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ANALYSIS OF THE PROJECTED OPERATIONAL EFFECTIVENESS OF DEVELOPM--ETC(U)

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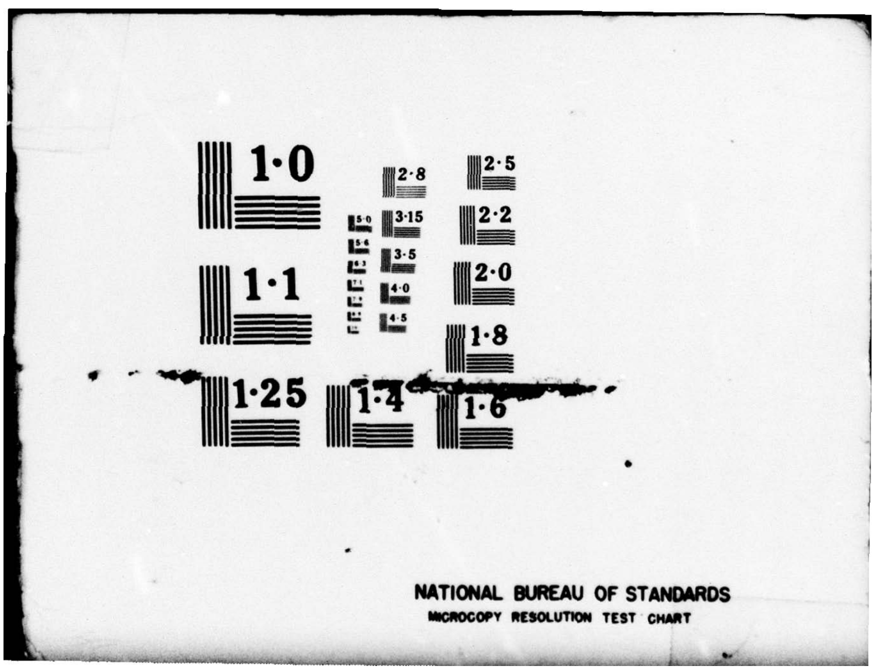
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NATIONAL BUREAU OF STANDARDS
MICROCOPY RESOLUTION TEST CHART

FINAL REPORT

CONTRACT NUMBER N00019-77-C-0110

ANALYSIS OF THE PROJECTED OPERATIONAL EFFECTIVENESS OF DEVELOPMENTAL WEAPON CONTROL AVIONICS HARDWARE

25 January 1978

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ANALYSIS OF THE PROJECTED OPERATIONAL EFFECTIVENESS OF DEVELOPMENTAL WEAPON CONTROL AVIONICS HARDWARE

This analysis addresses four systems:

A. All-Weather Attack Avionics

B. Night Angle Rate Bombing System

C. Multi-Spectral Target Detection and Cueing System

D. Head Coupled Display

A. All-Weather Attack Avionics

This project was in the formative stage throughout most of the period during which TSI carried out its analysis. These efforts were tailored toward the VAMX platform which was a conceptual all-weather attack aircraft. During the requirements determination phase of this effort, TSI created and presented a briefing on potential VAMX technical and operational problems. ~~A copy of this briefing is included as Attachment A to this report.~~

The principal focus of this briefing was the problems associated with the conduct of close air support/battlefield interdiction in a dense environment such as central Europe. There are a number of very complex problems associated with the close air support/battlefield interdiction mission in a dense environment for which there are no solutions currently in hand. For instance, there is the problem of the extremely large number of targets and very dense ground-to-air defense environment which is associated with central Europe scenarios. To be effective in such an environment means that:

a) The surface-to-air defenses must be neutralized sufficiently to enable attack aircraft to operate with acceptable attrition.

b) To help in limiting attrition, the number of passes made by each attack aircraft must be minimized.

c) To be successful in blunting an attack, a large percentage of the attacking tanks must be destroyed in a relatively short period of time.

