SUBJECT: Status of Development of FEI for Evaluation of E Series Fire Control Systems

Four methods of approach were decided upon in light of theoretical considerations and preliminary investigations. These methods follow and will be described in detail:

a. Steroscopic ranging as F(time).

b. Sonic detection of rocket crossover and stadiametric measurements of miss-distance.

c. Radar ranging and stadiametric measurement of miss-distance.

d. Strip camera on target.

(1) Stereoscopic ranging theory runs something as follows, neglecting boresight and zeroing procedures:

Two cameras with their shutter openings correlated time-wise have both target and missile in their common field of view. As missile plane and target plane approach each other, the angular distances d_1 and d_2 become more nearly equal until they xxxxxxxxxxxxxxxxxxxxxxxx are equivalent at crossover. Apparent distances of missile from target is measured successively from each camera's film and is plotted on a common graph with time as the independent variable crossover time occurs at intersection of the lines. The frames nearest this is used to measure the miss-distance statiametricly.

On the old phase of 54A, about last May, a pair of non-synchronous Tulsas were mounted in the tip tanks of an 84 chase-plane. Lights were used for time correlation. No assessable film was obtained from several passes through loss of film from one camera in processing and inability of pilots to fly through the complete pass and keep the rockets in the field of view of both cameras.

During the months of November, December and January, ground firing tests were run on Santa Rosa Island in an attempt to validate this method of stereoranging. Several missions film could not be assessed for lack of suitable ground reference points. About the last of January, several successful runs were made. Mr Prince and Mr Rush have this film as well as that of all earlier runs. There should be eight or ten hundred feet. Resolution of the rocket motor is also unknown (since the rocket itself cannot be resolved) so tests of various types of color film were made in an effort to improve resolution. High speed 70mm Hulchers were tested at this time. These also were ground firing tests. All of this film except for two rolls of unprocessed Ansco has been given to Mr Rush.

F84 #423 was wired to use a pair of tip tanks with M-IV synchronous cameras. This aircraft was transferred before there was an opportunity to test the installation. Aircraft #970 is undergoing installation of rather elaborate instrumentation for FEI. This includes a stereo pair of M-IV synchronous cameras. Except for ground check and boresight the stereo installation is complete; however, the aircraft is AOCP at present.

This method has much to recommend it, even though it is an unknown quantity as far as proven results go. From theoretical and preliminary practical results it looks feasible to track a very small number of rockets. Accuracies cannot be absolutely predicted until more data has been gathered. There is some film assessment problem with this. Other than that, this method is relatively simple.

(2) The principle of the sonic detection of crossover and stadiametric ranging runs as follows: There is a shock wave of large magnitude associated with a projectile of the size and speed of the NOTS rocket. By means of a suitable transducer and transmitter on the target, the time of nearest approach to the target plus the distance of nearest approach multiplied by propagation constant of the wave can be related time-wise to a camera's shutter openings. The camera will be following a distance behind and along the path of the projectile. It then becomes a problem of relating the rocket which caused the wave to the photograph nearest the time of disturbance and then ranging the miss-distance stadiametricly.

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In June of 54, Iproposed this method as a possible solution. Some rough measurements were made during a ground firing test for an idea of the magnitude and characteristics of the wave. Results showed a wave of large amplitude but frequency characteristics could not be determined. As a test of the ability to record these waves from a towed target a crude system consisting of a 4.25mc AM transmitter with periodic transducer on the banner target and a BC 454 reciever and oscillograph in the firing or tow craft was proposed. A bread board was made of this system using a simulated pulse. Results were favorable so the diagram and descriptions of the system were given to Mr. Bauer. Shortly afterward ADA/54-A was reactivated with a priority of two (2) but with no method at all of determining miss-distance. The Electronics Lab was given a work order to build a suitable transmitter along with my diagrams. Upon my return from TDY no progress had been made on the transmitter so I constructed a crude Heising modulated power oscillator powered by dunk batteries in a streamlined case mounted between radar reflector and target harness. A consolidated oscillograph was used in the B-45 tow craft to record the output of the liason receiver. Numerous flights were made with this gear. After losing one or two targets to towing difficulty and transducer oscillator powers to a short, several recording were made at the approximate time of fire. There was no direct liason between firing craft and tow craft, only between flighter and Satan and tow and Satan. At our distances unreliable communication coupled with limited oscillograph tape and delays in relay of attach time to us reduced the number of recordings that were coincident with firings to one or possibly two. On one of these the target was shot away. The recording showed several distinct and unique disturbances but other aspects of the recording made it difficult to absolutely relate these to the projectiles crossing. All records of these flights were turned over to Mr. Eddy for study.

