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THE PILOT'S TASK
IN HIGH PERFORMANCE
ALL-WEATHER AIRCRAFT

by

HARRY J. OLDER

F. K. BERRIEN

SEYMOUR RINGEL

Under

Contract Number N8onr-69404

Office of Naval Research, United States Navy

INSTITUTE FOR RESEARCH IN HUMAN RELATIONS
PHILADELPHIA WASHINGTON

February 1952

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CHAPTER I

INTRODUCTION

This project has attempted to improve air-borne all-weather radar equipment from the standpoint of its use by the radar operator or pilot. Attention has been concentrated on the simplification of console design, radar displays, and manipulated controls in both single and two-place all-weather aircraft.

Background

The United States Navy currently has a number of high performance all-weather fighter type aircraft either in operation or under development. One of the advanced operational aircraft of this type -- the F3D -- requires two trained men: A pilot and a radar operator. Some projected plans for future interceptor aircraft call for the elimination of the radar operator, leaving complete responsibility to the pilot. The Military Requirements and Development Branch (Op 551) of DCNOAir became concerned about the number and complexity of separate tasks which were to be required of the pilot in the operation of projected single-seat night interceptors.

Ideally an interceptor should have high speed and long endurance. The addition of heavy radar gear in itself must reduce one or both of these features. When the equipment becomes so complicated that the pilot cannot be expected to operate it and simultaneously fly his airplane as in the case of the APQ-35¹, the addition of a second man imposes still further limitations on speed and endurance.

This question of one- versus two-man operation led to a proposal that the Institute for Research in Human Relations investigate the feasibility of having the pilot handle both jobs and, if one-man operation were possible, to investigate those activities which could be made automatic or could be further simplified. It was hoped that by a detailed action-by-action study of what each man does in a two-man interceptor during a

1. Navy designation for radar system installed in F3D.

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series of typical search and attack problems, it would be possible to determine the wisdom of concentrating future development on one- or two-place interceptors.

The Field Situation

Once research had begun on this problem, the investigators discovered that very few of the advanced radar equipped aircraft were available for study. The F3D was assigned to operating squadrons but it was difficult to obtain access to any of these aircraft for experimental work. The most advanced equipment in operation, the APQ-35, was available on bench setups at the Naval Aviation Electronics Service Unit, Naval Receiving Station, Anacostia, and at the Electronics Test Unit, Naval Air Test Center, Patuxent, but no equipment was available for using either simulated or real targets in a systematic way. A similar condition was found at the Westinghouse Electric Company in Baltimore where the equipment was manufactured. Operating squadrons at Moffet Field and El Toro which had F3D's were committed to training schedules that prevented assignment of planes to this project.

Even if aircraft equipped with APQ-35 had been available, several other considerations entered into the problem of conducting an activity analysis in field situations. The F3D is so designed that it would be unsafe for a third person to fly as an observer. The cockpit space is so limited that the use of cameras and recorders would have presented great difficulty. In order to record adequately the operations performed by the two men, it would have been necessary to install a battery of synchronized cameras. Because a hood is required in order to view the scope in the plane in daylight operations, there was the problem of photographing the operations and scope displays simultaneously.

An attempt was also made to obtain access to the F3D operational flight trainer as a substitute for actual performance observation. Link Aviation Corporation did not complete acceptance tests of the F3D, OFT at Binghamton until about 1 November 1951. Although this trainer was in operation for a short period, it was soon modified and partially rebuilt.

In view of all the above considerations, the proposed activity analysis had to be abandoned.

In addition to the practical problems discussed above, early investigation indicated that the major problems as defined in the proposal appeared unrealistic. Although a two-man equipment was in operation, manufacturers of the radar equipment for all-weather

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interceptor aircraft were concentrating on the development of one-man systems. Some of these developments were at the prototype and mock-up stages. After consultation with cognizant personnel in the Department of the Navy, it was agreed that the orientation of the project should be modified. The problem as approached in the last several months of the project was essentially one in human engineering in which the Institute provided manufacturers with A/I radar development contracts with human engineering consulting service.

Because a large body of human engineering research was unknown to electronics engineers, the Institute was in a position to render a service that should result in savings and improved man-machine systems.

The Role of the Human Engineer in the Design of Aircraft Equipment

The role of the human engineering psychologist is to aid the design engineer in meeting the human requirements of equipment in the optimum manner. His advice and consultation can be valuable at three critical stages in the development of new equipment: The planning stage, the mock-up, and the operational testing stages. When equipment design is at the blueprint stage the human engineer can bring to bear his knowledge of body dimensions, the shape and size of work space required, the range and strength of limb movement and the intellectual demands which will be made upon the operator. In this way, he can advise on whether or not the equipment will be comfortable for the average operator, will most efficiently aid in the performance of the task at hand, and if the equipment can be operated by the average pilot, radar operator or other designated personnel.

The human engineer can also consult on the development of equipment items which are primarily display or control in nature. Display markings, instrument dials, control knobs and panels and the like must be adapted to the conditions of operation and must be designed with regard to other tasks the operator may be performing simultaneously.

In the design of the equipment, special attention should be given to achieving optimum integration of the crew or operator and the equipment. The major points to be considered are: Space for the operator's stations and the arrangement and design of controls; design of visual and other display information; safety features; environmental conditions such as illumination, noise level, vibration, temperature and ventilation; and the utilization of skills already existent in available operators. These points are critical in the development and planning of equipment and should be taken into consideration at the earliest stage.

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Later, at the prototype and mock-up stages, it is important for a human engineer to be present in order to observe actual lay-out of the equipment and to take into consideration those problems which were not apparent on the design board and which become obvious when the blueprints are translated into three dimensional models.

Human engineers can contribute materially to operational testing programs, assisting in designing procedures for tests, and in the evaluation and interpretation of the findings of such tests. The information gained by human engineers engaged in acceptance testing can be useful in the preparation of future equipment. Thus, the planning and development of new designs becomes a circular process in which the human engineer can give valuable advice at every stage.

This is a report of the findings of this series of studies which it is felt either have had or will have practical usefulness to the Navy. More complete discussions of several of the points covered here can be found in the various Periodic Status Reports which have been submitted under this contract.

* * * * *

In the course of these studies at least one visit was made to each of the following activities:

U. S. Naval Test Center, Patuxent River, Maryland
 Composite Squadron 4, NAS, Atlantic City, New Jersey
 Composite Squadron 3, NAS, Moffet Field, California
 VMF(N)542 MCAS, El Toro, California
 Fairbetu Pac, NAS, San Diego, California
 Naval Air Service Electronics Unit, Anacostia, D. C.
 USS Oriskany, #CV-34, FPO, New York

Bell Telephone Laboratories, Whippany, New Jersey
 Westinghouse Electric, Baltimore, Maryland
 General Electric Corporation, Schenectady, New York
 Sperry Gyroscope Company, Great Neck, Long Island
 Link Aviation Company, Binghamton, New York
 Hughes Aviation Corporation, Los Angeles, California
 North American Aircraft, Los Angeles, California
 Capehart-Farnsworth, Fort Wayne, Indiana
 Raytheon Manufacturing Corporation, Waltham, Massachusetts

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CHAPTER II

STUDIES OF THE A/N APQ-35 RADAR INSTALLATION

Since the APQ-35 was the operating equipment in the F3D, attention was first directed toward that installation. Interviews were conducted with 10 APQ-35 radar operators and three F3D pilots. From their comments, the operating difficulties encountered in using the present gear were isolated. Human engineering principles and findings, which could be applied to improve the ease and the speed with which the equipment could be employed, were studied and integrated with the comments. The results of this two level approach to the problem -- operating reactions and general knowledge -- were applied to a design of a simplified console. This redesign was made in order to illustrate the kind of recommendations resulting from this type of research, and because Westinghouse Electric Company was engaged in the design of APQ-43 (same as APQ-35 without APS-28 tail warning.)

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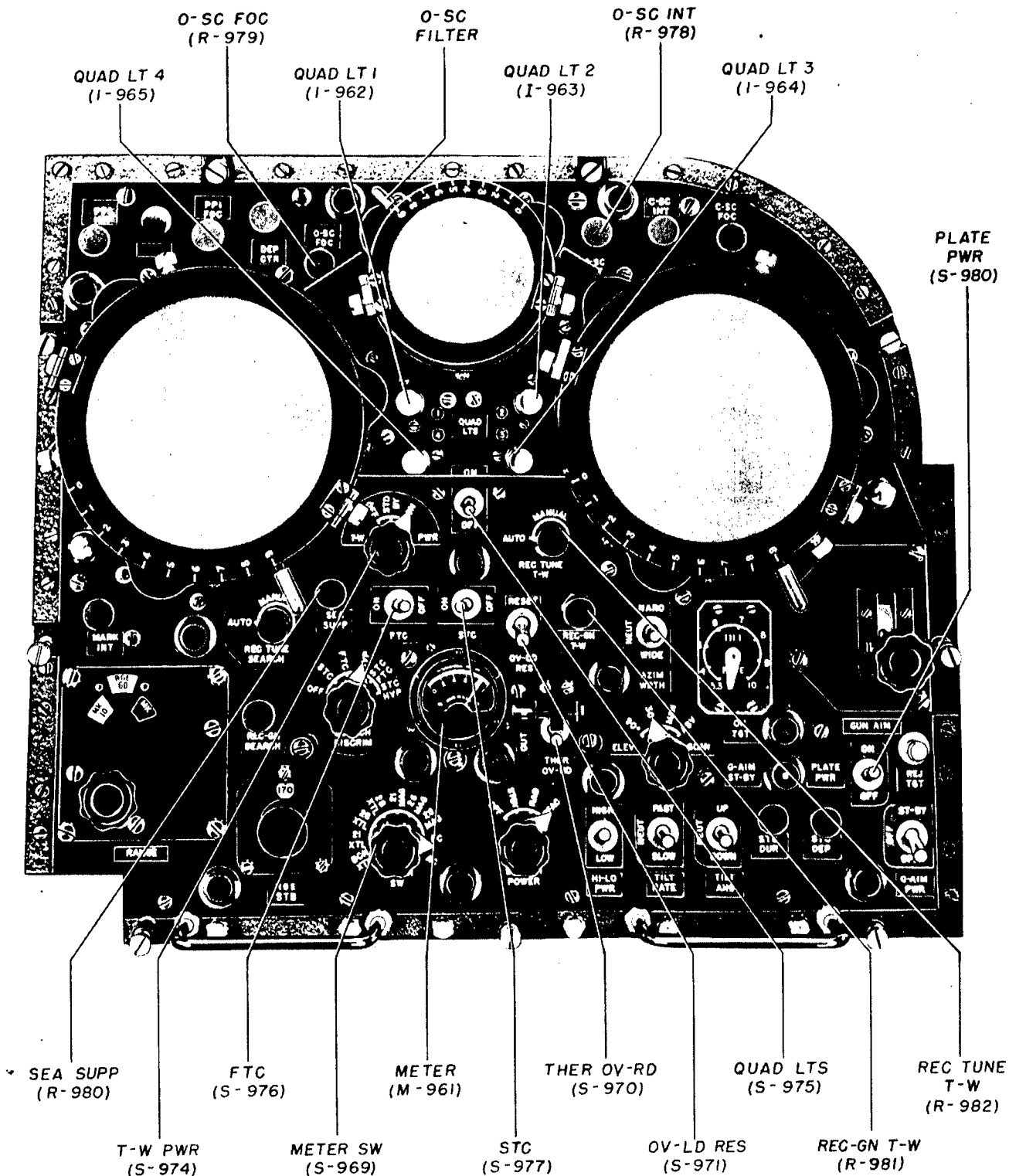


