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A SIMULATOR STUDY OF A PICTORIAL NAVIGATION DISPLAY IN INSTRUMENT DEPARTURES OF THE SUPERSONIC TRANSPORT

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A SIMULATOR STUDY OF A PICTORIAL NAVIGATION DISPLAY IN INSTRUMENT DEPARTURES OF THE SUPERSONIC TRANSPORT

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SUMMARY

In order to assess the merits of a pictorial navigation display for the supersonic transport, a study was conducted in which a north-oriented moving-map-type pictorial display was used for navigating along specified departure routes. The pictorial display was mounted in the supersonic transport (SST) ground-based simulator located at the Langley Research Center and the tests were made during the course of a cooperative NASA-FAA simulation program to study the problems connected with the introduction of the supersonic transport into the air traffic control system.

The tests indicated that the deviations from course for the runs in which the pictorial display was used were generally small and of the same order as those using conventional navigation instrumentation. There was some difficulty in holding course in the turns, especially at the higher speeds.

A reduction in the communication workload in the terminal area was realized with the use of the pictorial display; however, it was the opinion of the pilots that the total workload (communication and navigation) was increased as compared with the workload when conventional navigation instrumentation is used.

The time and fuel used for the SST departures utilizing the pictorial display did not indicate any improvement in consistency as compared with the time and fuel used for departures in which the SST was radar vectored through the terminal area.

Pilot opinion concerning the features of the pictorial display were generally favorable. However, there were recommendations for relocating the display unit directly in front of the pilot and for improving the readability of the information depicted on the screen.

INTRODUCTION

Navigation of aircraft by means of airborne pictorial navigation displays has been found to be beneficial in increasing the air traffic control (ATC) system capability of handling traffic in both high- and medium-density terminal areas for subsonic aircraft (ref. 1). Future air traffic control system concepts envisage a requirement for pictorial navigation displays for expedited operations in high-density terminal areas.

In view of the probable requirement for a pictorial navigation display for the supersonic transport (SST), a simulator study was conducted with a north-oriented moving-map-type pictorial display in connection with SST departure operations. This study was made during the course of a cooperative NASA-FAA (National Aeronautics and Space Administration-Federal Aviation Agency) simulation program to study the problems associated with the introduction of the supersonic transport into the air traffic control system. The SST simulator utilized in the study was located at the NASA Langley Research Center and was piloted during the tests by airline pilots. The FAA ATC simulator located at the National Aviation Facility Experimental Center (NAFEC) was used to provide a real-time air traffic control environment.

The objectives of the study were to determine the suitability of this type of display, to establish acceptable scales for both terminal and en route area maps, and to define operational problems with regard to the use of a pictorial display for SST terminal area operations.

EQUIPMENT

Supersonic Transport and Air Traffic Control Simulators

The flight compartment and flight instrumentation of the SST simulator (fig. 1) located at Langley Research Center are similar to those of current jet transport aircraft with instrument ranges modified only to cover the higher altitude and Mach number operation of the supersonic transport. In addition to this equipment, six analog computers were used to solve the six-degree-of-freedom motion equations for the delta-wing type of supersonic transport used in the present investigation.

The real-time simulated ATC environment was provided by the FAA with their ATC simulator facilities located at NAFEC in Atlantic City, New Jersey. Data transmission and communications between the SST simulator and the ATC simulation facilities is effected over leased private telephone lines. A detailed description of the equipment, method of simulation, and associated facilities is given in reference 2.

Pictorial Display

The optical projector type of pictorial display used in the present investigation is shown in figure 2. For illustrative purposes, a terminal area map is positioned over the screen to represent the projected view as seen by the pilot. Features of the display include a north-oriented moving map with an aircraft symbol fixed in position in the center of the screen. As a heading change is initiated, the aircraft symbol and attached cursor rotate, heading scale information being depicted at the edge of the screen. There is no permanent record of the track being made good on this pictorial display.

A photograph of the pictorial display unit and the related equipment, consisting of a control unit and an amplifier unit, is shown in figure 3(a). The front panel of the control unit contains the controls necessary for turning on the lamp, controlling the brightness, selecting either the en route or terminal area map, and activating the servo mechanisms.

The display unit contains the film transparency mounted on a cylinder which is driven longitudinally and in rotation by servo-mechanisms for north-south and east-west movements. A photograph showing the display unit interior is shown in figure 3(b). The front of the display unit has a translucent (acrylic plastic) projection screen which measures $5\frac{1}{2}$ inches (13.97 cm) by $7\frac{1}{2}$ inches (19.05 cm).

The input signals to the display for aircraft position and heading were furnished by analog computers. Position signals were accurate to 1/2 mile on the 5-mile-per-inch scale, and to 1 mile on the 10-mile-per-inch scale; the heading signal was accurate to 1^{o}. The installed positions of the pictorial display and control unit in the flight instrument display panel are shown in figure 1.

The ground track maps used in the study depicted basic airway, navigation, and some air traffic control information. Maps covering two different areas (en route and terminal) were utilized in the test. The en route map covered the total test area of 400 by 400 n. mi. (740.8 by 740.8 km) whereas the terminal map covered an area of 120 by 120 n. mi. (222 by 222 km) in the vicinity of the airport. For the en route map, three scales (40, 20, and 10 n. mi. per inch or 29.2, 14.6, and 7.3 km per cm) were tested whereas for the terminal map, two scales (10 and 5 n. mi. per inch or 7.3 and 3.65 km per cm) were tested. Representations of the screen view for each of the map scales tested for both the en route and terminal area maps are shown in figures 4 and 5.

TEST METHOD

Supersonic Transport Operating Procedures

The test program consisted of real-time simulated instrument flight rules (IFR) departure operations of the supersonic transport from the John F. Kennedy International Airport in the multiairport New York area. All traffic was under positive control of the simulated New York Air Route Traffic Control Center, adjacent centers, and Kennedy departure, arrival, and tower facilities. Piloting of the SST simulator was done by 2-man crews from United Air Lines and Trans World Air Lines experienced in flying subsonic jets and familiar with the New York area.

The SST climb, as well as engine and structural schedule limitations, are shown in figure 6. For the ascent, after the initial accelerated climb following take-off, a climb at 325 knots indicated airspeed (IAS) was used up to 47,500 feet altitude (14,478 meters). At this point, a Mach number-altitude schedule representing a sonic-boom overpressure limit of 2.0 pounds per square foot (95.7 newtons/square meter) was followed up to 57,000 feet (17,373 meters) through use of a pitch command programed on a flight director, and a climb at 500 knots IAS (257 meters/second) was then used to cruise conditions of a Mach number of 3.0 at 67,000 or 71,000 feet (20,421 or 21,584 meters).