During October I was given the assignment of developing T.E.I. and a more intensive investigation was made into all aspects of the Sonic pickup as it became known. Many recordings were made on range 22 of shock waves using various transducers and transmitters. The value of this work lay in gaining experience in the nature, recording, and transmission of such transients which is still a relatively new art. Much of the data from this work was destroyed as it is of only passing interest and of value only in improving measurement. Some of the data was kept for illustrative purpose. This has been collected and labeled. During this period the early transmitter and BC 454 was checked against 50 cal. and 20 mm and found to be adquate to record the trainsients under ground conditions. Further tests were run with an improved transmitter, this time on Santa Rosa Island with ground launched NOTS rockets. This transmitter also seemed capable of reproduction of the transients. However, there were several glaring shortcomings of an A.M system when compared to F.M.. These were the large power requirements for modulation, electrical interference, and to some extent, lack of fidelity. Consequently an F.M. system was developed. As more work was done and data collected it became obvious that detecting, transmitting, and recording the data was no longer the primary problem but that data assessment and probable accuracies were taking on increasing importance, so an attempt was made to assess film taken from a T-110 gun on range 22. The shock waves were readily obtained but smoke from the projectile made photography impossible.

Several F. M. transmitter models have been constructed. Basically, they are all of the following design: a capacitive transducer modulating a feedback oscillator which drives a power amplifier.

A prototype for use on a 9'x30' or 9'x45' banner target has been designed and built. Preliminary design is complete on a prototype model for the S-27 glider. Three or four rough models were thrown together for use on parachute targets to be dropped and fired upon by 86's and 94's. Auxiliary equipment, including receivers, filters, oscillographs, etc, to monitor the transmitters has been constructed and assembled for use in a C-47 or similar craft. These units are complete and ready for use. Missions have been scheduled at least four times and cancelled because of weather.

The purpose of these drops is to try to establish optimum design values for the transducer elements and to establish the period of and parameters for variation of period of the transients. Value of information gained would be increased tremendously if 970 came in commission for then it would be possible to check all aspects of the Sonic pick-up as well as obtain valuable data from the stereo pair and some information from the A-scope.

With the use of the improved transducers, transmission systems and filters to suppress wind and other noises, the problem of this method should be one merely of application. Undetermined factors are the ability to account for time lags of large miss-distances, maximum numbers of rockets that can be recorded and related to film and areas of pickup.

(3) I proposed the following method as another possible solution to this problem. It has acquired the name of 'A-scope". Theory of it runs as follows: Use radar with A-scope presentation to range the rockets and target and correlate this time to the shutter opening of a camera photographing rockets flight through the target plane and oriented along the axis of rocket flight. When target and rockets range become coincident, the frame nearest this time is read and miss-distance ranged stadiametricly.

During October, I constructed a relatively crude A-scope to be used with the APG 40 on the firing craft. This was photographed by a Mod III camera synchronized with another camera on the plane. 970 was the plane on which this was installed and this aircraft has, with the exception of a few hours, been out of commission since that time. During the few hours it was in, there were no targets for it to fire against. This complete lack of tow facilities prompted my development of the parachuted corner reflectors as a test vehicle for instrumentation. Several runs were made against aircraft targets and data recorded. Prints of this and film of air and ground checks are labeled.

