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26 May 1967

To: Lt. Col. J. P. O'Toole

From: R. C. Hansen

Subject: Operational Concept for the MOL/DORIAN Manned/Automatic Configuration

Reference: Letter from R. C. Hansen, same subject, dated 14 April 1967.

The purpose of this letter is to transmit the attached study, MOL DORIAN OPERATIONAL CONCEPT - AVAILABILITY OF ALTERNATE TARGETS.

The attached study completes the written action item promised in the referenced letter. A briefing on the study results can be given at your convenience anytime subsequent to 2 June 1967.

The results of this study indicates that an operational concept embodying portions of the Group (Voting) and the Time-To-Go (Sequential) concepts provides considerable advantages over either pure strategy. With very little modification of the on-board logic the advantage of additional alternates offered by the sequential method can be had while at the same time permitting voting and retaining the capability of knowing, on the ground, what path is followed by the primary optics when interdicted.

It is our recommendation that the combined concept be adopted immediately. With the formal adoption of the concept follow-on studies will be made to refine and improve on the concept. For example, it is generally conceded that the number of alternates available will normally exceed the system's capability to look at them all. If the nominal time allocated to each alternate is not used, how can this excess time be utilized to look at additional alternates? The planning and implementation of these additional alternates is an example of such a follow-on study.

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OPERATIONS ANALYSIS AND MISSION PLANNING STUDY

MOL DORIAN OPERATIONS CONCEPT

AVAILABILITY OF ALTERNATE TARGETS

26 MAY 1967

STUDY CONDUCTED BY
R. N. GEDDES

CONTRIBUTORS
M. E. SHUCART
D. R. THOMPSON
W. L. BROGAN (Satellite Navigation Dept.)
L. MACLEAY, Major, (SAFSL 7-C)

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ABSTRACT

The studies presented here develop both analytical expressions and numerical results for the availability of alternate targets. Continuation of the studies performed in Reference (4) (WHS-328) is performed showing the conditions under which it would be advantageous to process alternates sequentially.

The primary results of these studies focus their attention on the determination of decision times for the voting concept. In particular the concept of the voting has been expanded to include all of the desirable features of sequentially processing while maintaining the simplicity and positive control features of the voting strategy. Section 17 of this report presents the summary, conclusions and specific recommendations for alternate target selection and the operational concepts.

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SECTION 1

INTRODUCTION

The studies presented here are a preliminary attempt to expose some of the salient features and tradeoffs associated with alternate target selection as well as decision processes. It is assumed throughout this report that the reader is familiar with the following documents:

1. Letter, Subject: Operational Concept for the MOL/DORIAN Manned/Automatic Configuration, March 21, 1967 (P-30969).
2. Letter, Subject: Comments on the Operational Concepts for the MOL/DORIAN Manned/Automatic Configuration, April 14, 1967.
3. Report, Parametric Profile Studies, WFS-112, January 12, 1967.
4. Report, Alternate Target Considerations, WHS-328, May 9, 1967.

The scope of the studies presented here is severely limited because of both time constraints and the inherent complexity of the problem. Many simplifying assumptions have been made for the sake of producing closed form expressions and simple graphical results. The real merit of these studies is to analytically demonstrate the nature of the problem rather than to present detailed solutions. The mission planning software contractor must initially undertake definitive studies which will ultimately lead to definition of alternate target strategies. The problems approached here are not concerned with the implementation of decision logic on the ground vs. on-board but rather treat the problem as one of a system optimization. The most general underlying assumption made in this analysis is that the primary optics path has been preselected, based upon an independent optimization criteria. The

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optimization of score is attempted by interdicting the primary path in favor of alternate targets. Ideally one would like to attack the problem of simultaneously picking the primary & alternate paths so as to maximize the score but the complications caused by attempting such an approach at this time preclude such an effort.

The approach taken with these studies has been to provide the analytical theory for processing alternates and then numerically plot tradeoffs utilizing reasonable values for system parameters. The necessary and sufficient conditions have been derived for special cases for alternate target candidates for both the voting and sequential strategies. These have been compared graphically to demonstrate the difference in availability of alternate targets as a function of the relative geometry and strategies.

SECTION 2

TARGET TIME LINE DEFINITIONS

A. Primary Optics Path. The primary optics path timeline is defined by three basic time parameters; the time that the mirror is slewing, the time during which the mirror is settling, and the time during which the mirror is tracking and photography is being performed. Figure (1) below represents a typical timeline for the primary optics path.

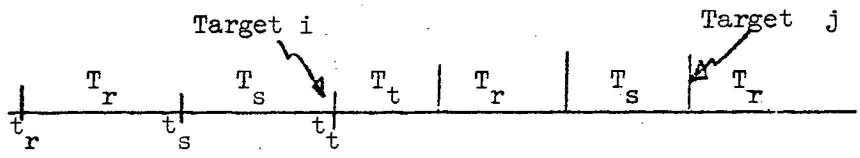

FIGURE 1

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In this notation, the "T's" represent the time duration of a given operation, while the "t's" represent the absolute time at the start of these operations. The specific definitions for the symbols used are given below.

T_r = slew time

T_s = settle time

T_t = tracking time

It should be noted that, in general, each "T" and "t" has associated with it a value "i" which represents "i-th" primary with which the "T" is associated.

B. Alternate Target Timelines. The alternate target timeline may be represented in a manner similar to the primary optics path. However, several distinct differences exist between the primary and alternate timelines. Figure (2) below represents a typical alternate timeline.

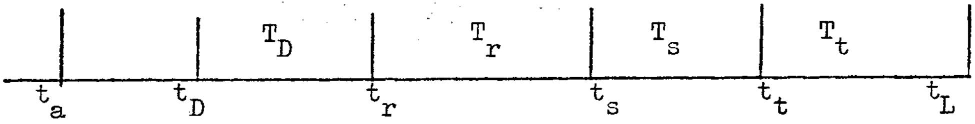

FIGURE 2

The same notation is adhered to as given above for the pimary path with the addition of several new terms:

1. t_a is defined as that time at which the alternate target may first be viewed by the acquisition scope. In terms of the template

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work (Reference 3), this corresponds to the vehicle time at which intersection of the ellipse and the alternate occurs.

2. t_L is defined as the last time at which a photograph may be taken of the alternate. If monoscopic photography is all that is required, then this time would correspond to the maximum allowable aft look angle.

3. T_D is defined as the minimum allowable dwell time which the crew can be assured of having in order to view the target for activity indicators. It should be noted that, in cases where the target is obscured, the actual time spent for viewing the target may be appreciably less than T_D.

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SECTION 3

EXPLANATION OF ALTERNATE VISIBILITY TIME, T_V

The visibility time T_V is presented in Equation (4) and is defined as the time interval between the latest possible time for completing a photographic operation (t_L) on a target and the earliest possible target acquisition time (t_a) using the ATS. The visibility time essentially encompasses the time during which the ATS is tracking the target (dwell time), the time for the primary optics to slew and settle and the time for the photographic operation.

$$T_V = \frac{h}{V} \left\{ \frac{\tan \phi}{\cos \Omega} + \tan \bar{\xi} \right\} = t_L - t_a \qquad (1)$$

where

$$\bar{\xi} = \cos^{-1} \frac{\cos \xi}{\cos \Omega} \qquad (2)$$

ξ = Maximum forward look angle with ATS

Ω = Target obliquity angle

ϕ = Photographic stereo convergence angle

$\frac{h}{V}$ = 20 seconds (based upon orbit selected)

Equation (1) assumes the latest possible time for initiating a photographic stereo sequence to correspond to the time of closest approach (t_{ca}). This assumption can be modified by merely adding or subtracing a characteristic lag time to or from equation (1) to account for other assumptions.

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Figures 3, 4 and 5 were generated based respectively upon stereo convergence angles of 15°, 20° and 25° by using equation (1) in conjunction with the appropriate parametric values. An $h/_V$ value of 20 seconds was used to generate these curves. This $^h/_V$ value is representative of the average value of $h\ /_V$ over the latitude regions of most interest ($h/_V$ is always within $\pm$ 1.2 seconds of the 20 second value over the latitude range from 80°N to 10°N descending).

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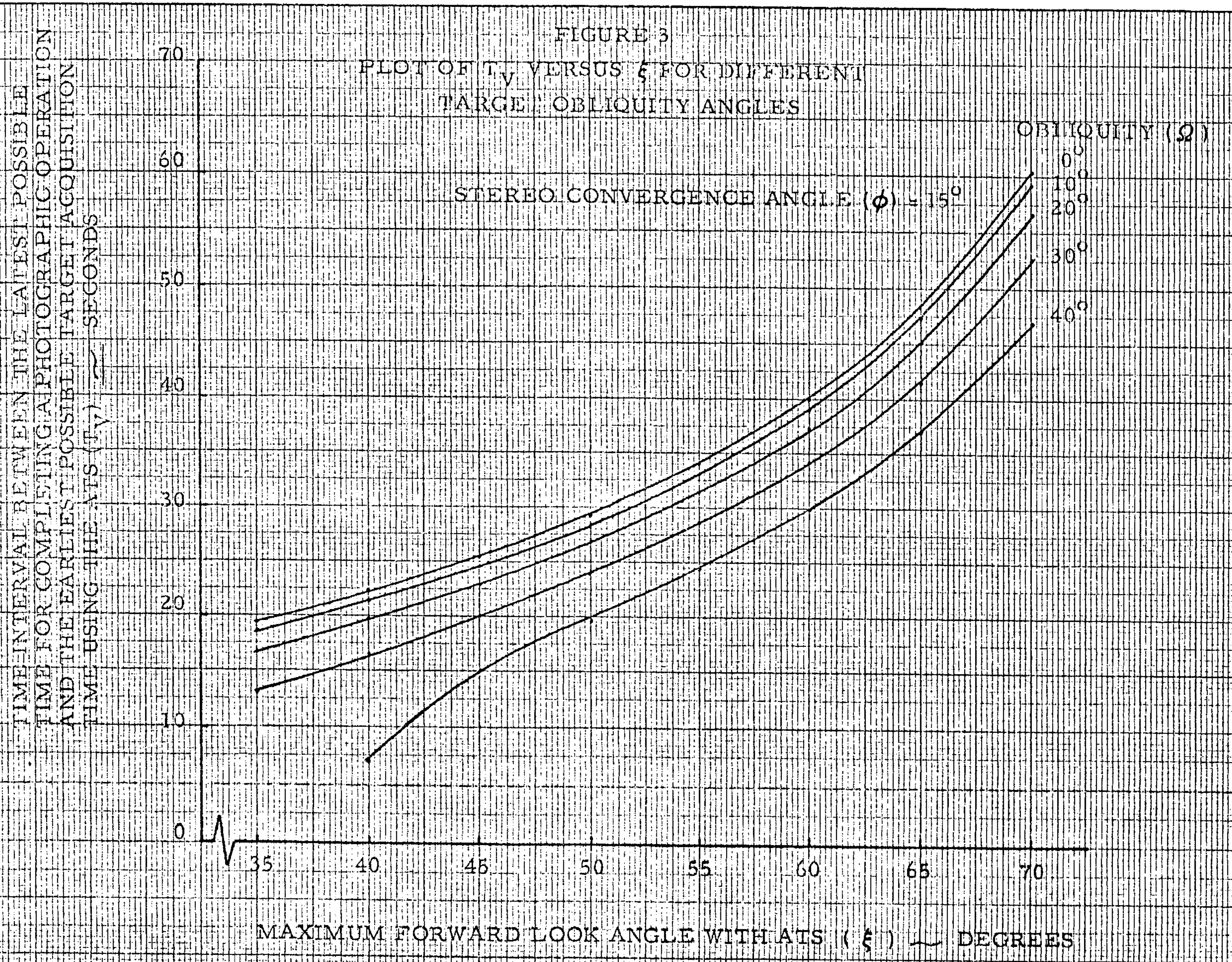