Pictorial Display Routes

The pictorial display routes followed in the departures are indicated by the dash-dot lines shown on the screen displays given in figures 4 and 5. The parallel routes used for en route operations are shown in figure 4(a) and were separated by 5 n. mi. (9.26 km). The direct routings and curved paths used in the terminal area to replace ground radar vectors are shown in figure 5(a).

RESULTS

Operational Problems

Navigation accuracy.- The pictorial display departure routes to the north through Huguenot (HUO) and Sparta (SAX) are shown as the solid lines in figure 7, and to the south through Coyle (CYN) are shown as the solid lines in figure 8; the test run tracks flown along these routes are shown as dashed lines. The map scales used for these test runs were 5 n. mi. per inch (3.65 km per cm) for the terminal area map, and 10 n. mi. per inch (7.3 km per cm) for the en route map. The areas shown in figures 7 and 8 lie entirely within the terminal area map. As can be seen in figure 7, there was some difficulty in the initial alinement of the SST at the start of the route to the north because of the high performance of the SST and the substantial heading changes required after take-off. The large deviations from course shown for two of the test runs to the north (runs A and B) during the initial alinement can be classified as errors on the part of the pilot. These errors were due to unfamiliarity of the pilot with the high performance of the SST and the relatively short experience of the pilot with the equipment.

The deviations from course along the straight portions of the pictorial display routes were of the order of 1 to 2 n. mi. (1.85 to 3.70 km). However, there was an increased difficulty in holding course in the turns, especially at the higher speeds (final turn in fig. 8), deviations of 3 to 4 n. mi. (5.56 to 7.41 km) being experienced. It is believed that the difficulty of holding course in the turns as indicated in figures 7 and 8 could be reduced by adjusting the radii of the turns of the pictorial display routes to match the performance of the SST.

It should be mentioned that the deviations from course shown are the result of both piloting performance or technique and the errors associated with analog computer input signals. Navigational system errors were not represented in the inputs to the pictorial display. In actual practice, therefore, where additional navigational system errors would be incurred, deviations from routes would be expected to be somewhat greater.

Communication-navigation workload.- With the use of the pictorial displays in the terminal area, the communication workload between the SST pilots and the air traffic controllers was effectively reduced. This reduction was possible because the pictorial display eliminated the need for radar vectoring by the air traffic controllers as well as the need for clearances to climb when clear of altitude-restricted areas. For the routes shown, the elimination of radar vectoring resulted in a reduction of from two to four messages in a 5- to 10-minute time period. Occasionally, the pilot relied completely on the pictorial display, and thus eliminated the additional requirement for radio frequency changes for position checks.

However, in order to navigate with reasonable accuracy along a specific route by using the pictorial display alone, the pilot reported that more attention and concentration on the display was required than that required in navigating with conventional instrumentation. Also, the first officer (co-pilot) reported that he devoted a large portion of his time to monitoring the pictorial display. It was the opinion of most of the airline crews that the total workload (both communication and navigation tasks being considered) for the crew was greater when navigating solely with a pictorial display than with the conventional instrumentation. Part of the increased workload is due to the fact that some of the work of the ground controller has been moved to the cockpit. A part of the increased workload was felt to be caused by the location of the pictorial display, which was well outside the normal instrument scan pattern.

Time and fuel comparison.- A comparison was made to determine whether utilization of the pictorial display for navigating along the designated routes in the terminal area resulted in a variation in time and fuel usage for the SST in reaching cruise conditions as compared with departures in which the SST was radar vectored by air traffic control through the terminal area.

Similar pictorial display and vectored test runs were used in the analysis, that is, those in which the supersonic transport was cleared to the same destination via similar routes. The time and fuel used for each of the runs in the investigation were adjusted to a common range value. The results are expressed in terms of percent of total mission time of 132 minutes and percent of total mission fuel of 165,000 lb. (See fig. 9.) From figure 9, it can be seen that the variation of time and fuel used by the SST in various runs along the pictorial display routes was only slightly less than the variation of time and fuel used by the SST along the vectored routes. Thus, there was no evidence that use of the pictorial display resulted in a significant reduction or minimizing of the variation of time and fuel as compared with the variation of time and fuel used in vectored test runs.

Pilots' Comments

The pilots were nearly unanimous in their acceptance of the pictorial display as an effective cockpit instrument. It was the opinion of most of the pilots that the pictorial display is an excellent navigation aid and could play a major role in assisting them in their piloting task.

Equipment features.- Pilots reported that the size of the pictorial display was satisfactory for the central location of the display unit; however, the preferred location would be directly in front of the pilot. Pilot opinion was that the frontal location would make possible a reduction in screen size, the display still being acceptable. One feature considered highly desirable was the rapid motion capability which enabled the pilot to move the aircraft position to a location on the map any distance and heading from the actual position. With this feature, the pilot would normally move the aircraft to a point ahead in order to study the route structure and anticipate any necessary action to be taken.

Maps.- Of the various map scales tested, the pilots preferred the 5 n. mi. per inch (3.65 km per cm) scale for the terminal map (fig. 5(b)), and generally preferred the 10 n. mi. per inch (7.30 km per cm) scale for the en route map (fig. 4(c)). However, a few pilots preferred the 20 n. mi. per inch (14.6 km per cm) scale for the en route map (fig. 4(b)) in order to have improved look-ahead capability. Concerning the ground track map structure, the pilots indicated that there was more detail shown on the terminal area map than was necessary such as unused airway routes, fixes, and holding space boundaries.

Suggested improvements.- With regard to the ground track maps, the pilots suggested using color coding of the routes for easier depiction of the desired course. In addition, some pilots would have preferred major geographical features (mountain ranges, large bodies of water) superimposed in color on the maps for reference. Also, it was suggested that basic information such as course, route identification, visual omni range (VOR), facility identification and frequency, and mileage between VOR facilities should be systematically placed along the routes so that this information is in view on the display screen at all times.

CONCLUDING REMARKS

A simulator investigation to determine the suitability of an optical projector type of pictorial moving-map display in connection with supersonic transport (SST) simulator operations in an air traffic control system has led to the following conclusions:

1. Most of the pilots expressed their general satisfaction with the pictorial display features and accepted the unit as an effective cockpit instrument.

2. Deviations from course when navigating with the pictorial display were generally small and of the same order as those utilizing conventional navigation instrumentation; however, some difficulty was experienced in the turns, especially at the higher speeds.

3. Use of the pictorial display was effective in reducing the communication workload in the terminal area. However, it was the opinion of most of the pilots that the total workload (communication and navigation) was greater when the pictorial display was used as compared with the workload when conventional navigation instrumentation was used.

