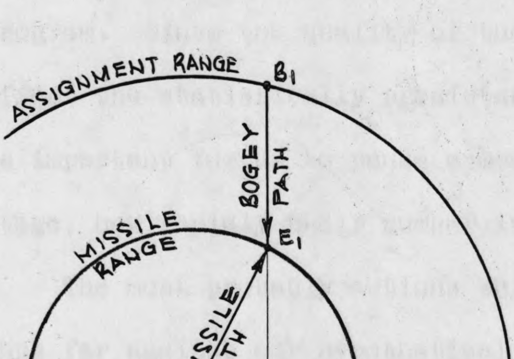

Figure 8

outside segments of the individual assignment circles may be connected to form an escalloped circle about the carrier which we will call the Overall Maximum Missile Assignment Range.

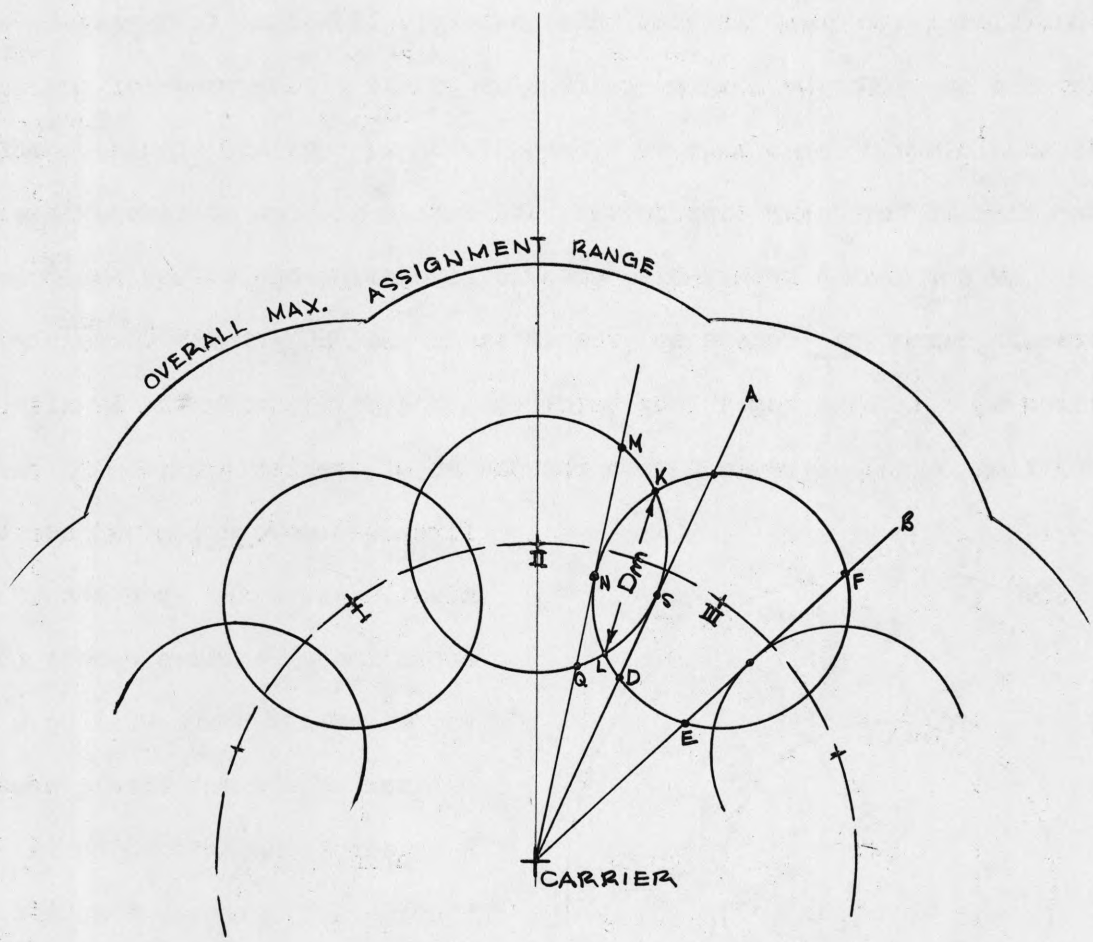

Figure 9

If the test bogey which we have followed through two alternative sequences of assignments is now somewhere between 66 and 70 miles from the carrier, he is well inside the maximum missile assignment range and there is probably not now time for three completely disjunctive, (non-concurrent) missile shots. However, by launching a second while the first missile is still in the air, and perhaps launching a third while the second is in the air, three shots can be achieved. If the probability of a kill with one shot is 0.63, the likelihood of the bogey's escaping three shots in the screen is 0.05. The overall probability of our test bogey's getting past all the weapons we have discussed, and arriving unharmed at the inside edge of the screen is on the order of 0.007 regardless of whether a replacement for CAP# 2 had or had not been launched immediately following the CAP# 2 intercept assignment. The important distinction between the two possibilities is the fact that in one case the effect of the second weapon assignment would have been known much earlier. In 37(.63) = 23 cases out of 100 the bogey will be killed on the second assignment and in these cases the earlier kill results in tying up parts of the defense system for significantly less time.

One-bogey Evaluation

Weapon Assignment

The results observed in the simple gedankenexperiment just completed illustrate a number of key characteristics of ICON I. The experiment was specific in so far as the control parameters were carefully chosen to match the particular weapons and deployment which we assumed for the task group. It was general in the respect that the particular flight path of the bogey was of little importance. Much the same behavior will be observed if the experiment is repeated with single bogeys flying other paths or with large numbers of bogeys which do not interact in any way.

To further substantiate the general statements about to be made, it is possible to run through a number of similar experiments, using different weapons and weapon deployments. A statistically large sample is not required for one to observe from these that, against one intruder:

1. The control parameters are flexible enough to provide reasonable weapon assignments from any reasonable weapon group in any reasonable deployment. The amount of intelligence displayed in any single action is strictly dependent on the judicious choice of control parameters for the particular deployment. Each single action of the program is merely a manifestation of that behavior which is "built-in" by the set of chosen control parameters.