Achieving these goals requires that a number of competing requirements be met. To begin with, neutralizing the defense in a typical central Europe attack would require most of the aircraft which a two-carrier fleet could put into the air. Soviet ground defenses which accompany advancing tanks are very numerous and varied. They span the gamut from the ZSU-23 rapid fire machine gun to missiles with a wide variety of guidance schemes. The surface-to-air missiles which will be encountered are the SA-6, SA-7, SA-8, SA-9 and SA-10. The probability of neutralizing this defense to the extent that attack aircraft using direct fire weapons can operate with reasonable attrition is almost nil. Most of these surface-to-air weapons are difficult to detect. The SA-7 is a shoulder-fired weapon that is undetectable until fired. The only way to counter this weapon is IR suppression or stay out of its lethal envelope. The other weapons cannot be distinguished from ordinary ground assault vehicles except during the short periods when they emit. Their firing tactic of move-and-shoot makes them very difficult to acquire and counter. In short, the probability of neutralizing the defenses enough to be able to operate with acceptable attrition rates is not very high.

Assuming that the defense has been neutralized to some extent, there are two reasons why an attack aircraft should be able to effectively expend its weapons load in a single pass. The first is survivability. Multiple passes over the same target area are always dangerous, even when the weapons are smaller calibre. In an area with the kind of defenses discussed earlier, multiple passes are suicidal.

The second reason that single pass capability is required is that it is necessary if a large armored attack is to be blunted. The frontal zone of these attacks is not expected to occupy a large area. Typically the front will span 10 kilometers or less. The compactness of such an area means that the number of attack aircraft over the target at any given instant must be very limited. Practical considerations such as command and control in an all-weather situation may dictate that only one aircraft be in the target area at a time. Therefore, the attack aircraft must be able to destroy several vehicles on a single pass. This means that the avionics system must be capable of acquiring targets and launching weapons rapidly. An off-axis attack weapon or cluster weapon with individually targeted munitions is needed because the attack aircraft will not be able to line up individually on each target. Neither the avionics system or weapons for such an aircraft exist today but they are achievable.

The requirement to operate in all-weather situations necessitates a degree of command, control, communication and navigation which we currently do not possess but which may be achievable with JTIDS. To prosecute an attack in bad weather conditions against an advancing column of tanks requires that attack aircraft be over the column on a nearly continuous basis. The amount of airspace available over the column will restrict the number of aircraft in the weapon delivery phase to only a few, possibly only one. Assuming that it is possible to achieve a degree of command and control that would allow 5 second spacing between aircraft over the column and further assuming that the recycle time (time an aircraft is over the target on the first pass to the time over target on the second pass) is two minutes means that there are a total of 24 aircraft required. These 24 aircraft must be very precisely controlled. The control problem is aggravated by the fact that the attack axis must be randomly varied so that the defenses do not have the advantage of being able to anticipate the direction of attack. The control problem is also complicated by the fact that the attack aircraft will not be operating in a sterile airspace area. There will be no-fire zones, free-fire areas, and artillery zones which must either be circumvented or coordinated with JTIDS, possibly in conjunction with an E-2C, could provide a solution to this control problem but it still leaves unanswered the question of how effective air power can be in this type of scenario.

Taken in total, it appears that the battlefield interdiction scenario where the number of targets is great and the defense is versatile and strong is a scenario in which no one, U.S. Navy or otherwise, can expect to be very successful. It appears that losses will be very high and vehicles destroyed insufficient to have any significant effect. In view of this, and in view of the limited number of attack aircraft which the Navy could expect to commit to battle, it appears that any Navy all-weather attack aircraft using direct attack weapons should be designed around less concentrated battlefield interdiction scenarios than that of central Europe. A battlefield interdiction capability which could counter on threats in the third world seems to be more compatible with Navy strengths as well as with the Navy's unique capability to project power into areas in the world which are not accessible to any other U.S. Forces.

In any event, destruction of land targets should have secondary consideration behind the destruction of seaborne targets. In the design of any Navy all-weather attack avionics system, first priority must be given to successfully destroying ship targets both at sea and in port. The strength of the defenses which ships can mount also dictates that the all-weather attack avionics system be standoff capable. This does not mean that a direct attack capability is not needed. From the system design standpoint, however, it means that the standoff capability will set more stringent requirements than the direct attack capability and will therefore drive the design.

It is recommended that the all-weather attack avionics system be oriented toward attack of ship targets with standoff weapons. A secondary objective should be attack of fixed and moving land targets with shorter range guided weapons such as Maverick. A standoff capability against stationary land targets is highly desirable. The avionics system should also retain the capability to attack with conventional freefall weapons and guns.

With respect to defense suppression and standoff attack, TSI performed an analysis of error sources and magnitudes associated with the passive detection of emitting targets. The point of departure for this analysis was a set of error equations developed for the Navy by another company. In the process of utilizing these equations, TSI discovered some significant errors which had evidently escaped the editing process. TSI therefore re-derived the equations to proceed with the analysis. The correct equations and their derivation are presented as Attachment B to this report.