The scope was taken to Yuma where check could be made only against air fired rockets without a target. Ringing in the IT's obscured the first portion of the trace but the rockets were readily discernible, even at long ranges. This film is labeled. Several things are immediately obvious from these checks. Pulse stretching is occurring in the G-40. This in turn reduces the distance resolution to an intolerable point. It is hardly acceptable, even as a test system with its .5 micro-second pulse without stretching.

In spite of the scanty data returns from this crude 'A-scope", it seems sufficient to me to warrant a great amount of effort to devise a system with the nedessary capabilities.

From theoretical considerations, it is easy to see that the primary problem is range resolution. It seems impractical to obtain this resolution with the G-40 for the necessary modifications would make the set useless as a component of the fire control system. It will be necessary to go to a redesigned set with the required resolution mounted one chase plane or possible in a pod on the firing craft.

Preliminary investigations show that it will be possible to obtain the necessary resolution by modifying the G-30 and apparently in general with almost any well designed set. The only argument against G-30 is its relatively low power but even this should be sufficient for the short ranges involved. More powerful sets can easily be utilized.

Preliminary design and construction had just started on modification of the G-30 when I was taken off this project. From this work, it appeared that the modification is entirely possible with no insurmountable problems. Theoretically, the idea appears perfectly sound and entirely feasible with all accuracies and the systems performance in almost every aspect depending upon distance resolution.

The crude A-scope was removed from 970 to replace the GSAP with a Mod III camera. *

*It was damaged on the trip to Yuma to the extent of a broken shaft on the amplitude pot and a bent shaft on the intensity control. It should be a matter of only a few minutes to replace these. This installation, because of pulse stretching occurring in the radar's amplifier, is probably of little value from qualitative standpoint.

(4) Of the four approaches pursued, a planar scoring camera,as proposed by Mr Bauer, mounted on an S-27 towed glider target, probably would, all additional factors neglected, yield the most information. The mechanism of this method runs as follows: Scoring camera will be stopped, started and correlated time-wise by radio link from a craft following the rockets flight path and photographing them. It will be a continuously moving film device covering a 360° vertical plane through the longitudinal axis of the target. Film speed will be roughly synchronized with the missiles image speed at a mean miss-distance. Exact time of crossover can be determined from this camera as can quadrant and an approximation of miss-distance. When this information is correlated with the other camera,miss-distance can be determined by stadiametric technique.

A prototype camera was built and ground tested. It consisted of two lens--one a wide angle and the other a standard 1" lens imaged on continuously moving 35mm film. Top coverage was only 130° and bottom coverage 90° . Ground fired rockets were easily resolved by both lens at distances to at least 75 feet.

Work was then started on an improved version covering 360° by using 8 lens and a mirror arrangement. This model has been completed but plagued by various troubles during ground testing. These have ranged from light leaks to sand in the camera gears. All of the troubles are apparently remedied, and the camera is ready for further ground tests.

An essential component of this system is the radio link. This phase was turned over to the Electronics Lab in November. They developed a tone modulation using the UHF communication of the aircraft. It was impossible to obrain more than one of the receivers, which they utilized in this system. This, coupled with other undesirable features of the system, caused its abandonment in December. At this time, Dr Hazel gave them complete circuit diagrams for a 95 mc transmitter and receivers. The receiver was completed during January by Mr Wayland. Apparently the transmitter is not finished, for we requested it to be installed in the modified tip tanks of 970 two weeks ago and it is not yet on. This control system has been breadboarded by me, using various configurations of receivers, transmitters, and frequencies. It appears to be a relatively straight forward problem of rather elementary proportions.

