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SPEECH BY MR. W. R. HUTCHINS BEFORE THE ANNUAL BANQUET OF THE RADIO CLUB OF AMERICA, FRIDAY, DECEMBER 5, 1958

Thank you for inviting me to tell you something about the Advanced Research Projects Agency, and the problems of ballistic missile defense on which we are working.

ARPA was established by law on February 7th of this year and charged with the responsibility for planning and directing advanced research projects assigned by the Secretary of Defense. Also, until establishment of the NASA, ARPA was charged with the advanced space projects of a non-military nature as designated by the President. Because of their unclassified, purely scientific character, it is these non-military space projects which have been associated most closely with ARPA in the public press, but the specific assignments which have been made by the Secretary of Defense include military satellites and other vehicles, research in the chemistry of propellants and the entire responsibility for advanced programs in defense against ballistic missiles. This includes the NIKE-ZEUS program which is a responsibility of the Director of Guided Missiles and is under contract to the Department of the Army.

The directive under which ARPA operates does not limit it to these assignments and the Secretary of Defense has stated that he does not intend our task to be so limited. Ordinarily the projects assigned to ARPA will fall into one or more of three categories: (1) those which by virtue of their advanced nature cannot be identified within the stated military mission of an individual military department, (2) those for which military missions can be identified as being of interest to more than one of the military departments, and (3) those which for various reasons must be pursued by an agency not subordinate to one or more of the military departments.

The Director of ARPA defends its budget before Congress in the same manner as the Secretaries of the three services. He is not hampered by any requirement that funds be used for some immediately definable weapon system; he has but to show that they will be used for useful advanced projects which can be judged to have probable military applications.

As I indicated before, ARPA has been assigned the task of working out an advanced ballistic missile defense system to improve upon or to succeed the NIKE-ZEUS and BMEWS systems which are currently under construction.

What I hope to do is to give a picture of the problems involved in ballistic missile defense and to illustrate the tremendous part electronics must certainly play in their solution. Most of us have a pretty good idea of the basic problem posed by the intercontinental ballistic missile.

In Figure 1 are indicated three of the trajectories which are possible to a missile which has a maximum range of 6,000 nautical miles. By calculations which are little more than elementary physics, it is possible to show that using the same total energy as is necessary to go 6,000 miles, an ICBM can go shorter distances and go either higher or lower than the optimum trajectory. A little consideration about your own experience with baseball will serve to remind you that this is so. Over a plane earth, you can throw a baseball a maximum distance if you throw it at a 45° angle. Or, if you use the same amount of energy, you can either throw a very high ball which lands nearer or you can throw a flatter trajectory and have a "fast" ball which lands nearer and sooner. Because of the curvature of the earth and the fact that 6,000 miles is about a quarter way around, the optimum angle for minimun energy is about 23° rather than 45°. There is nothing fundamental about a 6,000 mile capability and there is every reason to believe, on the basis of the size of their Sputniks, that the Russians can probably send a fairly heavy warhead greater distances or, at their discretion, have them arrive at the target at angles other than 23°. This, of