B. Night Angle Rate Bombing System (NARBS)

There are two aspects of the NARBS program which are of interest to the Navy. These are: 1) a set of equations for delivery of ballistic weapons. The equations are based on the rate of change of the angle between the aircraft and the target, and 2) a head coupled display which projects FLIR imagery on the helmet visor directly in front of the pilot's eye.

The NARBS weapon delivery equations were particularly developed for the A-4 aircraft which had neither a target sensor nor an inertial platform. The NARBS equations produce the same accuracy as the A-7's highly accurate digital system. It appears that further work on the NARBS weapon delivery equations is not justified. There are no attack aircraft being built or being planned which cannot implement the A-7 type of weapon delivery equations and there are no advantages of increased accuracy to be gained by using NARBS equations. It is recommended that work on these equations be terminated.

The head coupled display work has not been strongly pursued by the Navy. This system showed great promise in giving the attack aircraft, particularly the single seat attack aircraft, a degree of flexibility which current systems do not have. All of the current systems are tied to a fixed display, either head up or head down. The A-7E TRAM, for instance, is tied to the HUD which restricts the head up field of view markedly. Head down systems are tied to a display which has a greater search field but which really requires a two man crew because of the head down nature of the system. The head coupled display would have allowed the operator to view any area within the FLIR field of view by turning his head in the direction he wanted to see. This provides a great advantage not only in target acquisition but also in the attack phase because the aircraft need not be constrained to a "fly-over-the-target" attack pattern. Chances for a successful first pass attack would be far greater with a head coupled system than with a HUD mounted system. Additionally, the system has the potential for being applied to radar derived imagery as well as FLIR and has the potential for use with a quick shoot off-axis attack missile.

However, since the Navy does not appear interested in head coupled sight work and since there appears to be no further justification for work on the Angle Rate Bombing System equations, it is recommended that work on the NARBS program per se be discontinued.

Future FLIR work will be difficult to justify. There are several factors which should be kept in mind when pursuing Infrared technology. These are:

1) The status of all-weather attack radar development. Although IR has the advantage of being passive and of presently having greater resolution, radar has greater overall potential because of its greater range and all-weather operation capabilities. Radar technology is now advancing very rapidly principally because of increased data processing capabilities while IR technology has become relatively mature. Since it is highly desirable to equip attack aircraft with one sensor rather than two, future IR work will have to be examined closely to ensure that it will actually be employed.

2) The basic justification for future IR system work will have to be either cost or performance. Such justification will probably be difficult to develop because of the maturity of the technology (substantial increases in performance are not likely) and the existence of a fixed 8 - 14 μ technology in inventory today which makes introduction of new technology difficult

because of the need to add more logistics capability and the need to provide trained personnel and additional test equipment. IR efforts in other than the 8 - 14 μ area become additionally difficult to justify because of compatibility with weapons and other IR systems.

C. Multi-Spectral Target Detection and Cueing

The operational payoff of this system is potentially quite high but a practical system will be difficult to design and employ. Difficulties in achieving adequate scan rate and scan volume could make the system optics large and difficult to install on an attack aircraft. The development of target detection algorithms will be extremely difficult because of the large variety of targets and even greater variation in target backgrounds. The need for high speed of detection complicates the algorithm development process enormously. TRISAT recognition speeds are probably too slow for the attack aircraft and TRISAT is dealing with a recognition problem that is basically much more simple than that of the Multi-Spectral Target Detection and Cueing system. Continued effort in the target detection area is justified but practical implementation may be a "too hard to do" problem perhaps even in the 1980's.

D. Head Coupled Display

As pointed out in the discussion of the Night Angle Rate Bombing System, the helmet mounted sight has a very high potential operational payoff. However, the Navy is not emphasizing this development and no progress was made in this program during the reporting period which has any significant impact on weapon control. It is recommended that this effort be terminated.