FIGURE 3

PLOT OF T_v VERSUS ξ FOR DIFFERENT TARGET OBLIQUITY ANGLES

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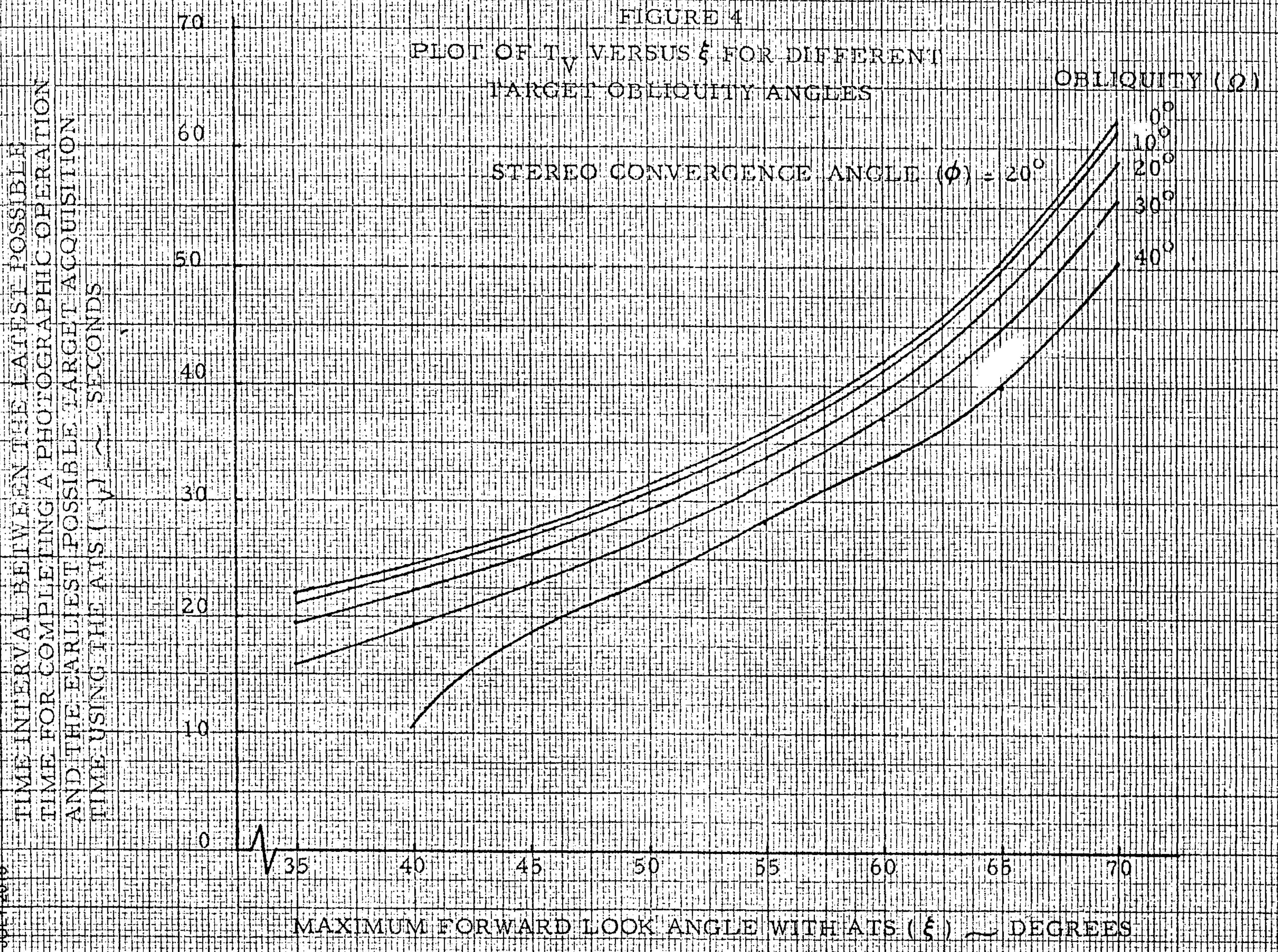

FIGURE 4

PLOT OF T_V VERSUS ξ FOR DIFFERENT TARGET OBLIQUITY ANGLES

STEREO CONVERGENCE ANGLE (ϕ) = 20°

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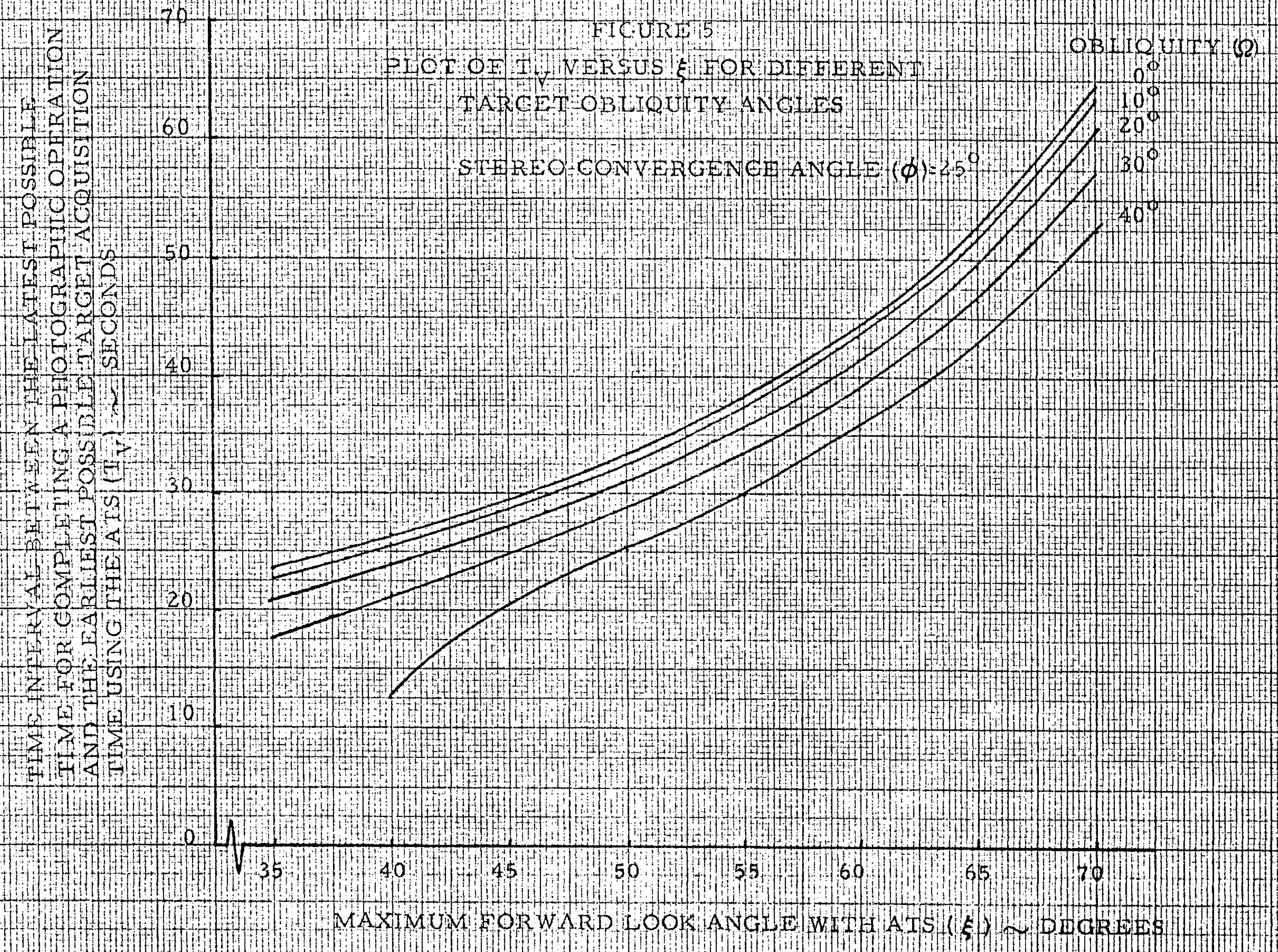

FIGURE 5

PLOT OF T_V VERSUS ξ FOR DIFFERENT TARGET OBLIQUITY ANGLES

STEREO-CONVERGENCE ANGLE (ϕ)=25°

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SECTION 4

NECESSARY AND SUFFICIENT CONDITIONS FOR A TARGET TO BE AN ALTERNATE CANDIDATE

The ground software must have some quantitative criteria by which it can determine the suitability of a target as an alternate. It seems reasonable for the ground software to select, initially, alternates based upon a criteria which allows the crew to have a guaranteed dwell time as well as there being sufficient time for diverting the primary optic's path to photograph the alternate target in the desired photographic mode. We define the term T_K by Equation (3) below as the time required to roll the primary optics from the primary path, allow it to settle, and track the alternate target for the necessary duration in order to accomplish the desired photographic sequence.

$$T_K = T_r + T_s + T_T \tag{3}$$

It becomes obvious that the necessary and sufficient condition for considering a target as an alternate candidate can be expressed as Equation (4) below.

$$T_V \geq T_K + T_D \tag{4}$$

An additional definition will be useful by decomposing the term T_K as given below by Equation (5).

$$T_K = T_C + T_r \tag{5}$$

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The term T_C represents the time allowed for camera operation. T_C is the settling time and the tracking time required and this term is independent of the relative geometry of targets. The term T_r, however, is specifically a function of the geometrical spacing of the targets. In most studies the pitch rate is double the roll rate. It is usually the case that the roll motion of the primary optics becomes the dominating conflict parameter and hence the roll history is used in the time line.

The template analysis referred to in Reference 3 represents a two dimensional plot of the constraints specified by Equation (4).