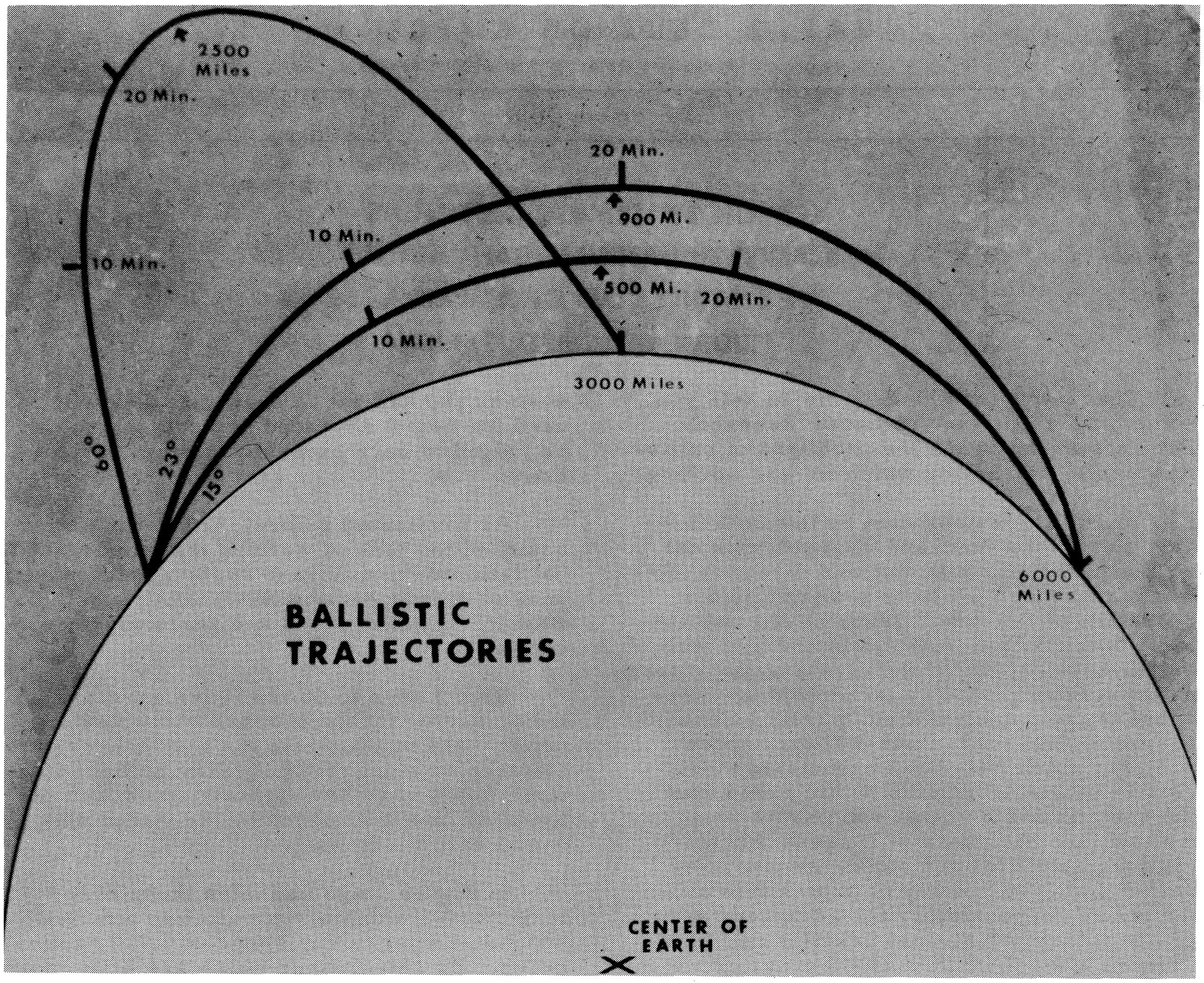

FIGURE 1
Three possible trajectories for a ballistic missile having 6,000 miles range capability.

course, increases the amount of sky that must be scanned by the defense in looking for enemy missiles.

Figure 2 is a map centered on North America. The lines drawn here illustrate the angles which the United States subtends at the boundaries of the Soviet Union and its satellites. Since ballistic missiles must fly in ellipses, the ground tracks of which must be great circles, it is not possible to have a ballistic missile fired from Soviet territory which flies outside of these lines and arrives in U.S. territory. With appreciably more energy it is possible to fire around the long way and approach in the opposite direction, but only at the expense of much greater flight time and considerable reduction in accuracy. Also launch points other than inside the Soviet Union cannot be completely ruled out. Ships and submarines, of course, can launch missiles of less range which will arrive from almost any direction on the North American continent. This is the basic problem.

As has been well publicized in the public press, the time of flight of intercontinental range missiles varies from 20 to 40 minutes or so for most of the likely trajectories. It is obvious then that in order to operate any sort of defensive system, or even to dive into holes, it is necessary to detect the enemy missile as soon after launching as possible.

Figure 1 shows that the apogee or mid-point of the flight of the ballistic missiles is many hundreds of miles above the earth. At such altitudes there is very little air indeed and consequently there is very little drag on objects. Under such conditions, the shape and size of an object has no effect on its flight path. Because of this, it is possible to blow up the booster rocket after it has done its job or to launch numbers of balloon-like or rod-like objects from the reentry body and to find that, except for their small velocity of separation, all of these objects can fly along the ballistic path together with the warhead. Such objects are classed as decoys. The defense is forced to identify the "ducks" from these decoys and so not waste firepower on a large amount of harmless trash.

It is very important to point out here that the ballistic missile is merely a method of throwing a warhead at the target by use of a rocket. As far as the rocket and trajectory are concerned, it is just as easy to throw anything else at the same target so long as the total weight of this "anything else" is the same. Therefore, instead of using a very large warhead, it is possible for the ballistic missile designer to use a smaller warhead and a large number of decoys, or, if he desires, to use several very small warheads instead of one big one. Now we see that while we might be able to tell the decoys from the warhead, we have the further problem of telling how many warheads there are. Having solved this problem at a distance of many hundreds of miles, we must then compute the trajectory of the true warhead and work out the means of intercepting it before it arrives at its target only a few short minutes later.