Figure 1. Console C-576/APQ-35, Operating Controls for Radar Set AN/APS-28.

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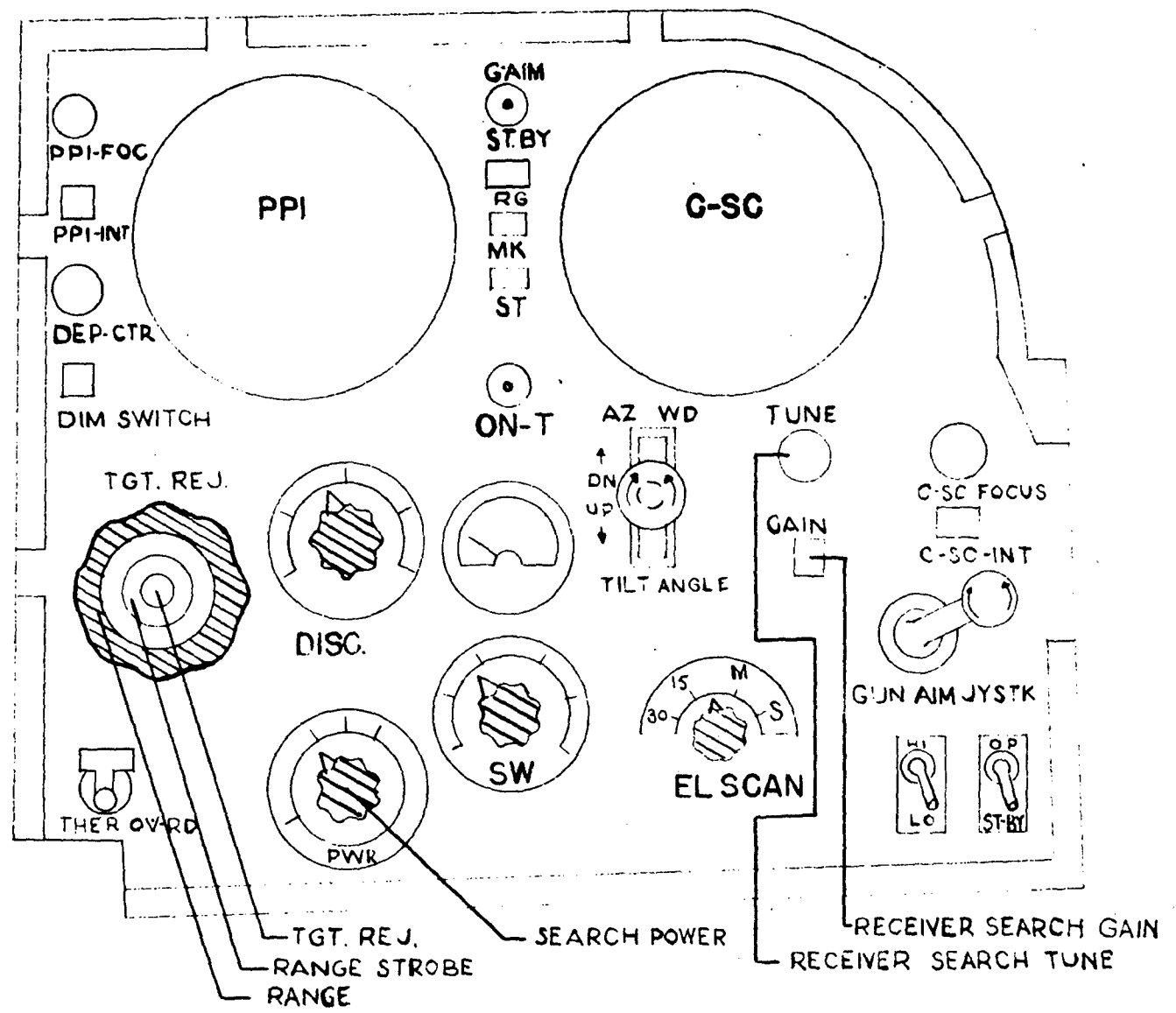
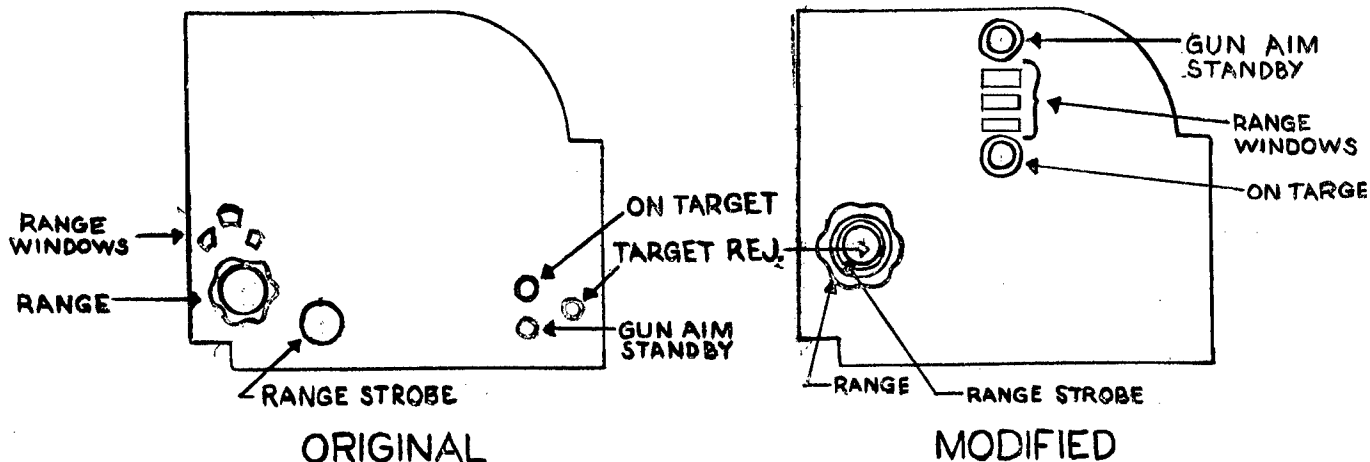


Figure 2.
RECOMMENDED MODIFICATION OF AN/APQ-35 CONSOLE

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RANGE, RANGE STROBE, AND
TARGET REJECT CONTROLS AND INDICATORSDifficulties with Original

1. Visually inspected indicators (a) Range Windows, (b) On-Target, and (c) Gun-Aim Standby Signal Lamps located in lower right and left hand corners, while main visual area is in upper half of console.

2. Target Reject Push Button too close to Gun-Aim Joy Stick with possibility of moving latter when operating Button. Forces action of right hand when that hand is already occupied with Joy Stick and left hand is inactive.

3. Range and Range Strobe Controls unnecessarily separated, Repositioning of right hand is required in moving from one to the other with possibility of lost time in groping.

Advantages of Modification

1. All visually inspected indicators are grouped in the center, upper half of the Console within the area covered by the Hood. This eliminates necessity for the Operator to remove his face from the Hood to see whether or not he is locked-on, at what range he is operating, etc.

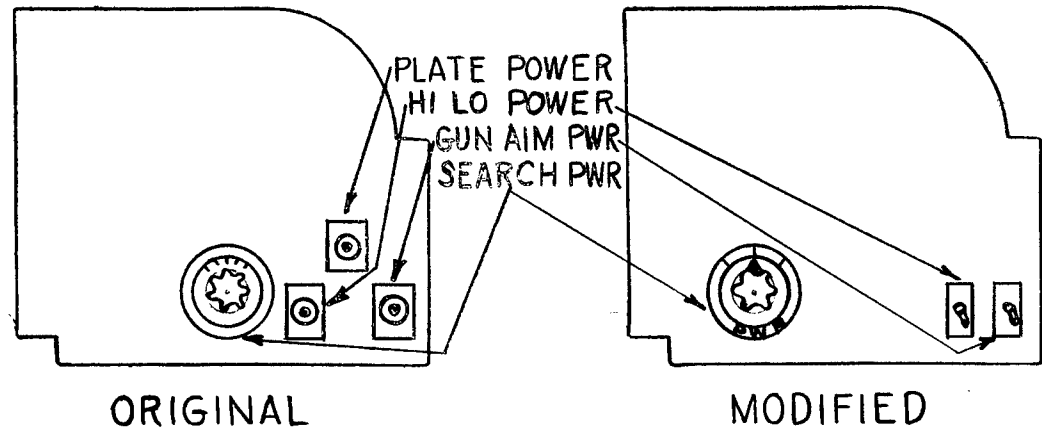
2. Target Reject is given to unoccupied left hand already positioned by Range and Range Strobe Controls.