SECTION 5

NECESSARY AND SUFFICIENT CONDITIONS FOR SELECTING AN ALTERNATE CANDIDATE FOR THE VOTING STRATEGY.

Figure (6) below represents a typical timeline for an alternate target.

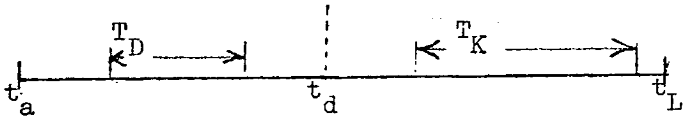

FIGURE 6

It will be noticed that there exists a new point in time t_d which is defined as the decision time. The introduction of this term gives rise to two additional constraints. Clearly the decision time must

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be set far enough forward in time from t_a so as to guarantee that adequate dwell time can be had to view the target before the decision is made. This condition is expressed below as Equation (6).

$$t_d - t_a \geq T_D \tag{6}$$

Additionally, the decision time must be set far enough in front of the time t_L so as to insure that all necessary camera and mirror operations can take place before time t_L is reached. This condition is given below by Equation (7).

$$t_L - t_d \geq T_K \tag{7}$$

Strictly speaking, Equation (6) and (7) are the necessary and sufficient conditions for determining whether or not a target is an alternate candidate under the voting concept, since the addition of Equation (6) and (7) yields Equation (4). As a matter of practicality, however, one would originally screen the alternate target using Equation (4) and then having selected the decision time further screen the alternate target by using Equation (6) and (7).

It is easy to imagine that the screening process previously mentioned does not take place independently of the selection of t_d. When the voting strategy is used it is the responsibility of the ground software to simultaneously select t_d appropriately so as to optimize via some predetermined criteria which is used to optimize alternate target selection. At the time of this writing there is no known criteria for selecting t_d.

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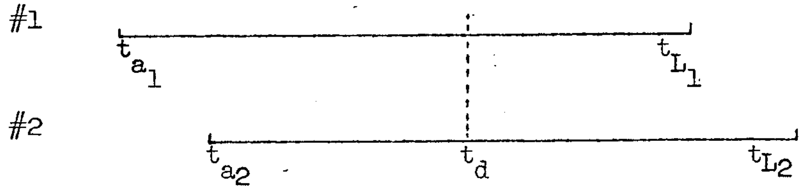
SECTION 6

EXAMINATION OF GEOMETRY CONSTRAINTS FOR TWO ALTERNATES UTILIZING THE VOTING STRATEGY

In this analysis certain simplifying assumptions need to be made in order to present results in a simple manner. The model which is considered here is shown in Figure 7 below.

FIGURE 7



Consider two alternates each with the same roll time T_r from the primary optics path. Without loss of generality it is further assumed that t_{a_2} is greater than t_{a_1}. The analysis proposed here considers only one ATS for viewing the alternates and tacitly assumes the other ATS to be committed to viewing the primary targets. Because of the ordering of the acquisition times it shall be assumed that the selection of the targets for viewing will be target alternate number 1 first and then alternate number 2.

Consider first the constraints applied to target number 2. This target will be viewed and after a suitable viewing time the decision time t_d will occur and a decision will be made between target number 1, target number 2, and the primary. Hence, from Equation (6) and (7) we may write the two primary constraints for alternate target 2 below.

$$t_{L_2} - t_d \geq T_K \qquad (8)$$

$$t_d - t_{a_2} \geq T_D \qquad (9)$$

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In order to write the constraints for alternate target #1 it is necessary to recognize two important exceptions to equation (6). After the dwell time has been spent on alternate target #1, the decision time must still be at least an additional amount of time in the future to allow for the dwell time of the number 2 alternate target and the slew and settle time of the ATS. The constraints for alternate target #1 are given below by Equations (10) and (11).

$$t_{L_1} - t_d \geq T_K \qquad (10)$$

$$t_d - t_{a_1} \geq T_D + T_D + T_B \qquad (11)$$

where T_B is the slew and settle time of the ATS.

Thus, Equations (8) through (11) define the geometric constraints for two targets being alternates as a function of their relative geometry. In particular, constraints from these equations shall be derived as a function of the differential acquisition time Δt_a and the roll time, t_r from the primary path to the selected alternate. Equations (8) and (11) may be added yielding Equation (12) below.

$$t_{L_2} - t_{a_1} \geq T_K + 2\,T_D + T_B \qquad (12)$$

Similarly Equations (9) and (10) may be combined yielding Equation (13) below.

$$t_{L_1} - t_{a_2} \geq T_D + T_K \qquad (13)$$

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Utilizing the definition to T_V given by Equation (1) it is possible to write Equations (12) and (13) in the form given below by equations (14) and (15).

$$t_{a_2} - t_{a_1} \geq 2T_D + T_B + T_C + T_r - T_{V_2} \quad (14)$$

$$t_{a_1} - t_{a_2} \geq T_D + T_C + T_r - T_{V_1} \quad (15)$$

The differential acquisition time term Δt_a is defined below by Equation (16).

$$\Delta t_a = t_{a_2} - t_{a_1} \quad (16)$$

Equations 8, 9, 10, and 11 may be combined to yield a third constraint given by equation (17) below.

$$T_{V_1} + T_{V_2} \geq 3\,T_D + T_B + 2\,T_C + 2\,T_r \quad (17)$$

Equations (18) through (22) are the five general constraint equations for defining the boundaries of the zone of compatable alternates when a voting strategy is employed.

$$\left.\begin{aligned} \Delta t_a &\geq 0 \quad (18) \\ T_r &\geq 0 \quad (19) \end{aligned}\right\} \text{1st Quadrant Only}$$

$$\Delta t_a \geq C_1 + T_r \quad (20)$$

$$\Delta t_a \leq C_2 - T_r \quad (21)$$

$$T_r \leq C_3 \quad (22)$$

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where

$$C_1 = 2\,T_D + T_B + T_C - T_{V_2} \qquad (23)$$

$$C_2 = T_{V_1} - T_D - T_C \qquad (24)$$

$$C_3 = \tfrac{1}{2}\,(T_{r_1} + T_{V_2} - 3\,T_D - T_B - 2\,T_C) \qquad (25)$$

Equations (18) through (22) are plotted in Figure 8 to illustrate the effect of the constraints.

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GEOMETRICAL ZONE FOR TWO ALTERNATES BEING COMPATIBLE

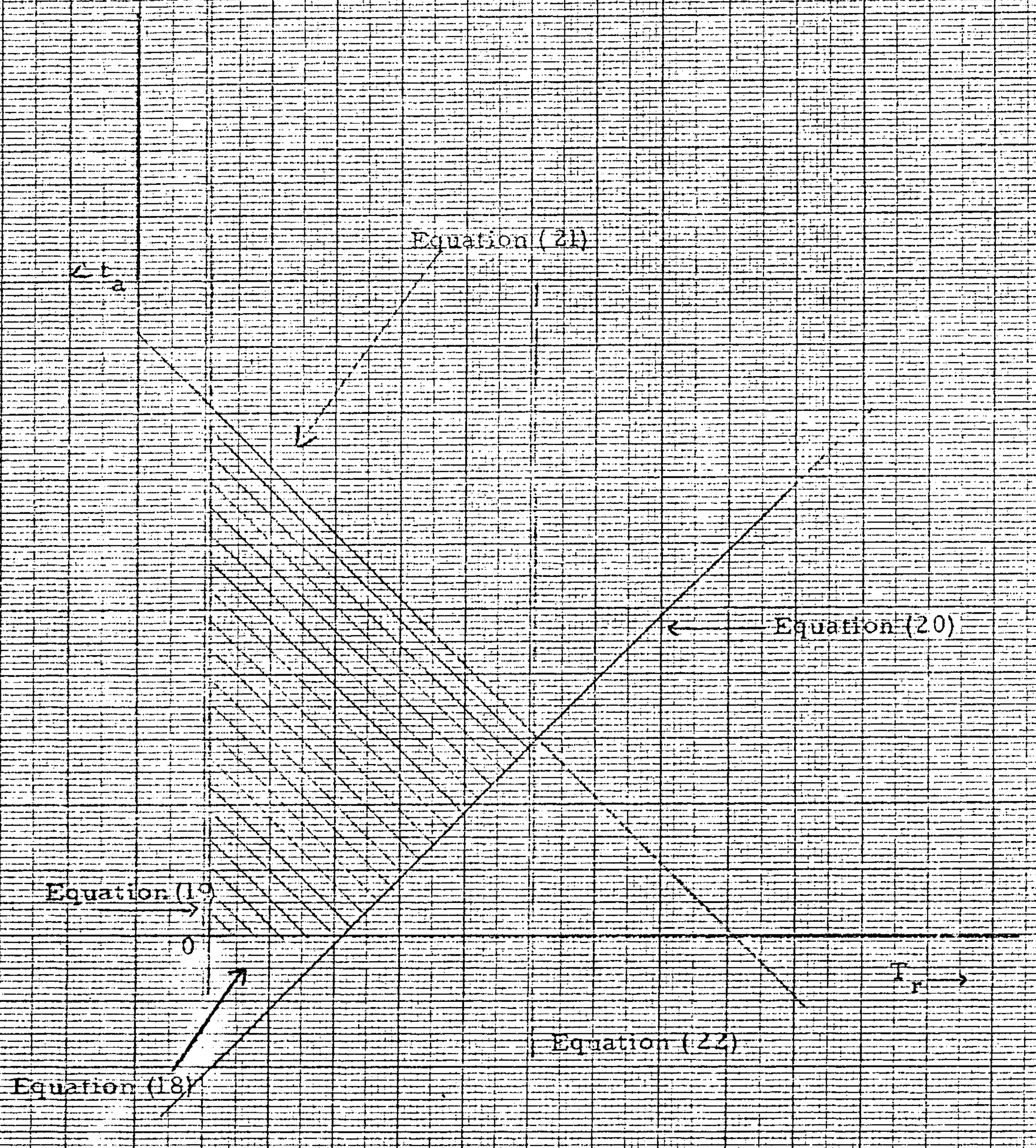

FIGURE (8)

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SECTION 7

NUMERICAL EXAMPLES OF CONFLICT ZONES FOR TWO ALTERNATES UTILIZING A VOTING STRATEGY

Figures 9, 10, 11 and 12 are plots of the zonal constraints for selected values of T_V. Table 1 gives the values of C_1, C_2 and C_3 for the corresponding values of T_V.

	$T_V = 20$	$T_V = 25$	$T_V = 30$	$T_V = 35$
C_1	4	-1	-6	-11
C_2	+ 4	+9	+14	+19
C_3	0	5	10	15

Table 1

In order to compute the above table, numerical values have been assumed for T_B, T_C and T_D.