In order to give an idea of the nature of the defense problem against ballistic missiles, I am going to use some illustrative examples which bear no particular relation to defensive systems actually under design or consideration.

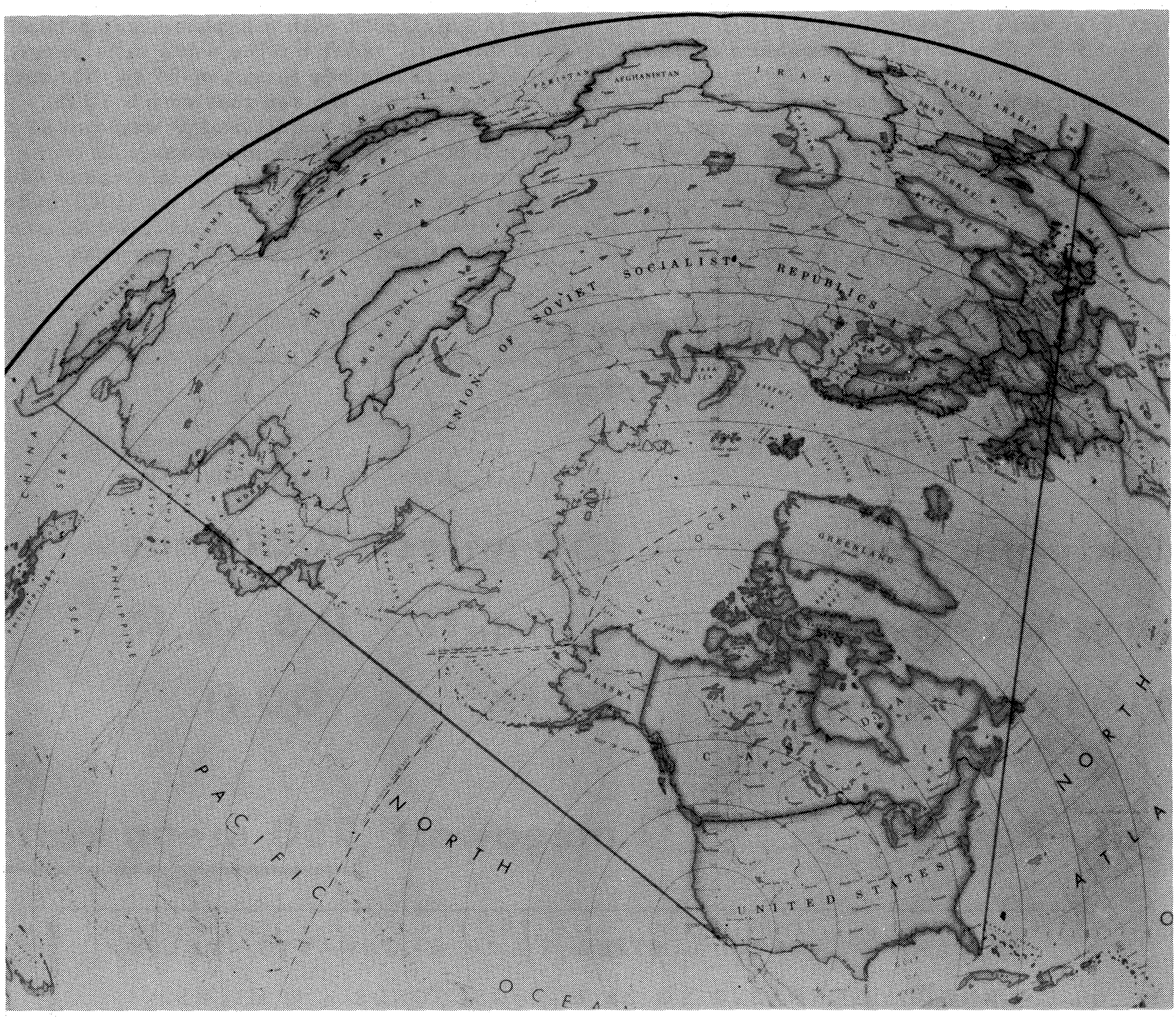

FIGURE 2
The straight lines are the outside limiting great circles which enclose all paths between Soviet territory and the U. S. A.

These simplified examples will permit you to understand a bit better the interplay of design considerations which make this problem so difficult.