3. All controls are "stacked" so that repositioning of left hand is eliminated, when moving from one control to another.

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SEARCH POWER AND ASSOCIATED SWITCHES

Difficulties with Original

1. In original design the system could not be placed in St-By condition unless (a) Search Power was turned to St-By, (b) Plate Power was moved to On, (c) Gun-Aim Power was moved to St-By and (d) Hi-Lo Power was moved to Lo.

Advantages of Modification

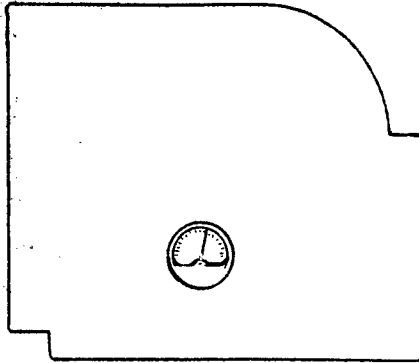
1. Search Power Switch would retain all original functions but tied to the St-By position would be the leads for (a) St-By Gun-Aim Power, (b) Lo Power for Hi-Lo Power, and (c) On for Plate Power. This modification still gives the Operator freedom to use High Power on Search without turning Gun-Aim to Operate position.

2. The system can be warmed up in one movement rather than four.

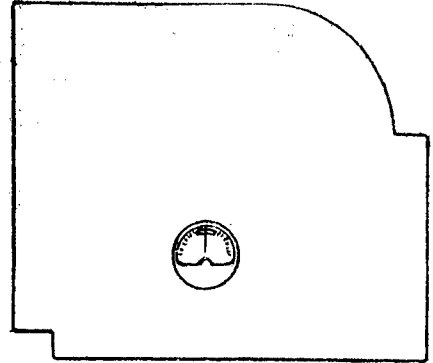
3. Eliminates possibility (often reported as a difficulty) of leaving Gun-Aim Power in Off position when moving toggle from St-By to Operate. Such a mistake requires a three minute delay in rewarming equipment.

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METER



ORIGINAL



MODIFIED

Difficulties with Original

1. In the original design, the Meter must read successively for settings on the Selector Switch going in the clock-wise direction as follows: 0.6, 0.3, 0.3, 0.3, 0.6, 0.32, 0.93, and 0.575 if Hi-Lo Power Switch is in Lo position. In Hi, reading No. 6 (0.32) becomes 0.92.

2. Illumination of Meter in current equipment is unsatisfactory to such an extent that it cannot be read unless an auxiliary light is directed on to the face.

Advantages of Modification

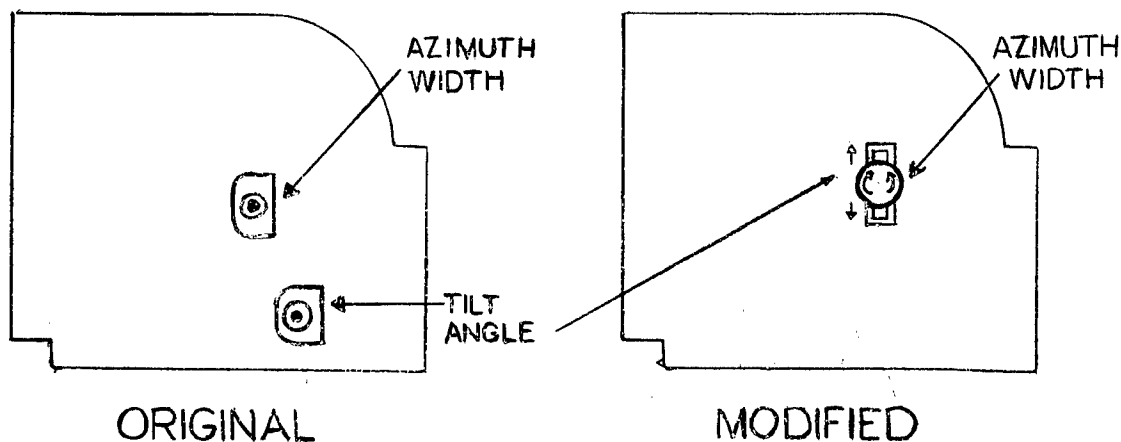
1. This retains the same function and position but should be calibrated so that each circuit selected by the Meter Switch will read in the same area of the scale (identified by color on the scale) if the circuit is operating within acceptable limits.

2. If possible, the face of the Meter should be back illuminated as on all the other labels.

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AZIMUTH WIDTH AND TILT ANGLE

Difficulties with Original

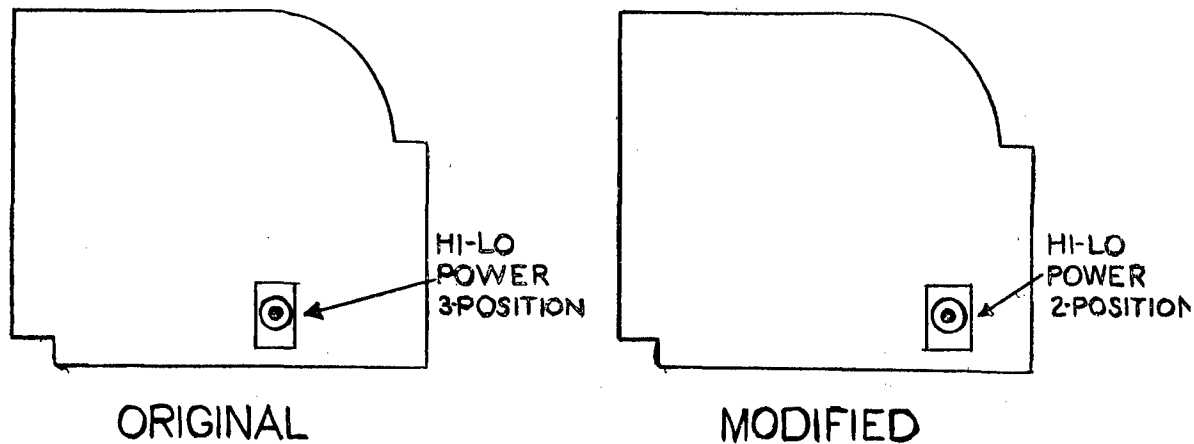
1. Azimuth width is controlled by an up (narrow) or down (wide) movement of a toggle switch - an "unnatural" movement to produce the effect desired.
2. Tilt angle is controlled by a toggle that requires only momentary control to produce a marked change. Fine adjustments are difficult.
3. It is sometimes desirable to operate both in a coordinated fashion but since both are positioned for the right hand only alternate control is possible.

Advantages of Modification

1. Both controls have been combined into a lever with a rotating knob. Moving the lever up or down will adjust the tilt angle while rotating the knob will control azimuth width. Coordinated control of both functions is thus possible without repositioning the hand.
2. Rotating the knob is a more "natural" way of controlling width.
3. A lever movable in the manner described is a natural way of controlling tilt angle and will provide for positive and fine adjustments.

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HI-LO POWER TOGGLE SWITCH

Difficulties with Original

1. Located in central section of console adjacent to similar switches having no functional relation.
2. Has three positions - Hi(up), Off (center), Lo (down) such that equipment may be inadvertently turned off when the intention is to shift from Lo to Hi.

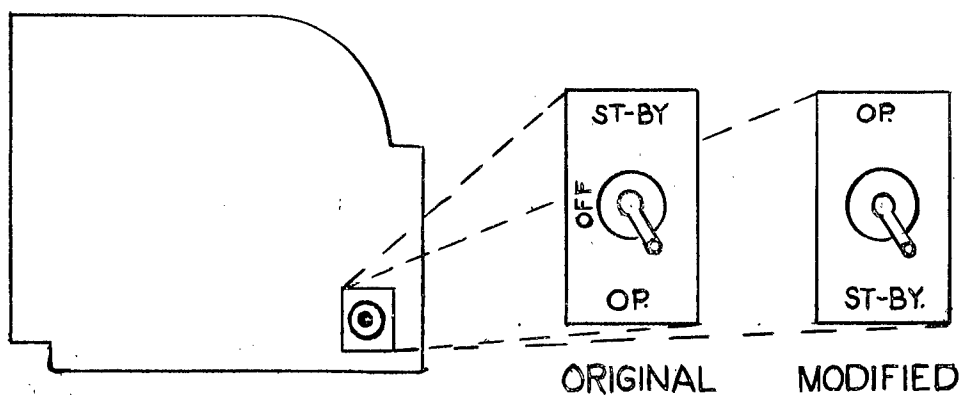
Advantages of Modification

1. Located adjacent to Gun-Aim Power Switch such that both switches must be in up position for lock-on.
2. Eliminating the Off (center) position prevents error described in (2) above.
3. Lo Power will come on when Search Power Selector Switch is turned to St-By (see page 7 Advantages of Modification, item 1). Built in delay is required in circuit to prevent overload if switch is inadvertently left in Hi position when turning off the system.

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GUN-AIM POWER TOGGLE SWITCH

Difficulties with Original

1. Operate position (down) is the reverse of Hi Power (up) position in Hi-Lo Power Switch. Both switches should be moved in same direction when equipment is readied for lock-on.

