NASA Technical Memorandum 80098

(NASA-TM-80098) A SIMULATION INVESTIGATION OF COCKPIT DISPLAY OF AIRCRAFT TRAFFIC DURING CURVED, DESCENDING, DECELERATING APPROACHES (NASA) 34 p HC A03/MF A01 CSCL 01D G3/06

N79-26052

Unclas 26026

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MAY 1979

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SUMMARY

This report presents the results of a simulation experiment involving the evaluation of cockpit display of aircraft traffic information. The experiment was conducted using taped time dependent, non-interactive traffic in an approach to landing situation and two levels of pilot control modes: 3-D automatic and computer augmented control. The tests involved two cases: the simulation aircraft flew approach paths which (a) followed another aircraft in between two other aircraft and (b) merged between two other aircraft. Speed control via manual throttles was used in all tests (path stretching was not allowed for maintaining separation between aircraft). The approaches were conducted while the simulation aircraft was conducting a curved, descending, decelerating approach to landing. Performance data sets were examined and subjective opinions regarding workload were gathered. Traffic positioning was varied to further evaluate the test subjects' monitoring performance.

The results indicate that reasonable approach task performance can be maintained when traffic information is displayed on an RNAV-type map for both merge and follow type situations. Measurable differences in mean and standard deviations of speed profile performance were determined for the inclusion of traffic positions into the display. Cognizance of traffic separation was established within the tests involving traffic situations and a trend toward reducing separation where large gaps existed was noted. Level of control mode effects produced mixed results. Subjective data indicated a sensitivity to control mode levels. Overall, the results are favorable toward presentation of traffic information during fixed path, curved, descending, decelerating approaches.

INTRODUCTION

For many years proposals have been made to display traffic information in the cockpit of aircraft. A sizable amount of work has been performed by various organizations. These research efforts have addressed many aspects of cockpit display of traffic information. An example is the study conducted by the Massachusetts Institute of Technology, references 1 and 2. The current research in advanced cockpit design of commercial aircraft, as evidenced by the Terminal Configured Vehicle Program (ref. 3) at Langley Research Center and the Short-Haul/Aircraft Research (ref. 4) at Ames Research Center, has increased interest in the Cockpit Display of Traffic Information (CDTI).

In spite of the excellent work presented in references 1 and 2 and elsewhere, many fundamental issues remain to be researched, especially in the conceptual aspects of future operations and procedures involving advanced ATC and aircraft proposals. Addition of traffic information to existing RNAV advanced electronic display formats is an issue which needs to be examined as a function of advanced control systems, curved, descending, short final paths, and merge or spacing situations. The experiments described herein address these situations in a limited and preliminary manner.

With the advanced features of the TCV 737 aft deck (ref. 3), experimental arrival routes can be successfully flown under a variety of control system levels. These experimental arrival paths have an implied speed profile due to the specified ground speeds at each waypoint. The speed profile can be viewed as deterministic (deceleration assumed constant between waypoints) and hence can be converted into a time profile given one fixed time in the path. Thus, each waypoint can be specified in time units if any entry time is given.

With the above capability, the question addressed by this experimental study was basically: Does the presentation of traffic information on the RNAV display affect the path time profile when the pilot is part of the control loop? In order to obtain some answers toward this objective, a two-fold approach was undertaken. First, a means of providing realistic traffic was sought for the simulation with the constraint that whatever was used in the simulation test could also be provided aboard the aircraft. Second, an experiment was sought which centered about curved, descending, decelerating, short final paths involving: (1) a situation in which a lead aircraft was placed on a common arrival route and ahead of the simulated TCV 737 aircraft (a follow case), and (2) a situation in which all other aircraft were on adjoining arrival routes (a merge case).

Both aspects of this approach were accomplished and the preliminary experiment was conducted using taped time dependent, non-interactive traffic in an approach to landing situation. Two levels of pilot control modes (3-D automatic and computer augmented manual) were included and speed control via manual throttles was used throughout the experiment. Speed profile accuracy, hence timing and separation values, at the outer fix was examined. Subjective opinions regarding workload were gathered. Traffic positioning was varied to substantiate quantitatively the monitoring of traffic by the test subject. Since the author served as the sole evaluation test subject, the results should be considered preliminary.

EXPERIMENTAL SYSTEM DESCRIPTION

Real-Time Simulation Configurations

Basic Aircraft.- The real-time TCV 737 simulation contained a baseline nonlinear representation of the B737-100 aircraft. The full flight envelope has been modeled via two and three variable table look-up functions for the aerodynamic coefficients. Flaps, speed brakes, gear, and throttle operations were simulated based upon the known aircraft characteristics. Engine dynamics regarding spool up and down performances have been matched to actual flight data. Control surfaces in the simulator have been modeled in detail including such items as lags, hystersis loops, etc.

Controls.- The TCV Simulator is equipped with a multi-level advanced control system. All levels include computer feeds to the control surfaces; even the so-called "manual" mode is really a "fly-by-wire" computer augmented mode. The levels of control available range from full automatic, both navigational and autoland, to a pilot "manual" mode.

There are two "manual" modes selectable by the pilot. As stated, each is computer augmented and is a form of control wheel steering (CWS). Each contains a rate command proportional to wheel and column inputs plus a hold condition upon neutralization of the controller input. Both modes, for example, contain a bank angle hold for steady turns. The major difference between the two modes, ATT CWS and VEL CWS, lies in the aircraft states that are being maintained or primarily maneuvered. In the ATT CWS mode control, control states are pitch in the longitudinal axis, and heading in the lateral axis whereas in the VEL CWS, the prime states being controlled are in the inertial directions of the velocity vector of the aircraft (namely the flight path angle γ_I and the track angle along the Earth). Note that the magnitude of the velocity vector is not a principal state being controlled here but rather is principally a function of other factors such as winds and throttle settings (fig. 1).

The navigational modes of control range from horizontal path following (2D), with flight path angle selectable, to horizontal path and vertical path following (3D) to a full 3D guidance plus speed profile control (4D). Of course, each mode requires the adequate definition of the desired flight path such as latitude and longitude, altitude, and ground speed at waypoints. In the latter mode (4D), the throttles are driven automatically with any delta speed change being obtained by a constant positive or negative acceleration.

Autothrottles are available via the control mode panel and an autoland system that includes decrab and flare can be employed when within either MLS or ILS coverage.

Displays.- The TCV Simulator contains electronic displays as primary sources of information to the pilot. One electronic display is devoted to attitude-direction type information, see Figure 2. Basically, the "stability" of the flight is maintained through this information. Note the scales on the left and bottom of Figure 2. These scales, when the display is under cruise mode, represent deviations in meters from the defined path. The left scale indicates vertical deviation between values of ±30.48 meters and the bottom scale indicates lateral offsets between values of ±152.4 meters. A more detailed description of the electronic attitude direction indicator (EADI) can be found in references 5 and 6.