ATTACHMENT A

VAMX TECHNICAL/OPERATIONAL PROBLEMS

VAMX TECHNICAL/OPERATIONAL PROBLEMS

VAMX MISSIONS:

- ANTI-SHIP
- DEEP STRIKE
- INTERDICTION
- CLOSE AIR SUPPORT
- BATTLEFIELD INTERDICTION

THE MOST DIFFICULT PROBLEM TO SOLVE IS
CLOSE AIR SUPPORT/BATTLEFIELD INTERDICTION

MAJOR PROBLEMS TO BE ADDRESSED ARE:

1. TARGET DESIGNATION

2. VERY LARGE NUMBER OF TARGETS

3. COMMAND AND CONTROL

4. SURVIVABILITY

TARGET DESIGNATION

- CAS TARGETS MUST BE DESIGNATED BY GROUND TROOPS.
- NO ALL-WEATHER DESIGNATOR EXISTS TODAY
- SIZE AND WEIGHT LIMITATIONS MAKE 10-16GHz DESIGNATORS IMPRACTICAL
- ONLY BET CURRENTLY IS 94GHz

VERY LARGE NUMBER OF TARGETS

- VAMX MUST HAVE:
  - Short Time on Target
  - Multiple Kill Per Pass Capability
- WEAPON OPTIONS
  - Individually Targeted
    - Multiple Simultaneous Shoot Capability
      - Acquisition, Verification & Weapon Assignment Difficult
      - Weapon Carriage May Be Difficult
      - Off-Axis Attack Capability Required
    - Semi-Active Weapon Requires Multiple Simultaneous Guidance Capability and Has Difficult Data Link Problem
    - Self-Contained Weapon Probably Expensive
  - Clustered Weapons
    - Effectiveness of Mines Questionable
    - Individually Guided Sub-Munitions Are High Risk

COMMAND AND CONTROL

- SMALL MANEUVER VOLUME
- MINIMUM NUMBER OF AIRCRAFT ON TARGET SIMULTANEOUSLY
- ARRIVAL TIMES ON TARGET MUST BE TIGHTLY CONTROLLED
- ATTACK COORDINATION AND CONTROL DIFFICULT

CONCLUSIONS

- CLOSE AIR SUPPORT AND BATTLEFIELD INTERDICTION REQUIREMENTS WILL DRIVE VAMX AVIONICS DESIGN.
- CLOSE AIR SUPPORT AND BATTLEFIELD INTERDICTION IN A "FULDA GAP" SCENARIO MAY NOT BE PRACTICAL.
- SIMULATION OF VAMX OPERATIONAL SCENARIOS SHOULD BE UNDERTAKEN.
- POTENTIAL OF CLUSTER MUNITIONS SHOULD BE ASSESSED.

ATTACHMENT B

ANALYSIS OF ERRORS IN LOCATING EMITTERS BY
TIME-DIFFERENCE-OF-ARRIVAL METHODS

ANALYSIS OF ERRORS IN LOCATING EMITTERS BY TIME-DIFFERENCE-OF-ARRIVAL METHODS

This analysis applies to location of emitters using time-difference of arrival techniques applied to a triad of receivers deployed with respect to the emitter as shown in Figure 1.