T_B = 2 seconds
T_C = 10 seconds
T_D = 6 seconds

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GEOMETRICAL ZONE FOR TWO ALTERNATES BEING COMPATIBLE UTILIZING A VOTING STRATEGY

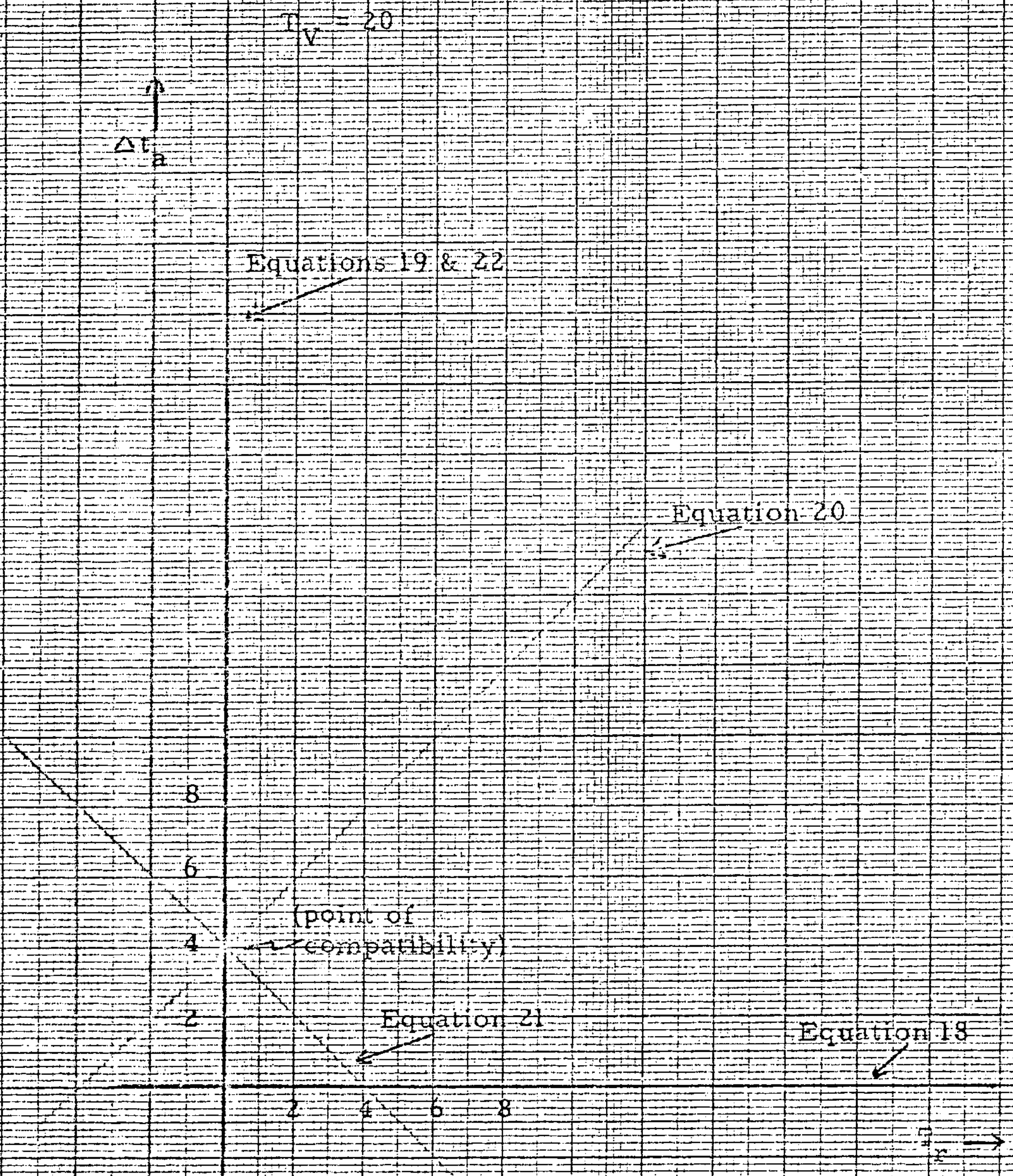

FIGURE 9

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GEOMETRICAL ZONE FOR TWO ALTERNATES BEING COMPATIBLE UTILIZING A VOTING STRATEGY

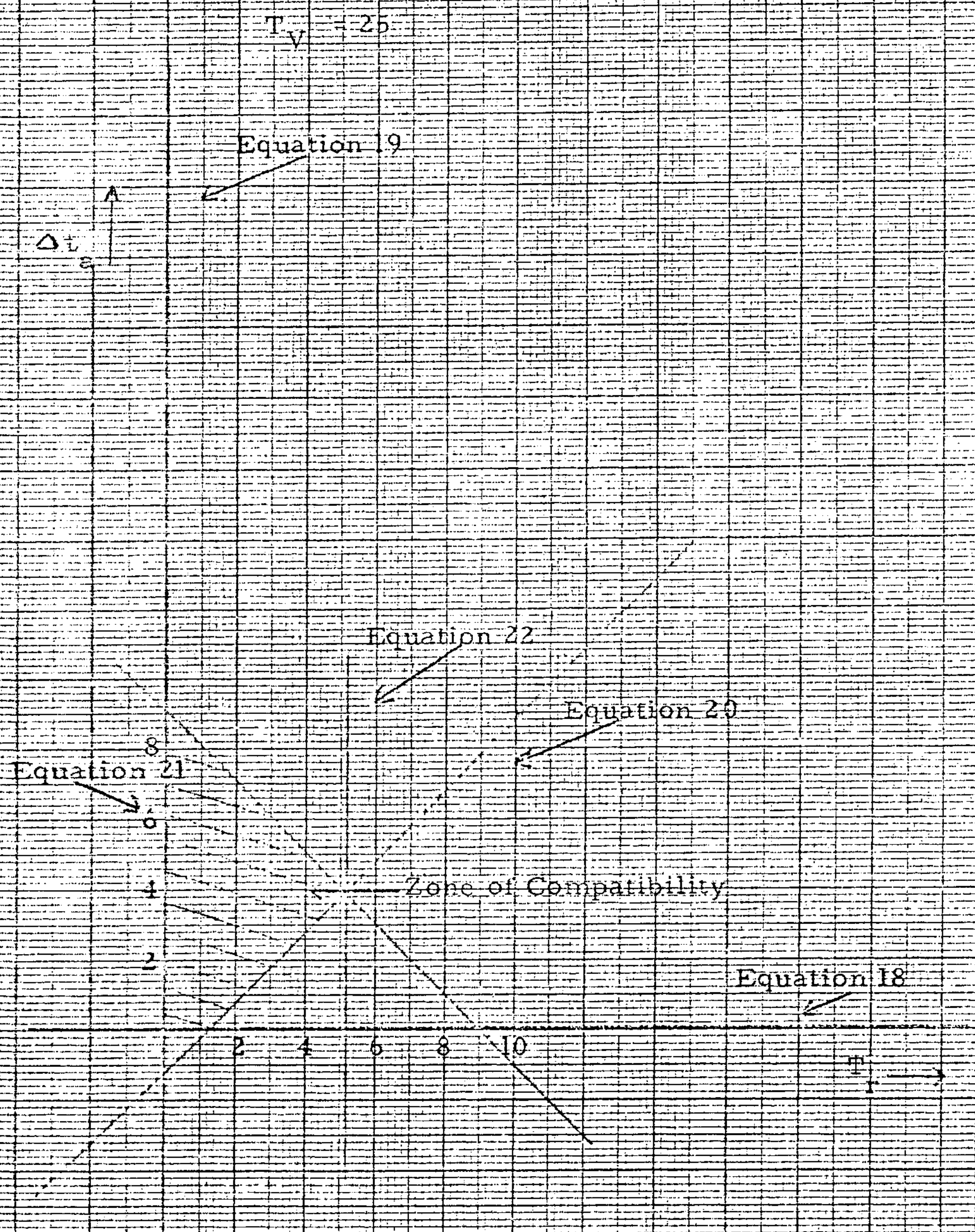

FIGURE 10

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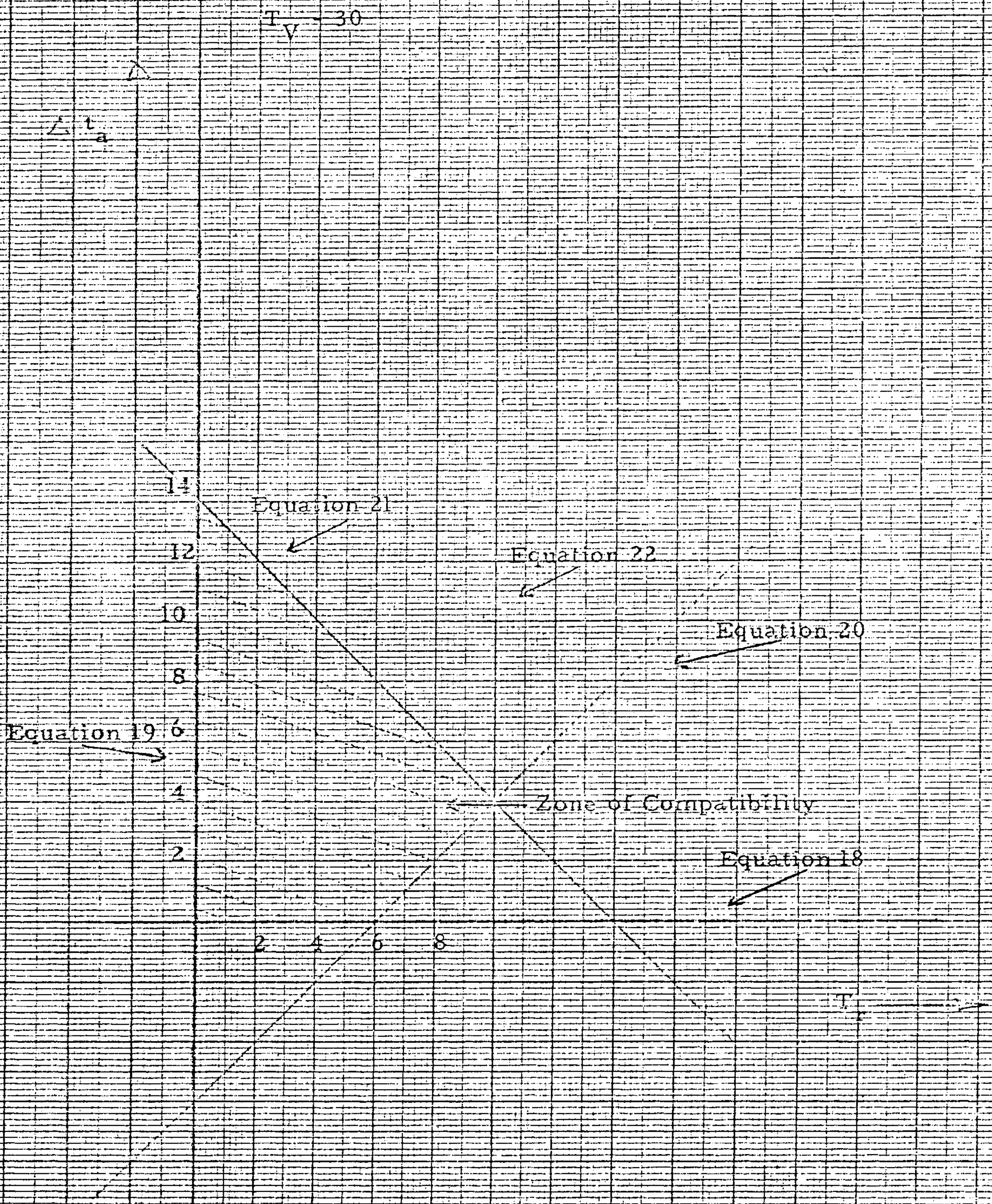