The second electronic display is primarily an RNAV display device. The 2-dimensional map associated with waypoints is graphically illustrated along with alpha-numeric labels, see Figure 3. The extreme upper position of the display contains a tape scale and pointer for track angle information. Alpha-numerics in the extreme bottom left- and right-hand corners indicate control mode selection, map scale, and ground speed. There is a mode control panel associated with the display which governs the map scale, orientation, and information options to be presented. Information options are programmed on the on/off buttons. Other aircraft or traffic targets are not a standard feature of this map display but were added specifically for this study and controlled in the cockpit through two of the on/off buttons with their regular functions deleted. The outline of the approach path for the traffic is presented as part of the traffic function. Map scales are controlled via an eight position rotary switch and range from 0.39 n. mi./cm (1 n. mi./inch) to 12.5 n. mi./cm (32 n. mi./inch). Track-up orientation is standard for flight work and a north-up orientation is sometimes used for pre-takeoff review of the flight plan. All simulator work was primarily track-up oriented.

A trend vector is available on the map and presents the predicted path 30, 60, and 90 seconds ahead of the aircraft. One exception on the trend vector occurs when 0.39 n. mi./cm (1 n. mi./inch) scale is selected, in that only 30 seconds of prediction is available. Coupled with the trend vector is a straight line along the track of the aircraft for the full scale of the map display. For this experiment, a map scale of 0.78 n. mi./cm (2 n. mi./inch) was used with a track-up mode.

Approach Paths and Traffic Flow

The two approach paths, DORA 1 and DORA 2, which are experimental Standard Terminal Arrival Routes (STAR's), are shown in Figures 4 and 5. These STAR's were selected from a group of experimental STAR designs formulated by the Terminal Configured Vehicle Project Office of Langley for an MLS demonstration at Montreal, Canada, during spring of 1978. The waypoints of both selected paths are co-located and only differ in the vertical plane and ground speeds. The alternate or dashed paths shown in Figures 6 and 7 are other arrival routes for the runway. One such route was a straight-in approach path, and the other was an offset approach with an intercept of the straight-in portion slightly less than 6 n. mi. out. Traffic was generated for each of these routes.

The traffic was generated by flying the real-time simulator along these alternate routes and the STAR. The necessary state variables were recorded for reproduction at 4-second intervals. Merging these recordings provided a master tape which contained several other aircraft that were spaced in a predesigned manner. The combined presentation of traffic, alternate route structure, and STAR geometry was displayed to the pilot on the RNAV display device.

The two STAR routes and combined traffic recordings were labeled case A and case B. The objectives associated with case A were: (1) to obtain subjective opinion regarding the monitoring of traffic during an approach, and (2) to measure the time/speed management of a curved, descending, decelerating, short final approach following a lead aircraft in the approach situation. The scenario contained three canned traffic aircraft and the "live" simulation, Figure 6. The "live" simulation was sequenced number three in the landing pattern. The number one sequenced aircraft appears along the straight approach route and the number two aircraft appears along the DORA 1 STAR ahead of the "live" simulator aircraft, thus providing lead traffic. The number four sequenced aircraft was flown on the intersecting alternate path. The relative positions of the traffic and the "live" simulation aircraft as shown in Figure 6 represent the initialization of traffic tapes in case A.

The second approach path and traffic scenario, case B, Figure 7, contained two traffic aircraft plus the "live" simulator aircraft. The objectives of the case B design were: (1) to obtain subjective opinion regarding the monitoring of traffic during an approach, and (2) to measure the time/speed management of a curved, descending, decelerating, short final arrival route with a merge between traffic arriving on an intersecting route. The "live" simulated aircraft was assigned the number two landing sequence slot. The number one aircraft for landing was arriving via the straight-in approach path and the number three aircraft appeared along the 6 n. mi. intercept approach path. The task required a merge of the "live" simulator aircraft adequately spaced (3 m. mi. minimum) between the two other aircraft at approximately 3 n. mi.

from threshold. Figure 7 shows the initial positions of traffic and the simulation aircraft of the above scenario at the start of traffic tapes. Figure 8 contains a photograph of this scene as presented on the RNAV display.

Range and bearings relative to the "live" simulator position for both case A and case B test conditions are given in Tables I and II for initial orientation of other aircraft, assuming the "live" aircraft at waypoint QUARY. The traffic recordings for both situations described above were transferred to cassette tapes and a method to allow the insertion of this information into the RNAV display on the flight aircraft was created for future flight test evaluations.

Experimental Design and Test Procedure

The experiment design matrix was augmented as the experiment proceeded and results were obtained. In total, the design took on three phases. Initially the tests involved a single control mode for automatic spatial path control, a 3-D navigation mode. Manual throttles were used for compliance with the speed profile and all initialization of traffic was begun at waypoint QUARY. The no traffic runs were randomly intermixed with the display of traffic runs. Eight trials were conducted for each case.

The operating instructions to the single test subject were to maintain the STAR route speed profile for the no traffic trials and the traffic trials. Manual throttle manipulation was required throughout the experiment as well as cognizance of other traffic positions when traffic was displayed. The test subject was also instructed to maintain, as a safety standard, at least a 3 n. mi. separation between his aircraft and other aircraft. The safety standard was to have precedence over maintaining a speed profile but did not imply that a 3 n. mi. separation station keeping was the principal task.

A second phase of experiments was developed in order to further ascertain whether or not the test subject was effectively monitoring the movement and spacing of the traffic. The start of the recorded data representing traffic positions was varied. A normal start was randomly mixed with a 10-second lead start and a 10-second lag start. This procedure was applied to both case A and case B. In these tests spacing was emphasized but again a 3 n. mi. separation was only a safety standard, not the primary goal. Presentation of traffic on the RNAV display was suppressed until 15 seconds after passage of waypoint QUARY in these runs so that a normal, lead, or lag start of traffic could not be determined solely by the appearance of traffic on the display. Five trials for each of the three start conditions were conducted in this phase of experimentation.

The third phase involved repeating the above two phases using velocity control wheel steering (VEL CWS) and manual throttles. It was assumed that this expansion of the controls factor would provide some measure of the effect of increased workload on the test subject. The test runs were alternated between case A and case B and the type of starts were randomly selected without test subject knowledge. However, the choice of case A or case B was known.

Measurements

Time at various points along the path and range to other traffic were recorded as the "live" aircraft changed legs (waypoints) in the designated path. Time and range to other traffic was also recorded. Continuous strip charts were maintained for each run. These recordings included time histories of range to each traffic aircraft, distance to go along the designated path, ground speed, and time error along path. Subjective opinion was gathered during all of the experiment.

RESULTS AND DISCUSSION

The standard for performance (performance implies time) was established by allowing the simulated aircraft to operate in the 4-D navigation mode along the prescribed path. The same initial conditions were used for all trials along a given path. For case A, the established standard was 180 seconds for the aircraft to traverse between waypoints QUARY and NORMA. Case B standard time was 192 seconds between waypoints QUARY and NORMA. Waypoint NORMA was chosen as the central examination point since it represents approximately 3 n. mi. from the touchdown zone and was the turnpoint toward final approach leg. Thus, the portions of focus of either case A or case B during the following discussion was from approximate start of traffic display to turn toward final approach (waypoint QUARY to waypoint NORMA).