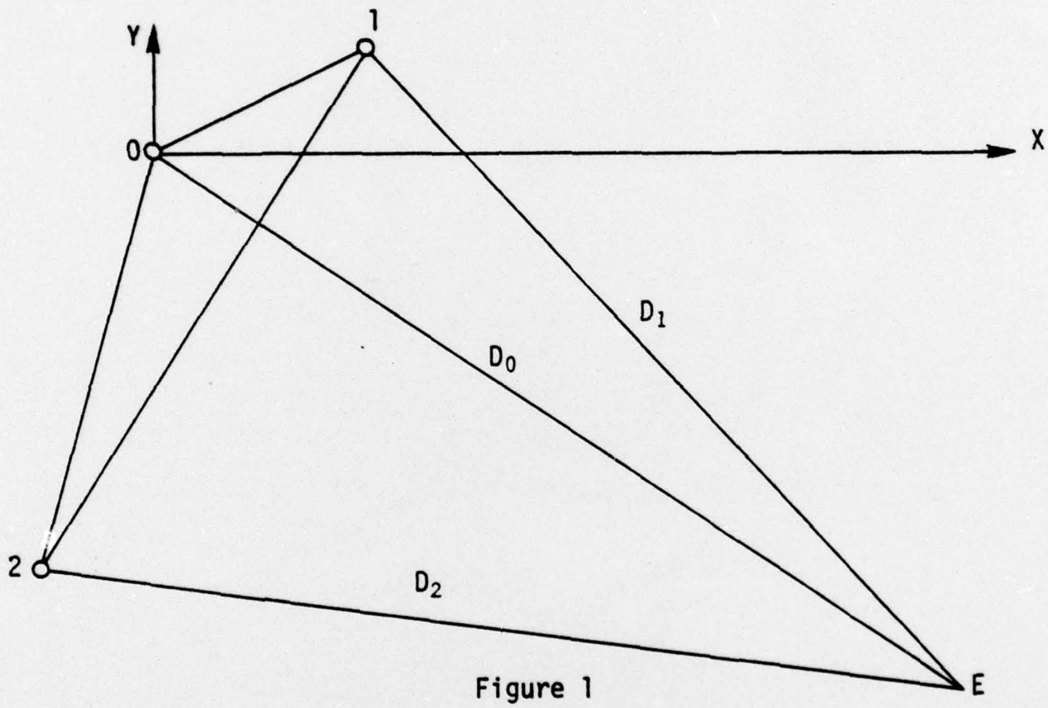

Figure 1

where:

0,1,2	Receiver locations
E	Emitter location
D_0,D_1,D_2	Distances from emitter to respective receivers

Figure 1 is a horizontal projection. Differences in elevation (or altitude, if the emitter or receiver is airborne) are also included in the analysis.

From Figure 1, the following geometric relations exist:

$$D_0^2 = (X_E-X_0)^2 + (Y_E-Y_0)^2 + (Z_E-Z_0)^2 \qquad \text{eq (1)}$$

$$D_1^2 = (X_E-X_1)^2 + (Y_E-Y_1)^2 + (Z_E-Z_1)^2 \qquad \text{eq (2)}$$

$$D_2^2 = (X_E-X_2)^2 + (Y_E-Y_2)^2 + (Z_E-Z_2)^2 \qquad \text{eq (3)}$$

Since the problem is to be solved in terms of the differences of arrival time at stations 0, 1 and 2, the following relationships are defined:

$$\Delta_1 = D_1-D_0 \qquad \text{eq (4)}$$

$$\Delta_2 = D_2-D_0 \qquad \text{eq (5)}$$

Equations (4) and (5), when divided by the speed of light, yield the time differences of arrival at the triad stations.

Equations (1), (2) and (3) therefore become:

$$D_0^2 = (X_E-X_0)^2 + (Y_E-Y_0)^2 + (Z_E-Z_0)^2 \qquad \text{eq (6)}$$

$$D_1^2 = (\Delta_1+D_0)^2 = (X_E-X_1)^2 + (Y_E-Y_1)^2 + (Z_E-Z_1)^2 \qquad \text{eq (7)}$$

$$D_2^2 = (\Delta_2+D_0^2) = (X_E-X_2)^2 + (Y_E-Y_2)^2 + (Z_E-Z_2)^2 \qquad \text{eq (8)}$$

Taking the total differential

$$D_0\, dD_0 = (X_E-X_0)(dX_E-dX_0) + (Y_E-Y_0)(dY_E-dY_0) + (Z_E-Z_0)(dZ_E-dZ_0) \qquad \text{eq (9)}$$

$$(\Delta_1+D_0)(d\Delta_1+dD_0) = (X_E-X_1)(dX_E-dX_1) + (Y_E-Y_1)(dY_E-dY_1) + (Z_E-Z_1)(dZ_E-dZ_1) \qquad \text{eq (10)}$$

$$(\Delta_2+D_0)(d\Delta_2+dD_0) = (X_E-X_2)(dX_E-dX_2) + (Y_E-Y_2)(dY_E-dY_2) + (Z_E-Z_2)(dZ_E-dZ_2) \qquad \text{eq (11)}$$

Multiplying gives

$$D_1 d\Delta_1 + D_1 dD_0 = (X_E-X_1)(dX_E-dX_1) + (Y_E-Y_1)(dY_E-dY_1) + (Z_E-Z_1)(dZ_E-dZ_1) \qquad \text{eq (12)}$$

$$D_2 d\Delta_2 + D_2 dD_0 = (X_E-X_2)(dX_E-dX_2) + (Y_E-Y_2)(dY_E-dY_2) + (Z_E-Z_2)(dZ_E-dZ_2) \qquad \text{eq (13)}$$

the terms D_1dD_0 and D_2dD_0 are rewritten as $\frac{D_1}{D_0} D_0dD_0$ and $\frac{D_2}{D_0} D_0dD_0$ and substitution for D_0dD_0 is made from eq (9) to give