2. Once the parameters are fixed, the effectiveness of any single action against an intruder is then determined chiefly by the weapons available.

3. The burden of providing available weapons rests upon the monitoring control personnel; the program relies upon them to think ahead in such matters as the furnishing and stationing of weapons.
4. The need for assignment changes must be detected by personnel and the changes executed via keyset.
5. Coordination of two or more weapons simultaneously against a single target cannot be done by the program itself. Coordination in the sense of weapon sequencing can be accomplished through the control program but only as a result of timely intervention (via simple keysets, etc.) by the monitoring personnel.

With these conclusions in mind, we may ask, "For a task group threatened by a single intruding aircraft, of what advantage is the ICON I version of automatic tactical control?" The answer to this question, if favorable, will lead quite naturally to "What is the advantage in a complex battle situation?"

To the first, the answer is apparent. Proper action of the program is critically dependent upon control personnel. It can do no better than the best that a wholly manual system can do. It can, however, perform those rapid calculations which are necessary to the best functioning of a manual system and which must often be crudely estimated; in this it may be regarded as a valuable assistant to the men. If, on the other hand, the men are regarded as the assistants, it can, with timely support, guarantee that a particular pre-conceived set or sequence of defense tactics will be carried out as conceived when the fleet deployment and control parameters are chosen.

While the one-bogey situation is important, it is not difficult to handle quite satisfactorily and is not a primary source of concern. The important potentialities for an automatic control system are most naturally to be found in the more complex, many-bogey situations where the numerical calculations may be staggering for humans and the myriad of command and bookkeeping details strains their handling capacity. When we have finished our remarks about the one-bogey case we shall discuss some more complicated situations.

Vectoring

It will perhaps have been noticed that throughout all of the foregoing discussion little mention has been made of control functions other than weapon assignment. Such other functions as are found in the ICON I program fall into one of two categories, threat evaluation or steering instructions, the latter of which may be further subdivided. Of the various steering calculations and commands which are undertaken by the program, only those for directing aircraft interceptions present any challenge to the tactician or the programmer. The rest are simple but adequate aids for rescue, rendezvous, return-to-base, and designation of targets or patrol stations.