The format for grouping results was to treat each case as a separate entity with regard to the analytic measures and to group the subjective data collectively. Both time and distance results were available. However, since the traffic tapes are non-interactive, these measures are really linearly dependent and therefore only distance is presented.

Case A

Table III presents the mean distances and their associated standard deviations for case A data. These results are grouped between (1) with and without traffic presentation for a normal start of the traffic, Table IIIa, and (2) various start positions for the taped traffic, Table IIIb. The tables span the two control levels associated with the experiment.

The results in Table IIIa show a pattern of increased separation for the condition where traffic was presented. Analysis of variance (ANOVA) testing indicated that the difference between with and without traffic presentation was significant above the 95 percent confidence level. The comparison of control level also indicated significant differences above the 95 percent confidence level. The interaction term did not indicate a significant difference. Examination of the standard deviations showed a significant difference between the two traffic cases within the manual control level but not for the 3-D control level.

The indications presented by these data are that the test subject was conscious of traffic and thus a backing off or increased separation effect occurred. An increase in the variability of separation was detected when traffic was presented in the manual control level results.

The data shown in Table IIIb provide a comparison of pilot interaction with the presentation of traffic when the spacing of the traffic was consistent with and askew with the proposed arrival route. In order to illustrate what happens when the tape driving the other traffic was started normally or delayed by 10 seconds or started early by 10 seconds, Figure 9 shows the theoretical spacing for each of the three conditions when examired at waypoint NORMA. With case A, the aircraft was assumed to arrive at the theoretical slot shown in this figure. As can be readily seen in the lag case results in Table IIIb, both control configurations show a marked deviation from the theoretical slot spacing of 2.75 n. mi. In order to achieve adequate spacing, as the results indicate, the test subject had to monitor the positioning of the other traffic and make deviations in terms of speed control from the proposed arrival path. This is interpreted as a further indication that the traffic positions were being effectively monitored.

The results of the lead trials show a very slight deviation from the theoretical spacing associated with this type of start, but not as large as those in the lag start trials. However, the spacing afforded by this type of start did not exert any spacing pressure (such as a 3 n. mi. violation) on the simulation aircraft and, thus, there was no incentive to make adjustments other than realizing that there was a larger gap between the simulation aircraft and the traffic in front. An indication of the difficulty of the lag start, relative to the other two traffic arrangements in Table IIIb, can be seen in the increased variation over the other two starts, even though this variation was not found to be significantly different.

The lag start appears to be the most difficult condition for the case A portion of the study and these starts contain the most variation in data, but the data indicate a cognizance of traffic with corrective action toward maintaining the 3 n. mi. safety standard.

Case B

The mean distances and their associated standard deviations for case B are presented in Table IV. These results are grouped in the same manner as those in case A.

The results of Table IVa, when compared to the standard, show a trend toward reducing the spacing between aircraft. Realizing that the proposed slot provides a spacing gap of 3.75 n. mi., the slight trend was toward less separation, although that was not the primary task.

The results of ANOVA testing were that control level effects were not significantly different at or above the 90 percent confidence level, but differences between with and without traffic presentation were found to be significant at a confidence level of 94 percent. Again the interaction term did not show a significant difference. As was the result in case A data, the standard deviations associated with manual control were significantly different. In addition, for case B the standard deviations associated with automatic (3D) were also found to be significantly different.

These results indicate that the presentation of traffic produces a measurable effect on the path following task, and when traffic was present there are apparent trends toward closing the gap between aircraft. An increased variability occurs when traffic monitoring was required.

Table IVb presents data grouped in accord with various start points of the fixed (in time) traffic tape. The theoretical spacing slots for the simulator aircraft under the three different conditions are shown in Figure 10. Again, the standard time was assumed to determine the theoretical slots. Observing the data in Table IVb, the general trend is toward reducing the separation with regard to the theoretical slot position. In general, more of a trend toward closing the spacing gap was noted within the manual control mode.

In the lead start, where there was a wide margin between the front traffic and the simulator aircraft, reductions in spacing occurred for both control configurations. Lag and normal start results also indicate a spacing reduction but not of the magnitude observed in the lead case. The trend toward reduction in spacing is consistent although spacing was not the primary task. These trends are interpreted as evidence of cognizance of traffic positions. The standard deviations comparison indicates that the lag start was again the most difficult. Testing indicates that the differences between the lag and normal standard deviations are significant at the 95 percent confidence level.

Subjective Results

The subjective data did not result from a formal questionnaire but were a general gathering of informal feelings following various sessions. The workload between control mode configurations was a clear issue and was, as expected, notably higher with the manual control mode. It was felt that the follow situation, case A, was more demanding than the merge situation, case B, and when coupled with the manual control mode, a marginally acceptable condition existed. This conclusion must be tempered with the fact that a learning effect seems to be embedded within the manual control mode trials, as the opinion of acceptability seemed to be shifting for the better in later sessions.

CONCLUDING REMARKS

The two cases, A and B, represented different situations with which the test subject had to cope, but certain trends were established that were very similar. Significant differences in speed profile performance were noted in both cases for the presentation of traffic. There was also a significant difference in standard deviations noted under both cases when traffic was presented. The lag start, where traffic was presented with less separation than normal, proved to present the most difficult task in both cases.

Control level differences were indicated only in the case A or follow situation. Variability differences between control levels were not consistently in favor of one mode although subjective opinion indicated a definite separation on the basis of workload in favor of the automatic.

A trend toward reducing separation in each of the situations in which a safety standard violation was not readily apparent was noted. There seemed to be a natural tendency toward reducing the spacing gap, even when this was not the primary task, when positions of traffic were presented. Further experiments would be required to substantiate this effect. Overall, the results definitely show that presentation of traffic positions was observed and comprehended fairly well.

The method of providing traffic to the displayed, pre-recorded time based records of actual simulation flights, has shown itself to be a valuable experimental tool within its apparent limitations and assumptions. This concept has given the experiment designer a simple means of arranging a realistically flown, repeatable situation. Within the limitation of assumption that the traffic is non-interactive, statistical measures can be accumulated without the additional burden of accounting for randomness in the traffic presentation. This pre-recorded data can be converted to proper formats and placed upon cassette tapes for use in compatible flight vehicles. Whereas the results of this preliminary experiment have produced what are believed to be valid trends, a note of caution should be observed in that a single test subject was used and further testing would be required for broadly applicable results.

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TABLE I.- CASE A INITIAL RANGE AND BEARING OF TRAFFIC RELATIVE TO LIVE SIMULATION AIRCRAFT.

Traffic (Sequenced)	Range (n. mi.)	Bearing (deg)
A/C 1	7.2	263 (9 o'clock)
A/C 2	3.3	287 (10 o'clock)
A/C 4	10.6	003 (12 o'clock)

TABLE II.- CASE B INITIAL RANGE AND BEARING OF TRAFFIC RELATIVE TO LIVE SIMULATION AIRCRAFT.