At the beginning of this phase of 54A, all conceivable approaches were explored theoretically. Dozens were thrown out immediately, including such ideas as obtaining crossover-time by nuclear radiation or magnetic fields from a magnetized rocket head. There are an almost infinite number of ways of solving this problem if the methods used are not restricting as to complexity. Project 456 is an example of a complex solution to the problem. Other approaches, which appear feasible but which were not explored, are doppler radar and small transmitters located in the rocket heads with a receiver on the target. A couple of these small units were breadboarded and worked quite well. The xxxx cost would be low per unit and accuracy should be high for a small number of missiles. This method would be more feasible where a small number of larger missiles are employed. xxx

SUMMARY: All four methods are still unknown factors as far as results from air-firings are concerned. Once 970 comes in commission there will be a pair ready for testing. This method is simple but from ground tests and previous air-firings it appears that the system will be capable of handling only a limited number of rockets. Its only other drawbacks, assuming that it is capable of reasonable accuracy, is some problem in data reduction. The sonic pick-up system appears to be complete and ready for testing. From other sonic FCI's and ground checks of this system, the question with this method is now one of data reduction. Since all design work has been completed on this and one working model is ready while a banner target prototype is also ready. Receiving gear is also ready. It should be a matter of only a couple of weeks to instrument either S-27 glider or tow targets. It will be limited in the number of missiles it can handle but not as limited as in the stereo pair. There is the problem of additional complexity and also of data reduction. The planar camera should be ground tested within a week and, if it proves successful, should, within a month, at least one system should be ready for flight test. This method has additional problems of increased complexity, data reduction problems, and in this case a data recovery problem.

The A-scope method I will have a crude test vehicle ready when 970 comes in.

Because of shortcomings of IT and video amplifiers in the G-40, this data would not be of much quantative use with the possible exceptions of single pair firings. However, this can, with a little effort in the right direction, be made into a simple and efficient system whose capabilities are limited only by the radars resolution and statiametric technique. The system is simple and reliable, with little data assessment problem and will be accurate to the degree which the radar is refined. Of all the methods, this seems the best solution. It indeed seems difficult to conceive of a simpler system which will meet the requirements of accuracy and handling large numbers of rockets.

prove feasibility of this system as a method suitable for field use, a complete system including radar, cameras, and A Scope was assembled. The R.T. unit of a G-30 was housed in a 120 gallon N-116 Napalm Tank along with an A Scope presentation which was photographed by a 35 mm camera whose shutter openings were synchronized with those of another 35 mm strike camera equipped with a 4" lens. This unit was hurriedly assembled suspended from an 86F and without preliminary tests taken to Yuma AFB where a large number of firings were being made. During the week, 8 firings were chased by this 86 with all 8 being successfully recorded. This instrumentation, in spite of its hurried design and construction and unnecessary complexity, required no maintenance. Several hits were recorded, thus affording a check against instrumentation accuracy which proved to be excellent. This was the first instance of a firing error indicator functioning successfully in the field. Several conferences were held with members of Air Defense and Training Commands as to the most satisfactory configuration of this system and it was decided that a chase plane equipped with this F.E.I. offered more advantages than any others. A unit was then designed using, with one exception, AF stock items which is simple enough to be reproduced by any Air Force installation equipped with machine shops and facilities for maintaining an "E" system. A prototype of the unit was assembled and tested here and will be given to Yuma for further tests. Complete details of construction and operation of this FEI are given in the attached appendix.

Since the concept of tracking missiles with pulsed radar is relatively new and opens a realm of possibilities in the missile field in general, its specific application as a practical F.E.I. for E system scoring will be described in some detail. ~~This scoring metho~~

This scoring method is extremely versatile, requiring basically only two sources of data, radar video information and photographic data from a strike camera. We have built a series of these Radar-Optic F.E.I.'s using various configurations. They have fallen into roughly two classes--units mounted on the firing craft and using system's radar for video, and those mounted on a chase plane with its own radar. The system described in the following is the Model 26 which was designed for field use. It consists of an unmodified G-30 Radar feeding a 4 tube sweep and wide chassis whose output is an "A" presentation on a 3JP11 Cathode Ray Tube. A modified lens combines the image along one edge of xx 35 mm film with strike photographs. A 40 frames per second camera is used. Housing for the unit is an M-116 Napalm Tank with necessary changes. Weight is approximately 125 pounds and drag is only slightly higher than a normal tank. The chase plane flies a fairly tight formation with firing craft and, during the last few seconds of a firing run, radar voltage is applied to the magnetron only during this period to eliminate possibility of interference, and cameras are turned on for ten or fifteen seconds.