4. There appeared to be no improvement in the variation of time and fuel used for SST departures in which the pictorial display was utilized as compared with departures in which the SST was radar vectored.

5. With the $5\frac{1}{2}$-inch by $7\frac{1}{2}$-inch (13.97 cm by 19.05 cm) viewing area of the pictorial display, the pilots preferred the 5 n. mi. per inch (3.65 km per cm) scale for the terminal map and generally preferred the 10 n. mi. per inch (7.3 km per cm) scale for the en route map.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., February 8, 1967,
720-04-00-05-23.

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1. Faison, Walter E.; and Sluka, Andrew L.: Dynamic Simulation Studies of Pictorial Navigation Displays As Aids to Air Traffic Control in a High-Density Terminal Area and a Medium-Density Terminal Area. NAFEC, FAA, Nov. 1961.

2. Sawyer, Richard H.; Stickle, Joseph W.; and Morris, Richard: A Simulator Study of the Supersonic Transport in the Air Traffic Control System. 1964 Proceedings National Aerospace Electronics Conference, IEEE, May 1964, pp. 352-356.

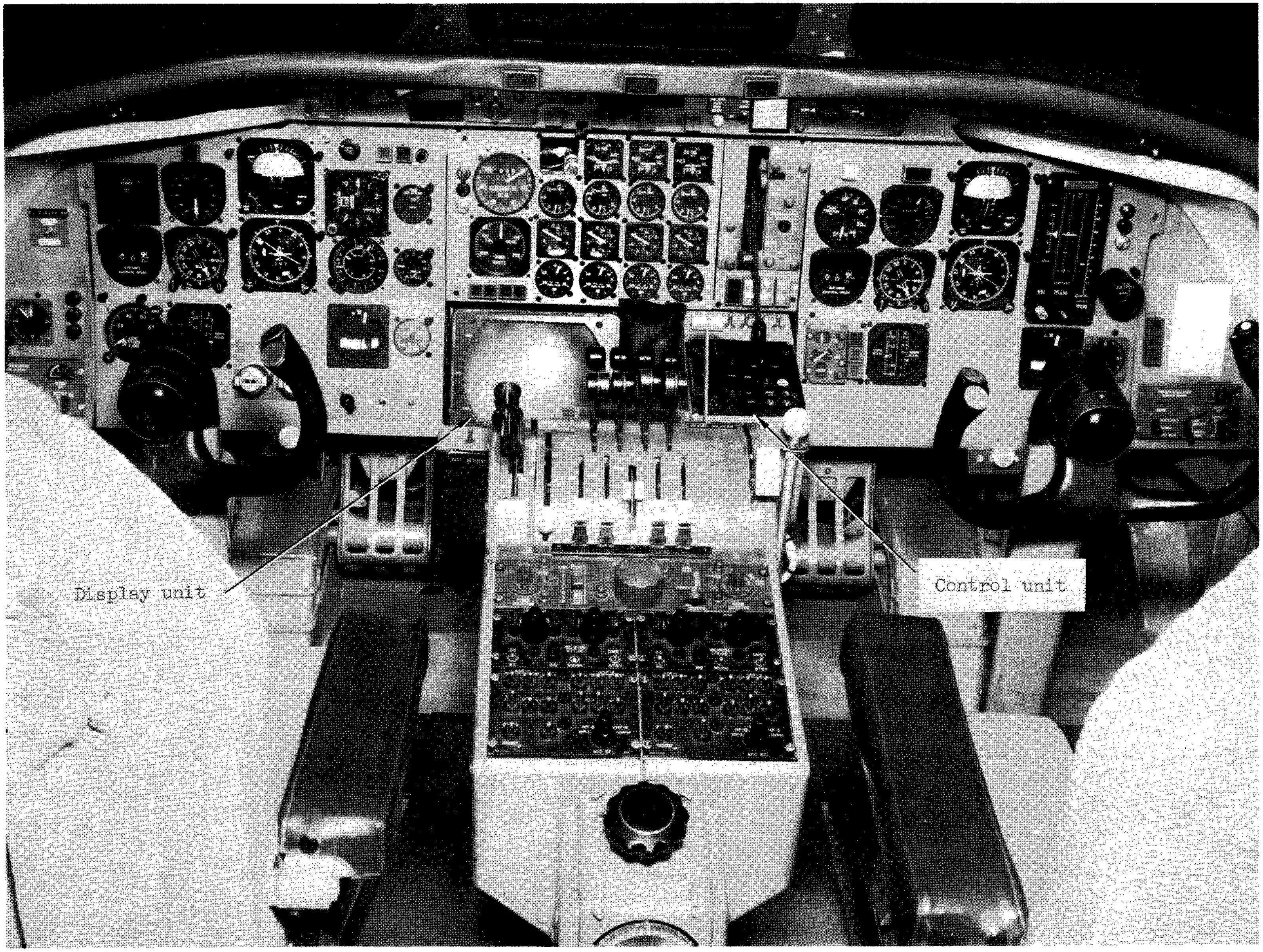


Figure 1.- View showing SST simulator flight instrumentation and location of pictorial display and control unit. L-65-9200.1

