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PRELIMINARY EVALUATION OF TIME AND DISTANCE SPACING CUES USING A COCKPIT DISPLAYED TARGET

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SUMMARY

A simulator evaluation was conducted to compare time and distance self-spacing cues wherein a pilot establishes and maintains separation from a cockpit displayed target. The study utilized Langley's Terminal Configured Vehicle simulator which represents an advanced aircraft employing cathode-ray tubes for primary flight displays and highly augmented flight control modes.

The study utilized three tasks, two in-trail rendezvous tasks (target straight-and-level and target turning) and one merge task. Three pilots flew each task twice, once with a time predictor cue and once with a distance predictor.

The results indicate that both time and distance spacing methods are operationally acceptable to the pilots. A slight preference was indicated by the pilots for the distance-based predictor in performing rendezvous and merging tasks. Analysis of the recorded data showed the spacing performance with both predictors was essentially the same.

INTRODUCTION

Cockpit Display of Traffic Information (CDTI) was first proposed over 30 years ago in the form of a ground-to-air television relay of a ground radar display. Since that time, numerous applications have been proposed and, in some cases, simulation or flight tests have been performed to explore them (see for example, references 1 through 4). Despite these efforts, however, there still remains many unanswered questions regarding the advantages and disadvantages of employing CDTI in the present and future ATC system.

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In an effort to explore these questions in a systematic manner, a Joint NASA/FAA CDTI program has been initiated. As part of this program, the Langley Research Center is investigating CDTI applications for both so-called conventional aircraft, wherein the traffic is presented on a Weather Radar Display, and advanced aircraft, in which the traffic is presented on a primary display such as an Electronic Horizontal Situation Indicator (EHSI) as was done in Reference 5.

The study reported herein addresses the advanced aircraft application and utilizes Langley's Terminal Configured Vehicle (TCV) simulator as a representative advanced aircraft configuration. The specific task involved self-spacing wherein the pilot established and maintained longitudinal separation from a lead aircraft based on his CDTI. Previous studies of this task have utilized range rings for the distance cue on the CDTI. In considering the advanced aircraft application, one of the questions that arose was whether or not there was a difference between controlling spacing based on a time interval compared to spacing based on a distance interval. In order to answer this question, a brief study was conducted using the TCV ground based simulator.

Three tasks were employed: an in-trail rendezvous with the target straight and level, an in-trail rendezvous with a turning target, and a merge behind a target flying straight and level. Equivalent time and distance cues were evaluated for each task by three test subjects. The results indicate that both methods would be operationally acceptable from the pilots' standpoint, and the spacing performance would be essentially the same.

SIMULATION FACILITY

General

The tests were conducted using the Terminal Configured Vehicle (TCV) fixed base simulator. This facility is configured to support the NASA TCV B-737 research aircraft shown in Figure 1 and described in Reference 6. The simulator cockpit shown in Figure 2 is a replica of the aft flight deck (AFD) installed on the research aircraft and is connected to a digital computer complex programmed to provide the full range of control and display options available on the aircraft. The computer program is a six degree-of-freedom simulation which includes nonlinear aerodynamic data, realistic engine dynamics, and a flight-control system model incorporating nonlinear actuators, hystersis, deadbands, etc. Atmospheric effects are also included in the computations.

Control Modes

The tests were conducted using automatic path following in both the horizontal and vertical planes. These modes are referred to as HOR PATH and VERT PATH in Reference 6. They are fully automatic, hands-off, control modes wherein the aircraft flys a programmed horizontal and vertical path.

Two speed control options were available, manual throttles and the Calibrated Airspeed Engage (CAS ENG) mode. The manual throttle mode was a standard non-automatic mode. The CAS ENG is an automatic mode which drives the throttles to capture and maintain a reference airspeed. The reference speed is selected using a knob on the Advanced Guidance and Control System (AGCS) control mode panel shown in Figure 3.

The pilot also had configuration control; specifically, he could control the landing gear, flaps, and speed brakes. Since use of the flaps is limited as a function of indicated airspeed, they are not generally used as speed control devices. The speed brakes and landing gear, on the other hand, were often used to increase the aircraft's deceleration if the closure rate on the target aircraft appeared too high to the pilot.

DISPLAYS

General

The simulator (as well as the AFD in the aircraft) was equipped with cathode-ray tubes for displaying both vertical and horizontal information. Remaining information pertinent to this study, such as airspeed, altitude, and engine status, was displayed on conventional dial-type instruments.

The vertical information display presented the Electronic Attitude Director Indicator (EADI) format reported in Reference 7. Since the tests described herein were conducted in the automatic path following mode, the EADI was used primarily to monitor the performance of the automatic system.

The horizontal information display was a navigation display which presented ownships position, a target aircraft, and supporting information in a moving map format. The display, shown in Figure 4, will be referred to herein as the CDTI. It is a track-up display with indications of both desired and actual magnetic track angle. Ownship is fixed in the center of the screen laterally and 12.7 cm (5 in) from the top of the screen vertically (which is 2/3 of the total display height). The reference point for ownship's symbol is the apex of the triangle as indicated on the figure.

The programmed route (horizontal path) for ownship, is displayed as a solid line while the targets path is displayed as a dashed line. When the target and ownship are on a common path the two path symbols coincide. There is also a straight trend vector which represents the instantaneous track angle of ownship.