Restating the problem of photographic scoring: Ranging of rockets miss by motion picture photography is easily accomplished by stadiametric techniques if (and only if) a rocket is in perpendicular plane normal to the longitudinal axis of the strike camer; i.e., a plane through the target paralell to the camera's film plane. First order accuracies are determined solely by the errors in detecting the cutting of target plane by rockets and relation of this to the strike camera film. Positional errors thus become a function of time errors as the target is in continuous linear motion . An example will illustrate: Assume that a single rocket crosses a target plane at some given time, missing the target aim point by 50 ft lead in azimuth. A photograph is taken 1/20 of a second later and miss-distance is assessed from this photograph. Elevation errors are negligible since vertical target velocity is zero and vertical rocket velocity relative to the firing aircraft arises only from gravity acceleration, which is on the order of 70 ft/sec at this point. Errors in azimuth will now vary directly as target speed. In this case, the missile will appear to have passed closer to the target by distance of target travel in 1/20 second. With a target speed of 300 ft/sec this error in azimuth would be 15 feet atainst an elevation error of 3.5 ft. It is obvious that the relation ~~xxxxxxinxxxxxxxingx~~ holds for this specific case. Error in assessing miss-distance in azimuth (ft) equals target velocity (ft/sec) times error in determining time of crossing rocket plane (second). Other much smaller errors are present in ranging technique but this time function errors predominates. This of course leads to another problem. Since rockets are fired during a relatively long period of time* the rocket pairs must be followed separately and crossover time recorded for each pair, or one pair must be chosen and the time of only pair's crossover be recorded. The first procedure is necessary for extremely accurate work in engineering tests. For evaluation of system accuracy, it is enough to know where the so-called strike rocket or pattern centroid goes, for it is this rocket which is theoretically designed to hit target aim point. Since neither missiles or fire control system is perfect, it is necessary to add rockets fired before and after the strike rockets to bring kill probability to a reasonable figure. It is the centroid which is scored with the system being described, although it is possible to score other rockets by interpolation. Radar sets used to determine range coincidence is an AN/APG-30, an airborne, low power, band set commonly used for range data on A series sights. It would be desireable to have a set with more power or an antenna of smaller beam angle, but this is more than offset by such factors as small size, light weight, simplicity and ease of maintenance.

(*Approximately 1.25 seconds for an 89D; .084 seconds for 86D; and .168 seconds for an F-94 for full salvos.)

Range information is displayed on 3" scope in an "A" presentation. In this presentation, the scope beam is started coincident with transmitter output pulse at one edge of the tube and is swept linearly along axis. Return pulse information is displayed along axis resulting in scale on which distance of objects from the set may be determined. Relative not absolute range is of primary interest here.

Since extremely short ranges are necessary here, some complications arise since the sets are designed for much longer ranges. Radar range factor is approximately 490 per micro-second, thus the .4 micro-sec pulse of a G-30 covers 196 feet in space; thus, objects closer together than this cannot be separated on a presentation. Ideally, pulse length would approach zero with position of each scanned object appearing as a single, narrow line. Unfortunately, practical limitations prevent this. A salvo of rockets appears as a single lengthen pulse, and the target as another relatively wide pulse. After a little experience, time of crossover for the centroid can be determined by inspection to within one frame of film run at 40 frames per second, even though p ulse width occupies a relatively large amount of trace width.