Traffic (Sequenced)	Range (n. mi.)	Bearing (deg)
A/C 1	7.1	289 (10 o'clock)
A/C 3	10.6	003 (12 o'clock)

TABLE III.- CASE A RESULTS

Standard = 3.1 n. mi.

	Without Traffic	With Traffic
Manual (VEL CWS)	$\bar{x}$ = 3.07 s = 0.047 n = 8	$\bar{x}$ = 3.20 s = 0.091 n = 8
Automatic (3D)	$\bar{x}$ = 2.99 s = 0.073 n = 8	$\bar{x}$ = 3.07 s = 0.077 n = 8

(a) Normal start of traffic grouping.

	Standard = 3.1 n. mi. Normal	Standard = 3.4 n. mi. Lead	Standard = 2.75 n. mi. Lag
Manual (VEL CWS)	$\bar{x}$ = 3.20 s = 0.091 n = 8	$\bar{x}$ = 3.32 s = 0.089 n = 5	$\bar{x}$ = 2.96 s = 0.110 n = 5
Automatic (3D)	$\bar{x}$ = 3.07 s = 0.077 n = 8	$\bar{x}$ = 3.26 s = 0.071 n = 5	$\bar{x}$ = 3.03 s = 0.084 n = 5

(b) Variable start of traffic grouping.

TABLE IV.- CASE B RESULTS

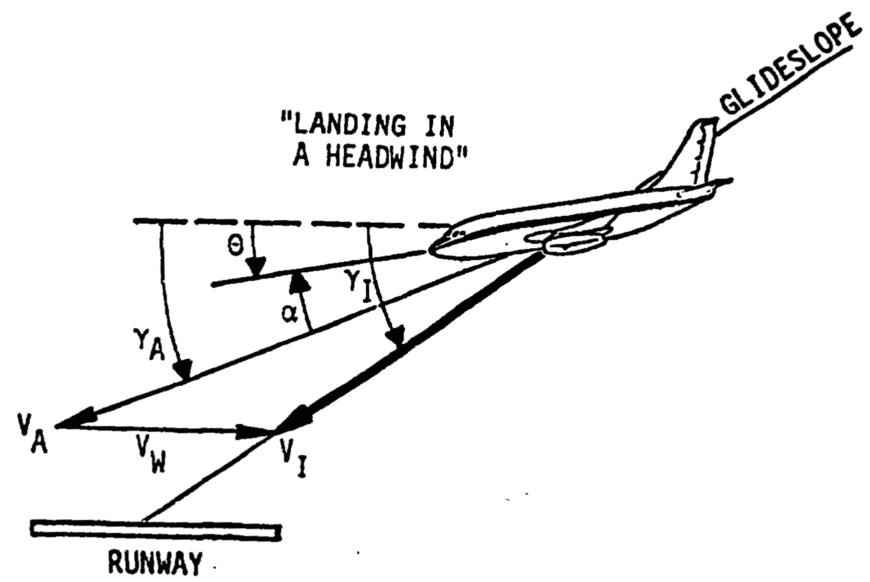
Standard = 3.75 n. mi.

	Without Traffic	With Traffic
Manual (VEL CWS)	x = 3.71 s = 0.068 n = 8	x = 3.56 s = 0.125 n = 8
Automatic (3D)	x = 3.74 s = 0.057 n = 8	x = 3.68 s = 0.139 n = 8

(a) Normal start of traffic grouping.

	Standard = 3.75 n. mi.	Standard = 4.1 n. mi.	Standard = 3.4 n. mi.
	Normal	Lead	Lag
Manual (VEL CWS)	x = 3.56 s = 0.125 n = 8	x = 3.76 s = 0.126 n = 5	x = 3.24 s = 0.161 n = 5
Automatic (3D)	x = 3.68 s = 0.139 n = 8	x = 3.69 s = 0.108 n = 5	x = 3.38 s = 0.144 n = 5

(b) Variable start of traffic grouping.



V_W = WIND VELOCITY VECTOR

V_A = AIRSPEED VELOCITY VECTOR

V_I = INERTIAL VELOCITY VECTOR

γ_I = INERTIAL FLIGHT PATH ANGLE

γ_A = AIR MASS REFERENCED FLIGHT PATH ANGLE

α = ANGLE OF ATTACK

Θ = PITCH ANGLE

Figure 1.- Velocity vector.

Figure 2.- EADI display.