$$D_1d\Delta_1 = (X_E-X_1)(dX_E-dX_1) + (Y_E-Y_1)(dY_E-dY_1) + (Z_E-Z_1)(dZ_E-dZ_1)$$
$$- \frac{D_1}{D_0}[(X_E-X_0)(dX_E-dX_0) + (Y_E-Y_0)(dY_E-dY_0) + (Z_E-Z_0)(dZ_E-dZ_0)] \qquad \text{eq (14)}$$

$$D_2d\Delta_2 = (X_E-X_2)(dX_E-dX_2) + (Y_E-Y_2)(dY_E-dY_2) + (Z_E-Z_2)(dZ_E-dZ_2)$$
$$- \frac{D_2}{D_0}[(X_E-X_0)(dX_E-dX_0) + (Y_E-Y_0)(dY_E-dY_0) + (Z_E-Z_0)(dZ_E-dZ_0) \qquad \text{eq (15)}$$

Collecting similar terms

$$D_1d\Delta_1 = \Big\{[(1-\frac{D_1}{D_0})X_E + \frac{D_1}{D_0}X_0-X_1]\,dX_E + [(1-\frac{D_1}{D_0})\,Y_E + \frac{D_1}{D_0}Y_0-Y_1]\,dY_E +$$
$$[(1-\frac{D_1}{D_0})Z_E + \frac{D_1}{D_0}Z_0-Z_1]\,dZ_E + \frac{D_1}{D_0}(X_E-X_0)\,dX_0 + \frac{D_1}{D_0}(Y_E-Y_0)\,dY_0 \qquad \text{eq (16)}$$
$$+ \frac{D_1}{D_0}(Z_E-Z_0)\,dZ_0 - (X_E-X_1)\,dX_1 - (Y_E-Y_1)\,dY_1 - (Z_E-Z_1)\,dZ_1\Big\}$$

$$D_2d\Delta_2 = \Big\{[(1-\frac{D_2}{D_0})\,X_E + \frac{D_2}{D_0}X_0-X_2]\,dX_E + [(1-\frac{D_2}{D_0})\,Y_E + \frac{D_2}{D_0}Y_0-Y_2]\,dY_E +$$
$$[(1-\frac{D_2}{D_0})\,Z_E + \frac{D_2}{D_0}Z_0-Z_2]\,dZ_E + \frac{D_2}{D_0}(X_E-X_0)\,dX_0 + \frac{D_2}{D_0}(Y_E-Y_0)\,dY_0 \qquad \text{eq (17)}$$
$$+ \frac{D_2}{D_0}(Z_E-Z_0)dZ_0 - (X_E-X_2)\,dX_2-(Y_E-Y_2)\,dY_2-(Z_E-Z_2)\,dZ_2\Big\}$$

Terms such as the first 3 terms of eq (16) and eq (17) are further consolidated as follows:

$$(1-\frac{D_1}{D_0})\,X_E + \frac{D_1}{D_0}X_0 - X_1 = (1-\frac{D_1}{D_0})\,X_E + \frac{D_1}{D_0}X_0 - X_1 - X_0 + X_0$$

$$= (1-\frac{D_1}{D_0})\,X_E - (1-\frac{D_1}{D_0})\,X_0 - X_1 + X_0$$

letting $U = (1-\frac{D_1}{D_0})$ this becomes

$$UX_E - UX_0 - X_1 + X_0$$

$$= (X_0 - X_1) + U(X_E - X_0)$$

similarly substituting $V = (1-\frac{D_2}{D_0})$ yields

$$D_1 d\Delta_1 = \Big\{[(X_0-X_1) + U(X_E-X_0)]\,dX_E + [(Y_0-Y_1) + U(Y_E-Y_0)]\,dY_E +$$

$$[(Z_0-Z_1) + U(Z_E-Z_0)]\,dZ_E + (1-U)(X_E-X_0)\,dX_0 + (1-U)(Y_E-Y_0)\,dY_0 \qquad \text{eq (18)}$$

$$+ (1-U)(Z_E-Z_0)\,dZ_0 - (X_E-X_1)\,dX_1 - (Y_E-Y_1)\,dY_1 - (Z_E-Z_1)\,dZ_1\Big\}$$

$$D_2 d\Delta_2 = \Big\{[(X_0-X_2) + V(X_E-X_0)]\,dX_E + [(Y_0-Y_2) + V(Y_E-Y_0)]\,dY_E +$$

$$[(Z_0-Z_2) + V(Z_E-Z_0)]\,dZ_E + (1-V)(X_E-X_0)\,dX_0 + (1-V)(Y_E-Y_0)\,dY_0 \qquad \text{eq (19)}$$

$$+ (1-V)(Z_E-Z_0)\,dZ_0 - (X_E-X_2)\,dX_2 - (Y_E-Y_2)\,dY_2 - (Z_E-Z_2)\,dZ_2\Big\}$$