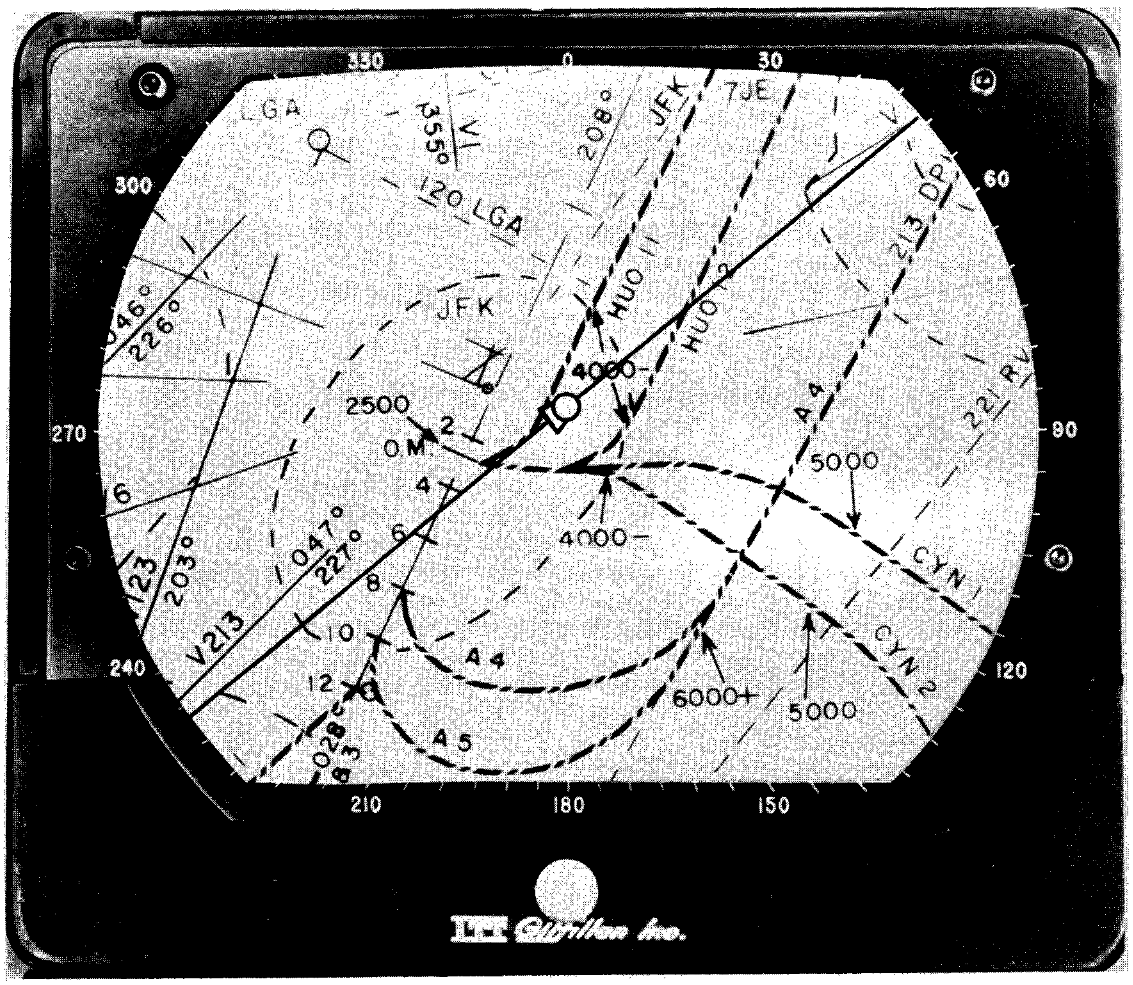
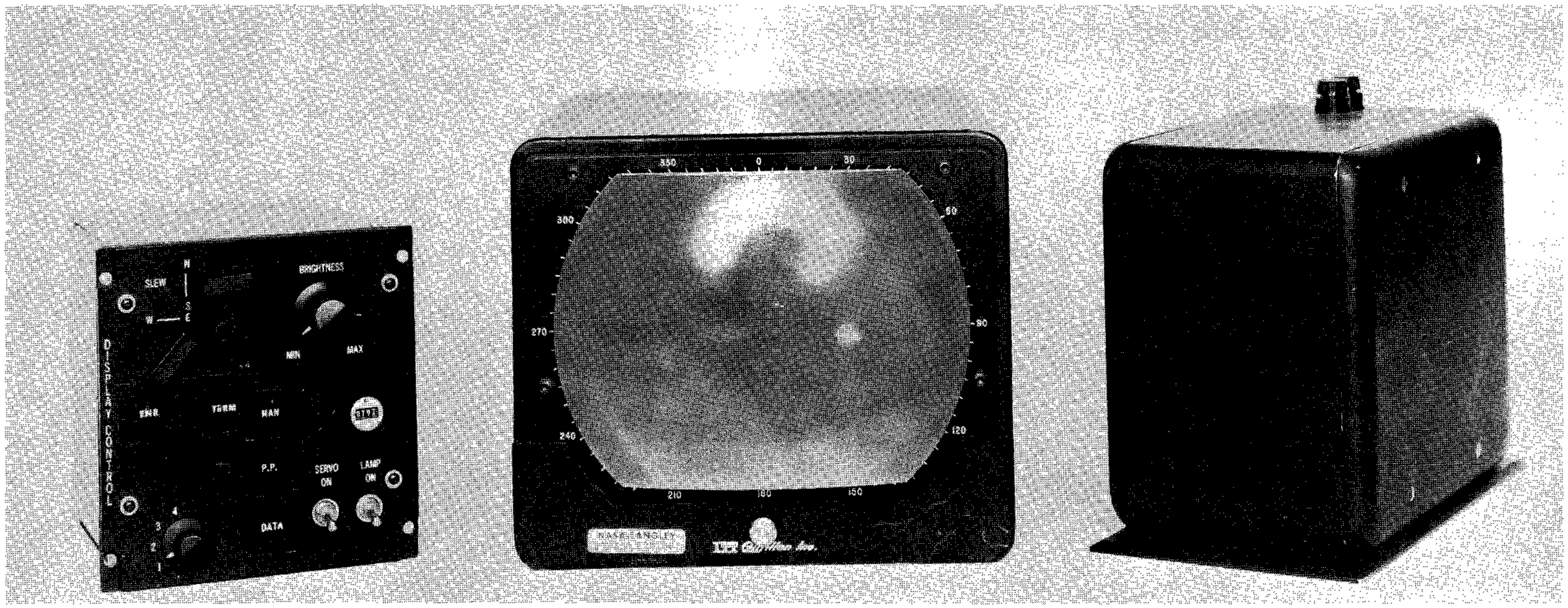
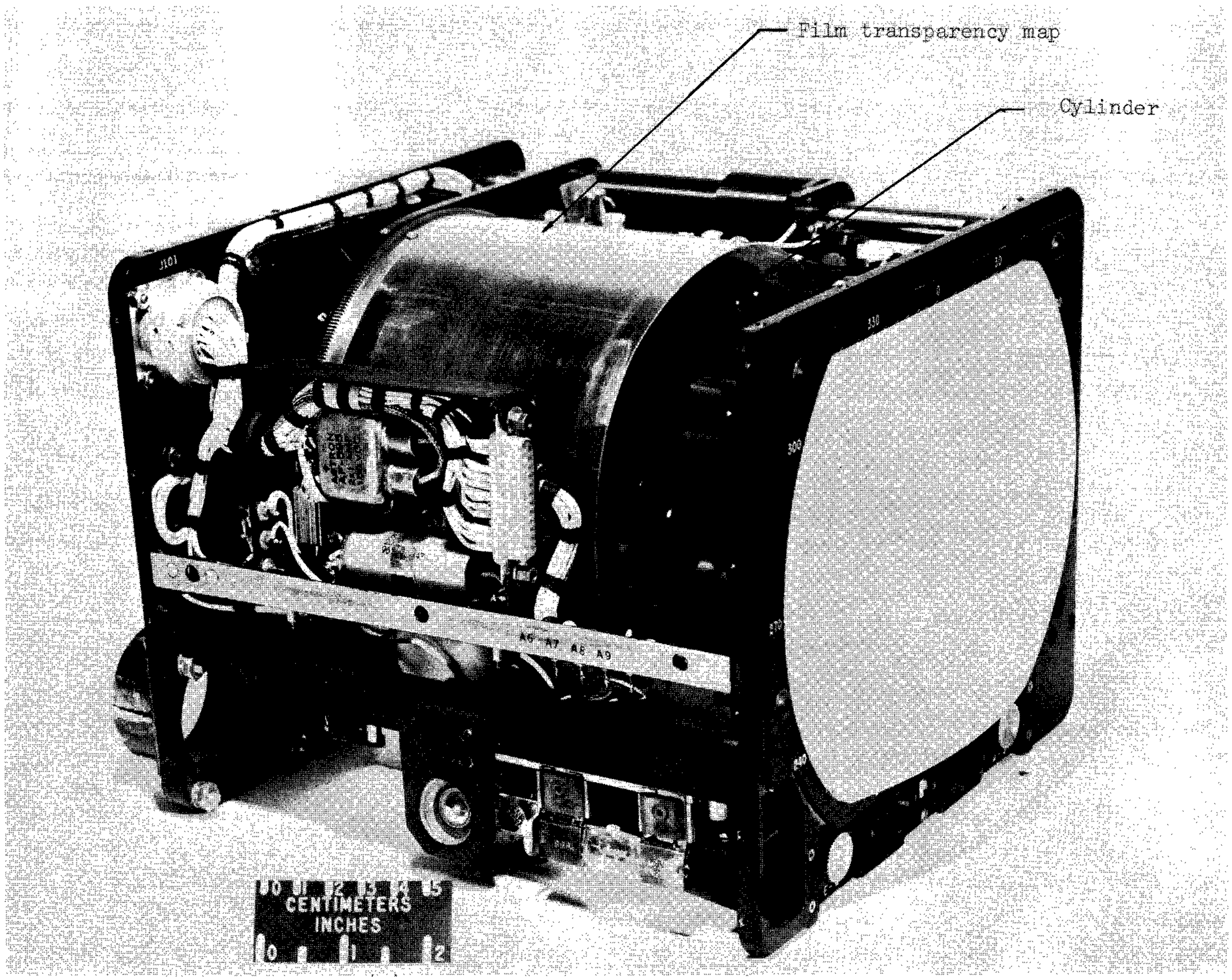