FIGURE 11

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GEOMETRICAL ZONE FOR TWO ALTERNATES BEING COMPATIBLE UTILIZING A VOTING STRATEGY

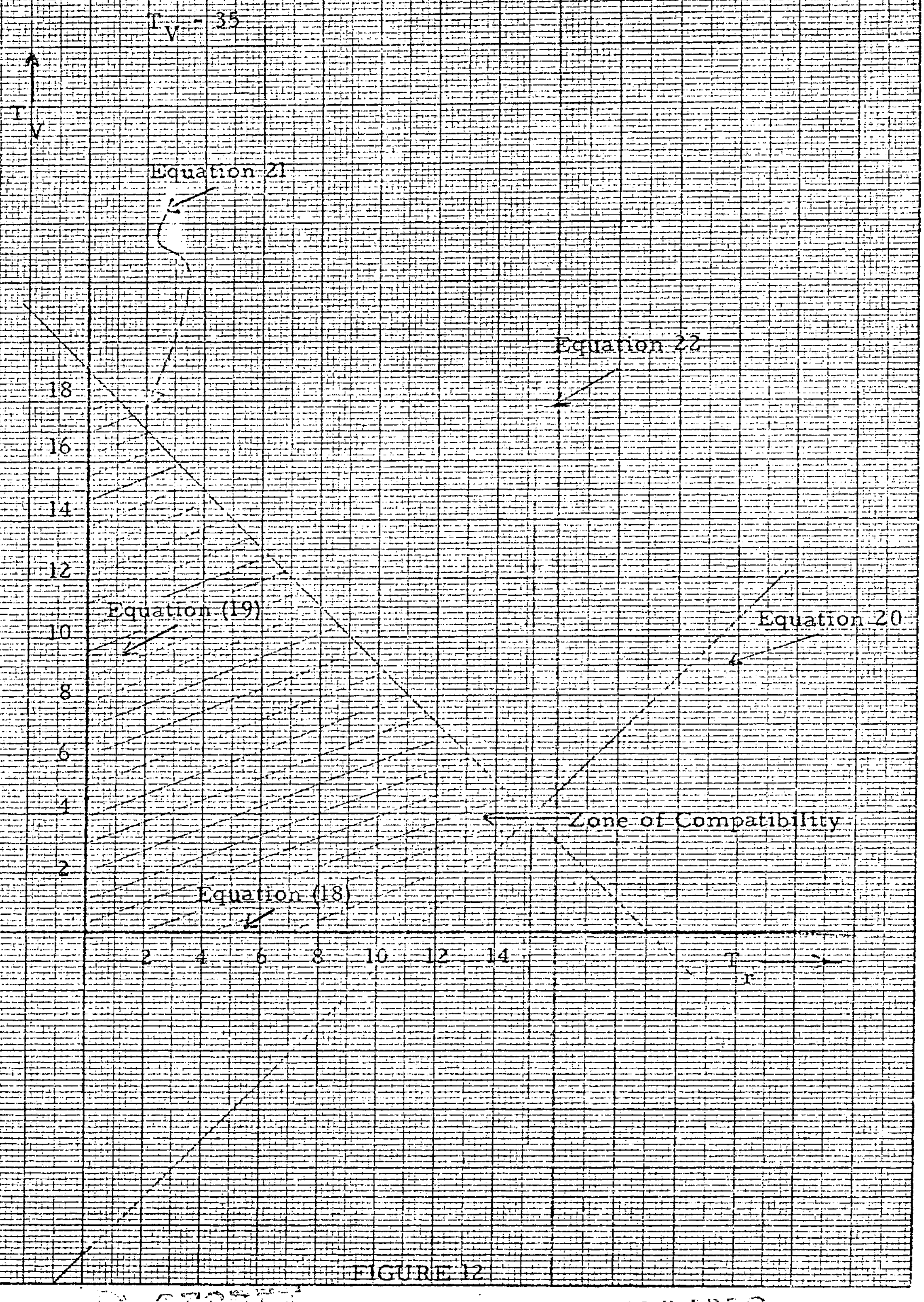

FIGURE 12

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SECTION 8

NECESSARY AND SUFFICIENT CONDITIONS FOR SELECTING N ALTERNATE TARGETS AS CANDIDATES UTILIZING A VOTING STRATEGY

Assume that there are N alternate targets which exist for some decision time, t_d, and that the alternates have been ordered such that the N^{th} target will be observed last. For the N^{th} target the constraint conditions are given below by Equations (25) and (26).

$$t_d - t_{a_N} \geq T_D \qquad (25)$$

$$t_{L_N} - t_d \geq T_K \qquad (26)$$

Consider now the $(N-1)^{th}$ target. As with the case of two alternates, the constraint conditions for this target are given below by Equations (27) and (28).

$$t_d - t_{a_{N-1}} \geq T_D + T_B + T_D \qquad (27)$$

$$t_{L_{N-1}} - t_d \geq T_K \qquad (28)$$

Consider the $(N-2)^{th}$ target. This target must accommodate in its constraint conditions not only its own dwell time but the dwell time associated with the $(N-1)^{th}$ alternate and the N^{th} alternate as well as the T_B associated with going from (N-2) to (N-1) and in going from (N-1) to N. Hence, the constraint conditions for this alternate are given below by Equations (29) and (30).

$$t_d - t_{a_{N-2}} \geq 3\ T_D + 2\ T_B \qquad (29)$$

$$t_{L_{N-2}} - t_d \geq T_K \qquad (30)$$

Repeating this process N times, the constraint conditions for the first target which would be selected for viewing are given below by Equations (31) and (32).

$$t_d - t_{a_1} \geq N\,T_D + (N-1)\,T_B \qquad (31)$$

$$t_{L_1} - t_d \geq T_K \qquad (32)$$

These equations may be generalized to provide the necessary and sufficient conditions to tell whether or not a selected group of targets are capable of being alternate targets for a given decision time. These conditions can be expressed by Equations (33) and (34) which are given below.

$$t_d - t_{a_i} \geq (N + 1 - i)\,T_D + (N - i)\,T_B \qquad (33)$$

$$t_{L_i} - t_d \geq T_K \qquad (34)$$

for all i $1 \leq i \leq N$

SECTION 9

MAXIMUM NUMBER OF ALTERNATE TARGETS AVAILABLE AS A FUNCTION OF T_V

In order to compute the maximum number of alternates available for a constant viewing time and decision time, we shall assume the most favorable geometry. This implies that the targets are arranged in such a manner as to provide perfect packing of the dwell times in the time

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available for dwell times. In this case we make the following assumptions for the values in the constraint equations given below.

$T_B = 2$

$T_K = T_r + 11 = 12$

$T_D = 6$

Combining Equations (31) and (32) we produce the general constraint equation given below as Equation (35).

$$t_L - t_a = T_V \geq N\, T_D + (N-1)\, T_B + T_K \qquad (35)$$

Substituting the constant generated in this equation we develop Equation (36) which provides us with the maximum number of alternates available by positioning the integer part of N which is generated.

$$\frac{T_V - 10}{8} \geq N \qquad (36)$$

Table 2 below is a listing of the maximum number of alternates.

N	TV
1	18
2	26
3	34
4	42

Table 2

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SECTION 10

COMPARISON OF GEOMETRICAL CONSTRAINTS BETWEEN THE VOTING STRATEGY AND SEQUENTIAL STRATEGY

The equation which determines geometrical constraints for two alternates utilizing sequential method of processing is derived by referring to Figure 13 below.

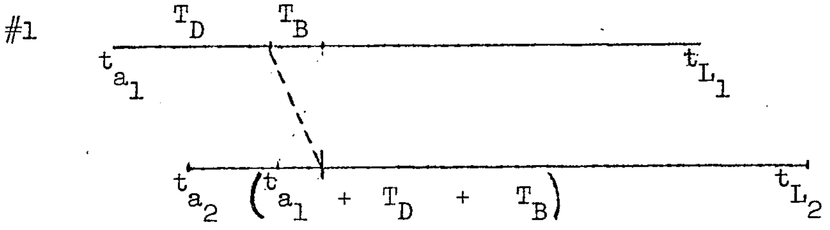

FIGURE 13

We begin by assuming that either alternates given above are acceptable by the general necessary and sufficient conditions for alternates as given by equation 4. It is further assumed that t_{a_2} is greater than t_{a_1} and that alternate 1 is selected for viewing before alternate 2.

The constraining equation which comes from this geometry arises from being able to get to Target 2 in time to dwell and operate the primary optics before t_{L_2}. The time at which the ATS begins to track the second alternate is equal to $t_{a_1} + T_D + T_B$. Hence, the constraint equation can be written as given below by Equation (37).

$$t_{L_2} - (t_{a_1} + T_B + T_D) \geq T_K + T_D \tag{37}$$

By utilizing the definition of T_V and further assuming that $T_{V_1} = T_{V_2}$ Equations (37) can be rewritten as Equation (38) and (39) below.

$$t_a \geq C_4 + T_r \tag{38}$$

$$C_4 = T_B + T_C + 2\,T_D - T_V \tag{39}$$

Compare these equations with Equations (20) and (23). We notice that the two are identical. Hence it becomes a straightforward manner to re-interpret Figure 8 as a constraint for sequential targets by neglecting the constraint imposed by Equations (21) and (22). This is given below in Figure 14.