Of the vectoring control for aircraft interceptions it may be said that, in the ICON I

1. The quality of vectoring is independent of traffic density and, therefore, that its evaluation for the one-bogey test is not unique.
2. The vectoring sub-routines have been purposely limited in scope and sophistication in order to squeeze them into an overall control program which, for the limited memory space of ILLIAC, is about as close-packed as can be conceived.
3. If the intercepting aircraft carry advanced weapons such as jump-up missiles and are therefore not required to gain a particular altitude differential nor approach from a fairly restricted angle, the control parameters can be set to guarantee good interceptions in all cases.
4. In the event of restricting requirements such as final approach angle and altitude, a human controller is needed

to monitor and occasionally over-ride ILLIAC's decisions. In this circumstance, the control program may be regarded as a supplement to a conventional air-control officer, (or team of officers) somewhat increasing the number of interceptions this man (these men) can handle concurrently.

5. The original vectoring routine is not the only one which can be invented which will fit into the program space provided. Others have been written and are still being evaluated.

6. Finally, the ICON I program should not stand or fall on the quality of its vectoring routines. Since the whole effort of the original design was to see if tactical control was within the capability of general purpose computing techniques, it would be quite cricket to design a whole new program which does nothing but excellent vectoring, if its design were such that it could be inserted into ICON I (or II or etc.) in an ILLIAC with enlarged memory. This effort is nearly completed.

Threat Evaluation

To estimate the goodness of that function called Threat Evaluation one must have some criterion or measuring standard and this pre-supposes an agreed purpose for threat evaluation. The value of information in warfare is not to satisfy curiosity but to govern action. Similarly, threat evaluation, which amounts to an operation on information, is performed to govern the special actions of weapons assignment. In fact some, among whom this writer may be numbered, may prefer to regard threat evaluation as a part of, and not distinct from, weapon assignment. However such an attitude is not reflected in ICON I because in it the threat calculation routines are all but independent; threat index is employed only for deciding whether or when to assign a weapon, with the threshold for weapon assignment the limiting value for threat. After assignment, threat calculations are dropped and cannot be re-instituted so long as the intruder is paired with a weapon.

Several variables and constants enter into each threat calculation, the variables defining the threatening characteristics, while the constants define the relative importance attached to them. The particular characteristics chosen for ICON I are: time-since-first-observed, proximity to the nearest Protectee, and closing velocity (on that Protectee). A fourth contribution may be added by control personnel on the basis of signal strength, resolved raid size or other intelligence they may possess. Although the equation in which these characteristics are combined is linear, the numerical range provided in the selectable weighting constants permits a wide choice in the behavior of the Threat Evaluation portion of the program. Several modes of behavior have been tested which demonstrate that they can be made to serve as a simple but, for some purposes, satisfactory method for delaying or triggering active resistance. Considerably more sophisticated schemes are being studied for future programs.

Many-bogey Evaluation

The one-bogey stress was applied to our control system in order to test the reliability or wisdom of the individual actions of the system, when the choice of action is not hampered by competition. It was demonstrated that the wisdom of any action is merely a manifestation of whatever wisdom was applied in the deployment of available weapons and the choice of control parameters. Wise or unwise, the actions occur reliably whenever the conditions for their occurrence are present. Some of the conditions may be: proximity of an intruder, availability of weapons, alertness and promptness of control personnel.

In the many-bogey case, competition for weapons and for attention of personnel may be expected to lower the quality of treatment which can be accorded one bogey and we must be very careful to separate the effects of these two strains. When testing a defense system it is quite all right to apply stresses which primarily overtax the command personnel in such a way that the system is personnel-limited. But one should avoid overwhelming the defenses of any test system in such a way as to exceed that inherent or ideal defensive capability which is chiefly determined by weapon supply, maneuverability and firepower. The personnel limitation may be a fault of the control program while the ultimate weapon limitation certainly is not. Therefore, before applying stresses which are designed to seriously strain a defense system, we should conscientiously attempt to determine the limits imposed by the weapons themselves.