Figure 2.- Pictorial naviation display in operating condition. (Approx. 2/3 full scale.)



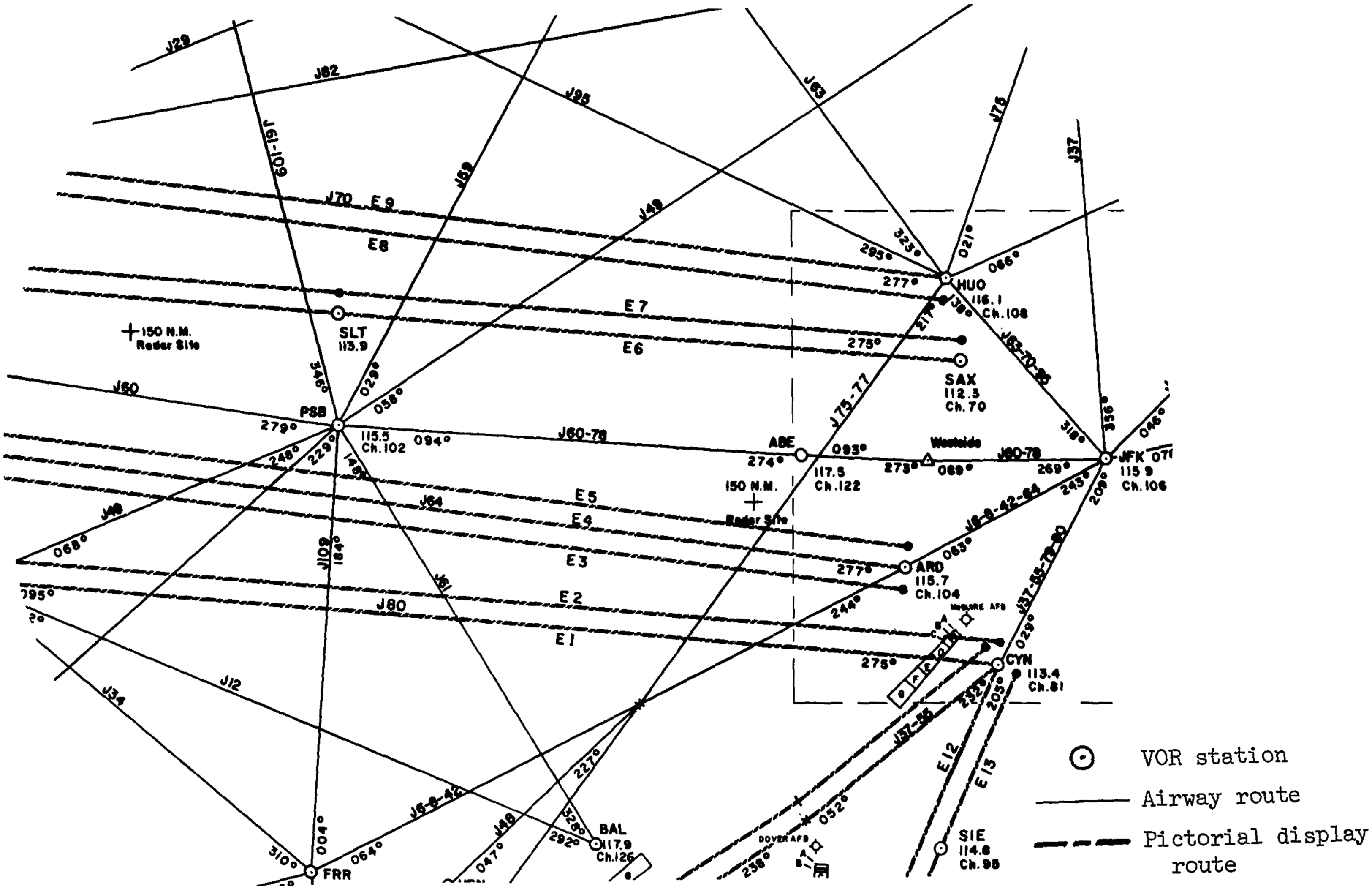
(a) Left to right: the control unit, the display unit, and the amplifier unit. L-65-6840.1

Figure 3.- Photographs of pictorial display components.