Six different map scales, .4, .8, 1.6, 3.1, 6.3, and 12.6, n.mi./cm (1, 2, 4, 8, 16, and 32 n.mi./in) are available to the pilot. The selected map scale is indicated by an alphanumeric tag in the lower left corner of the display. Other readouts include the control mode (G-3D for the fully coupled mode) and groundspeed of ownship in knots.

Trend Vectors

Two different trend vectors were employed in this study, a time-based vector and a distance-based vector. The time-based vector is the standard predictor used in the TCV program and is composed of three segments, as shown in Figure 4. These segments indicate where the aircraft is projected to be in 30, 60, and 90 seconds. The gaps between segments are 6 seconds in length and the vector curves as a function of the aircraft's turning radius. For this experiment, only the 30 and 60 second segments were displayed on the .4 n.mi/cm (1 n.mi./in.) map scale. All three segments were displayed on the remaining map scales.

The distance-based vector developed for this study is shown in Figure 5. It was also composed of three segments. These segments were 1/2 n.mi. in length with 1/2 n.mi. gaps between them. The end of each segment, therefore, represented 1, 2, and 3 n.mi. range from ownship. The segments were displayed on all map scales and the vector curved as a function of turn radius.

Target

The target's position was displayed using the symbology shown on Figure 4. The target's position relative to the background map was updated once every 5 seconds, while ownships position, the trend vectors, and track angle readouts, were updated "continuously" (16 times per second). As such, the target moved in a leapfrog fashion, jumping forward at the update and then remaining fixed relative to the ground between updates. If the display update were based on the target's position at that instant, then the actual range to the target would be displayed to the pilot once every 5 seconds. In between updates, the target would appear closer to ownship than it actually was.

During the present study, data specifying the target's position had been pre-recorded once every 4 seconds using a technique developed for the study reported in Reference 4. The 4 second data rate was chosen to represent the data rate of the Discrete Address Beacon System, one anticipated source of target data in the future ATC environment. During a test run, the appropriate target data was recalled and used to update the CDTI. The use of the two discrete update rates (4 seconds for the data and 5 seconds for the display) however, resulted in a noticeable beat frequency in the target's displayed position. The target would take three short jumps and one long jump every 20 seconds. The actual range to the target would only be accurately displayed following the long jump (once every 20 seconds), and this would be true only if the display update was based on target position data at that instant. Otherwise the target would always appear to be closer than it actually was.

During the rendezvous and merge tasks, the pilots did not wait for the long updates to occur when establishing their initial in-trail position. Once stabilized, however, they waited for at least two long updates (40 seconds) before taking any action to alter their spacing.

TEST PROCEDURE

Task Description

Three tasks were employed in the present study as shown in Figure 6. Tasks I and II were in-trail rendezvous tasks modeled loosely after cases 1 and 3 of Reference 8. Task III was a merge task.

In task I, the target flew straight and level at 183 knots groundspeed (approximately 160 knots indicated airspeed). Ownships initial condition (shown in Figure 6) was 6 n.mi. behind the target, at the same altitude and speed. The pilot's task was to close up to and maintain 3 n.mi. with the distance vector or 60 seconds (3.05 n.mi.) with the time vector. The closure was to be done "as rapidly as possible." The pilot could use either the autothrottle (CAS ENG) mode or manual throttles for speed control. In addition, he had full configuration control (flaps, gear, and speed brakes), which could also be used to augment his speed control capability.

In task II, the target flew at a constant groundspeed of 231 knots (approximately 195 knots indicated airspeed) and constant altitude. The target made a 60^o right turn at the beginning of the task. Ownship was positioned 5 n.mi. behind the target at the same speed and altitude.

The pilot's task was identical to task I, however, the time-distance relationship was not. The 60 second spacing on the target of task II was equivalent to 3.85 n.mi., whereas in task I it was 3.05 n.mi. It should also be emphasized that, since the aircraft was flown in a 3-D mode (path-coupled), the pilot could not control spacing by altering his flight path. The pilot did, however, have the same speed control options in task II as he had in task I.

In task III, the target flew straight and level at 188 knots groundspeed (160 knots indicated airspeed). Figure 6 illustrates the initial conditions for task III. The target was 10 n.mi. from the merge point, whereas ownship was 15 n.mi., and traveling at the same speed and altitude. If the pilot took no action at all, he would end up slightly under 5 n.mi. behind the target owing to the curved path transition at the waypoint. His task was to close up and maintain 60 seconds, or 3 n.mi., spacing from the target depending on the type vector employed.

Test Sequence

Three NASA test pilots served as subjects for this study. Each subject was familiar with the simulator and the time based predictor vector. Since the distance based vector was similar, no familiarization tests were performed, although the pilots were allowed to repeat any runs they so desired. (Only one request to repeat a run occurred during the entire testing.) The pilots flew tasks I, II, and III in order, first with the time vector, and then with the distance vector. During each run, range, airspeed, groundspeed, and acceleration were recorded at a rate of four samples per second.

RESULTS AND DISCUSSION

Pilot Opinion

Results of a questionnaire given to the pilots following the test sessions indicated that they considered both time and distance spacing to be operationally acceptable. A slight preference was shown for the distance vector for the rendezvous and merge tasks. Overall, task I was thought to be somewhat easier than tasks II and III.