2. Third position at center permits operator to make error in shifting from St-By to Operate.

Advantages of Modification

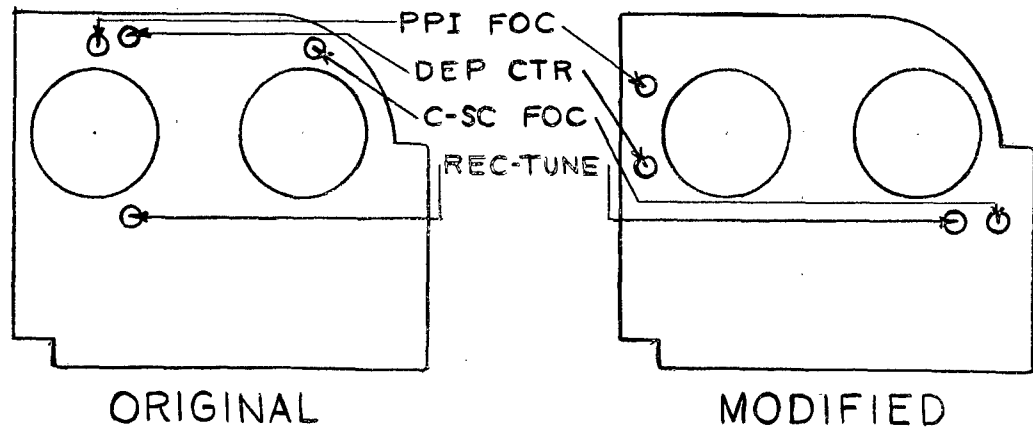
1. Position of Operate (up) has been changed to conform with H-Lo Power Switch.

2. Eliminating central (Off) position of toggle prevents error described in (2) above.

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PPI FOCUS, DEPRESSED CENTER, C SCOPE FOCUS, RECEIVER TUNE CONTROLS

Difficulties with Original

1. Controls located without regard to distribution of activity load on each hand when adjusting these functions.
2. PPI Focus and Depressed Center Controls located in positions requiring excessive reaching around and over the Viewing Hood when in place.
3. Receiver Tune placed for operation by left hand while right is relatively "unloaded".

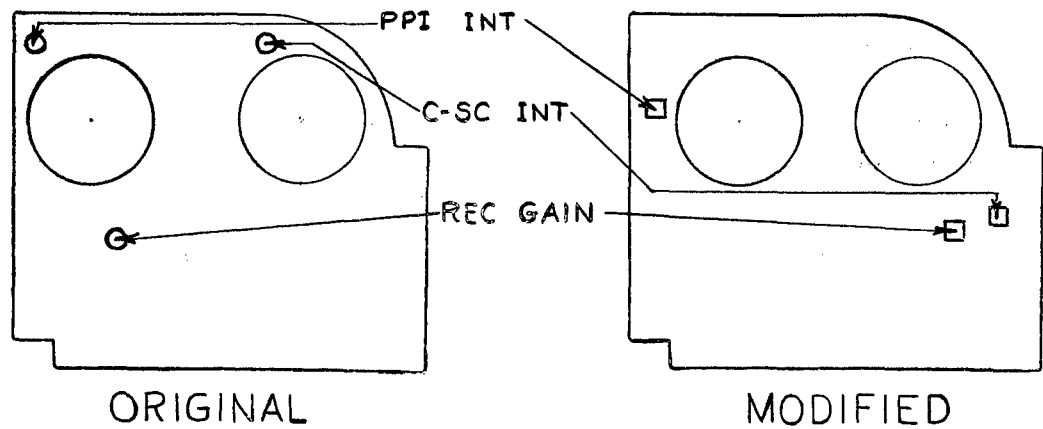
Advantages of Modification

1. Positioned adjacent to visual displays affected by adjustments and in such locations that reaching over Hood is eliminated.
2. Receiver Tune is positioned for operation by right hand thus balancing activity load of both hands.
3. All these controls are shape coded to distinguish them from associated intensity controls.

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PPI INTENSITY, C SCOPE INTENSITY, RECEIVER GAIN CONTROLS

Difficulties with Original

1. Placed near and easily confused with associated focus controls.
2. Position of Receiver Gain Control over-loads left hand.

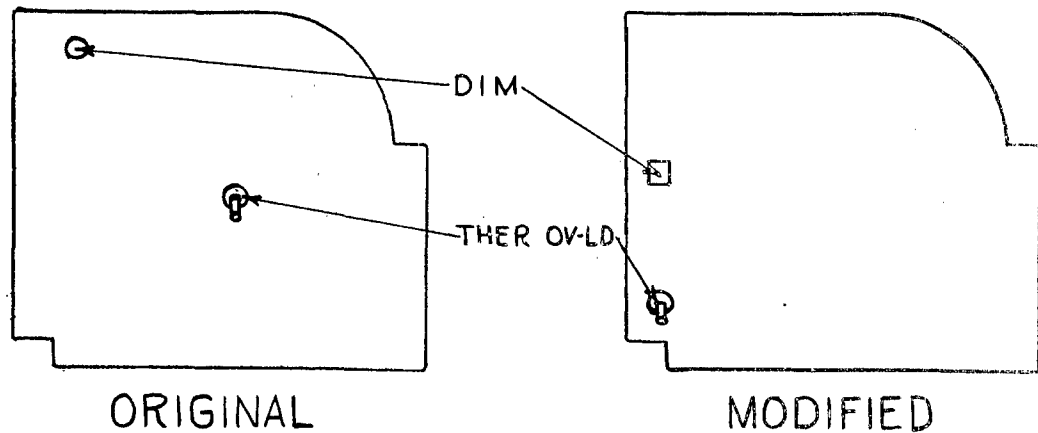
Advantages of Modification

1. Shape coded to minimize confusions with focus controls.
2. Receiver Gain Control transferred to right hand, thus balancing the activity loading of both hands.

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DIM SWITCH AND THERMAL OVER-LOAD RESET SWITCH

Difficulties with Original

1. Dim Switch
 - a. Located above Hood in awkward position.
 - b. Easily confused with adjacent controls (PPI Intensity, PPI Focus, Depressed Center).
 - c. Only two intensities provided.
 - d. Controlled panel illumination of pilot's display (APG-26).
2. Thermal Over-Load Reset Switch is located centrally and in a space more advantageously assigned for frequently used controls.

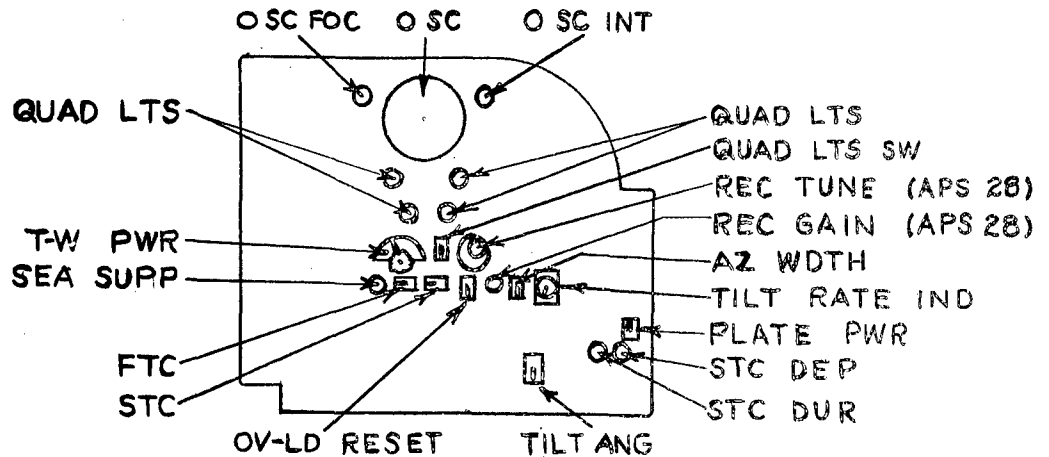
Advantages of Modification

1. Dim Switch
 - a. Located in accessible position.
 - b. Shape coded to minimize confusion with adjacent controls.
 - c. Should be designed to give gradual rather than step-wise adjustment.
 - d. Should not be connected with pilot's display.
2. Thermal Over-Load Reset Switch is located in accessible but marginal area because it is used only once in the life of the equipment.

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CONTROLS AND DISPLAYS REMOVED FROM CONSOLE



All APS-28 controls and displays have been removed because this unit was thought by some Navy personnel to be unnecessary, particularly under the tactical conditions anticipated (close control).

TILT RATE SWITCH AND TILT RATE INDICATOR:

Eliminated because RO's report they set the rate at, or near, the maximum and do not readjust the rate from that point on.

STC DUR AND STC DEP CONTROLS:

Eliminated because RO's report these are unnecessary refined adjustments that are rarely used and even when used produce only minor improvements in PPI displays.

PLATE POWER SWITCH:

Eliminated but the functions have been combined with the St-By contact of the Search Power Switch.

AZIMUTH WIDTH SWITCH:

Eliminated but functions have been combined with AZ WD and Tilt Angle Joy Stick.

TILT RATE SWITCH:

Eliminated but functions have been combined with AZ WD and Tilt Angle Joy Stick.

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CHAPTER III

STUDIES OF THE A/N APQ-41 RADAR INSTALLATION

It was the purpose of the Institute to investigate the operational experience and problems related to APQ-41 intercept radar gear which was installed in an F2H-2N and an R4D. Nearly two weeks (20 August to 31 August 1951) were spent in gathering first hand information at the Naval Air Test Center, Patuxent River, Maryland. In addition to inspecting the equipment, both the civilian project engineers and the project test pilots were questioned regarding the operating problems with the gear in both the F2H-2N and in the R4D. The following were the main problems that appeared to demand consideration from a human engineering standpoint.

Range Selector Switches and Other Hand Controls

All pilots and operators found the push buttons required for changing from one range to another to be very satisfactory. These buttons were positioned in such a way that it was not necessary to inspect them visually in order to know which range was being fed into the scope.

The ranges for the gear in the R4D were modified temporarily from 6, 30, 100 and 200 miles to 6, 15, 100 and 200 miles. It was difficult to determine what ranges other than the six mile range should be provided before more facts about range performance were known and before decisions had been made regarding the tactical employment of the airplane.

The pilots' wishes varied concerning range markers electronically presented on the scopes. Two problems existed with respect to these range markers.

1. Brightness -- A variable brightness control would enable one to perform with maximum effectiveness under both day and night conditions.
2. Presence or absence -- Some pilots, under certain conditions, preferred elimination of range markers since they tend to clutter up the scope, particularly when the range strobe is also presented.

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Therefore: An intensity adjustment control for range markers should be provided near the scope itself. This should allow an intensity range from zero to approximately the present brightness.