For the sake of illustration I am going to consider an interceptor system which consists of early warning by radar, tracking by another radar, computation by equipment located on the ground, and a ground-to-air interceptor missile. This is only one of a great many systems of which we can conceive which have a capability of destroying ballistic missiles, and I am going to assume that the radar early warning is located so that it detects the ballistic missile before apogee. As can be seen by looking again at Figure 1, apogee occurs at something less than 20 minutes before impact. We therefore have about 20 minutes after early warning to solve our interception problem. Now let's assume that we have located a tracking radar of a many hundreds of miles range in the general area which is to be defended -- let us say somewhere on Long Island. This radar will then have to pick up the missile about 8 to 10 minutes before impact as it is approaching somewhere near the Arctic Circle. The tracking radar then examines the target upon which it is locked and decides whether it is one target or a number of objects, some of which are doubtlessly decoys. It has the problem of figuring out, perhaps by jumping from one object to another and examining it, which are genuine and which are decoys.

The computer then calculates the trajectories of the real objects from the tracking data, assigns suitable interceptor missiles, tells them when to launch, and in which direction to fly so that they may make an interception (hopefully still some considerable distance away from the ballistic missiles' impact point). We see therefore that the total time of the engagement is of the order of five minutes.

It is only by use of electronics, and very advanced sophisticated electronics at that, that we can possibly hope to perform all of these functions in so short a time. Let us look now at the requirements on some of these components -- for instance, the long range mile tracking radar that was mentioned above. Figure 3 shows a comparison of the radar we are talking about with a hypothetical S-band anti-aircraft radar having a 100 mile range on a typical bomber target of 50 sq. ft. radar cross-section. We see that with a 10 ft. diameter antenna such a radar would need to have a one megawatt peak power. In comparison, a long range anti-missile radar which must see a 1/2 sq. ft. target at 1,000 miles, say, even with a 100 ft. antenna, would need to have a peak power of 250 megawatts.

S-BAND TRACKERS

- 1 microsecond pulse

	Anti-Aircraft	Anti-Missile
Maximum Range	100 miles	1000 miles
Target Cross-section	50 sq. ft.	0.5 sq. ft.
Antenna Diameter	10 ft.	100 ft.
Peak Power	1 megawatt	250 megawatts

IF PEAK POWER IS LIMITED TO 10 MEGAWATTS, PULSE LENGTH INCREASES TO 25 MICROSECONDS = 2 MILES.

FIGURE 3
Comparison of Radars for Anti-aircraft and Anti-missile use.

At the present time, peak powers of 250 megawatts are considered impracticable. If we decide to reduce the peak power to 10 megawatts, in order to keep the same range, it is necessary to widen the pulse to 25 microseconds. Such a pulse is two miles wide and therefore will have difficulties resolving different targets in the cloud of warheads and decoys that is being examined. It is apparent that with such a radar which comes up against true physical limitations in its design, it is necessary to use tricks in order to get sufficient performance. A straight-forward approach is not sufficient. When tricks are resorted to, the complexity of the radar gets greater and the radar becomes more expensive. More expensive than the air defense radar we mentioned before by a factor of ten to a hundred times.

Until recently, the anti-aircraft radar's output was connected to scopes that were observed by human operators. Recently, in going to the SAGE and Missile Master Systems, electronic data processors have started to take the place of humans. In the ballistic missile defense era, humans may not even be able to comprehend the information on monitor scopes. Electronic machinery will do all the operation on the radar data. This means a complex electronic computer problem in addition to the already complex radar. Not only must the electronic data processor track single objects, as has been done for years with tracking radars, but it must track and maintain detailed data on the characteristics of a large number of objects, perhaps several hundred. Once it has decided which object is a true target, the computer must calculate the trajectory and predict an interception point. It must then communicate with the interceptor missile (which has already been launched in the proper direction and which is now approaching intercept). Since the interceptor may now be several hundred miles from the radar, there is a communications problem. The computer needs to know where the interceptor is and what its course and speed are so that it may properly control the interceptor to collision with the target.

To try to indicate the magnitude of the task involved, it takes several minutes for an IBM 704 to calculate a trajectory from a few radar data points. An IBM 704 is one of the large scientific data processing machines and itself occupies several hundred feet of floor space. In order to calculate an intercept, it undoubtedly would require more equipment than this, or at least more complex equipment.

What has been described is a single interception of a single ballistic missile. Some consideration of the probable tactics which might be used in a ballistic missile war will immediately indicate that it is more probable that a large number of missiles would be sent over simultaneously. It is then necessary to assign trackers to each of these, to assign interceptor missiles to each target, to decide which areas need the greatest amount of defense, and which ballistic missiles are likely to be harmless. The computation system must make all these decisions in such a short time that the effectiveness of the defense is not reduced thereby.