The slight preference for the distance vector stems from the fact that the vector maintains constant length, regardless of the aircraft's speed. The time vector on the other hand, changes length on the fixed scale map as aircraft speed changes. Although a simplified analysis indicated that the time vector could be used to advantage for the final "capture" of the target, the variable length characteristic apparently offset this advantage.

Data Analysis

Figure 7 is a plot of range as a function of time for one of the task I runs. This particular run was chosen since it illustrates a case with an overshoot (.14 n.mi.) during rendezvous.

The time to close on the target was chosen to be the elapsed time from the start of the run to the point where ownship was 3.4 n.mi. behind the target. The value of 3.4 n.mi. was selected so that the change in range from the starting point to the measurement point (2.6 n.mi.), was the same as that used in the study reported in Reference 8. Using this criteria, the time to close was 165 seconds for the run shown in Figure 7.

The mean and standard deviation of the range was computed for the final 4 minutes of the run to obtain an indication of the tracking performance. Only the final portion of the run was used to insure that the rendezvous transients had disappeared. Preliminary analysis indicated that selecting an interval which included the final portion of the rendezvous resulted in significantly higher standard deviations.

Tracking Performance

Due to data processing problems, only four runs were suitable for analyzing the steady state tracking performance. As such, the findings described below are recognized as being very tentative and should be treated accordingly.

The tracking biases ranged from +.02 to +.41 n.mi. (+ is long). The type vector employed (time or distance) had no apparent affect on the biases. These biases are somewhat larger than those obtained during the tests reported in Reference 8 (+.1 to -.12 n.mi.) and may have been caused by the beat frequency phenomina described earlier.

The standard deviation taken over the last 4 minutes of tracking ranged from .02 to .05 n.mi. The lower standard deviations (.02 and .03) were with the time vector and the higher ones (.04 and .05) were with the distance vector. These standard deviations were all equal to, or better than, those obtained during the tests reported in Reference 8.

Rendezvous Task

The data from tasks I and II were analyzed from the standpoint of the in-trail rendezvous characteristics. The results were as follows:

There was no apparent correlation between the time to close on a target from an in-trail position and the type of vector employed. The times to acquire spacing in task I were comparable to those obtained during the case 1 tests of Reference 8, but tended towards the high side. One run exceeded 200 seconds.

Only two overshoots were experienced in nine runs, one of .14 n.mi. (time vector) and one of .02 n.mi. (distance vector). The study of Reference 8 reported five overshoots in nine runs with values up to .4 n.mi.

The deceleration levels employed by the pilots were in the 1 to 2 knots/second range, similar to the results of Reference 8.

The velocity used to overtake the target was independent of the vector used. In task I, the pilots used an average overtake velocity of 65 knots which resulted in a groundspeed of about 250 knots (215 KIAS). In task II, where the target was flying about 40 knots faster than in task I, a higher groundspeed, 270 knots (230 KIAS) was used to overtake the target, but the resulting overtake velocity was less than task I, averaging out at about 40 knots.

Merge Task

An analysis of the data from task III indicated a tendency toward overshooting the desired spacing during the merge with both time and distance vectors. The overshoots generally occurred after the merge point (up to 1 minute after), however, on one run the overshoot occurred about 15 seconds before the merge point. The largest overshoot was about 0.6 n.mi. In all cases, the pilots were aware of the impending overshoot, but elected to accept it rather than execute a configuration change to prevent it.

CONCLUDING REMARKS

While it is recognized that these test results are based on a limited amount of data and scenarios involving a single target and a single-axis piloting task, the relative answers obtained should be applicable to more complex, "real-world" situations.

On the basis of the tests described herein, all of the pilots agreed that either time or distance spacing would be operationally acceptable. The quantitative data indicates that the performance obtained with both cues was essentially the same. The pilots indicated a slight preference for the distance-predictor for rendezvous and merging tasks, partly because it was somewhat easier to see than the time-predictor.

The "beat-frequency" motion of the displayed target, resulting from different update rates on the measurement and display of the target's position, made it difficult for the pilot to estimate the range to the target. This could account for the tendency of the spacing bias to be larger than a previous study involving a similar task.

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Figure 1. - TCV research aircraft.