In R-89 this subject is considered in some detail and may be useful in weapon system planning or in quantitative evaluation of complex control programs. For the present report no such detail is needed for the simple evaluation which should be adequate for ICON I.

For the one-bogey stress we assumed a screen whose ships were distributed 30 miles apart on a 50-mile circle about the carrier. To avoid the detailed analyses described in R-89 we shall simply assume that this spacing gives sufficient overlap to guarantee three successive shots (on a shoot-look-shoot basis) against any bogey which flies through the screen. If the accuracy of the AA missile is 0.85 and the high explosive head has a probability for inflicting lethal damage, within this accuracy, of 0.75*, then the overall kill probability of a single shot is 0.85 x 0.75 = 0.63. Since any missile shot has a finite probability of missing its kill, any intruding aircraft has a finite chance of penetrating the screen unscathed, no matter how many shots are fired at him. However, so long as at least three shots can be guaranteed for each bogey whenever necessary, the penetration probability will be an acceptably low 0.05. With this in mind let us examine the behavior of our hypothetical carrier task group when controlled by ICON I and faced with enough incoming enemy planes to compete for assignment to the weapons available.

In Figure 10 we illustrate the task group much as we did in Figure 7. However, the screen is diagrammed somewhat differently to show its cellular character. In Figure 9 there are certain limiting paths such as AO, BO, or MO which outline the spaces through which radial bogey

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* The kill probability figures employed here are not to be construed as accurate for any particular extant missile. They represent a reasonable guess which will serve our present purpose just as well as authoritatively correct values.

paths will lie wholly in areas of independent firepower courage. Such an area is CDEF in Figure 9. Separating these are regions through which any radial path will encounter some area (such as KLNS) of overlap. If we ignore all but radial paths we may re-draw Figure 9, in a simplified form, incorporating it into Figure 10.