The Hand Control for the range strobe was improperly geared when the equipment was on the six mile range. Pilots reported that the range strobe moved too rapidly across the face of the scope and they were not sure in which direction the Control had to be turned, in advance of actual turning, to bring the strobe on the scope. Engineers reported that it was impossible to change the gearing of the range strobe with relation to the Hand Control when shifting from one range to another. The ball-type Hand Control was often inadvertently moved when pressing the Lock-On Button, thus throwing the range strobe from its position. A pistol-type control, provided with a knob to be operated by the thumb, was proposed for evaluation and if developed may have reduced this difficulty. However, the ratio of thumb movement to range strobe movement needs further careful consideration.

Therefore: Two alternative modifications were recommended.

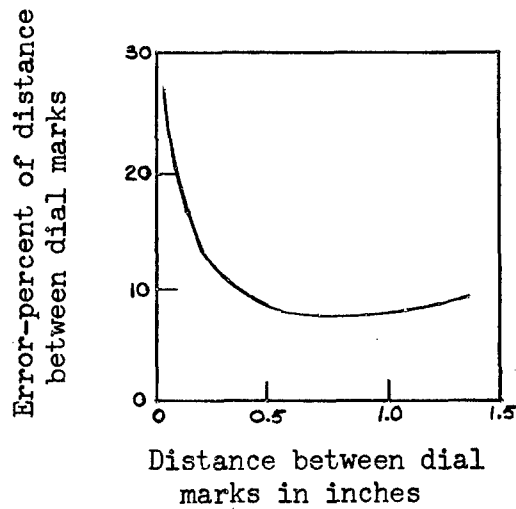
1. The gearing should be changed so that approximately 90° of knob movement is required for moving the strobe over the entire six mile range, and a raised ridge should be provided on the Strobe Control knob to fix the position of the strobe at three miles, the center of the scope on the six mile range.
2. The Range Buttons on the control panel might be modified so that the range strobe is automatically set at the mid-position of whatever range is being fed into the equipment. Further adjustments of the strobe could then be achieved by moving the Strobe Control knob.

Range Clocks

Pilots reported that the range markers on the Range Clock were too far apart and that it was difficult to estimate position between the markers.

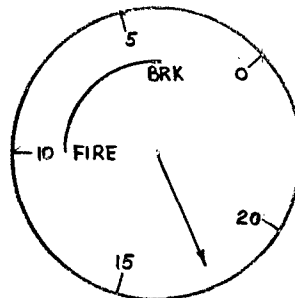
The following curve shows the relation between size of dial intervals and errors in reading pointer positions. (From Grether, W. F. and Williams, A. C., Jr. Speed and accuracy of dial reading as a function of dial diameter and angular separation of scale division. In Fitts, P. M. (Ed.) Psychological research on equipment design. U. S. Printing Office, 1947, 101-109.)

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Other studies have indicated that the pointer should move in the clock-wise direction as the variable being measured increases. In this instance, the psychologically important variable is closeness. For this reason the range numbers were arranged to show increasing closeness in the clock-wise direction.

Therefore: The dial design shown below takes into account these factors and the space limitations on the panel.



Note: Actual firing range to be indicated will depend on armament on plane.

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Scope - Target Visibility

The pilots involved complained of their inability to see targets adequately because of low persistency of the target blips. Persistency of blips can be increased by changing the type of phosphor coating on the tube face; however, Westinghouse engineers reported that such an increase in persistency would result in reducing the definition of targets.

The viewing situation almost required that the pilot watch the sweep line moving back and forth and observe carefully any momentary increase in brightness as the line passed a target. This demanded constant pursuit and saccadic eye movements and close attention to a moving line four inches long in order to perceive a target. Ocular fatigue was obviously a factor to be considered. One experienced radar operator reported that he found it necessary to rest his eyes about once per minute.

The visibility of target blips is affected by a least five factors:

1. the duration of the blip,
2. the contrast between the blip and background,
3. the size of the blip,
4. the brightness of the background, and
5. the distractions presented by other information on the scope and preoccupation of the pilot with other instruments and necessary operations.

Experimental studies have already been reported which deal with the interrelationships of the first four factors and the minimal conditions for seeing target blips can be specified. The relationships are graphically presented on page 22, Figure 1. Item 4 merits an experimental study if equipment and facilities can be made available.

At this point it is well to point out that the conditions of viewing the scope are such that for brief periods, the eyes of the pilot are, for all practical purposes, "blind". It is known, for example, that a saccadic eye movement (of which there are probably several in the course of watching a complete cycle on the radar scope) of only 50, requires 29 milliseconds, during which time it is not possible to see. Assuming a minimum blip of 1/32nd inch in lateral size and a speed of sweep of three inches per second, the blip will appear for about 10

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milliseconds. (These are the conditions in the APQ-41). Such a blip, if it occurred during a 5° saccadic eye movement, would not be seen. Manipulation of the factors listed above and in Figure 1. can increase visibility in predictable directions. In addition, experimental findings indicate that for small blips, visibility increases more rapidly with pulse length (producing a taller blip) than with beam width.

Therefore: It was recommended that the visibility of blips be increased by one or a combination of the following methods:

1. Reduce the speed of scanning.
2. Increase the pulse length.
3. Increase the persistency of the blip (phosphors).
4. Increase the beam width.
5. Decrease the bias (increase brightness).
6. Increase the pulse repetition frequency.

Such modifications would increase the possibility of seeing targets at search ranges for which the equipment was designed.

Scope Confusion

Some pilots wanted to reduce the number of reference marks on the scope presentation and at the same time they wanted additional information. Specifically, the range markers, the altitude line, and the double lines representing the range strobe cluttered the face of the scope and would have obscured a target that coincided with any one of them. On the other hand, these pilots wanted a gyro horizon line on the B scope. Under existing conditions, the gyro horizon appeared only after the target was bracketed by the range strobe. On the original equipment, range markers were presented as follows:

| <u>Total Range</u> | <u>Marker at Each</u> | <u>Scope Face Distance</u> |
|--------------------|-----------------------|----------------------------|
| 200 miles | 40 miles | .8 inch |
| 100 miles | 20 miles | .8 inch |
| 30 miles | 5 miles | .67 inch |
| 6 miles | 2 miles | 1.33 inch |

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Laboratory studies indicate that accuracy is greatest in reading scales with intervals of .6 to 1.5 inches between markers.

Therefore: It is unnecessary to provide more than two range markers, 1.33 inches apart, on the B scope, which is four inches tall. At the six mile range these would represent respectively: two and four miles; at the 15 mile range setting, they would represent five and 10 miles; at 30 mile range, 10 and 20 miles. At longer ranges the original design should be retained.

Laboratory studies have also indicated that a gyro horizon presentation need not cover the entire width of the scope in order to give the pilot all necessary information.

Therefore: Gyro horizon could be presented on each edge of the B scope without obscuring the middle 90° of search sweep.

Position of Scope and Hood Construction

Angular position of the scope was such that it was difficult to read it while using the hood unless the pilot moved his seat as high as possible. This was not a desirable position since much of the time his crash helmet hit the canopy.

The hood used for daylight operation was improperly fitted to the face and allowed face reflections to appear on the scope. Although a temporary modification of the hood was incorporated on the F2H-2N gear which improved the condition somewhat, there still remained the problem of good fit, especially with the use of an oxygen mask.

Therefore: It was recommended that a hood be designed with two possible adjustments in mind.

1. The hood should be adjustable in length, possibly with an accordian type construction, permitting it to be pulled toward the face and locked in position when needed and collapsed when the pilot is not viewing the scope.
2. The face end of the hood should be adjustable in the vertical dimension so that it may be depressed or elevated as the pilot adjusts his seat. Furthermore, the molding around the face piece should be made of flexible, soft materials so that a good fit can be obtained.

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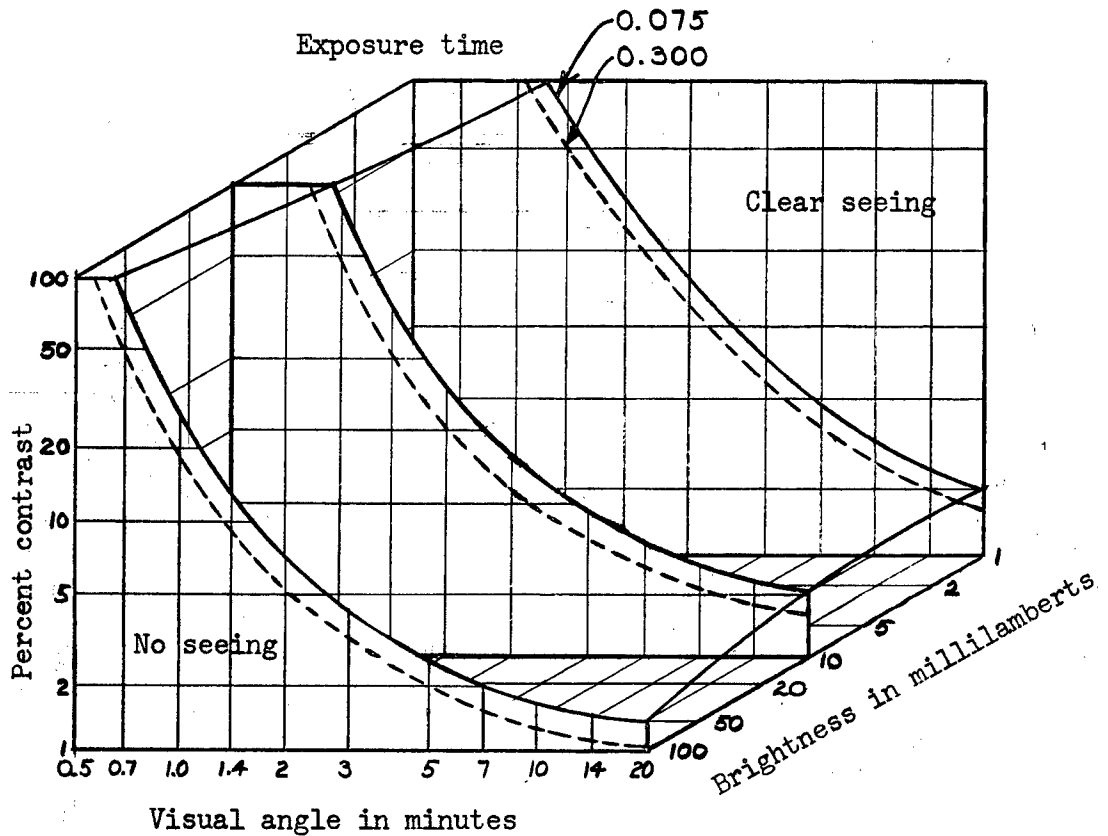


FIGURE 1. The curved three-dimensional surface shows the relationship among object size, contrast, and background brightness for two exposure times. We can see things clearly if the combination of seeing conditions is above the curved surface; we cannot see if the seeing conditions fall below the surface. (Cobb, P. W. & Moss, F. K. The effect of brightness on the precision of visually controlled operations. J. Frank. Instit., 1925, 199, 507-512.)