At forty frames per second, the maximum azimuth time error is less than 1/40 second times tow speed. ~~At present tow speed~~ At present tow speed, this is on the order of 7 ft, ~~elevation~~ Elevation error is negligible. Once the instant of crossover of the centroid is found, it is necessary only to select the centroid of the pattern from strike photographs and determine magnitude of miss stadiametrically. For use with present targets, a slide projector would be desirable but not necessary. Experience here has shown that pattern centroid is extremely close to the center of a circle which encloses all but obviously wild rockets. Choosing this point becomes simple after observing several strike films. Once this point is chosen, magnitude of miss is determined by comparison of image distance of centroid from aimpoint* to ~~image~~ (See Page 18 for footnote)

is determined by comparison of image distance of centroid from aimpoint* to image distance of target.

This sytem has much to recommend it. Indeed it is difficult to conceive of another system with the advantages of no target limitations, simple data reductions, and a record of firing passes realistic enough to offer incentive to a pilot to study his performance. To accurately evaluate a pass with any form of FEI it is necessary to have a record of pilots" performance to determine errors introduced from steering.

As mentioned before, the use of radar to obtain range data from missiles has many applications. It should be an extremely valuable tool in ballistics studies of velocity, acceleration, and pair dispersion. As an FEI system, its value is obvious. Many possibilities exists for its immediate utilization. There is no reason why the Model 26 FEI, as described in the appendix, should not be immediately reproduced for use at bases where firing programs are being conducted. At present, it seems impractical to equip individual fighters with this system, even though it would involve only s simple "black box" and a camera. Such an installation would be far simpler than the Nadar equipment which is presently scheduled for installation. It would be of vastly more use. Value of an FEI system needs no further justification.

Use of this sytem should have far reaching effect on targets. Now instead of having to use banners as a crude attempt at scoring, only function of a target need be provision of a radar target with realistic performance. A logical target configuration would be a radar reflector enclosed in a streamlined structure offering small drag. Once drag is reduced to a low figure, it is possible to reduce cable size weight and drag as well as reduce tow reels. size weight and complexity. With this reduction in size weight and drag, the

(*Aimpoint on a non-reflective banner with corner reflectors attached is of course the feflectors. It will vary with reflective targets.)

next logical step is use of fighter craft to obtain realistic performance. Work has been done toward developing small low drag radar reflective targets by at least two companies, one of whose targets has the added feature of frangibility which should be extremely attractive for training use. A protype of a high speed target was recently constructed here and preliminary tests of it are under way. Drag of such targets are approximately 50 lbs at 300 knots T.A.S., while weight is 20 lbs or less. Radar reflector area is equivalent to a 3 ft diameter convential round reflector. These are commercially available nylon fishing lines which have adequate strength to tow these targets. With small cable, reel sizes can be cut to reasonable figures. It is a relatively minor problem to design a reel such that it could be carried under the wing of a fighter in a nacelle which could also partially house the target for takeoff. Probably most practical of all, would be a target and small reel which could be attached to a conventional bomb or tank rack of a fighter. Once airborne, the target could be released and after completion of mission, both target and cable be detached from aircraft. This is an entirely feasible system even from an economic standpoint, since cable and target should cost less than $40. 00. At present, a marquisette target and reflector cost almost $300.00. Seven of the smaller targets, discarded after every mission, would provide much longer time in the air than a single banner. These targets would provide performances which banners never can. If cost of maintenance of a present bomber type tow plane are compared to those of a fighter using smaller targets, target price becomes insignificant. Fighter type tow craft would provide individual squadron with presently lacking tow facilities. There are many squadrons which, if tow facilities were provided, could carry on firing programs rather than "shadow boxing" which is what the present training amounts to.

The radar optic scoring system described is a presently available for immediate application to scoring of "E" systems equipped interceptors. New, and presently unique, methods are involved but this is necessary if we are to close the ten year lag that presently exists in tow target facilities.