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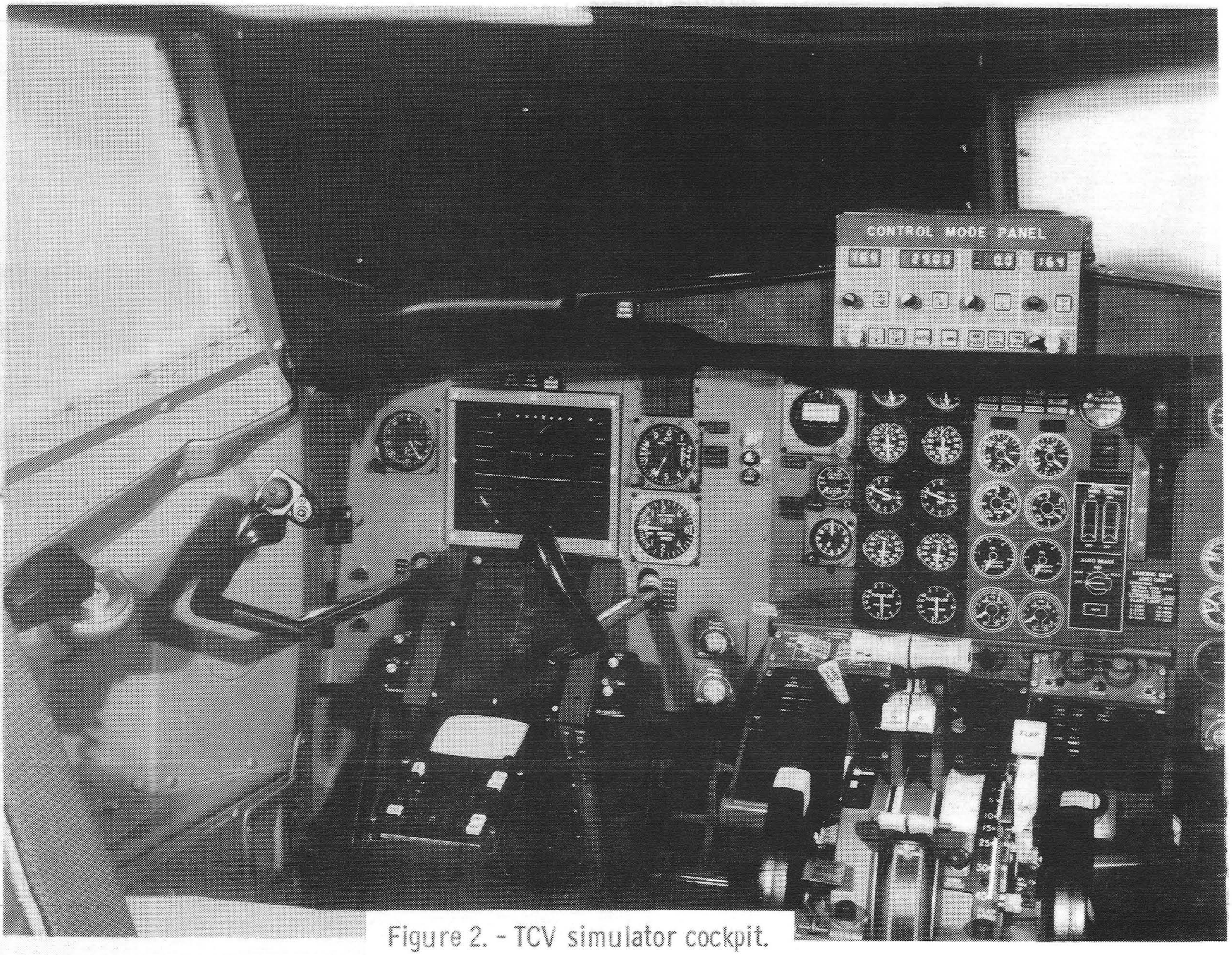

Figure 2. - TCV simulator cockpit.

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Figure 3. - AGCS control mode panel.