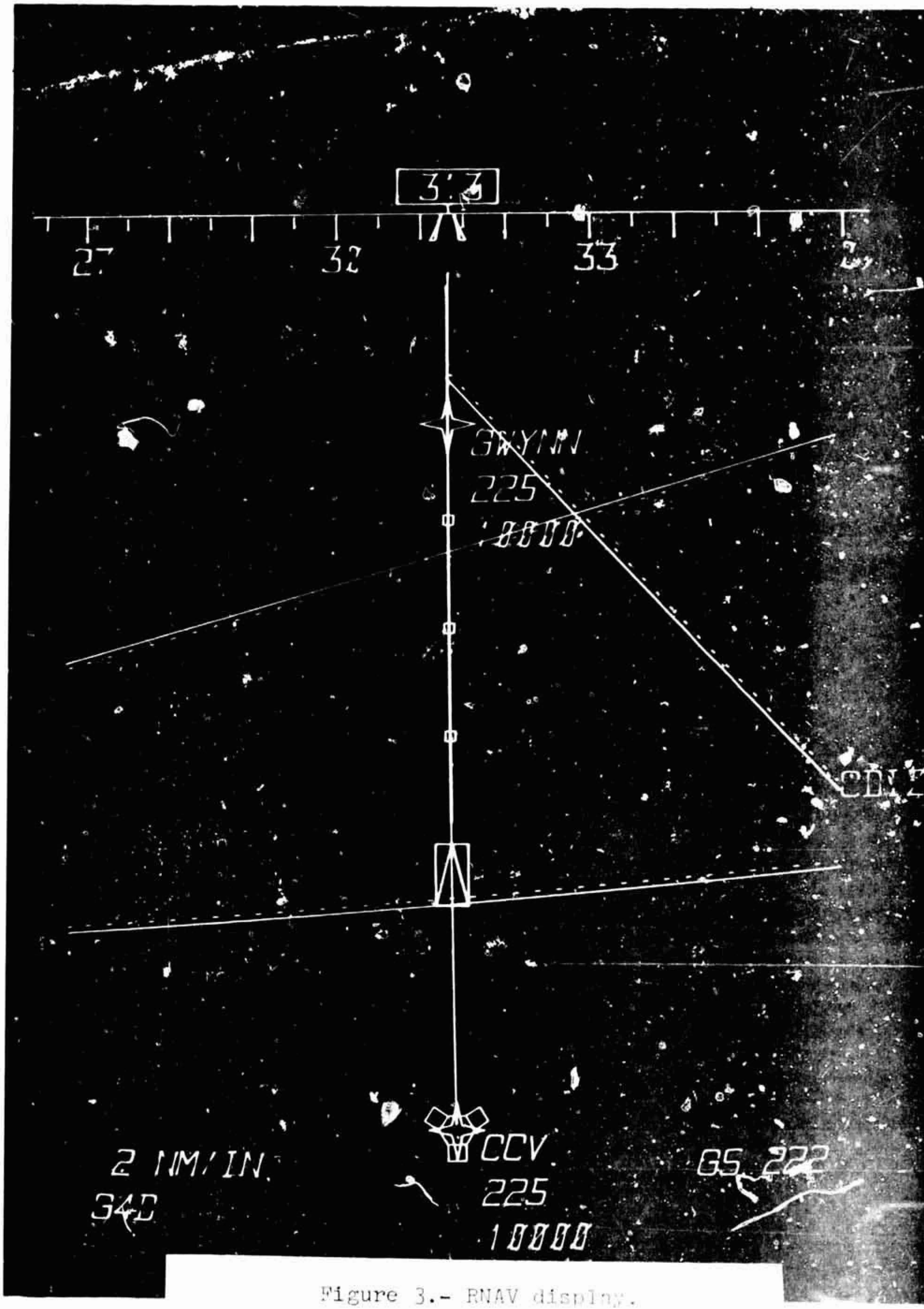


Figure 3.- RNAV display.

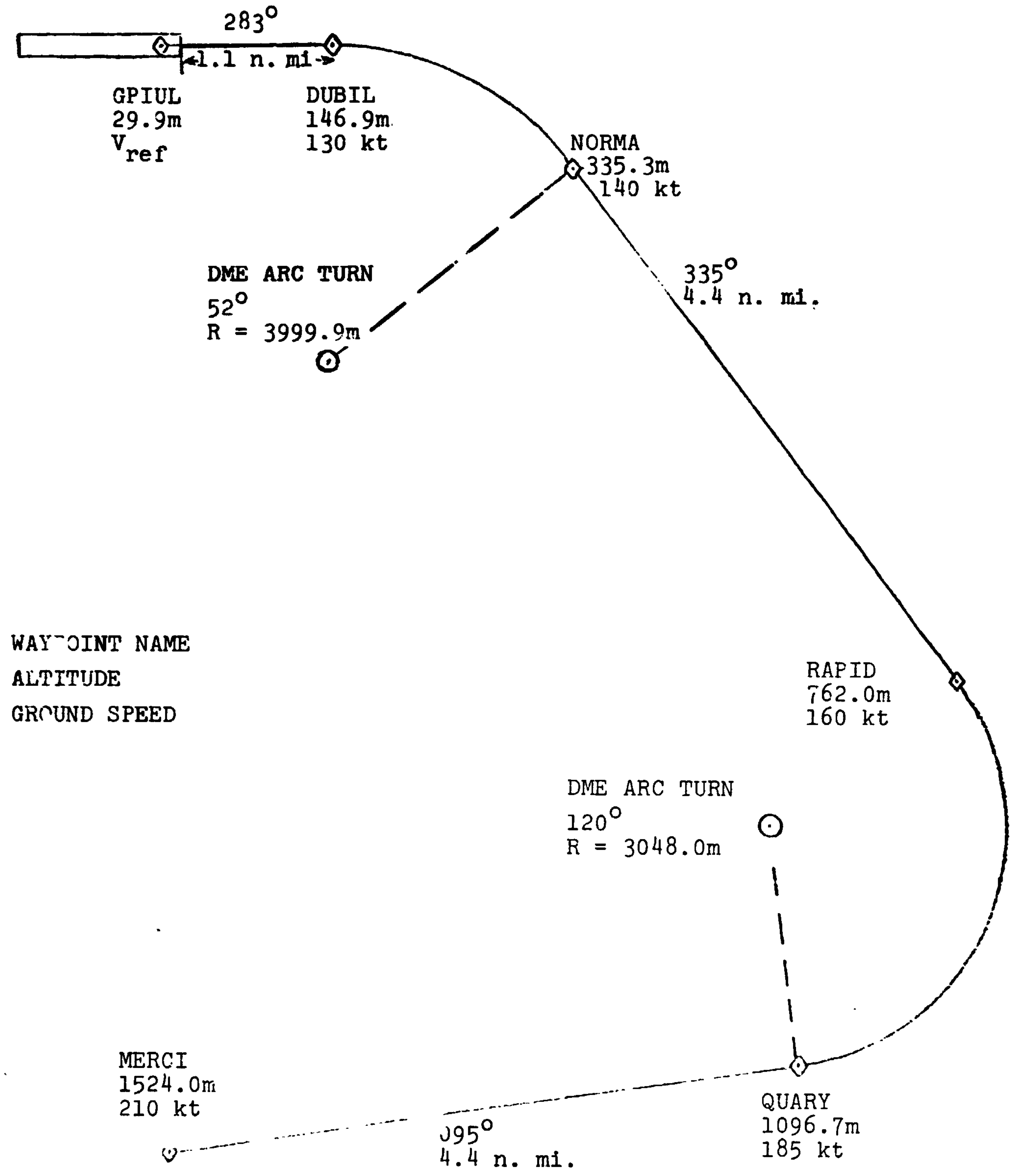


Figure 4.- STAR DORA 1.