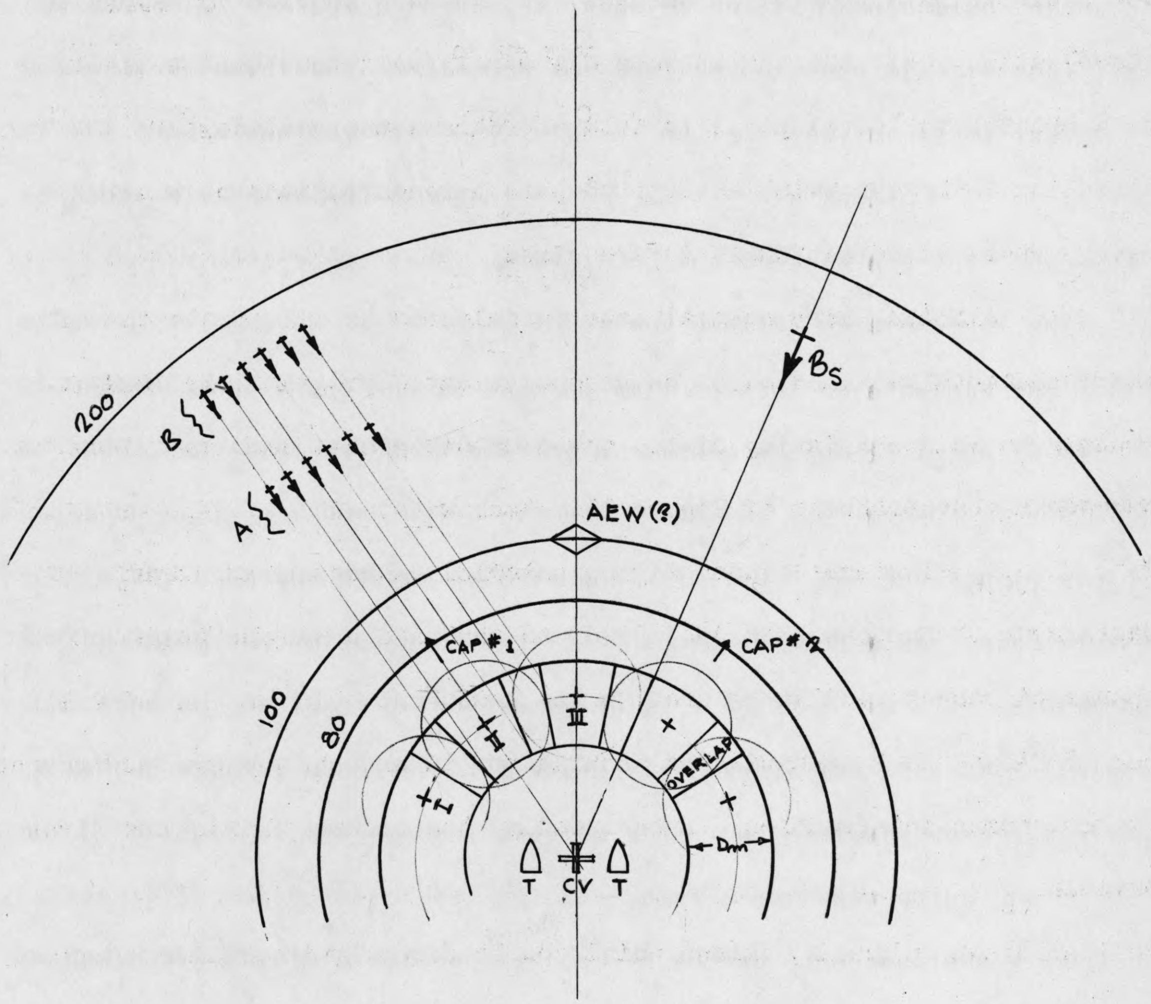

Figure 10

Without "flying" any bogeys against this array one observation of importance may be pointed out. In order to fully implement any screen design which, by its minimum depth D_m, guarantees three completely separate shots at any single bogey, some provision must be made for coordinating missile fire from adjacent ships when the bogey passes through a region of overlap. Although ICON I assumes the responsibility for designating all airborne targets, it does not provide for any such coordination. For the moment we shall merely point out this weakness as a problem for development in future programs and confine our attention to bogeys which attempt to pass through regions of single cover, where coordination is not required.

The following very special case is selected to illustrate one of the fundamental weaknesses of an unsophisticated program like ICON I. Consider a raid consisting of two waves of six planes each as illustrated in the northwest of Figure 10. Each wave, ($A_{1,2,3,4,5,6}$ and $B_{1,2,3,4,5,6}$) features planes flying parallel courses about eight miles apart. Suppose that just prior to the raid a single target, B_s, appears in the surveillance area to the northeast. If so, ILLIAC will commit CAP #2 to B_s and will do nothing to (later) change that assignment without human intervention. Subsequently, the radars pick up the first wave, $A_{1,2,3,4,5,6}$.

As drawn, plane A_3 flies radial course directly toward the carrier. He and his wing men, A_2 and A_4, will all pass into the same screen cell at the same time if unopposed. Since the particular bogey which CAP # 2 will receive for an assignment is determined, in ICON I, largely by chance, there is a strong possibility that this bogey will be neither

A_2A_3 or A_4. If the missile facilities of the ship in the cell can engage a maximum of two independent targets simultaneously* and the kill probability of each shot is 0.63, the penetration probability for a single intruder will be .05, and for two simultaneous planes will be 2 x .05 = 0.1. But the penetration probability for three will be considerably higher than 3 x .05. The two which are first engaged will saturate the facilities unless one of them is shot down, whereupon a weapon will be freed and can be brought to bear on the third, hitherto unengaged, bogey. However, at best there will be time for not more than two non-concurrent missile flights against him, and the overall chance of his getting through is considerably greater than 0.05. As a matter of fact, if the shoot-look-shoot rule is strictly observed, it is almost exactly 0.15 which gives an overall leakage probability of cell III for the first wave of 0.10 + 0.15 = 0.25.