Electronic battle direction of magnitude such as this requires inter-connection of units covering a large portion of the country. Warning and acquisition information must be fed from the stations in the far north and from other locations remote from the interceptor sites. This is a communications or data transmission problem of the first magnitude. Because the communications have to be ready to operate at any time, it is necessary to have private lines for this purpose standing by 100% of the time. The problem of how best to interconnect the various units of the system for lowest cost and maximum efficiency requires a great deal of study.

For instance, let us consider that long range tracking radar that we were talking about earlier. The data communicated to it from the early warning radar is short and straight-forward. It is simply a message which says that there is a missile at a certain location in space. The tracker searches this volume in space, locks on, tracks, feeds information to the computer. At this point the computer may find that it is tracking a missile intended, not for New York City, but for Columbus, Ohio. The most efficient thing might be to have this tracker instruct the Columbus defenses and guide the Columbus interceptor. In this case all of the guidance messages need to be transmitted from New York to Columbus. Likewise the Detroit radar may have to participate in the interception of a missile destined for Boston. Now if we simply interconnect every site with every other possible site with which it may need to communicate, we find that we have a genuine rat's nest of communication lines completely covering the country.

This is not the entire problem however. There must be provision for human monitoring of the system and an opportunity for decisions based on up-to-date accurate information of the situation, with chance for manual override of any decision made by the computing machinery. The obvious way to do this is to connect a line from each unit of the system to a central headquarters where monitoring takes place -- again a mass of circuits which must operate all the time. As if this weren't enough, one more consideration must be added. The system must operate during an enemy attack, when very likely some enemy nuclear warheads will land. The system must still function with unknown pieces of it bombed out. Again, the obvious way is to duplicate all the circuits by very different routes.

Now let me sum up the picture I have painted here. Let us say that there are 100 defense points and that each must be connected with each other. This gives us 100 factorial circuits. This is a ridiculously large number. An alternative possibility is to use some sort of common bus system where all the information is transmitted over one single circuit. Such a system is very likely to overload unless an excessively high data rate, and hence bandwidth, is employed.

The final element of the active defense system is the interceptor itself. An axiom of anti-aircraft interception has always been that the interceptor must have a speed advantage, that is, it must be flying faster than the aircraft that it is attacking. If this is not done, it is obvious that there are many situations in which the anti-aircraft missile gets into a situation where it is chasing something which is going faster, and therefore is outrunning it. A ballistic missile, though, operates at Mach 21 and above, and when it reenters the atmosphere, very special precautions have to be taken to prevent it from burning up. An interceptor which has to fly up through the atmosphere has similar problems and would assuredly burn up were it going as fast or faster than the ICBM which is its target. A speed advantage therefore is only a hoped-for ultimate goal.

In the meantime we must conceive of interceptor systems which are capable of operating at a speed disadvantage. The speed disadvantage means that the interceptor must somehow position itself in the path of the ballistic missile in such a way that the ballistic missile will fly into it. The reason that this is possible, of course, is that the ballistic missile is by definition "ballastic", in other words free-falling; so that it is possible to predict its future position very accurately from its past positions. This fact alone causes us to use entirely different versions of the intercept guidance equation and hence to impose some very different requirements on the autopilot system in the interceptor missile.

Another thing which causes great differences in the autopilot design is the lack of a sensible aerodynamic atmosphere at the altitude at which intercepts must be made. When an airplane or a missile makes a turn in the atmosphere, it banks and places its wings in such a way that a skid is prevented. Outside the atmosphere, there is no such fluid as the air and only the propulsive force of engines may be employed for reaction. Figure 4 is intended to indicate the maneuvers a steerable rocket motor must make. This is a conventional missile having the rocket motor considerably aft of the center of gravity. The first thing is to turn the rocket motor to one side which will produce some skidding motion, but chiefly will cause a rotation about the center of gravity. After the missile has rotated through the proper angle and is headed in a suitable direction, the rocket motor is fired in the opposite direction to stop the rotation. However, the missile is still moving along almost the original flight path. It is then necessary to fire the motor straight ahead, that is, through the center of gravity, sufficiently to result in the desired flight path. Such a maneuver is considerably more complicated than that performed in the atmosphere and serves to illustrate another problem which must be solved.

I have tried to show very briefly now the problem of intercepting a ballistic missile is considerably different and considerably more difficult than those problems we have had to solve in the past. It is necessary to make major improvements in the state of the art of radar, computing machines and computation, communications, and missile design and guidance in order that there may be any possibility of making a successful interception.

Let me conclude by outlining how the kind of system I have been imagining would work overall; so as to show that there are not only problems of the major components I mentioned but also serious operational problems of equal magnitude.