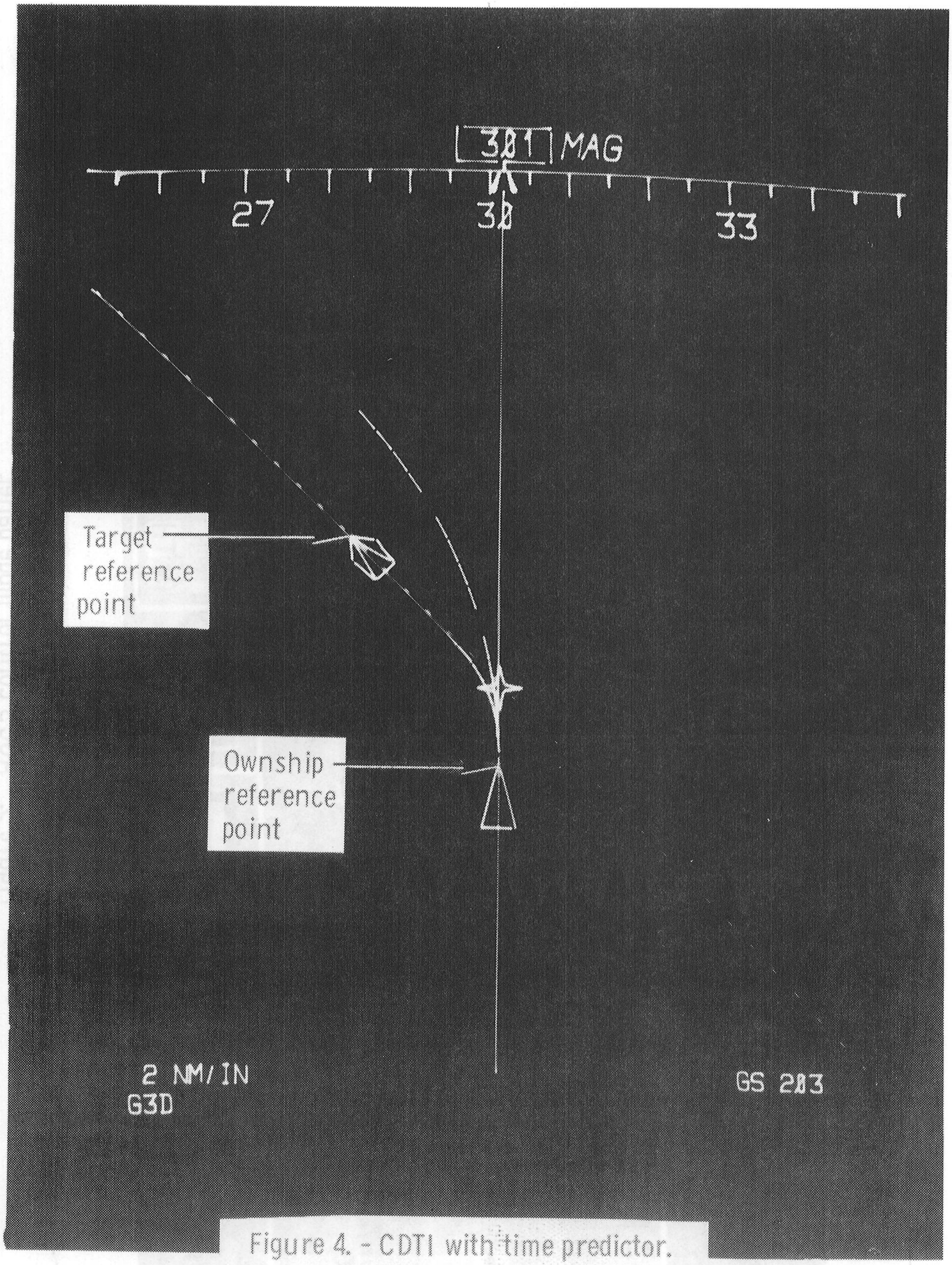

Figure 4. - CDTI with time predictor.

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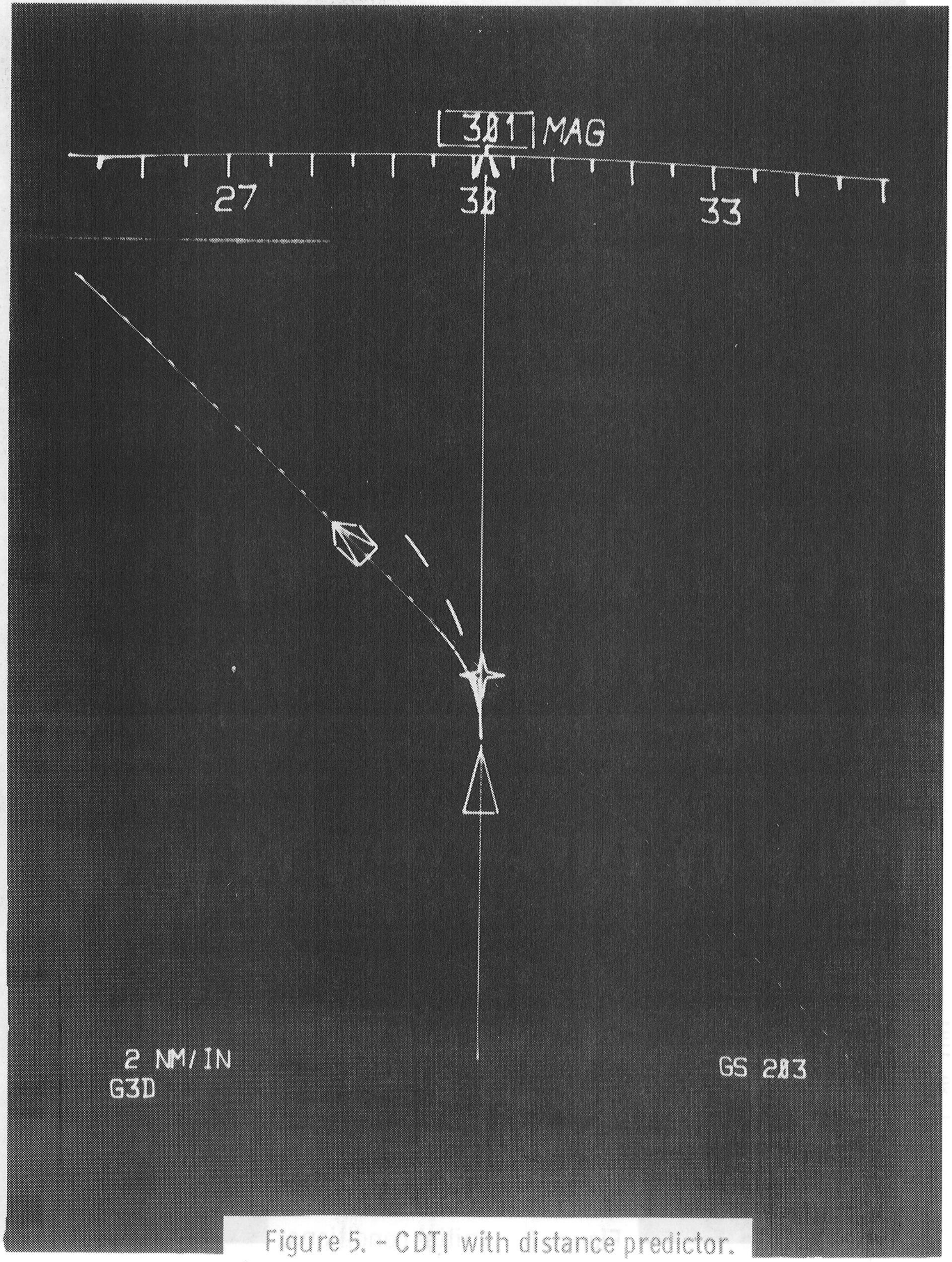

Figure 5. - CDTI with distance predictor.