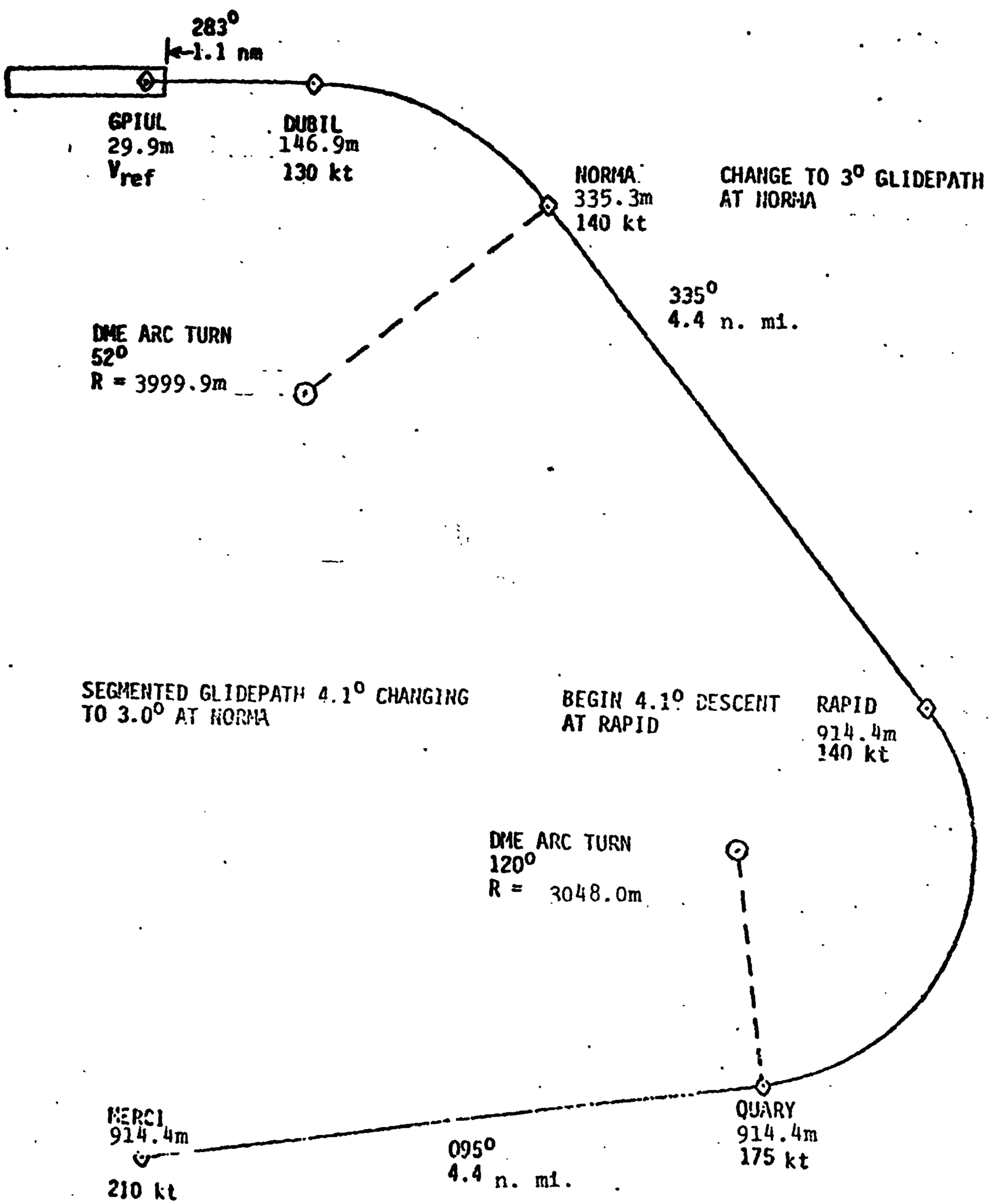


Figure 5 - STAR DORA 2.

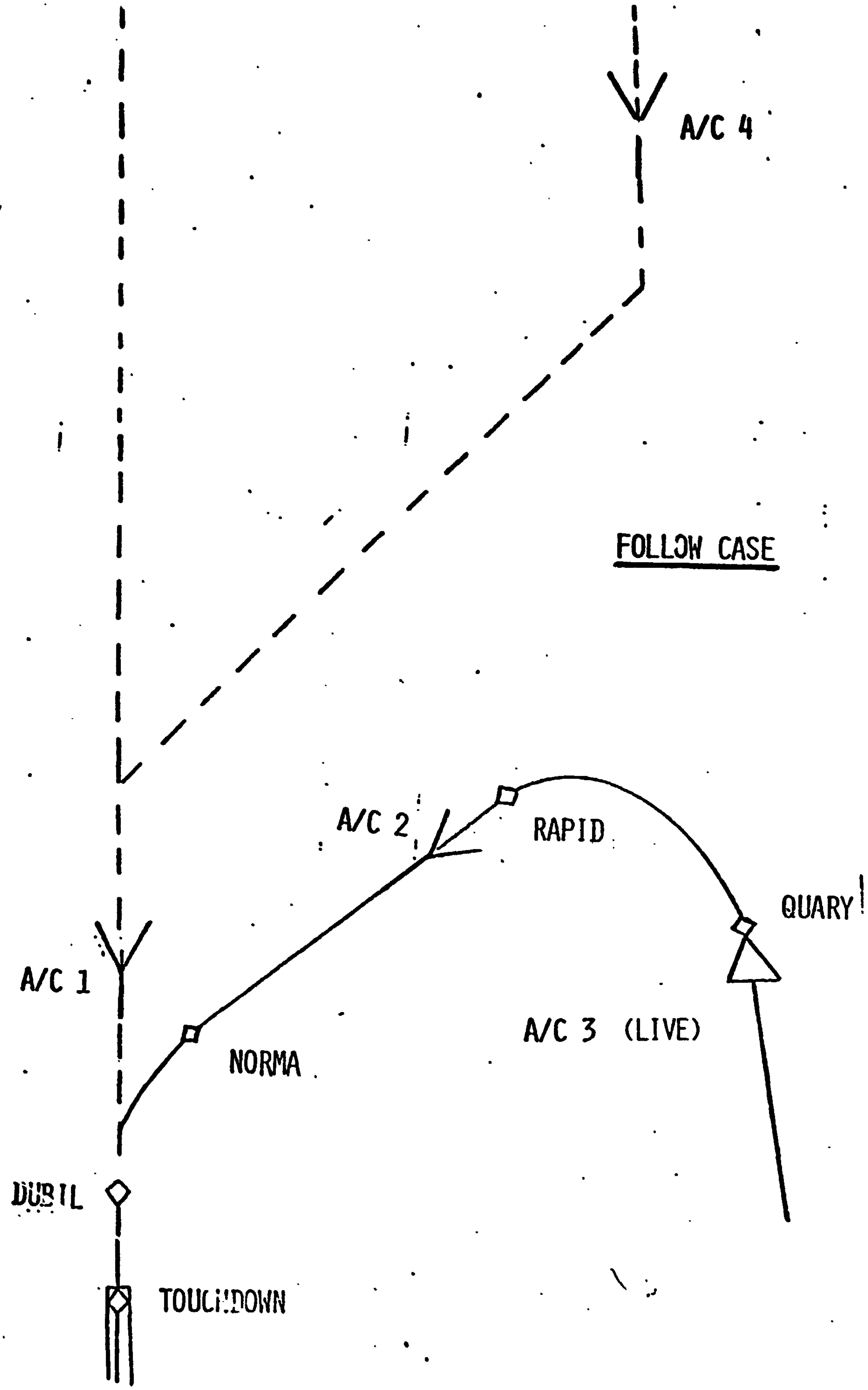


Figure 6.- Initial positions for case A.