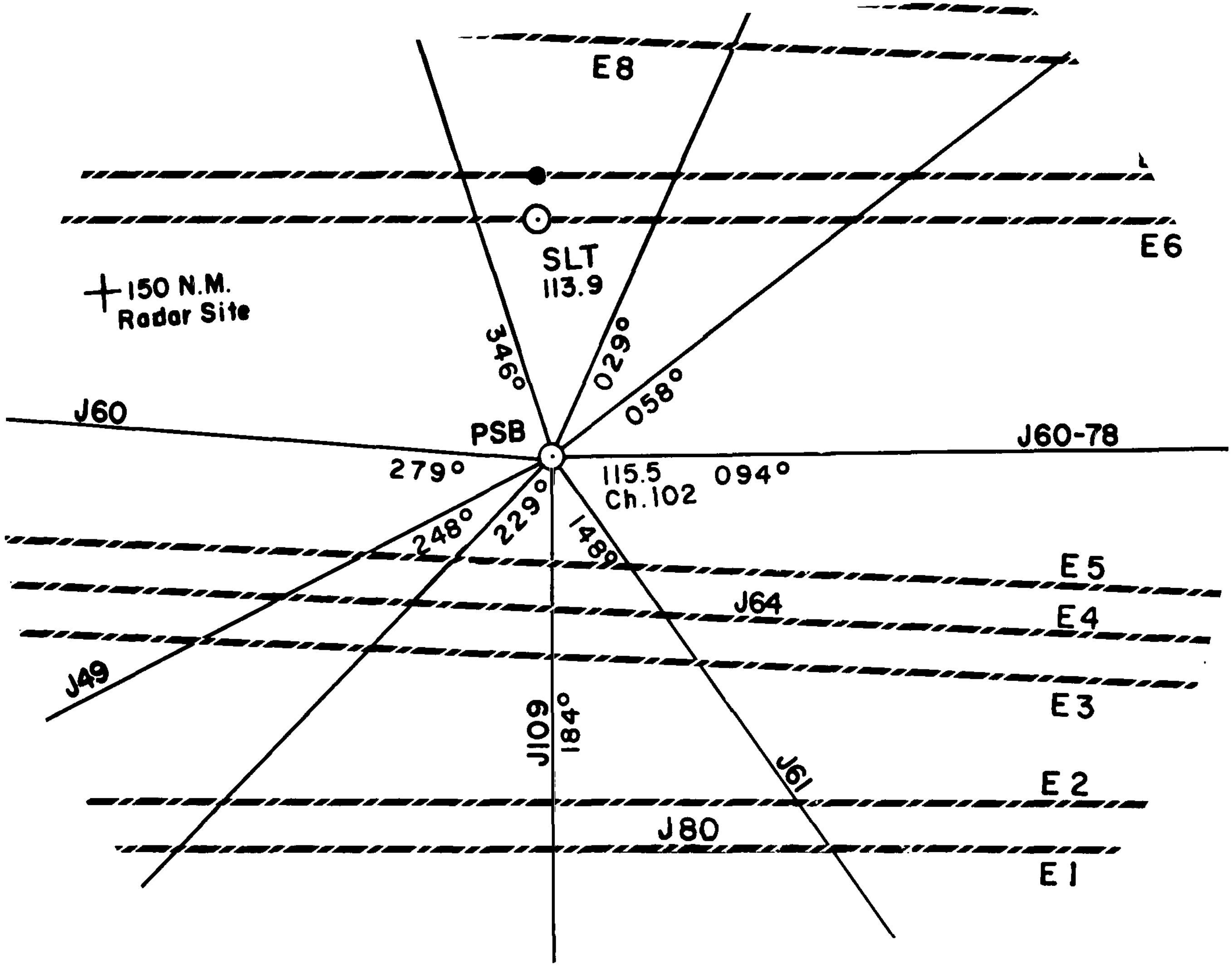
(b) Interior of the display unit. L-66-10178.1

Figure 3.- Concluded.



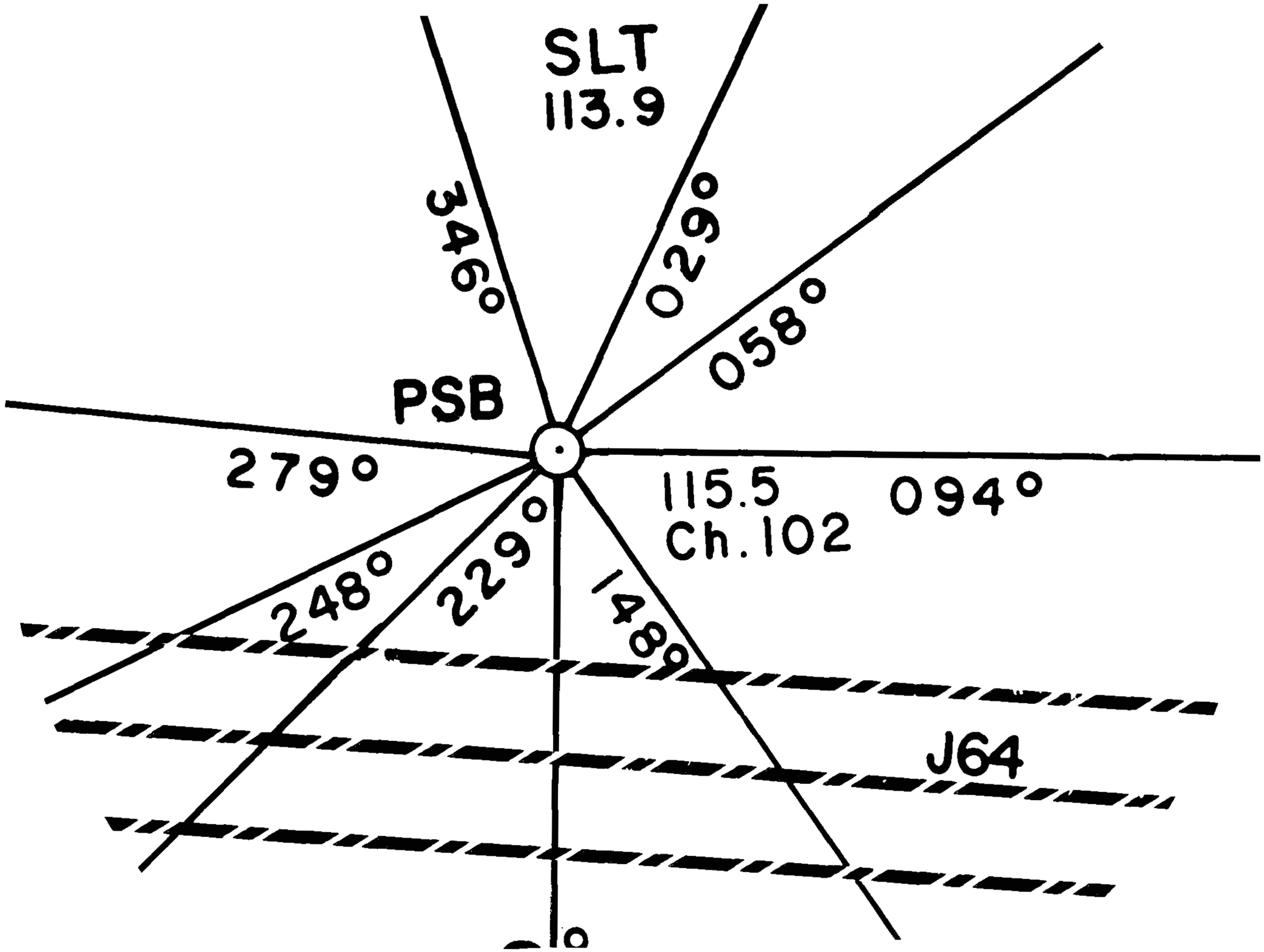
(a) En route map; 40 n. mi. per inch (29.2 km per cm).