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GEOMETRICAL ZONE FOR TWO ALTERNATES BEING COMPATIBLE UTILIZING A SEQUENTIAL STRATEGY

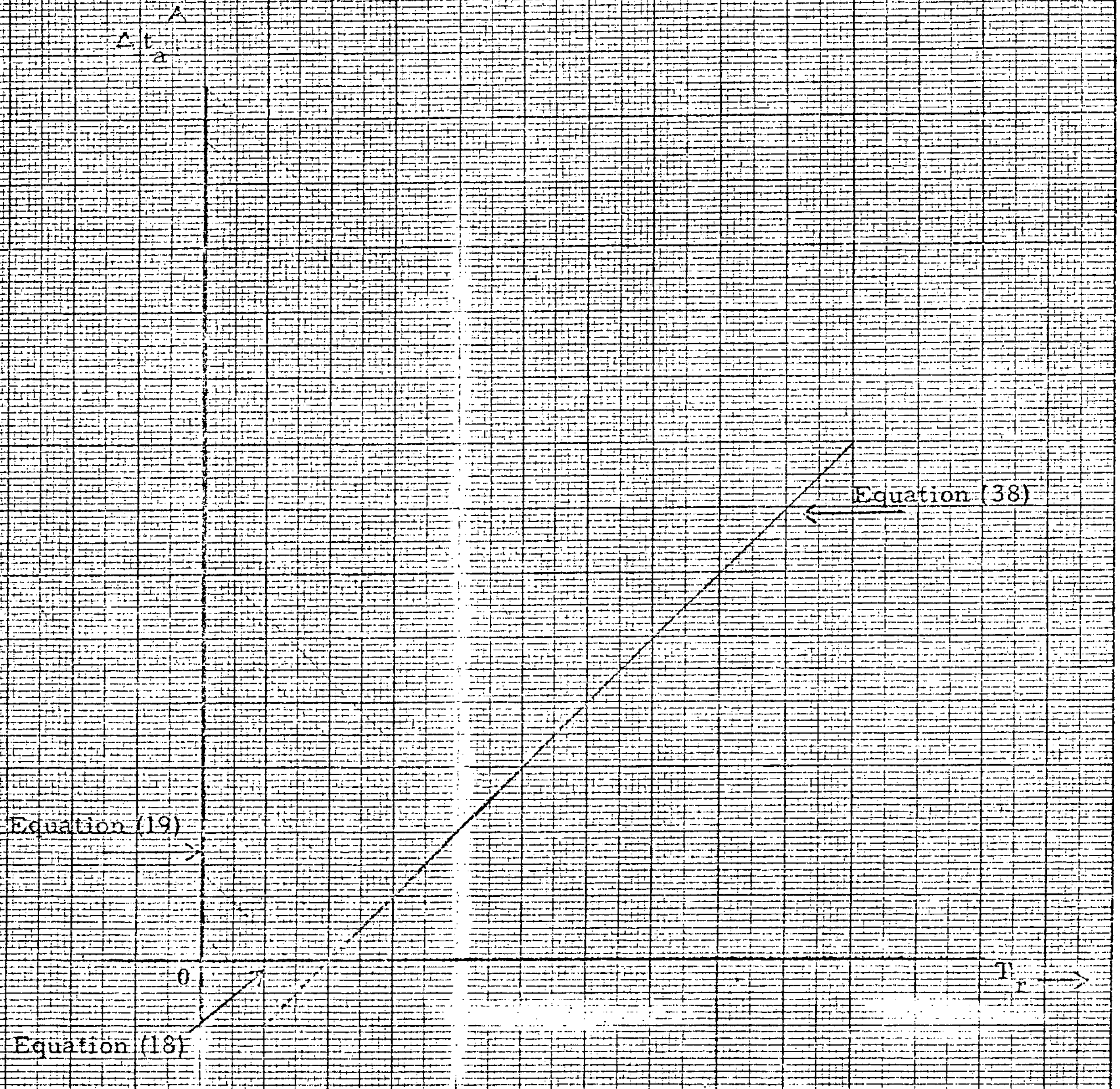

FIGURE 14

K+E 10 X 10 TO THE CENTIMETER 46 1513
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SECTION 11

COMPARISON OF THREE ALTERNATES VIEWED SEQUENTIALLY VS TWO ALTERNATES VOTED UPON

As can be seen from the previous analysis, geometry conditions may exist where targets can be processed sequentially but could not become available simultaneously for a given decision time. When this is the case, it may be best to process them sequentially even though the sequential processing does not take place in order of descending weights. As was demonstrated previously in Reference 4, failure to process targets sequentially in order of descending weights will produce an average score less than by the voting method. The analysis here, however, concerns itself with the processing of three targets sequentially (in a non-optimal manner) as opposed to two targets using a voting strategy.

Expected Score for the Voting Strategy. The average score $\bar{W}$ for two targets in a voting strategy can be derived as given in Reference 4. In so doing it is assumed that two targets have equal apriori probabilities and the weight of W_1 is greater than the weight W_2. The false alarm rates are assumed $= 0$ and recognition probability $= 1$. Since this analysis is concerned with differential in performance between the two strategies, it is not necessary to account for terms relating only to inactivity. Equation (40), below, gives the expected score for

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voting strategy on two targets.

$$\bar{W} = P^2 W_1 + PQW_1 + QPW_2 + K \tag{40}$$

Average Score for the Sequential Strategy

The sequential strategy further assumes an additional third target which is called W_3. Equation (41) below considers the expected score for this case.

$$\bar{W} = P^3 \left(\frac{W_1 + W_2 + W_3}{3} \right) + PQ^2 (W_1 + W_2 + W_3) + QP^2 \left(\frac{W_1 + W_2}{2} + \frac{W_1 + W_3}{2} + \frac{W_2 + W_3}{2} \right) + K \tag{41}$$

The term $\frac{W_1 + W_2 + W_3}{3}$ is the average score obtained when all three targets are active. The term $(W_1 + W_2 + W_3)$ represents the score when only one target is active in each of three cases. The term $\left(\frac{W_1 + W_2}{2} + \frac{W_1 + W_3}{2} + \frac{W_2 + W_3}{2} \right)$ represents the average score for each of three cases when two targets are active.

The differential score between sequential and voting strategies is given below by Equation (42)

$$\Delta W = P\left(-PW_1 - Q(W_1 + W_2) + \left(\frac{P^2}{3} + Q^2 + QP\right)(W_1 + W_2 + W_3)\right) \tag{42}$$

ΔW represents the expected score of the sequential strategy minus the expected score of the voting strategy. After some simplification it is possible to write ΔW in the form of equation (43) below.

$$\Delta W = P\left(\frac{P^2}{2} (W_1 + W_2 + W_3) + Q W_3 - P W_1 \right) \tag{43}$$

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When $\Delta W > 0$ then the sequential strategy will outperform the voting strategy. Conversely when $\Delta W < 0$, then the voting score is superior. Thus, the necessary sufficient condition for $\Delta W > 0$ (sequential superior) is given by Equation (44)

$$\frac{P^2}{3}(W_1 + W_2 + W_3) + Q W_3 \geq PW_1 \tag{44}$$

Unfortunately Equation (44) is not easily interpreted. It can be shown however that there exists relatively simple sufficient conditions. Equation (45) is the simplest sufficient condition.

$$\frac{W_1}{W_3} \leq \left(\frac{1}{P} - 1 \right) \tag{45}$$

A slightly better sufficient condition can be derived incorporating all W_1 and W_3 terms and this is given below by Equation (46).

$$\frac{W_1}{W_3} \leq \frac{3}{P\,(3-P)} - 1 \tag{46}$$

Equation (46) is plotted in Figure 15 to show the area for which $\Delta W > 0$.

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D ~~SECRET~~ SPECIAL HANDLING

SUFFICIENT CONDITION CONSTRAINT
FOR SEQUENTIAL VS. VOTING STRATEGIES

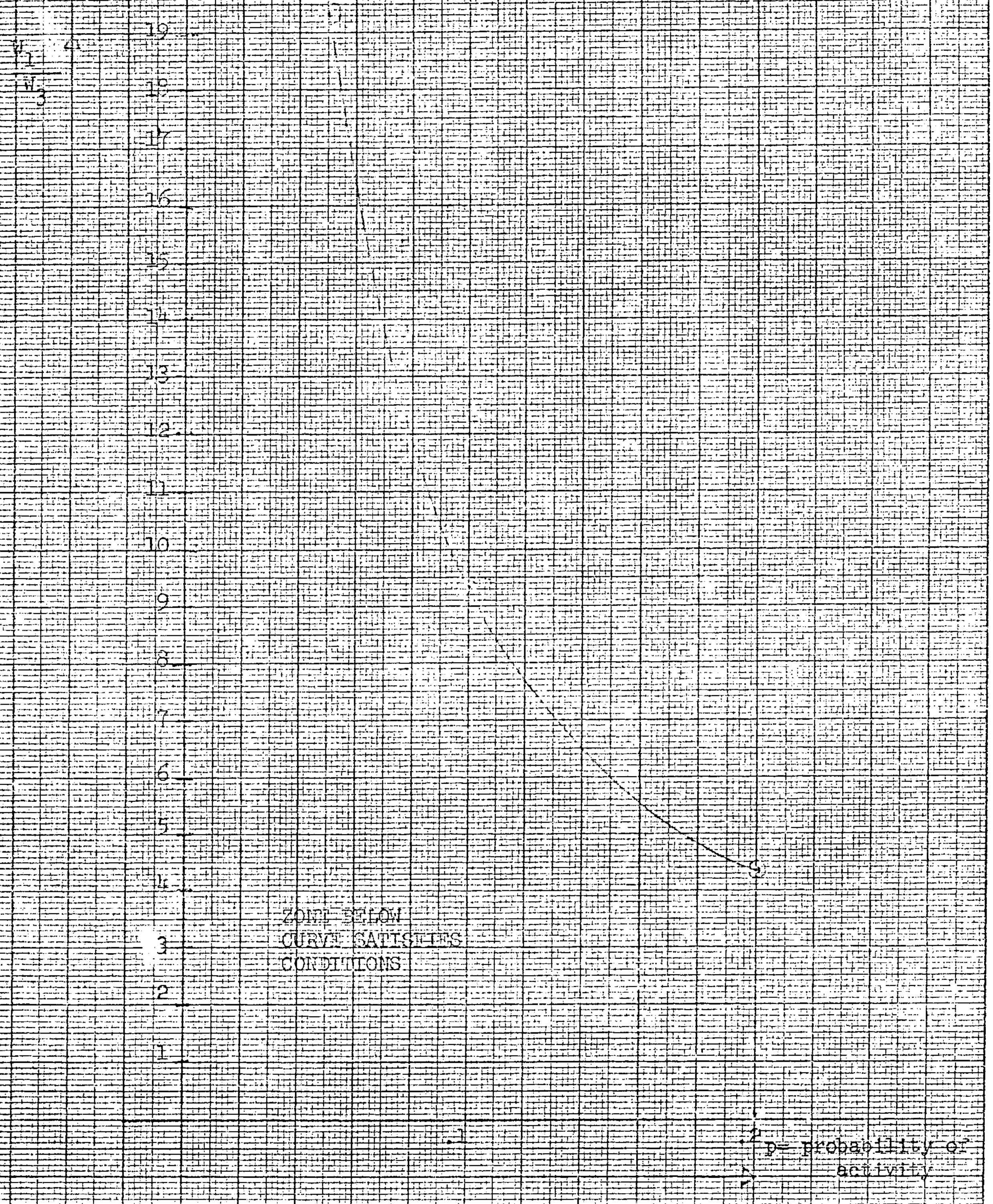

FIGURE 15

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SECTION 12

CONSTRAINTS ON THE SELECTION OF THE DECISION TIME

Consider the case of two alternates. Assume that the alternate targets have a T_V such that there is a range over which t_d may be chosen and specify the bands of this range by $t_{d\ min}$ and $t_{d_{max}}$. Hence, the inequality is given by Equation (45) below.

$$t_{d\ min} \leq t_d \leq t_{d\ max} \qquad (45)$$

Figure (16) below represents the primary optics time line for one primary to be photographed in stereo with three possible cases for t_d.