Apparently, the best tactics is to treat the whole weapon complex as an integrated, coordinated set instead of independent subsets of weapon types or of individual weapons. The first line defenses, interceptors and Talos, should be employed to reduce local densities of incoming raids in order to prevent possible saturation of any parts of the deeper defenses. A slightly more sophisticated program than ICON I would at least review the situation from time to time and would have changed the assignment of CAP # 2 to an assignment in the northwest against $A_{2,3,4}$ or $B_{2,3,4}$ where he could do the most good, leaving bogey

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* For simplicity ignore the possibility of multiplex operation. The same principles apply against multiplex installations when the raid density is higher.

B_s unopposed, if necessary, until he reaches missile range. It would also have made sure that CAP #1 would be directed against A_2, A_3, A_4, B_2, B_3 or B_4 rather than A_1, A_5, A_6, B_1, B_5, or B_6.

The example under discussion has so far not taken account of Talos. In order to illustrate the particular weakness we wish to point out, we can keep the example as it is and ignore Talos, or increase the bogey density sufficiently to saturate Talos. In either case the result will be the same. ILLIAC will fail to treat the situation as anything more than a collection of independent bogeys, unrelated to each other and related to certain weapons only on a 1:1 basis. It will fail to foresee the possible saturation of any cells in the medium range missile screen and will not change any of the bogey-CAP or bogey-Talos pairings which it makes.

The example was chosen to illustrate one aspect of the fact that ICON I often cannot make intelligent use of a weapon system. In making an assignment it takes a very narrow view of a tiny portion of the battle situation. Against each individual bogey, taking one at a time, it assigns one available weapon which will make a good (and early) match for him, and these simple pairings are never undone without human intervention. Other aspects of weapon coordination and integration could be exploited in a sophisticated program and might be studied with simple models like the task group described above. It does not seem necessary to pursue the matter further for ICON I.

A simpler weapon system which has been studied in the Applications Research Division* of the Naval Research Laboratory employs only a single

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* Systems Analysis Branch, H. W. Sinaiko and E. P. Buckley

weapon type and provides an excellent model for displaying numbers of undesirable characteristics. In the absence of confusing numbers of tracks and confusing types of weapons these same weaknesses show up more starkly than in a more typical fleet situation. In this model, exactly three combat air patrol craft are airborne at all times to defend a ten-mile circular target area. The patrol stations are located at 120° intervals around a 30-mile circle concentric with the target. In our use of the model the following rules pertained:

1. Organization. Enemy targets are inserted, via 15J1C simulators, into the Cornfield radar data processor, sent to, and automatically tracked by, TASC. The clear picture produced by TASC is displayed on a 19-inch P-19 Charactron and is sent in parallel to ILLIAC which, by suitable input and output connections, becomes the major control function in the Cornfield complex.

   One man, seated at the 19-inch display, assumes overall tactical responsibility, monitoring ILLIAC's actions, and exerting tactical command with the help of one air control monitor and a keyset operator.

   Two 15J1C "pilots" fly CAP under the control of ILLIAC and the air control monitor.

   An enemy coordinator plans and executes his attacks with the help of two or more 15J1C operators. The only restrictions on his operations are described in rules 2. and 3. below.

2. Surveillance Range is limited to 120 miles. Enemy raids may be initiated anywhere between 120 and 90 miles from the

center of the protected area.

3. Traffic Density is limited to a maximum of nine tracks, three of which are CAP. This allows the enemy a maximum of six bogeys at one time, but a further restriction permits only three of these to make a persistent attempt to penetrate the 30-mile CAP circle.

4. Manual Intervention is restricted to allow ILLIAC free rein, within reason. An interception is terminated only if

   (a) it is successfully completed

   or when (b) the bogey is outside the 60-mile circle and has no closing velocity.

   No assignment changes other than those connected with (a) and (b) are permitted except changes in CAP station.

In this or any other model, against many bogeys, ICON I's vectoring shows no change in quality from that of the one-bogey case. In the assignment of weapons, the simple model is sufficient to show up three of the program's four basic shortcomings, for examples of these appear whenever manned interceptors are controlled:

1. Crossed Assignment. There are occasions when it would be desirable to exchange assignments between two interceptors, to provide one or both with an earlier interception. The inability of the computer to make any change in assignment leads to two special problems (1. and 2.) for the multi-bogey case. These situations are not sensed by the computer and any change of assignment must be done manually.