Figure 4.- Full-scale representation of the screen of the pictorial display.



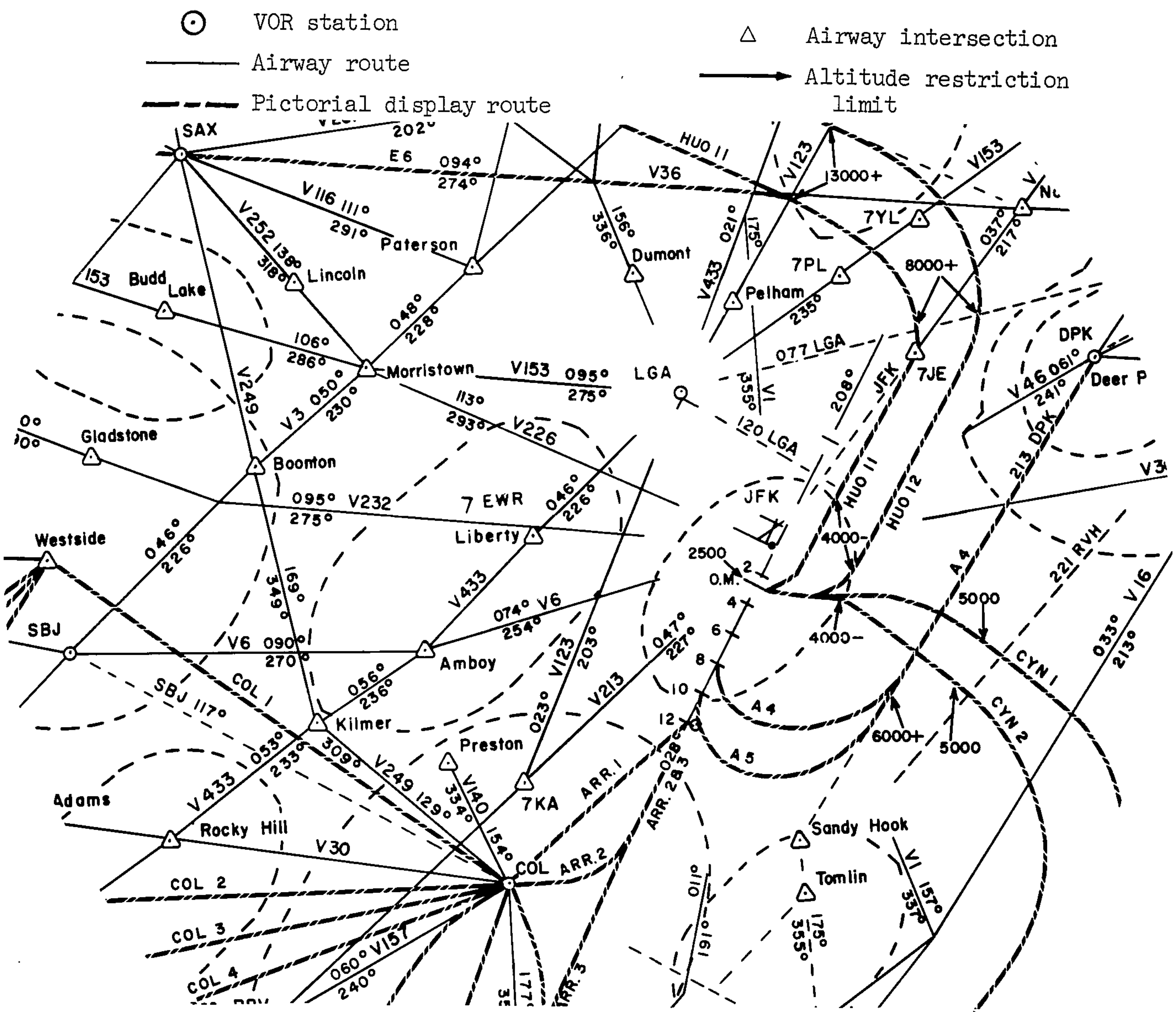
(b) En route map; 20 n. mi. per inch (14.6 km per cm).

Figure 4.- Continued.