Let me assume that the early warning system detects ten objects in ballistic trajectories headed in the general direction of the United States. It immediately sends the message to U. S. offensive and defense headquarters to all parts of the country, where it appears as a yellow alert. The yellow alert causes the defensive system to be warmed up. It also alerts the Civil Defense authorities and starts many other operations.

Very shortly after the alert, the early warning system is able to have a sufficient track so as to inform the defense complex that all ten of the objects are headed toward the Northern Middle West, as an example. The assignment computer then instructs all trackers in the Middle West to search for and lock on the incoming objects. As soon as a tracker finds an object and locks on it, the improved data that it obtains is relayed to all other trackers so that they will not also track the same object (without special assignment).

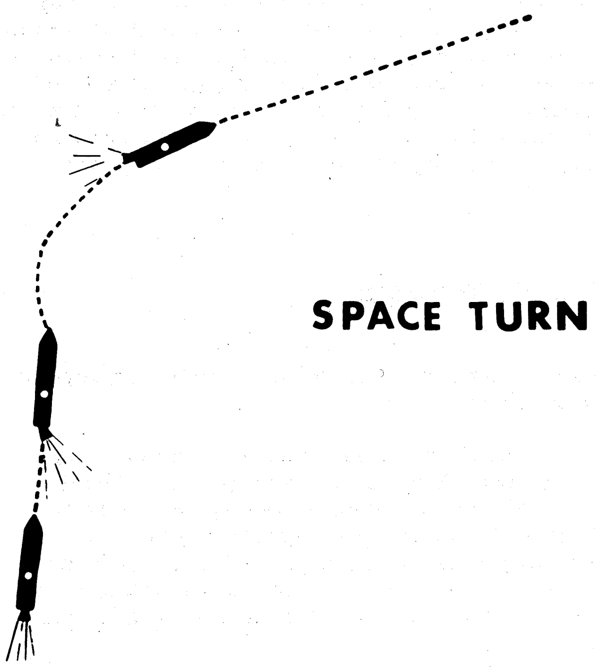

FIGURE 4
An attempt to illustrate some of the maneuvers vers necessary to make a turn without aerodynamic reaction.

Remember that these other trackers are located over an area of tens of thousands of square miles. Therefore, there will be tremendous parallax between the various elements of the tracking network. Position transmission is thus made more difficult.

Another complication is that the ballistic missile is traveling on a true ballistic course outside the atmosphere and therefore is not affected by the rotation of the earth. Hence the earth rotates under it, and predictions of impact must make allowance for this rotation, which, in a half-hour, amounts to some 500 miles at the equator.

The early tracking data is used to give an improved impact prediction for interceptor assignment. An interceptor missile near the predicted impact point is assigned to the interception and is launched at a time which is calculated to be approximately correct. This question of timing is very important since there is no speed advantage. The interceptor must be launched at exactly the correct time so that it arrives not only at the correct point in space but at just the instant of time when the ballistic missile is travelling through that point in space. The problem is made more difficult if there is a group of decoys being tracked on the same general course, because at the launch time the true target warhead will probably not have been identified. Therefore, only an approximate course can be given to the interceptor. The interceptor must not only have a very high speed so as to take a minimum of time arriving at the proper point in space, but it must also have very great maneuverability so that it may make corrections in mid-flight after the warhead has been identified.

Once the interceptor is launched, some method must be provided to tell the computer the location, course, and speed of the interceptor as well as the location, course, and speed of its target, the ballistic missile. Given these quantities for both missiles, it should, in principle, be possible to cause the interceptor to maneuver so that it arrives at a point in space at the same time as does the ballistic missile. This then is an interception.

The imaginary system I have described up to now has left off most of the detailed complications of the problem which make the solution even more difficult than I have described. Of course, many of these necessary sophistications either exist in NIKE-ZEUS or will be added later.

ARPA is currently engaged in sponsoring a very large research effort on all the facets of the defensive problem, in order to meet every conceivable form of the ballistic missile threat. We are studying the physics of the upper atmosphere and its interaction with objects and with electromagnetic radiation. We are making measurements on actual ballistic missiles using radar, optical and all other devices that we are able to think of. We are sponsoring experiments in very elaborate high power radars having great accuracy and resolution and having range capability far greater than have ever been built up to now. We are supporting work on the controls and propulsion for missiles which operate both inside the atmosphere and in a vacuum and which have high speed and high maneuverability. We are investigating many destruction methods against ballistic missiles and we are sponsoring studies on systems concepts which are intended to tie all these things together in various ways. In addition to all this, we are trying to get several groups in this country thinking about the problem as a whole so that they may come up with entirely new concepts which can form the basis for further research and, we hope, for still better systems in the future.