Converting to a matrix format:

$$dE = M_1^{-1}\,[M_2 dN + M_3 dT + M_4 dZ + M_5 dH] \qquad \text{eq (20)}$$

where $dE = \begin{vmatrix} dX_E \\ dY_E \end{vmatrix}$ emitter location errors in horizontal plane

$$M_1 = \begin{vmatrix} [X_0-X_1) + U(X_E-X_0)] & [(Y_0-Y_1) + U(Y_E-Y_0)] \\ [X_0-X_2) + V(X_E-X_0)] & [(Y_0-Y_2) + V(Y_E-Y_0)] \end{vmatrix}$$

$$M_2 = \begin{vmatrix} -(1-U)(X_E-X_0) & -(1-U)(Y_E-Y_0) & (X_E-X_1) & (Y_E-Y_1) & 0 & 0 \\ -(1-V)(X_E-X_0) & -(1-V)(Y_E-Y_0) & 0 & 0 & (X_E-X_2) & (Y_E-Y_2) \end{vmatrix}$$

$$dN = \begin{vmatrix} dX_0 \\ dY_0 \\ dX_1 \\ dY_1 \\ dX_2 \\ dY_2 \end{vmatrix}$$

Triad navigation errors

$$M_3 = \begin{vmatrix} D_1 & 0 \\ 0 & D_2 \end{vmatrix}$$

$$dT = \begin{vmatrix} d\Delta_1 \\ d\Delta_2 \end{vmatrix}$$

Since $d\Delta = Cdt$ where C = speed of light and t = time, a very close approximation results if $d\Delta$ is replaced by dt where t is measured in nanoseconds. dT then becomes

$$dT = \begin{vmatrix} dt_1 \\ dt_2 \end{vmatrix}$$

dT has the dimension dt^2

In order to account for timing errors at each of the platforms, dt_1 and dt_2 are replaced by their equivalents from eq (4) and eq (5):

$$dT = \begin{vmatrix} dT_1 - dT_0 \\ dT_2 - dT_0 \end{vmatrix}$$

$$\text{or} \quad \begin{vmatrix} -1 & 1 & 0 \\ -1 & 0 & 1 \end{vmatrix} \begin{vmatrix} dT_0 \\ dT_1 \\ dT_2 \end{vmatrix}$$

so that

$$M_3 dT = \begin{vmatrix} D_1 & 0 \\ 0 & D_2 \end{vmatrix} \begin{vmatrix} -1 & 1 & 0 \\ -1 & 0 & 1 \end{vmatrix} \begin{vmatrix} dT_0 \\ dT_1 \\ dT_2 \end{vmatrix} = \begin{vmatrix} -D_1 & D_1 & 0 \\ -D_2 & 0 & D_2 \end{vmatrix} \begin{vmatrix} dT_0 \\ dT_1 \\ dT_2 \end{vmatrix}$$

where dT_0, dT_1 and dT_2 are timing errors at platforms 0, 1 and 2 respectively. The errors result not only from measurement errors but also from propagation anomalies between the emitter and platforms. Propagation errors are small compared to the errors resulting from platform position error and timing errors and will therefore be ignored.

$$M_4 = \begin{vmatrix} -(1-U)(Z_E-Z_0) & (Z_E-Z_1) & 0 \\ -(1-V)(Z_E-Z_0) & 0 & (Z_E-Z_2) \end{vmatrix}$$

$$dZ = \begin{vmatrix} dZ_0 \\ dZ_1 \\ dZ_2 \end{vmatrix} \qquad \text{Triad altitude errors}$$

$$M_5 = \begin{vmatrix} -(Z_0-Z_1) & -U(Z_E-Z_0) \\ -(Z_0-Z_2) & -V(Z_E-Z_0) \end{vmatrix}$$

$$dH = \begin{vmatrix} dZ_E \\ dZ_E \end{vmatrix} \qquad \text{Emitter altitude estimation error.}$$