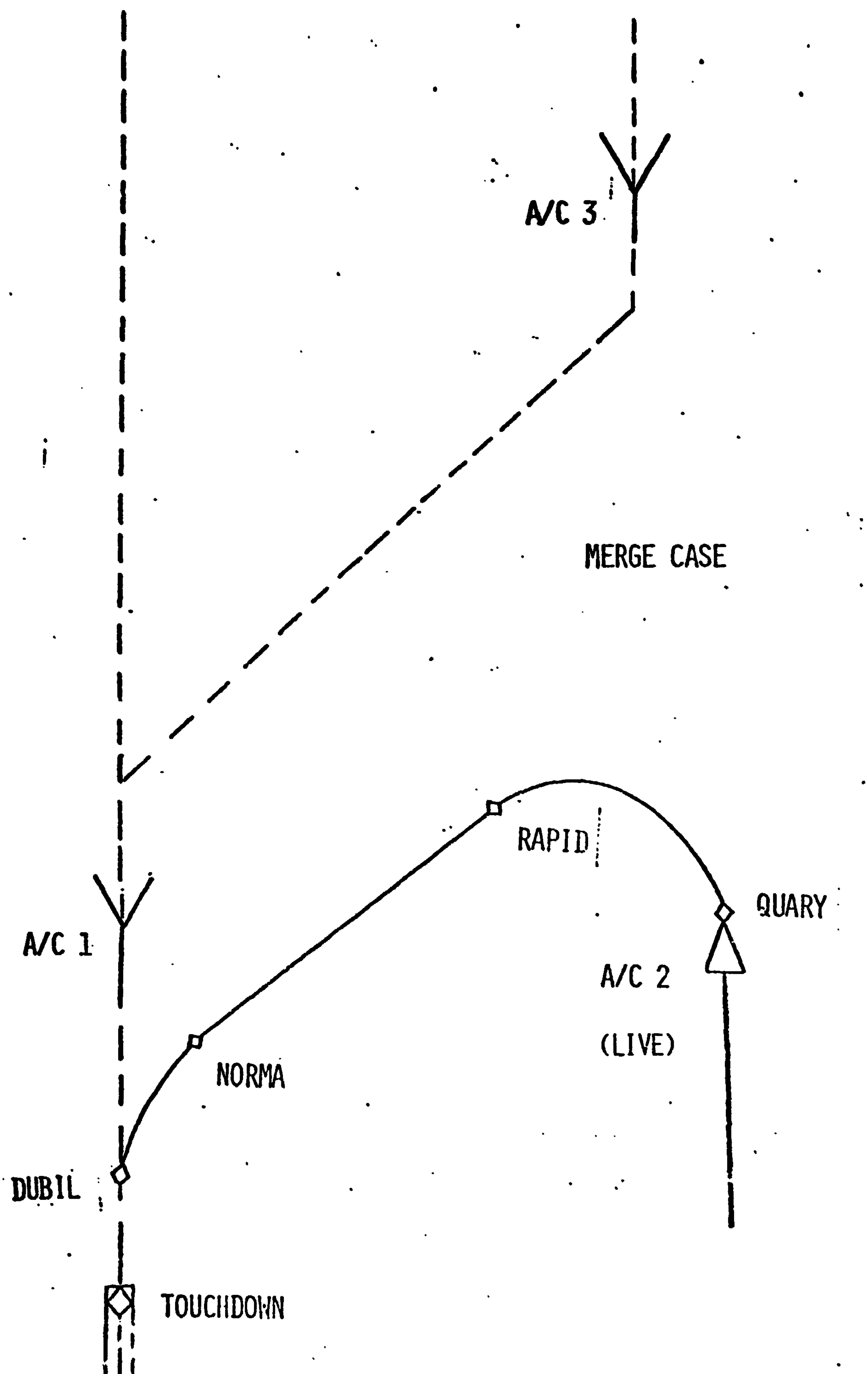


Figure 7.- Initial positions for case B.

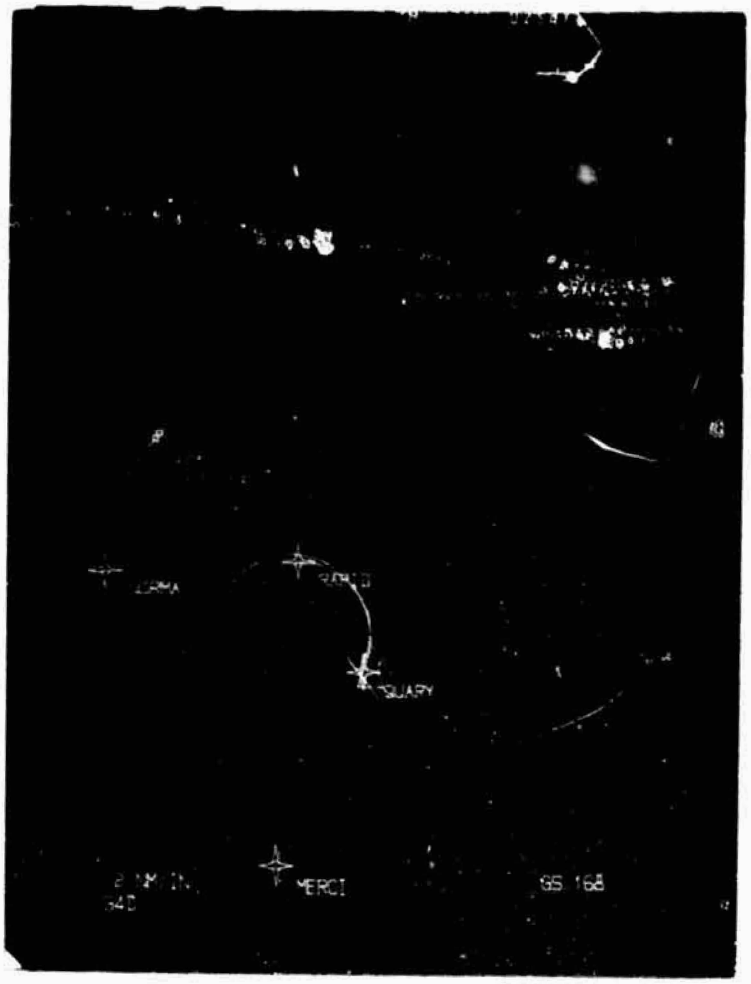


Figure 8.- Case B presentation of traffic on EHSI.