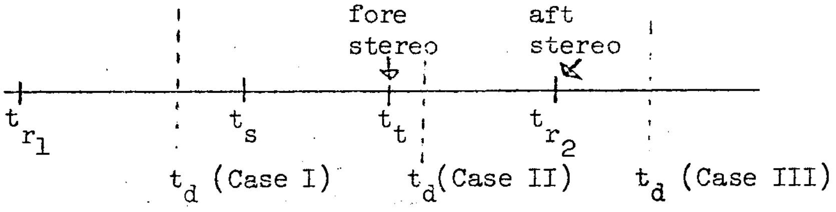

FIGURE (16)

The three cases of decision times illustrated above can be expressed as follows:

Case I $t_d < t_t$ (both photographs lost)

Case II $t_t < t_d < t_r$ (aft photograph lost)

Case III $t_d \geq t_{r_2}$ (primary photographed)

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It should be noted that the constraint expressed by Equation (45) arises solely from the relative geometry of the alternates and the primary optics path. Two other constraints can be derived similar to equation (45) by considering both the effect of interdiction on the primary optics path with respect to loss of successive primary targets and the scheduling of the other ATS to view the primary target.

Consider first the constraint imposed by successor primaries. Assume that the primary optics, if divered to an alternate will return to the primary path upon completion of the photographic sequence of the alternate. It is thus possible to relate the time of interdiction (t_d) to the time of return to the primary path (t_p) for a given alternate. Functionally we have by equation (46) for alternate (i)

$$t_p = f_i \quad (t_d) \tag{46}$$

Having determined t_p it is possible to estimate the loss of score (primaries) caused by interdiction at a particular value of t_d.

Define the term L_i (t_d) to be the expected loss in score by interdicting at t_d. Define the expected score of alternate (i) as E_i (t_d) when interdicted at time t_d. Then we have the further constraint that t_d must satisfy Equation (47) below.

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$$\Delta\, w = E_i\ (t_d) - L_i\,(t_d) \geq 0 \qquad (47)$$

Consider now the constraint imposed by viewing the primary. For any given alternate, there exists some maximum ATS viewing angle which corresponds to some time t_ξ. In general it can be assumed that interdiction will not take place until the primary is observed for activity. This constraint can be stated by Equation (48) below.

$$t_d > t_{\xi_i} \qquad (48)$$

SECTION 13

CONSTRAINTS FOR SEQUENTIALLY PROCESSING ALTERNATES WHICH ARE NOT TIME ORDERED

The constraints which are derived here demonstrate the conditions under which two alternates can be sequentially processed in an optimum manner even though the lower priority alternate occurs first in time. Refer to Figure (17) below.

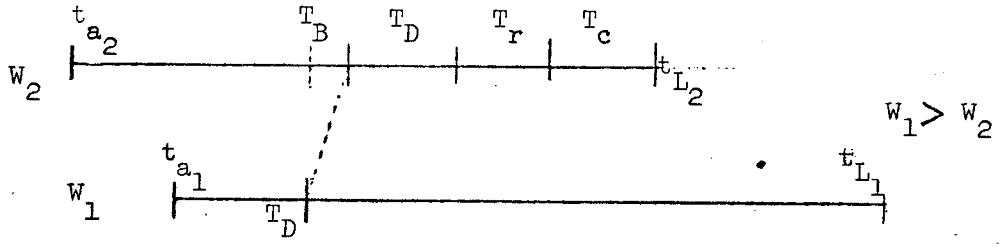

FIGURE (17)

It is possible to write the constraint equation (49) below by assuming that W_1 is viewed first and then W_2 is viewed and if found active must be photographed before t_{L_2}.

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$$t_{a_1} + T_D + T_B + T_D + T_r + T_C \leq t_{L_2} \qquad (49)$$

Utilizing the definition of T_V, it is possible to write Equation (49) in the form of Equations 50 and 51 below.

$$\Delta t_a \leq C_5 - T_r \qquad (50)$$

where $$C_5 = T_V - 2\,T_D - T_B - T_C \qquad (51)$$

Assuming $T_D = 6$, $T_B = 2$, and $T_C = 10$, then the minimum value of T_V is 24 seconds. Hence Equation (50) can be plotted as shown in Figure (17).

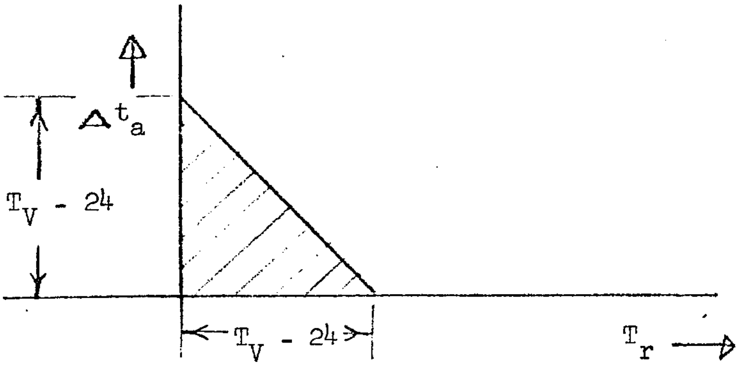

FIGURE (17)

This zone may be superimposed over Figures 10, 11, and 12 to show where it is possible to obtain identical results with either strategy.

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SECTION 14

COMPARISON OF VOTING VERSUS SEQUENTIAL STRATEGIES FOR TWO ALTERNATES

There are four separate cases which need to be examined in order to compare the performance of two strategies for various geometries. These four cases may be represented by Table 3 below. In this Table it is assumed that the expected score of alternate #1 is greater than the expected score of alternate #2. Each case is then considered in detail.

Case	t_a	Sequential Possible	Voting Possible
I	$t_{a_2} > t_{a_1}$	Yes	No
II	$t_{a_2} > t_{a_1}$	Yes	Yes
III	$t_{a_1} > t_{a_2}$	Yes (Non-optimal)	Yes
IV	$t_{a_1} > t_{a_2}$	Yes (Optimal)	Yes

TABLE 3

Case I

Consider the two alternates described by Figure 18 below.

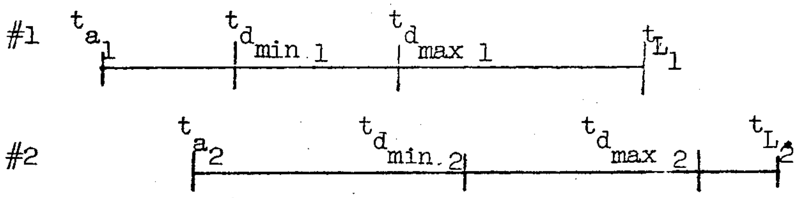

FIGURE (18)

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It is apparent from Figure (18) that there exists no single decision time for both alternates #1 and #2. The alternates can, however, be processed sequentially. The obvious way to recitify this shortcoming in voting is to allow for two decision times, namely t_{d_1} and t_{d_2}. By allowing two decision times, several important concepts are raised and these are discussed below.

a. <u>By introducing two decision times for the two alternates rather than one decision time the inherent mathematical advantage (when it exists) of voting over sequentially processing alternate targets disappears</u>. The net effect of installing two decision times in this example is to really operate in a hybrid mode where alternates are processed sequentially but the actual interdiction of the primary optical path occurs at predetermined times, namely the t_d's.

b. Consider the effects of implementing two t_d's relatively close to each other. Such a situation may very well arise when other constraints mentioned earlier further restrict the placement of the t_d's. Refer to Figure (19) which is the timeline for the ATS.

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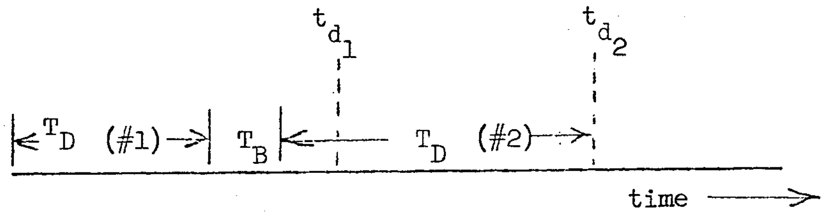

FIGURE (19)

The scenario for such a timeline sequence for an ATS would proceed as follows:

Alternate #1 is presented to the ATS for viewing and the recommended dwell time T_D displayed along with the decision time t_{d_1}. Note, however, if the crew member rejects alternate #1 after the recommended viewing time he will be viewing alternate #2 while the "vote" is being made on alternate #1 (and possibly alternate #2). It is not clear how the display/implementation for this situation would be achieved. Alternatively the crew member may wish to postpone his inputs until after the recommended viewing time T_D. He will then be looking at alternate #2 with less than the required viewing time. Moreover, it is not apparent how this condition of using excessive viewing time for alternate #1 can be displayed to the crew so as to inform them of the consequences on alternate #2.

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c. The effects of two t_d's on the primary optics timeline needs to be examined. Refer to Figure (20). which shows a typical primary optics timeline with the two t_d's superimposed.

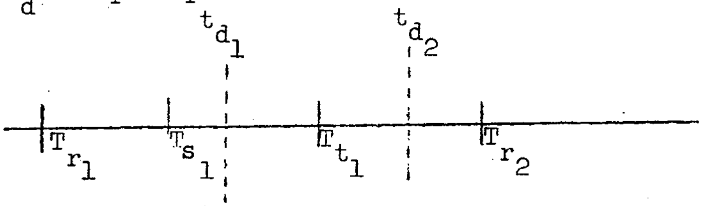

FIGURE (20)

There are six cases to be examined concerning the relative placement of t_{d_1} and t_{d_2} on the primary optics timeline. These can be represented by Table 4, which enumerates the six possible placements of the two decision times.