2. <u>Decoys</u>. The program is particularly vulnerable to decoys which head for the target to obtain a weapon assignment and then turn aside, drawing the paired interceptor away with them.

3. <u>Intercept Sequencing</u>. There are some occasions when an interceptor could come into range of several bogeys, one after another, such as by flying down a string formation. The program does nothing to either accomplish or avoid such contingencies.

Like the fourth weakness (in weapon coordination) already discussed, these three stem from the same two facts: the computer, through its ICON I program, can never consider the overall situation, nor any fraction of it greater than one bogey and one potentially, or actually, paired weapon; and the computer can never on its own initiative undo any action it initiates.

Concluding Remarks

It is believed at this laboratory that in any realistic fleet situation there will be a need for periodic reconsideration of weapon assignments and that any effective control program must have this ability. It is foreseen that the provision for such a feature must be accomplished in such a way as to avoid unstable or oscillatory behavior.

The ability to reconsider will avoid, among other things, many of the decoy traps to which a naive program is vulnerable. A type of assignment not found in ICON I could also assist in this function. Such a special assignment might take the form of a guarding maneuver similar to the defensive shift of football.

An ideal program should employ its weapons as a coordinated complex rather than as a population of independent types or individuals. Numerous opportunities for coordination and teamwork and for the avoidance of interference present themselves in the course of a battle. Even among the fixed defense there is often need for coordinated fire and for target hand-over. At the very least, when fast, highly mobile weapons or platforms are operated outside a fixed perimeter defense, they should be employed to reduce local densities of intruders in order to minimize saturation of any of the cells of the fixed perimeter. ICON I cannot do anything of this sort because it does not predict, does not reconsider, and recognizes neither pattern nor any subset of group characteristics (such as density, centroid, parallel courses, etc.) Future, sophisticated programs must employ some measure(s) of the overall situation and avoid treating area situations as though they were equivalent to the sum of the individual situation elements (individual bogeys and pairs).

With its strong dependence on personnel to control the availability of weapons, to change or terminate assignments, and to prevent assignment saturation of surface-based weapons, ICON I cannot be justified as anything more than a first demonstration of the feasibility of automation in tactical control and a guide to future programs. To justify its existence, an operational program must handle simple situations with much greater sophistication, or it must satisfactorily handle much higher traffic densities, than humans can. Since the ultimate goal is a program to handle high densities with great sophistication, it is important to accomplish the divorce from dependence upon personnel early in the course of program evolution.

While it is believed that automation of tactical control can and should be designed so as not to depend upon intervention by control personnel, it should be understood that this does not imply that automation should be independent of humans in the sense of not being subject to their command during action. So long as men are held responsible for military action and so long as there remain any control functions which might occasionally profit from refinement by human intervention, control computers should be programmed to work efficiently with or without humans. When controlled by ICON I, most actions of ILLIAC can be anticipated or countermanded by personnel, either by changing the clear picture information being sent to ILLIAC or by changing parameters or orders in the program itself. A well-founded objection to ICON I is that too many classes of interventions require changes in the program, a method which is inherently awkward. For those interventions which can be accomplished by a change in clear picture information, the present facilities indicate that, in spite of the ever-present desire to minimize equipment size and complexity, a certain amount of extra instrumentation will be highly desirable if it significantly facilitates manual intervention. Anything which can be done in program design to permit extensive use of pointers or hooks and other highly human-engineered controls for identification, scratching, or insertion or extraction of other information will pay substantial dividends in operational value.

Toward better tactical automation, present work at this laboratory is being directed along three main lines. A new program, ICON II, has been written to study some techniques in re-assessment and re-assignment for a single weapon type. Basic thinking is being applied to the fundamentals of tactics, and terms such as "threat" are being carefully defined in order to achieve an intelligent understanding of the proper use of threat estimates and means for their accurate calculation in future programs; advanced sorting techniques for weapon assignment are being sought for practical reduction to automation. Finally, an advanced vectoring program to provide accurate, stable mid-course guidance and to guarantee specified final approach attitudes and altitudes is almost completed.

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