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CHAPTER IV

THE ELIMINATION OF THE HAND CONTROL

In a Periodic Status Report dated 15 October 1951, the Institute recommended that serious attention be given to the possibility of eliminating the Hand Control used for positioning the Antenna or Cursor on airborne interceptor radar equipment. The advantages which would result from eliminating the Hand Control are:

1. Simplification of operations.

Under the proposed design the pilot has the option for automatic or manual lock-on. If he wishes to lock-on an enemy target, that target must be dead ahead of the interceptor. Manipulation of the Range-Gate Control can take place while maneuvering the plane. This manipulation must be performed in both systems. With the current Hand Control System there are times when he should follow this dead ahead procedure and other occasions when he should decide, after observing the movement of his target on the scope, whether he should use his Hand Control, or maneuver his plane, or both.

2. Freedom of left hand.

The left hand is almost entirely relieved of any "radar load" except for the adjustment of Range-Gate and Lock-On Button. This permits more continuous control of power plant or allows for easy adjustments in focus, brightness, or contrast of radar presentation.

3. Some weight saving.

Elimination of Hand Control and associated servos represents a small weight advantage.

4. A significant space saving in the cockpit.

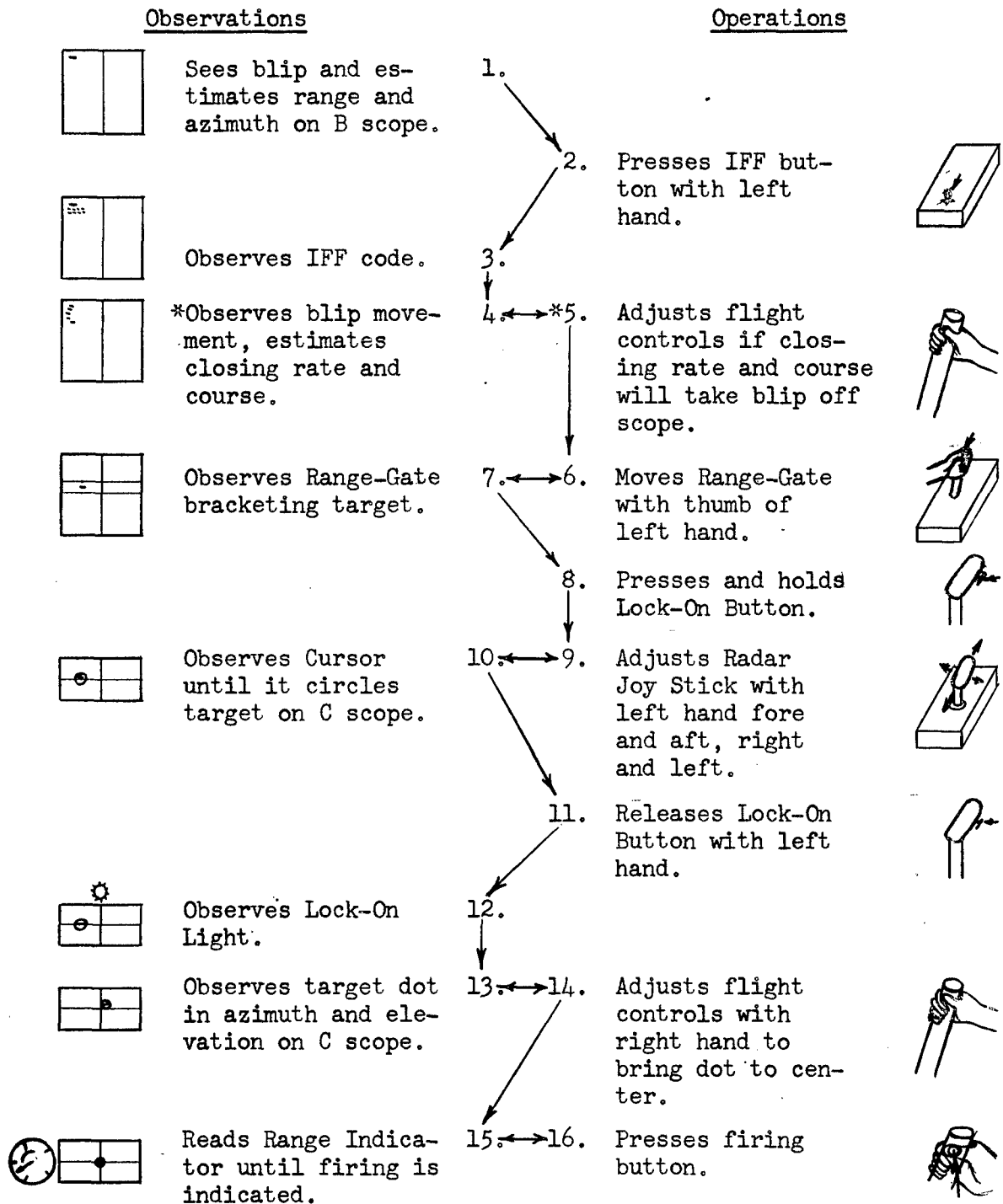
5. Reduction of training time.

The proposed design would simplify and reduce training time. The exact saving is impossible to determine but would certainly be significant.

An activity breakdown of the movements and observations required in locking-on a target with equipment provided with a Hand Control is indicated in Figure 2.

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Current Sequence



* See page 25 for explanation.

FIGURE 2. Observations and Operations Required in Target Selection and Lock-On Phases of AN/APQ Equipment.

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It should be pointed out that this sequence of operations and observations assumes that IFF will be checked at the beginning of the problems. It was impossible to make any time studies of the actual sequence of events but without doubt some time is required for the adjustment of the Hand Control which positions the Cursor, and eventually the Antenna, in the direction of the selected target.

An analysis of the pilot's job during the search phase indicated that when the target appears initially at the azimuth margin, the pilot will be forced to make a critical decision on fragmentary information. Figure 3, on page 26 shows that a target first appearing 50° to the left and flying at 450 knots quickly disappears from the scope if it is flying on any course outside of the limits of 008° 072° . In other words, more than three fourths of the total possible courses which the intruder may be following if picked up at the azimuth edge of the searched area require that the interceptor pilot turn toward the target. On the other hand, if the target were flying within the limits mentioned above and the speeds were as shown in Figure 3, the interceptor pilot should fly straight while manipulating the Hand Control in order to get the best advantage of his equipment. The difficulty arises out of the fact that the pilot cannot readily determine the target's course from his available radar information and consequently is forced to observe the blip on the B scope for perhaps 10 to 20 seconds before he can integrate estimates of closing rate and relative course, on the basis of which he might then be able to decide whether he should or should not attempt to bring the blip toward the center of the B scope. With rapid closing speeds (forward area approaches) a delay of only five seconds in making such a decision would mean the difference between solution and no solution. With slow closing speeds a premature turn toward the target could reduce the advantages which the Hand Control System theoretically possesses. It should be emphasized that the degree of this advantage depends on how closely the situation approximates optimum conditions of fighter direction, radar information, pilot experience, etc.

The situation is further complicated by the fact that the limits of intruder courses permitting a straight course for the interceptor, depends upon the speed of the intruder. If we assume a speed of 400 knots for the intruder the permissible course angles are reduced to 023° to 057° . (See Figure 3.). Therefore, it becomes apparent that a decision to turn or not to turn depends on many factors: Speed of the two planes, courses, and other factors mentioned above. The second factor is difficult for the pilot to determine and the first is almost impossible. Hence, to play safe the pilot will probably turn toward the blip to avoid losing it, as has been reported.

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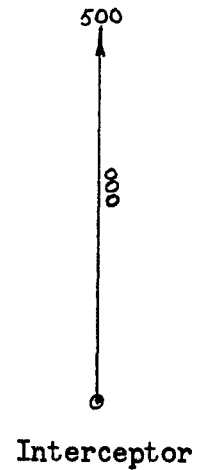
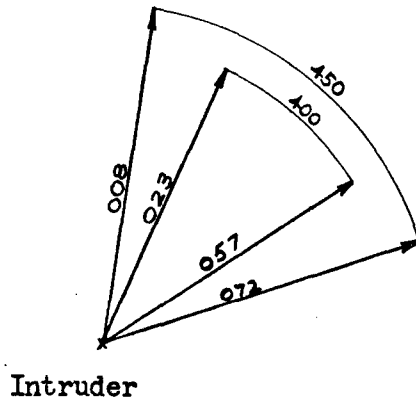


FIGURE 3. Showing limits of intruder courses which permit the interceptor to fly a straight course while manipulating Hand Control prior to lock-on. Interceptor speed assumed is 500 knots. The larger angle (008 - 072) holds true if intruder speed is 450 knots. Smaller angle (023 - 057) holds for intruder speed of 400 knots.