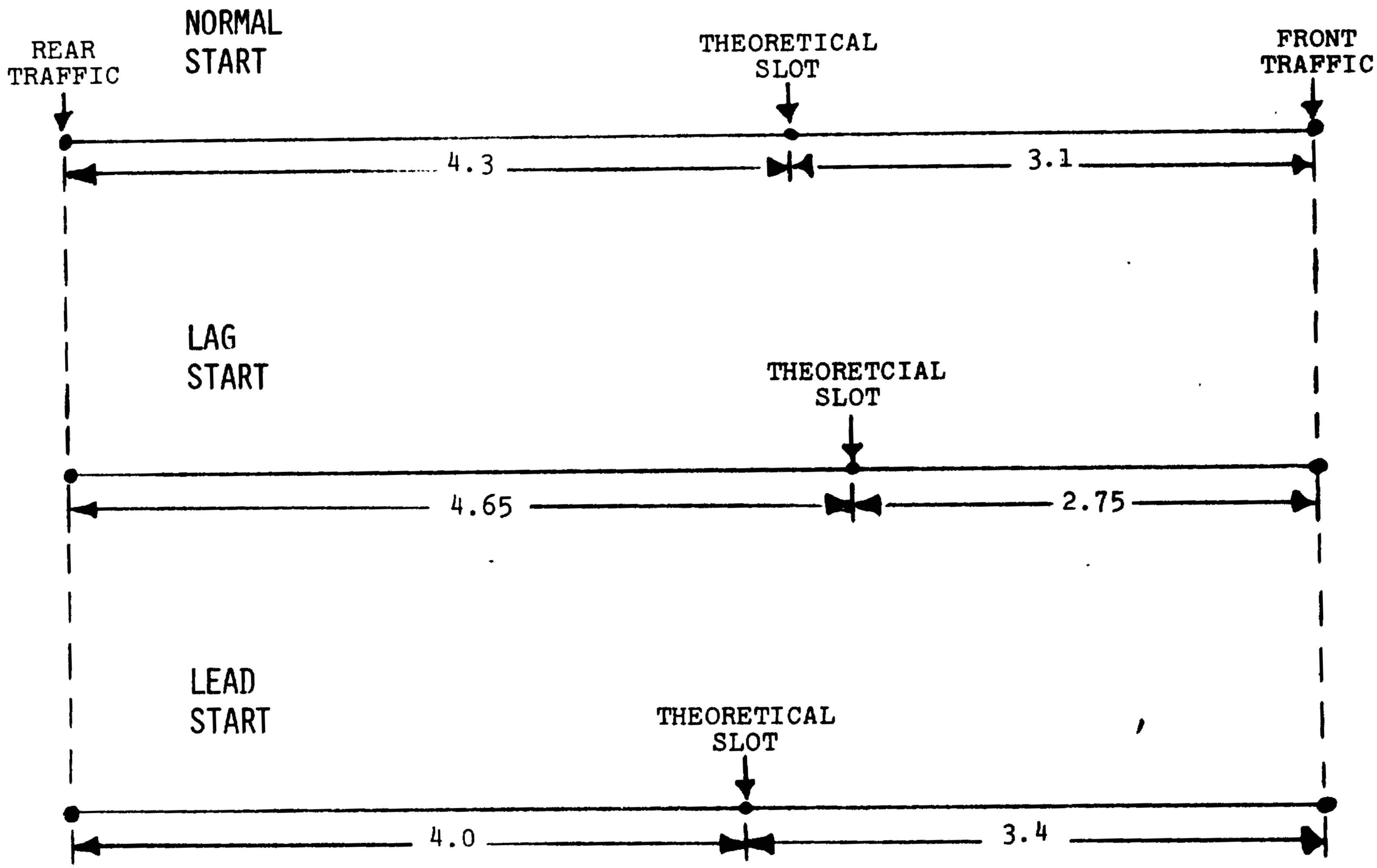


Figure 9.- Theoretical spacing in nautical miles for case A.

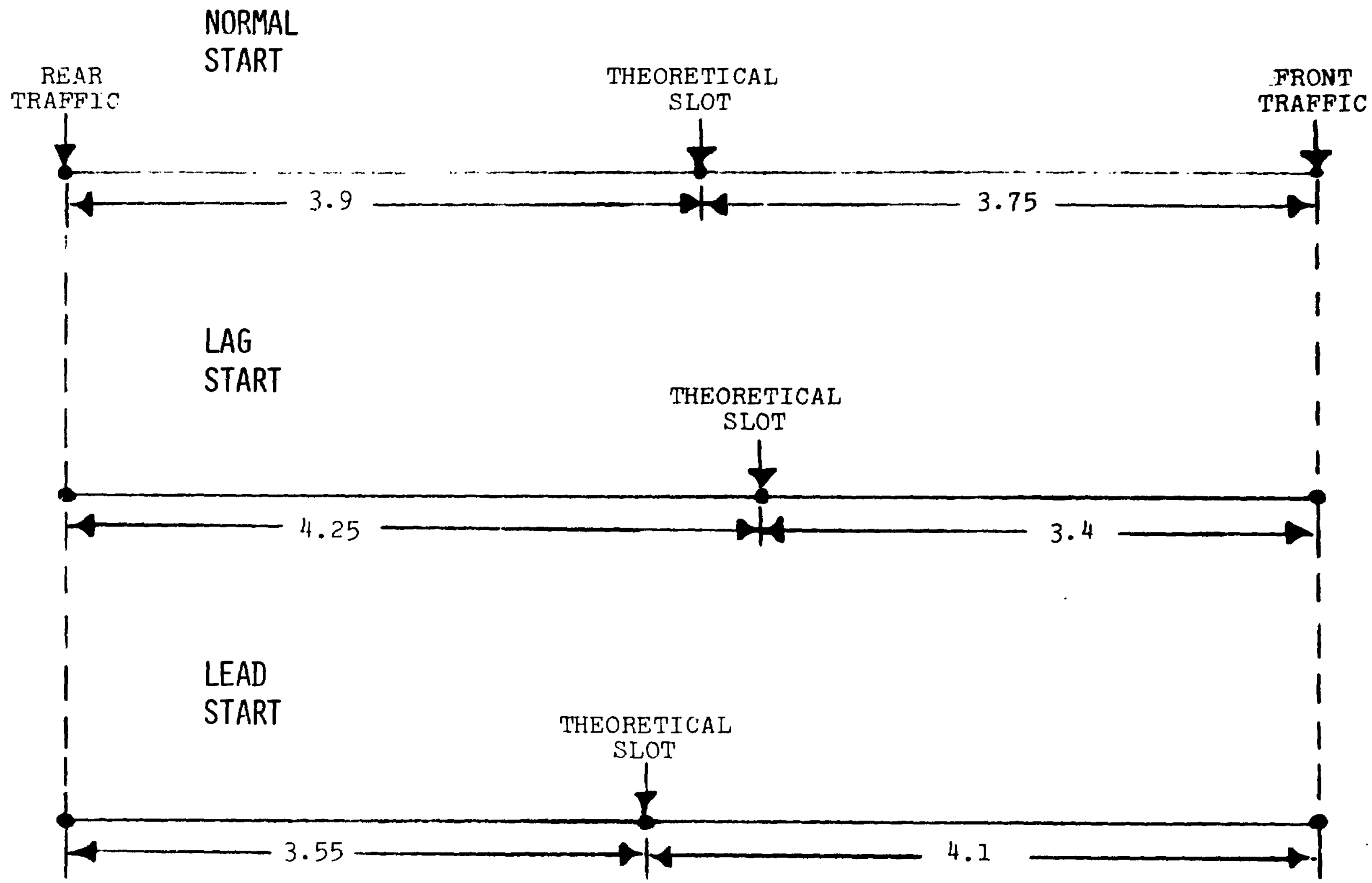


Figure 10.- Theoretical spacing in nautical miles for case B.

1. Report No. NASA TM 80098	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle A SIMULATION INVESTIGATION OF COCKPIT DISPLAY OF AIRCRAFT TRAFFIC DURING CURVED, DESCENDING, DECELERATING APPROACHES		5. Report Date May 1979
		6. Performing Organization Code
7. Author(s) George G. Steinmetz		8. Performing Organization Report No.
		10. Work Unit No.
9. Performing Organization Name and Address NASA Langley Research Center Hampton, Virginia 23665		11. Contract or Grant No.
		13. Type of Report and Period Covered Technical Memorandum
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, DC 20546		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

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The results indicate that reasonable approach task performance can be maintained when traffic information is displayed on an RNAV-type mpa for both merge and follow type situations. Overall, the results are favorable toward presentation of traffic information during fixed path, curved, descending, decelerating approaches.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Cockpit display of air traffic Terminal Configured Vehicle Curved decelerating approache	Unclassified--Unlimited Subject Category 06

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	33	$4.50

* For sale by the National Technical Information Service, Springfield, Virginia 22161