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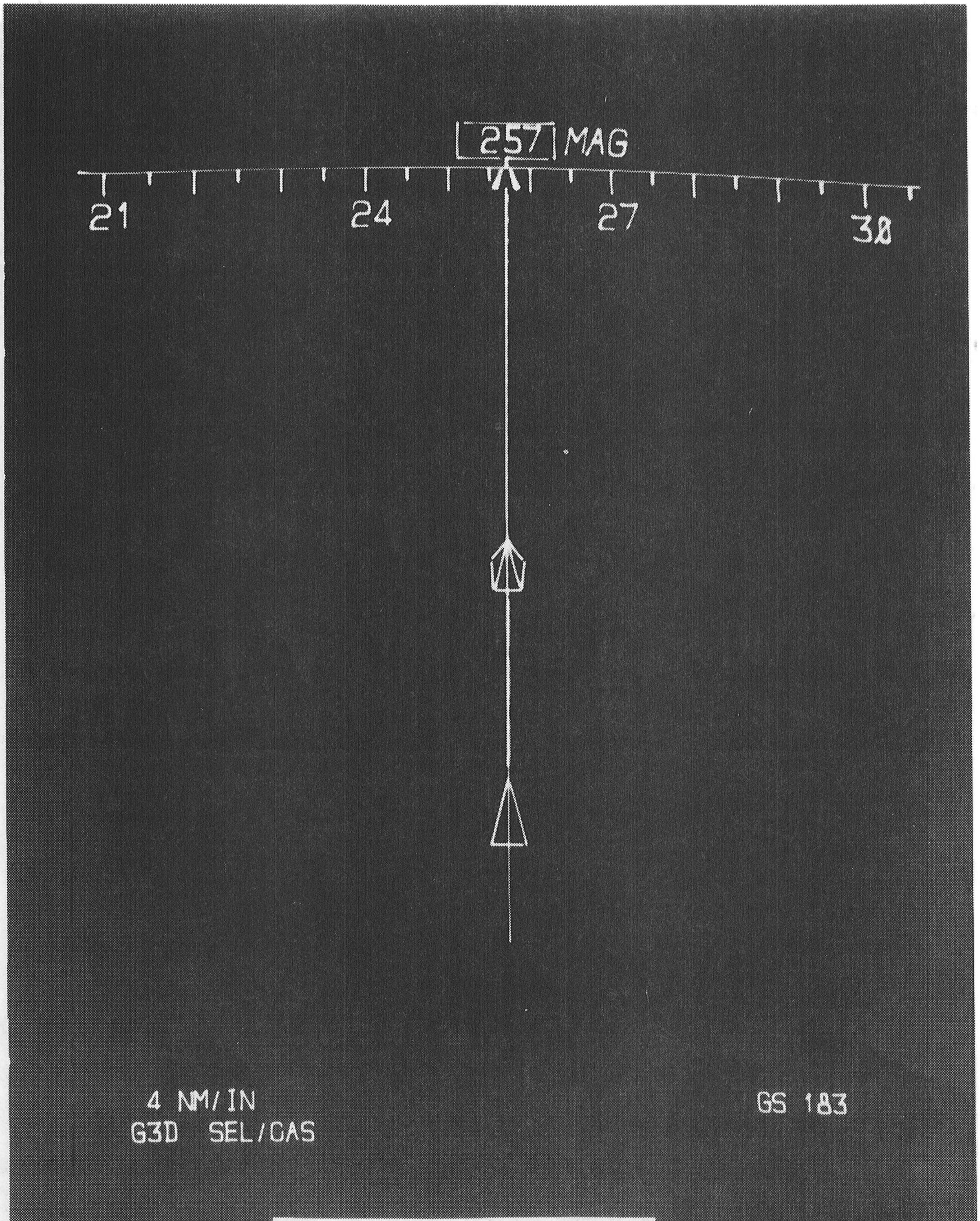