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In summary, the intercept pilot will in many cases attempt to bring the target blip to the center of his B scope if there is some doubt as to the best solution to the problem. In some situations this will have the effect of reducing whatever theoretical advantage the Hand Control has. It has also been reported by pilots that there is a strong "natural" tendency to turn the nose of their plane toward the intruder even on simple problems. This common practice would be standard procedure in the Nose-On Lock-On System.

Because of these conditions, the time required for manipulating the Hand Control and the difficulty involved in making the necessary adjustments as reported in the field, the research team constructed a sequence of observations and operations based upon the assumption that no Hand Control was available. Under this assumption the pilot would have to turn his aircraft in the direction of a target to bring it to the center of his scope in order to lock-on. It was assumed that the equipment could be so constructed that an area plus or minus 4° of center would be a semi-automatic lock-on area if a target appeared within it. Under these assumptions a modified sequence of operations was outlined and is given in Figure 4.

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Modified Sequence

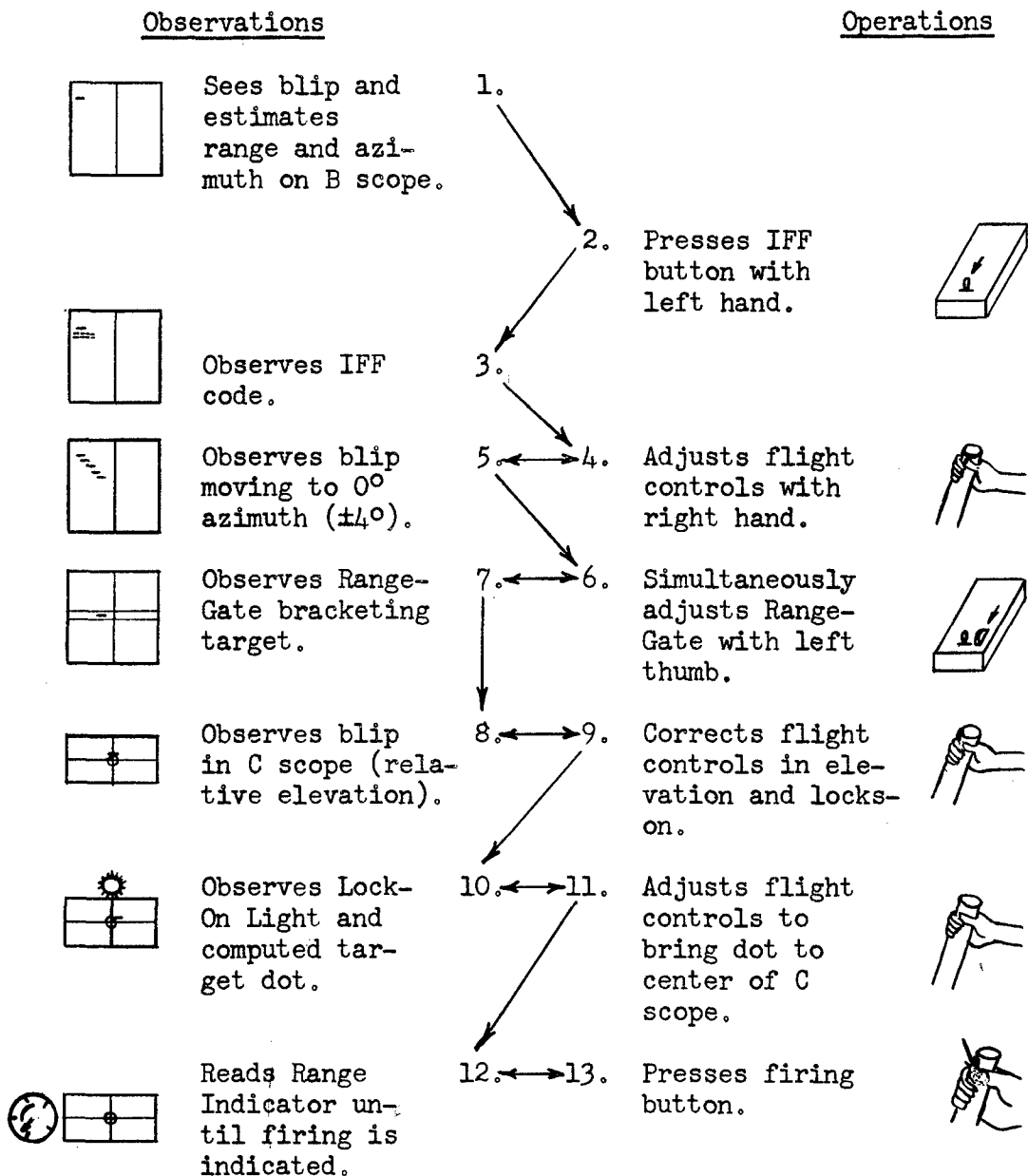


FIGURE 4. Observations and Operations Required in Target Selection and Lock-On Phases of AN/APQ Equipment.

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A comparison of Figure 2. and Figure 4. indicates that the total number of operations and observations in any one cycle could be reduced from approximately 16 to 13. Fewer decisions and less time would be involved. It was proposed further that the pilot be given the option of pre-setting his equipment for automatic or manual lock-on by pressing a button on the console in the Nose-On Lock-On System.

As a further test of these systems, a series of combat situations were drawn all of which appeared in earlier Periodic Status Reports (Number 3 and Supplement to Number 3). No definite conclusions can be stated on the bases of those solutions which were selected since they were arbitrarily chosen from many possibilities. This arbitrary selection was necessary in order to present the problems on paper. It is felt that no real "representative" problems can be depicted on paper since the great number of factors involved are variable and make for several possible solutions to each problem. It is, therefore, strongly recommended that the actual working superiority of one system over another be demonstrated through an experimental situation, where under one condition the Hand Control is used and under another condition the Hand Control is simply lashed down so that lock-on is achieved only when the intruder is dead ahead.

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CHAPTER V

CONSULTING IN ON-GOING DEVELOPMENTS

As pointed out earlier, few manufacturing concerns in the A/I radar field have been able to employ human engineers on their staffs. It was consequently found that most companies are not aware of the considerable amount of information existing in this field relevant to A/I radar problems. The Institute, therefore, took as part of its task the provision of consultation on those problems where it seemed appropriate. Following is a brief discussion of each consultation which it is felt will probably result in modifications of equipment.

The APQ-42 Control Panel

The APQ-42 is under development by the General Electric Company for single-seat operation. While the control panel was in the mock-up stage, two members of the Institute staff visited the company, consulted with the engineering staff and made recommendations concerning its design. These recommendations are examples of the kinds of advice possible while equipment is still at the mock-up stage.

An Over-Load Reset toggle switch, provided with a guard was located in the forward right hand corner of the control panel. Just above this switch was one of the Master Engine switches, also a guarded toggle. (See Figure 5.) According to General Electric it was BuAer's recommendation that this Over-Load Reset switch be located at the point described on the grounds that it would be rarely used and therefore the pilot, in operating APQ-42, would not inadvertently hit a Master Engine switch. It was recommended that the position of the Over-Load Reset switch be reconsidered for these reasons:

1. This is a position easily reached by the pilot and therefore one in which a frequently used control should be placed, other things being equal. The Over-Load Reset switch is one that will be employed only once in the life of the equipment.
2. Push button switches used in the transition from the search to the lock-on phase were located below and behind the Hand Control in such positions that

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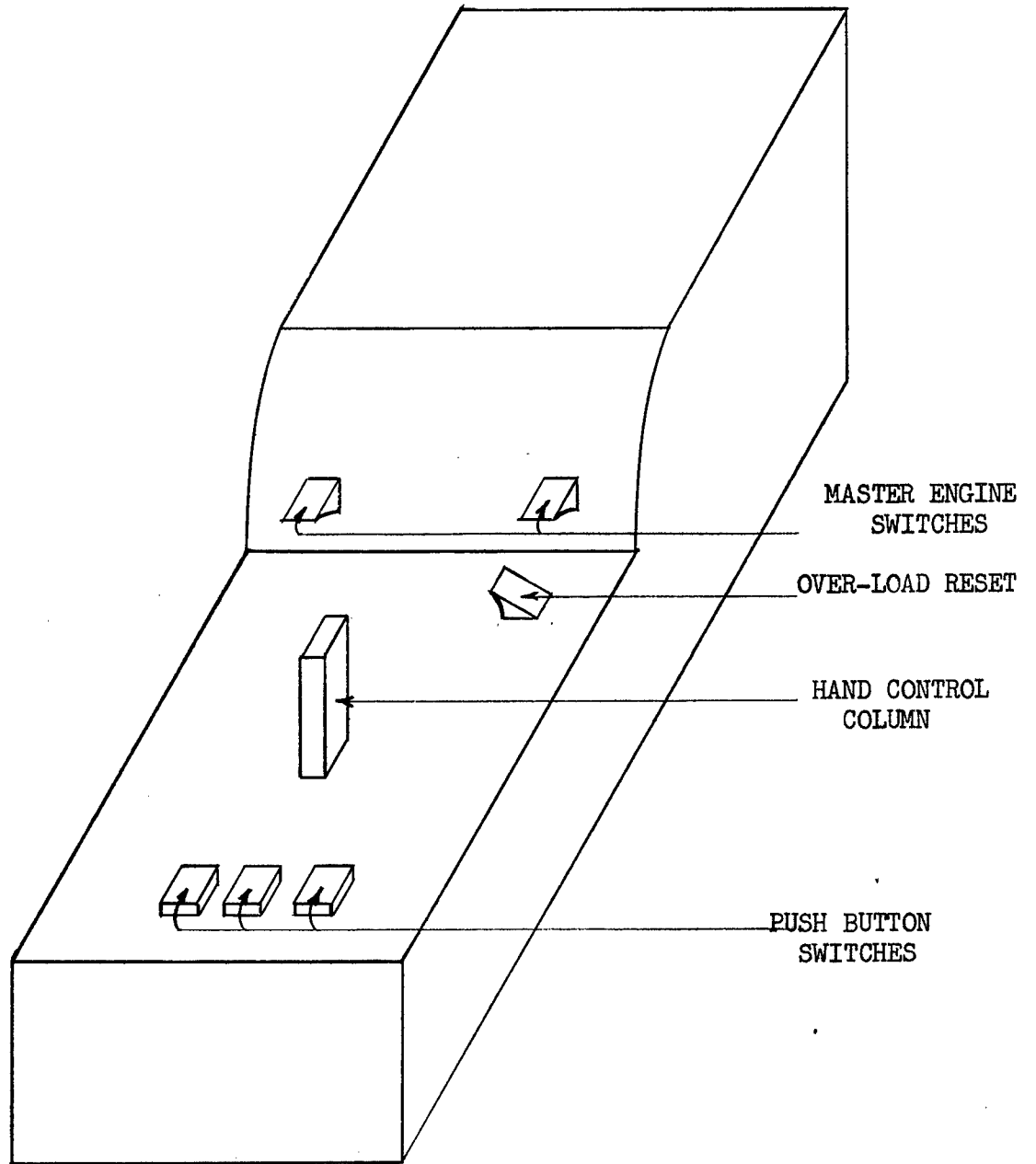


FIGURE 5. Incomplete Schematic Drawing of APQ-42 Mock-Up Control Panel.