All this costs money. But all this research and development, even extended considerably beyond what we are doing today, is expensive compared with the damage which could be caused to this country were a full scale ballistic missile war to take place. All this is even inexpensive in comparison with the cost of actually building the complete defensive system. The cost of the research and development on one of these large systems is usually of the order of 5 or 10% of the final installed cost. If we double our research and development budget, it is quite possible that the improvements which derive from this would actually save the additional development costs in the form of reduction of over-all costs by 5 or 10%. Let us continue our research and development at a high level, even higher than that presently employed, because our weapons are constantly getting more costly and more complicated and the only way in which we can minimize our costs is by more thorough study and design.

ARMSTRONG PATENTS RULED VALID

The United States District Court in New York has recently upheld the validity of the FM patents of our late and esteemed Fellow, Major Edwin H. Armstrong. Judge Edmund L. Palmieri's findings were contained in a 100 page decision in a suit brought by the estate of Major Armstrong against the Emerson Radio & Phonograph Corp.

Many members will be warmly pleased to learn that the inventive contributions of Major Armstrong have been fully and legally recognized.

Of perhaps even greater import is that this is the first instance in years, of which your Editor is aware at least, in the radio-electronic industry in which patents have been adjudicated in favor of the inventor. Perhaps this decision marks a turning point in the application of patent law in this industry.

RADIO CLUB PEOPLE

Frank Gunther, past President 1956-57 of the Club, has been elected Executive Vice President and General Manager of Radio Engineering Laboratories, Inc., a wholly owned subsidiary of Dynamics Corp. of America. Frank, a 34-year veteran with R. E. L., became Vice President in 1929 and has served in virtually every department of the company. He is an active amateur, W2ALS, in Dongan Hills, Staten Island. R. E. L. is a leading manufacturer of receiving and transmitting equipment for "tropo scatter" long distance techniques.

BACK ISSUES AVAILABLE

Back issues of a number of issues of The Proceedings of the Radio Club are available to the members at $1.00 per copy. Call or write the club office for specific requests. Miss Kunkel will be happy to assist you.

Also on the available list is the 1 BCG Commemorative issue, dated October 1950. This issue commemorates the First Transatlantic short wave message which was accomplished in December 1921. It is the complete, well-illustrated story of the events leading up to, and the fulfillment of this historic event.

ACKNOWLEDGMENT

Grateful acknowledgment was made in the Golden Anniversary Year Book to the many sponsors who made the Year Book possible.

Some contributions, however, arrived too late to have the names of the contributors included. These contributors graciously accepted our apologies and insisted on making their contributions regardless.

We take pleasure in acknowledging their contributions to the Year Book, in this issue of Proceedings.

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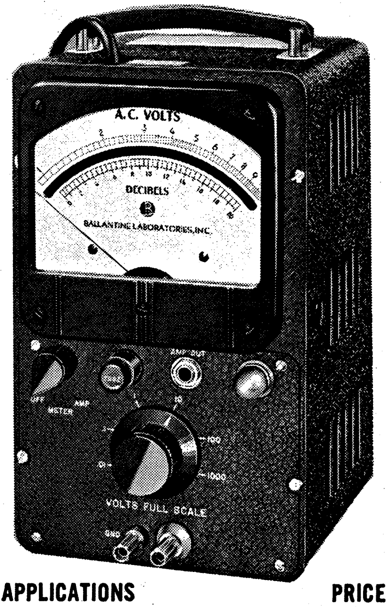

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All prices shown are net, F.O.B. Boonton, New Jersey, and are subject to change without notice.