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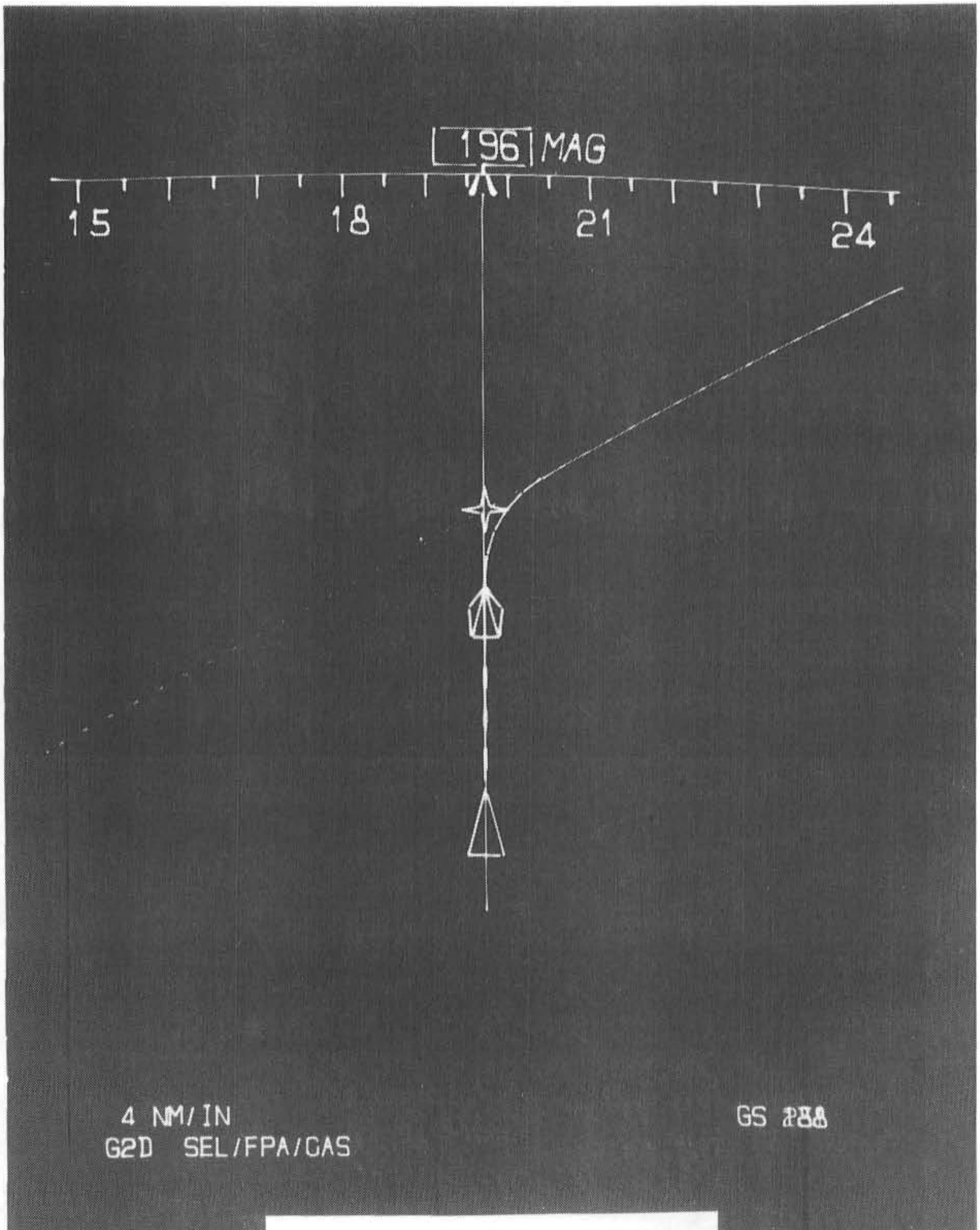
(a) Task I with time predictor.

Figure 6. - Initial conditions.



(b) Task II with distance predictor.

Figure 6. - Continued.

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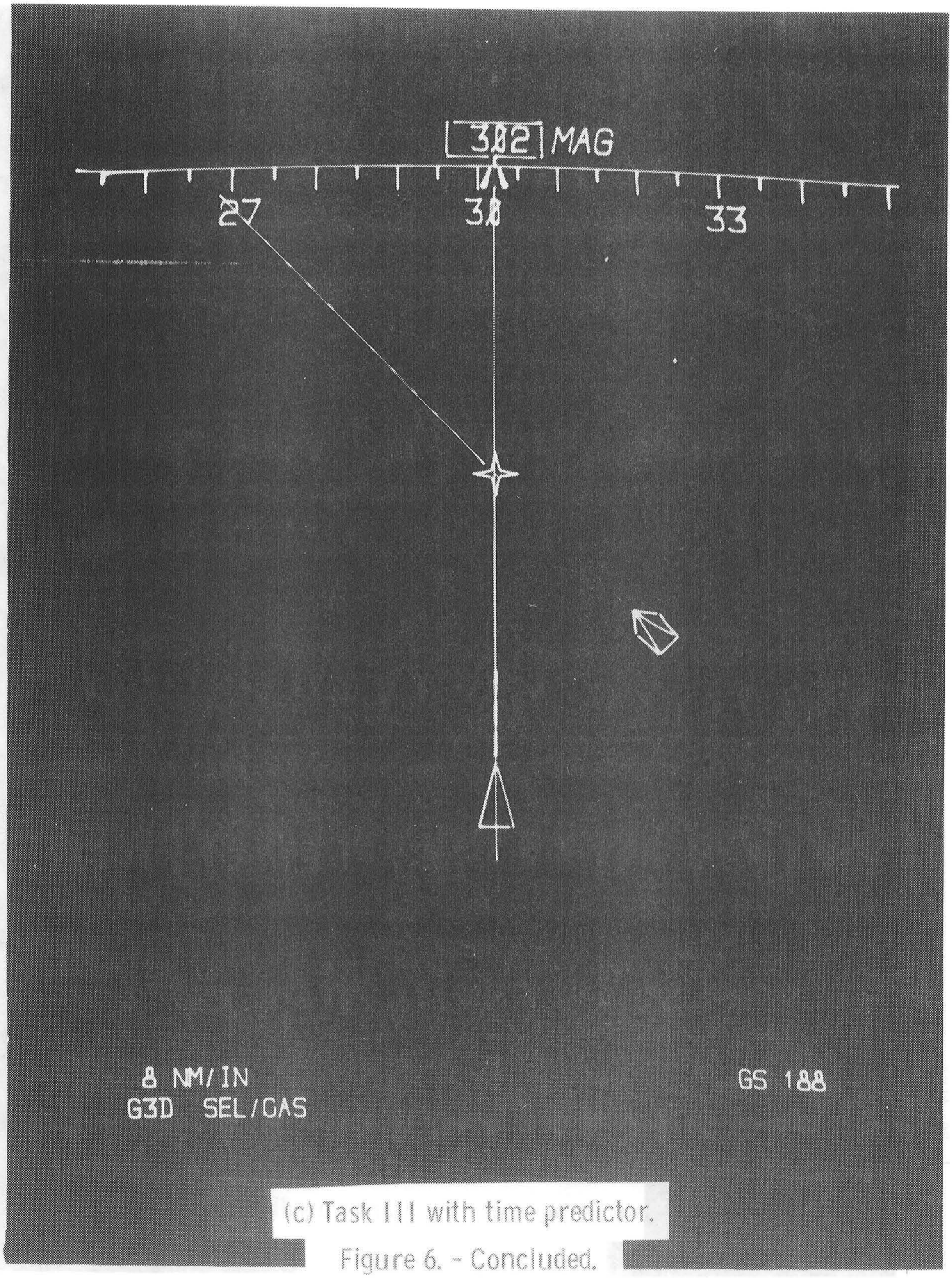