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roughly 50 per cent of pilots would not be able to reach them unless they leaned forward about three or four inches. (This percentage was determined by reference to measurements obtained from nearly 3,000 aviation cadets during World War II.) This difficulty resulted from the fact that the distance from the push buttons to a fixed structure behind the pilot's seat was so short that it was impossible to reach the buttons unless the elbow was raised from its normal position.

3. Relocation of the Over-Load Reset switch would provide space for at least one or possibly two of the above mentioned push buttons in a more favorable position.
4. Since the operation of the guarded Master Engine switches required an upward movement of the finger, followed immediately by an extension of the forefinger and then a downward movement, it was extremely unlikely that they would be inadvertently operated when the pilot was intending to make only a downward motion.

The APQ-41 Hand Control

The original Hand Control for APQ-41 was a ball-type with a Lock-On Button at the top. This Hand Control proved ineffective in operation. Rotating the ball moved the Range-Gate and adjusting the position of the ball right and left, fore and aft controlled Cursor position. The movement of the hand in depressing the Lock-On Button was apt to displace the other two controls which had already been set. Clearly, the three items: Range-Gate Control, Cursor Control and Lock-On Button had to be redesigned to form a unit in which one would not interfere with the other yet which could be operated by one hand in fairly rapid sequence. In consultation with the Institute, the Hand Control on the APQ-41 was modified to a cylindrical grip with the Range-Gate Control operated by flexion and extension of the thumb and the Lock-On Button controlled by the middle finger only. Cursor control was achieved by gross movement of the whole cylinder.

Consultations with Raytheon

This suggestion was also transmitted to engineers at the Raytheon Corporation who were working on the APG-43. This model was still in the development stage when the engineers were contemplating the use of the ball-type control. The Institute also suggested

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to Raytheon that they consider the possibility of designing a viewing hood of the type earlier recommended to Westinghouse for APQ-35 and APQ-41. This was an accordion type hood which would permit the pilot to pull the face portion out from the console toward the normal head position. When there was no need to view the scope, the pilot could push the hood away from his face.

Consultations Concerning Color Displays

Several manufacturers are experimenting with the use of color displays. There is good reason to believe that the introduction of color may provide for improved presentations since this additional variable could be employed to symbolize relative elevation, IFF, or any one of several other important conditions. Institute personnel suggested, however, that development along these lines might produce unexpected complications because the complexities of color perception under the illumination conditions of a darkened cockpit are largely unknown. For example, the effect of afterimages under conditions of dark adaptation and red lighting have not been investigated thoroughly enough to know what reversals in perception may occur with particular colors. All manufacturers investigating the use of color presentations were informed of the need for caution concerning these problems.

Consultations with Hughes Aircraft Corporation

The radar console design for the APG-37 is now being developed by the Hughes Aircraft Corporation. The Institute representative who visited and consulted with the Hughes engineers discussed the problems relevant to shape and positioning of the Hand Control and the location of various other controls on the console. The engineers were referred to publications pertinent to the problems of shape coding and dark adaptation. Shape coding findings that have been published may not be immediately applicable to pilots wearing flying gloves and using knobs smaller than those used in the original studies. The difference in feel between several shapes is, of course, reduced when wearing gloves and therefore the possibilities of error are increased. The entire console is so designed as to fit into a relatively small space at the left side of the pilot. The position for the console will be an awkward one in terms of arm reach and therefore the difficulty of kinesthetic recognition under unfavorable conditions presents an area of concern. The present design also has variously shaped knobs designed for a standard shaft. This makes it possible for maintenance personnel to place the "right knob on the wrong shaft". Thus if the pilot has learned his controls by the shape of the knob, a mix-up in knobs would mean a high probability of error.

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CHAPTER VI

RECOMMENDATIONS FOR FURTHER RESEARCH

During the course of the research on the problems discussed in this report, several areas which have not been fully explored became apparent. These are presented here as indications of the areas which seem to the present investigators to warrant additional study.

The Hand Control

In the body of this report, the consideration of the elimination of the Hand Control from single-place interceptor radar was discussed. It is recommended that a field test of this system be made. Flight tests of the APQ-41, the APG-36, or another operating one-man radar set in which the Hand Control is rendered inoperative and the Lock-On Cursor centered on the B scope, would provide definitive data on the advantages or disadvantages of the Hand Control. Problems which might have been overlooked in the theoretical analysis of the combat problems presented in earlier reports will become apparent in an operational field test.

General Visibility Problem in Radar

The problem of visibility of target blips on scopes has been a topic of considerable experimentation in psychological laboratories for the last five years, yet the established information does not seem to have come to the attention of radar engineers designing new equipment.

For example, the engineers seem to be striving to create a bright, high contrast blip on a dark screen. It has been established that weak target signals can be seen best if a certain degree of brightness is deliberately added to the screen.

At the same time, the precise amount of brightness that will enhance visibility of target blips cannot be specified in electrical or other physical terms because of the variability in response characteristics of phosphors within any given tube type. Consequently, it has been suggested that a simple psychophysical test be employed by each operator each time he uses a scope to establish the scope brightness that will give him best target visibility. This test requires an artificial signal which could be built into

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the radar indicator and turned on when adjusting the equipment during preflight check.

Another factor is the manner in which an operator actually scans the scope. Some operators try to follow the beam as it sweeps back and forth across the B scope. Others report that they fixate a small segment in the upper left corner, watching that area for several seconds, and then move their gaze to an adjacent area. Either of these patterns of viewing may or may not be the best. A systematic study should be performed to determine which method of scanning the scope is most effective.

The Institute also suggests a systematic exploration of the possibility of using polaroid filters to improve visibility. At the present time there are conflicting data as to the effect of such filters. Some squadrons report increased visibility and some electronics engineers have expressed the same opinion. Laboratory studies and theoretical considerations lead to the expectation that visibility would not be improved except insofar as specular reflections from the tube face are reduced. However, no controlled studies isolating such variables as filter color, duration of signal, and intensity of signal have been reported. Such a study would experimentally determine the effect of polaroid filters and give conclusive evidence as to their value.

Human Engineering Consultation at Mock-Up Stage

It is generally recommended that a human engineering psychologist be included on mock-up boards of new gear. The importance of the human element in operating aircraft and radar gear has been indicated previously. It is critical that equipment be designed with the operator in mind. The pilot's ability to perceive information presented on scopes and to manipulate controls, depends upon the total situation in which operations occur. Distractions present in the environment, the need to shift attention from one instrument to another, and the like are important elements which are not apparent when gear is on the designing board, but which do become apparent once mock-ups are built. Therefore, the necessity for the presence of a board member who has some engineering and theoretical background as well as an over-all orientation including the human aspects of operation becomes apparent.

Representative Evaluation Personnel

In the course of their observations Institute personnel have been impressed with the experience and skill of the persons assigned to evaluate the radar equipment at the Naval Air Test Center, Patuxent.

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They probably represent the best and most highly trained observers of air-borne radar to be found anywhere. It is possible, however, that the performance which these men get out of the equipment will not be typical of the performance achieved by less skilled pilots and operators in the fleet. It is, therefore, recommended that approximately 20 regular night fighter pilots drawn from operation squadrons be assigned temporary additional duty at the Naval Air Test Center for the purpose of flying each new radar installation and making reports concerning it.

Presentation of Radar Information

In air-borne interceptor radar installations now in operation and new ones under development, the method of presenting information to the pilot or operator is almost exclusively through the use of a series of symbols displayed on the face of an oscilloscope. The typical presentation involves the use of as many as six or seven symbols simultaneously, to present such things as azimuth, elevation, range, closing rate, attitude of own aircraft, etc. The pilot's task includes translating mentally these symbols into other symbols (words and digits) such as miles, seconds, yards, feet, angles. After transferring these pictured symbols into mental constructs, the pilot must then consider the facts represented so as to estimate the best possible thing for him to do. These pictured symbols are, of course, constantly changing which further increases the complexity of the pilot's task.

It is suggested that consideration be given to the hypothesis that perhaps the scope presentation is not the best one possible for enabling the pilot to make rapid and accurate decisions as to what to do.

It is possible that the energy which provides the symbols which now appear on the radar scope could be used in a manner to tell the pilot more directly what to do. Perhaps one step in the symbolism could be eliminated by having computers tell the pilot directly, in numbers, what the range, elevation, etc. are. It might even be possible to achieve a more direct result in which the computer would feed the pilot direct information on what to do rather than giving him information which he must integrate in order to make such a decision.

It is felt strongly that steps in this direction must be taken in the light of the speeds now being contemplated. The two steps through symbolic presentation to a decision as to what to do require so much time that many intercept problems which will occur will be incapable of solution unless more direct information is presented to the pilot.

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It is proposed that a development contract be written with one of the radar manufacturers to investigate the problem. Such a contract would provide for the employment of at least two human engineering psychologists and would be written in such a way as to allow the widest latitude to the contractor in investigating new and untried methods of presenting radar information.

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