	TIMELINE INTERVALS		
Sub-Case	T_{r_1} + T_{s_1}	T_{t_1}	T_{r_2}
A	t_{d_1} & t_{d_2}		
B	t_{d_1}	t_{d_2}	
C	t_{d_1}		t_{d_2}
D		t_{d_1} & t_{d_2}	
E		t_{d_1}	t_{d_2}
F			t_{d_1} & t_{d_2}

TABLE 3

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It should be clear that when a decision time falls in the $T_{r_1} + T_{s_1}$ column, then interdiction at that time will cause total loss of primary #1. When a decision time falls in the T_{t_1} column, then interdiction at that time will cause partial loss of primary #1 (fore stereo only) and possible successors. Finally, when a decision time falls in the T_{r_2} column, then interdiction at that time will not cause a loss of primary #1 but will cause a total loss of primary #2.

From the above discussion it follows that even though the alternates may be regarded as "grouped" or in close conflict, they may cause conflict with different primary targets because of decision time constraints.

Case II

Consider the two alternates described by Figure (21) below.

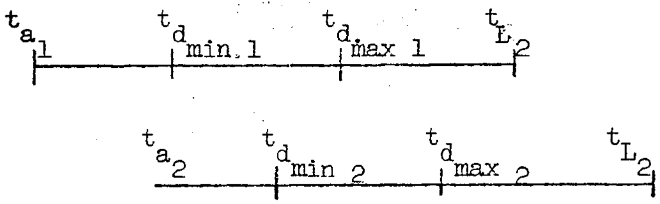

FIGURE 21

It is apparent from Figure 21 that there exists a range of t_d's which simultaneously satisfy both alternates. The only difference in processing these alternates sequentially versus voting lies in

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in the time at which interdiction might take place and hence the photographic angles at which the alternate will be photographed. The sequential processing allows more flexibility for choosing preferred modes of photography for Target #1, since the time of interdiction need not be a function of target #2.

As demonstrated in Reference (4), as long as the alternates are viewed in decending order of weight, then the expected score of the two strategies are identical.

Case III

Consider the two alternates described by Figure 22 below.

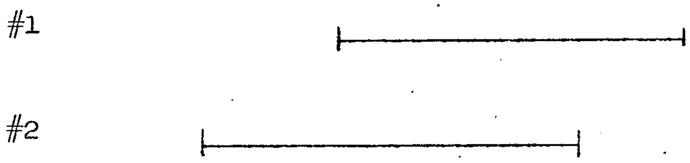

FIGURE 22

For this case, Figure 22 is drawn such that the conditions of Equation (50) are satisfied, i.e., first alternate #1 and then alternate #2 are to be viewed for activity. The expected scores will be identical for both voting and sequential, with the exception

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that there will be a loss in the range of photographic angles with which the primary optics can photograph alternate #2. If this constraint lowers the expected score of the sequence, then it would appear to be better to vote (at least once) than to sequentially process the two alternates.

Case IV

Consider the two alternates described by Figure 22, not satisfying the conditions of Equation (50), i.e., the sequence of #1, #2 is not possible. In this instance it is clearly better to implement the voting strategy.

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SECTION 15

OPTIMIZATION OF ALTERNATE TARGET SELECTION AND DECISION TIME

The analysis presented so far has been concerned primarily with the constraints associated with alternate target and decision time selection. This section briefly discusses some concepts of how these selections may be made. It should be emphasized that much of the criteria for selection will be developed during the early phases of the mission planning software and that it is not the scope of the studies to attack such a problem.

The enchancement (or degradation) of the total probable score when interdicting the primary in favor of an alternate depends upon three factors:

1. The expected score from the alternate. This depends on the priority number, the probability of activity, presence of activity indicators, false alarm and recognition errors, weather, decision time, etc.
2. The expected loss of score from primary path if optics are diverted to an alternate and then returned to the primary after a sequence. This depends on relative geometry and t_d.
3. Visibility of primary path (weather): If obscured, then the loss in item (2) is reduced.

The effect of Item (1) as a function of decision time is shown in Figure 23. This reflects the fact that there is some preferred (optimal) time to take an alternate.

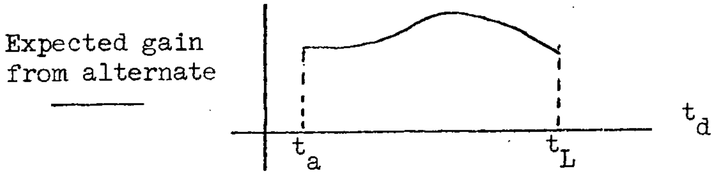

FIGURE 23

The loss in Item (2) may grow larger the longer the decision time is delayed, but may experience discrete discontinuities also. That is, waiting for a period of time may allow completion of one primary sequence while causing a loss in the next primary sequence. The exact shape of the loss curve is unknown, but may be assumed to be represented by Figure 24.

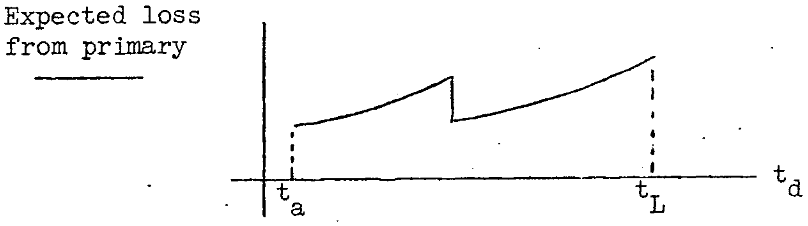

FIGURE 24

Item 3 will add or subtract a bias onto Figure 24. The overall net gain to be expected from interdiction is obtained by combining the three effects, as shown in Figure 25.

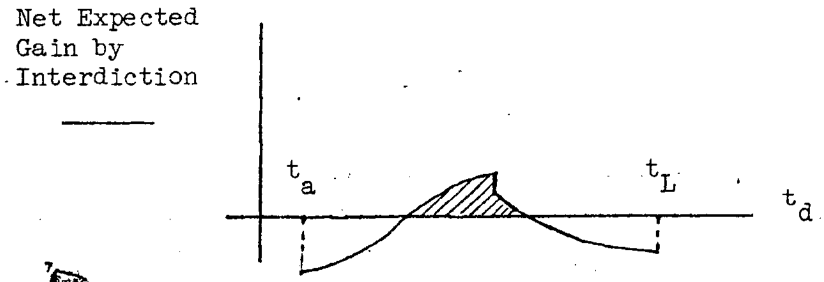

FIGURE 25

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An alternate would not be considered unless Figure 25 has a net positive value for some rante of t_d1 (Inactive low priority alternates loose more on primary than they could add.)

In considering alternate strategies, the weight assigned to alternates should include not only a priority number based on the value of the target, but also the relative geometry dependent term accounting for the probable loss in the primary if interdiction occurs. That is, all considerations of Figure 25 should be accounted for. Most of these considerations could be pre-computed, with the crew supplying inputs on activity and weather. These inputs would, in effect, shift Figure 25 upward or downward. Thus, some targets will never be feasible alternates even if there are no geometrical constraints. (i.e.: no part of Figure 25 positive.) Other targets will be feasible alternates if active, but not if inactive. Thus, they would always be viewed for activity. Still other targets will be feasible alternates, even if inactive, if the primary path is obscured by clouds. There will never be alternates that will always be preferred over the primary. They would be on the primary if they were that important. Thus, Figure 25 will have some negative values under certain conditions for all targets.

SECTION 16

REAL TIME SCHEDULING OF ALTERNATE TARGETS

Consider a timeline for an ATS where there are three alternate targets to be viewed, each with a nominal recommended viewing time. The situation will often arise where the entire recommended viewing time will not be utilized to determine the state of the alternates. In the case of weather it will take only a fractional portion of the time allotted to determine status. After the crew has rejected the alternates originally scheduled for the ATS it would be desirable to present additional alternates, if available, for viewing. The problem with doing this scheduling on the ground lies with the fact that it is not possible to predict how long it will take the crew to observe the alternates and hence the ground cannot preschedule these additional alternates.

The probable solution to this problem will require the ground software to select groups of reserve alternates to be sent to the MOL and let the on-board computer access this pool in real time when the conditions permit additional viewing of alternates. The ability for the on-board computer to select, in real time, additional alternates presents some implementation problems which will need to be studied in as much as no such capability exists to date.

SECTION 17

CONCLUSIONS AND RECOMMENDATIONS

Sections 2 through 10 of this report developed the analytical constraints (necessary and sufficient conditions) for the candidacy of alternate targets utilizing both the voting and sequential strategies. These results were presented graphically, for numerical values assumed for certain system parameters. While the analysis performed here was concerned with only two alternates at the same roll angle, and utilized only one ATS scope, certain extensions can be implied by these studies. The assumptions of having both alternates at the same roll angle may be interpreted as two alternates at different roll angles with the average roll angle being the one used in the analysis. Section 9 demonstrated that it is highly improbable that ATS will ever be able to scheduled to view more than three alternates for a given decision time, hence the limitation of two alternates and an implied primary do not seem restructive when one considers the potential utilization of the system. Finally, the inclusion of a second ATS only strengthens arguments given for utilizing a hybrid voting strategy.

Section 11 of this report is a continuation of the decision strategy analysis presented in the report of Reference (4). In particular it derived the sufficient conditions whereby it is better to examine three alternates sequentially in a non-optimal manner rather than to examine two alternats utilizing a voting strategy.

Section 12 addresses the inverse question of selecting the decision time rather than selecting the alternates. In particular certain general

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criteria are derived which constrain the placement of decision times. Section 15 further considers the optimization of the decision time within the constraints previously described. The general criteria by which decision times will be selected was presented and it was stated that the further development of this criteria will be the responsibility of the mission planning software contractor during early phases of development.

Section 16 is included in this report to demonstrate some of the current shortcomings of the implementation of alternate targets and the need for doing more work in this area.

Section 14 addresses the question of the actual strategy which will be used. In this section it is demonstrated that by judiciously selecting additional decision times it is possible to eliminate any requirement for sequentially processing. It should be emphasized, however, that when decision times are placed relatively close together then the statistical performance of the system approaches that of the sequential method. The primary concept, however, is that decision times are placed on the time line so as to guarantee availability of alternates, and decision times are not necessarily selected based upon geometric groupings of targets.

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The implementation of utilizing decision times in this manner will require only minor modifications to the existing on-board computer software.

Such modifications would go to simple changes in uplink message data card format, i.e. appropriate flags, and to the on-board computer logic. With respect to the logic modification, it is proposed that no change be made in the manner the computer operates on groups containing primaries. Additional logic, however, will be required to recognize the flag for and operate on the groups containing alternates alone. Because the operational program sequence involves a functional deletion, i.e. if there are no valid activity inputs prior to t_d, no specific commands would be given to the primary optics at t_d, the necessary logic modifications appear to be small.

It is strongly recommended that these minor modifications be incorporated into the on-board computer software at the earliest possible date. Upon selection of the mission planning software contractor he should be directed to spend a major portion of his effort to further define and consider implementation of the overall problem of alternate target selection.