(c) Task III with time predictor.

Figure 6. - Concluded.

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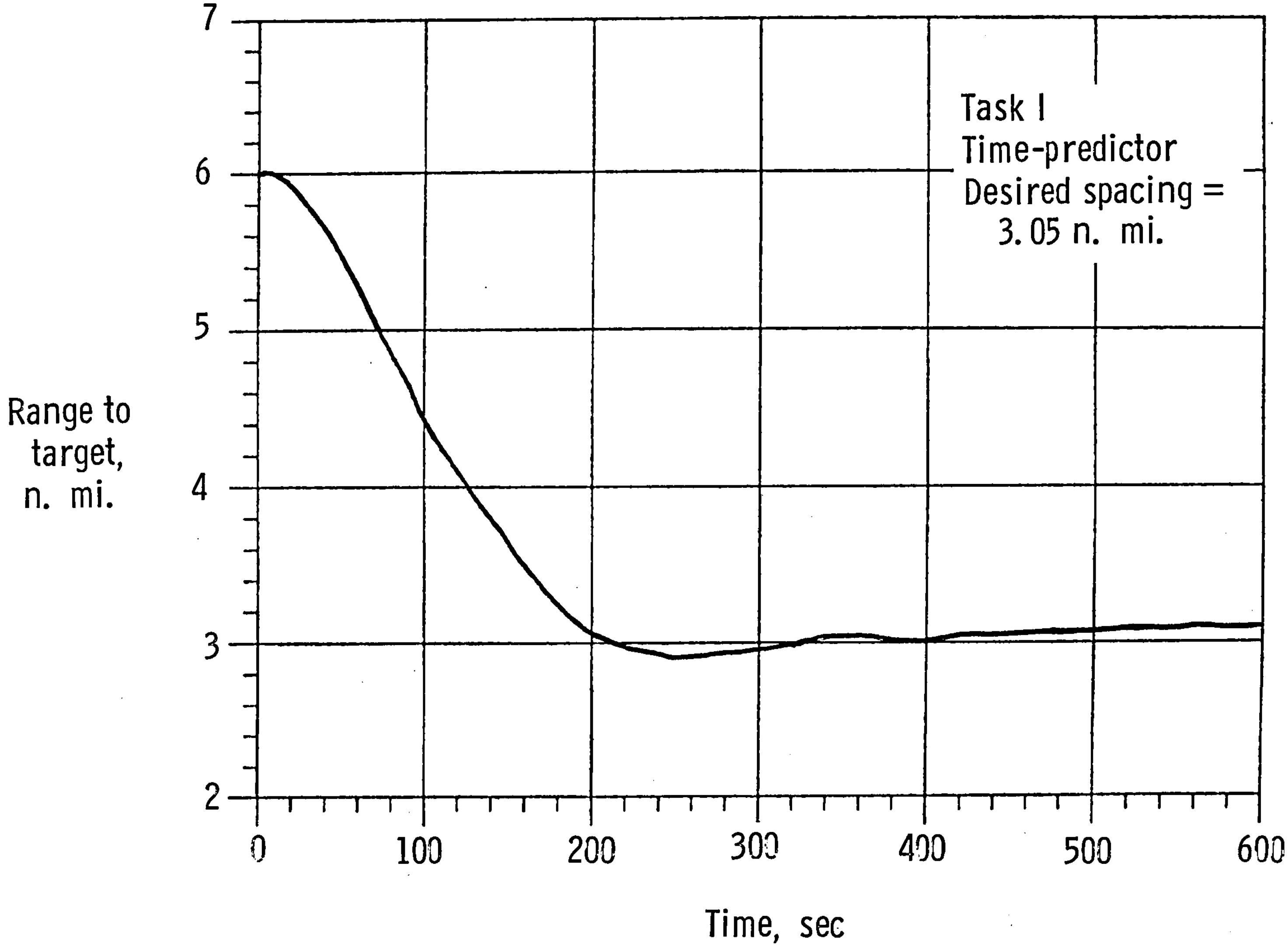

Figure 7. - Aircraft separation as a function of time.

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16. Abstract

A brief simulator evaluation was conducted to compare time and distance predictors for self-spacing on a cockpit displayed target. The pilot's task was to close up and maintain a pre-specified spacing interval for both in-trail and merging scenarios. The results indicate that both time and distance spacing methods are operationally acceptable to the pilots and the spacing performance of both methods is essentially the same. A slight preference was indicated by the pilots for the distance-based predictor for the rendezvous and merging tasks.

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