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300-E Voltmeter	30 CPS–100 KC	300 µV–300 V	2 meg shunted by 20 or 30 pf, depending on voltage range	2%	For mounting on 9½ inch relay rack. Rear connections for input, power, and decade switching.	$255
302-C Voltmeter, Battery Operated	2 CPS–150 KC	100 µV–1000 V	2 meg shunted by 10 or 25 pf, depending on voltage range	3% 5 CPS–100 KC; 5% elsewhere	Portable, battery-operated; no hum, with gain to 60 db. May be used on ungrounded or symmetrical circuits.	$255
305-A Voltmeter Peak Reading	5 CPS–500 KC, sine waves. Pulses, 0.5 µs up and 5 PPS up	1 MV–1000 V Peak or Peak-to-Peak	2 meg shunted by 10 or 25 pf, depending on voltage range	2%, sine waves 20 CPS to 200 KC; 4% elsewhere. 3%, pulses above 3 µs and 100 PPS, and up to 5% other conditions	Measures Peak or Peak-to-Peak value of any repetitive waveform, distorted or undistorted sinewaves, or pulses. Its operating mode can be selected to respond to a peak to peak and positive or negative peak of the waveform.	$395
310-A Voltmeter	10 CPS–2 MC or 5 CPS–4 MC as a null detector	100 µV–100 V (Down to 40 µV at reduced accuracy)	2 meg shunted by 9 or 19 pf, depending on voltage range	3% 15 CPS–1 MC; 5% elsewhere	Multi-purpose broadband VTVM for measurements such as low and high-level acoustics, low-level vibration, carrier telephone transmission, ultrasonic, and rf measurements. For use as an extremely sensitive null detector for signals as low as 10 microvolts.	$250
314 Voltmeter Wide Band	15 CPS–6 MC	1 MV–1000 V (100 µV–1 MV without probe)	11 meg shunted by 8 pf with probe, or 1 meg shunted by 25 pf without probe	3% 15 CPS–3 MC; 5% elsewhere	Wide-range unit of great sensitivity to facilitate development and servicing of equipment in video applications, and R.F. heating, vibration, ultrasonics, piezo-electricity, etc.	$300
316 Voltmeter Very Low Frequency	0.05 CPS–30 KC	0.02 V–200 V Peak-to-Peak	10 meg shunted by 17 or 40 pf, depending on voltage range	3%	For development, design and routine testing of automatic control systems involving low frequency servomechanisms and where sub-audio frequencies down to 0.01 cps are encountered. Minimum pointer "flutter" down to 0.05 cps.	$330
320 Voltmeter True RMS	5 CPS–500 KC	100 µV–320 V	10 meg shunted by 8 or 18 pf, depending on voltage range	3% 15 CPS–150 KC; 5% elsewhere	Determines true root-mean-square magnitudes of periodic complex waves or voice potentials. Built-in calibrator. Crest factor range at full scale is 4.5 for high voltage scale and 15 for low voltage scale. Immune to severe overload.	$445
220-C Decade Amplifier, Battery Operated	10 CPS–150 KC	Amplifies precisely 10 times or 100 times, as selected	5 meg shunted by 15 pf	2%	To increase sensitivity of Model 300 to 20 µv. Provides no-hum preamplifier of accurate gain over wide band. Output source impedance less than 900 ohms in series with 2 µf for 10 x gain, and less than 7000 ohms in series with 2 µf for 100 x gain.	$110

420 **DC and AC Precision Calibrator**	Provides accurate, convenient way of calibrating voltmeters, oscillographs, and other voltage-sensitive devices. Voltage Range: 0-10 V RMS, Peak-to-Peak, or DC. Frequency: 1 KC. Accuracy: better than 0.5% above 1 MV. Distortion and Hum: less than 0.25%. Setting Resolution: approaches 0.01% above 10 MV. Output Impedance (AC): 2-20 ohms depending on range setting. Output Impedance (DC): 0-4000 ohms depending on dial setting. Price: $365
520 **Direct Reading Capacitance Meter**	Provides one of the most convenient ways of measuring capacitance over an extremely wide range of values as encountered in paper, plastic, mica, ceramic, and air-dielectric types. Capacitance Range: 0.01 pf to 12 µF. Accuracy: 2% above 0.1 pf; 5% below 0.1 pf with dissipation factors as high as 0.05. Test Frequency: 1 KC. "Go-No-Go" acceptance limit pointers may be set to any desired limits, making it easy for completely untrained personnel to make accurate selections. Price: $295
700 **Sensitive Inverter**	A stable, precise voltmeter accessory that permits the measurement of DC potentials as low as 10 microvolts by converting the DC into a precisely amplified AC signal to which a Ballantine voltmeter is responsive. Input Voltage Range: 10 µv — 100 V DC. Features a built-in calibrator of 0.25% accuracy. Accuracy: better than 1% above 100 µv; Input Resistance: 10 meg for 1:100 or 50 meg for 10:1. May be used with Ballantine series 600 Shunt Resistors to measure DC from 0.01 µa to 10 a. Price: $365
710 **Linear AC to DC Converter**	Converts an AC voltage to a precise DC voltage which can be measured with a DC device such as a Type K Potentiometer, Digital DC Voltmeter, Recorder, etc. Features accuracy better than 0.25%. Input Voltage Range: 1 MV — 1000 V. Frequency Range: 30 cps — 250 KC. Input Impedance: 2 meg shunted by 15 pf, except 2 meg shunted by 25 pf on most sensitive range. Accuracy: ±0.25% 50 cps — 10 KC; ±0.5% 30 cps — 50 KC; ±1% above 50 KC. Price: $450

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