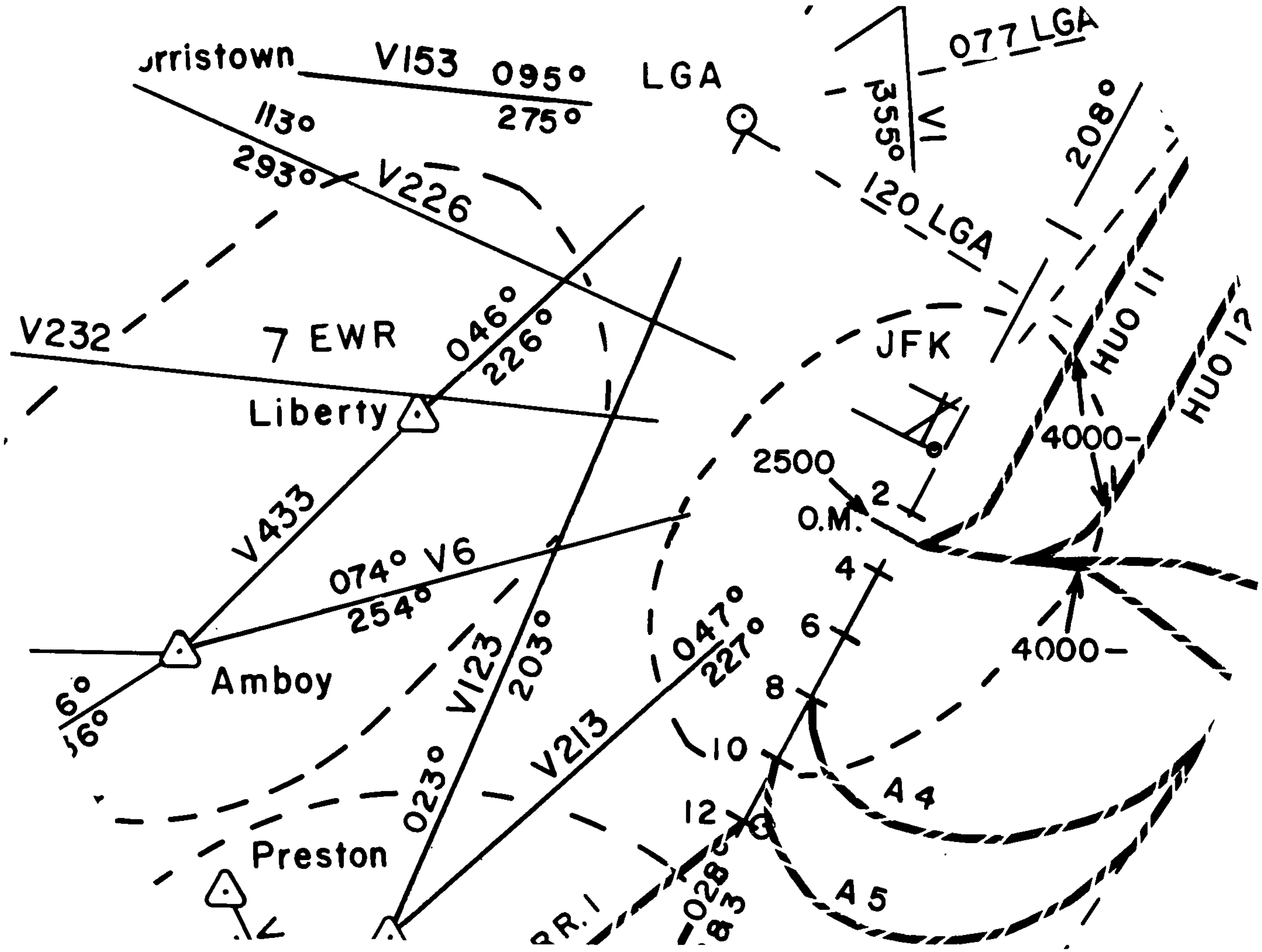
(c) En route map; 10 n. mi. per inch (7.3 km per cm).

Figure 4.- Concluded.



(a) Terminal area map; 10 n. mi. per inch (7.3 km per cm).

Figure 5.- Full-scale representation of the screen of the pictorial display.



(b) Terminal area map; 5 n. mi. per inch (3.65 km per cm).

Figure 5.- Concluded.

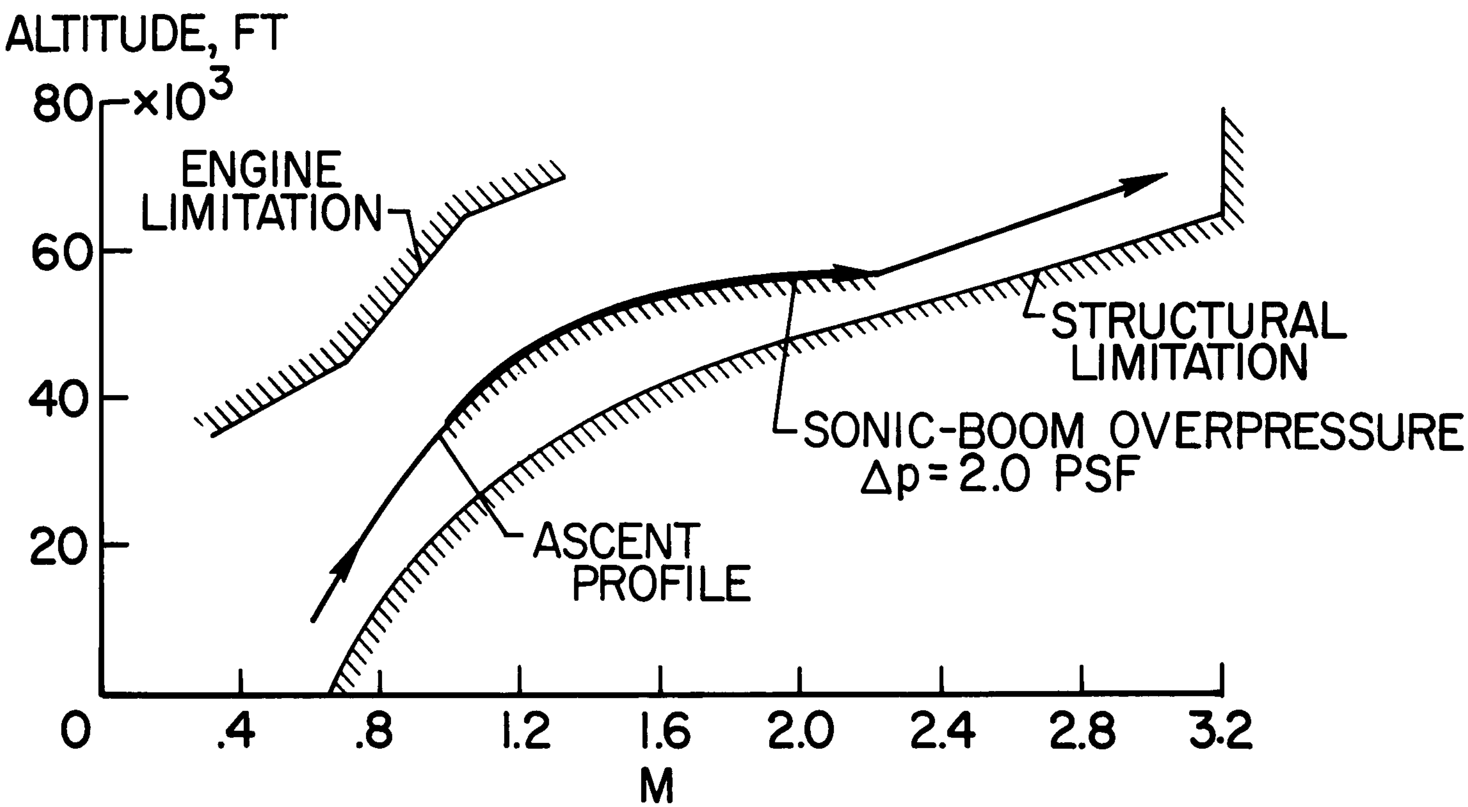


Figure 6.- Climb profile and limitations.

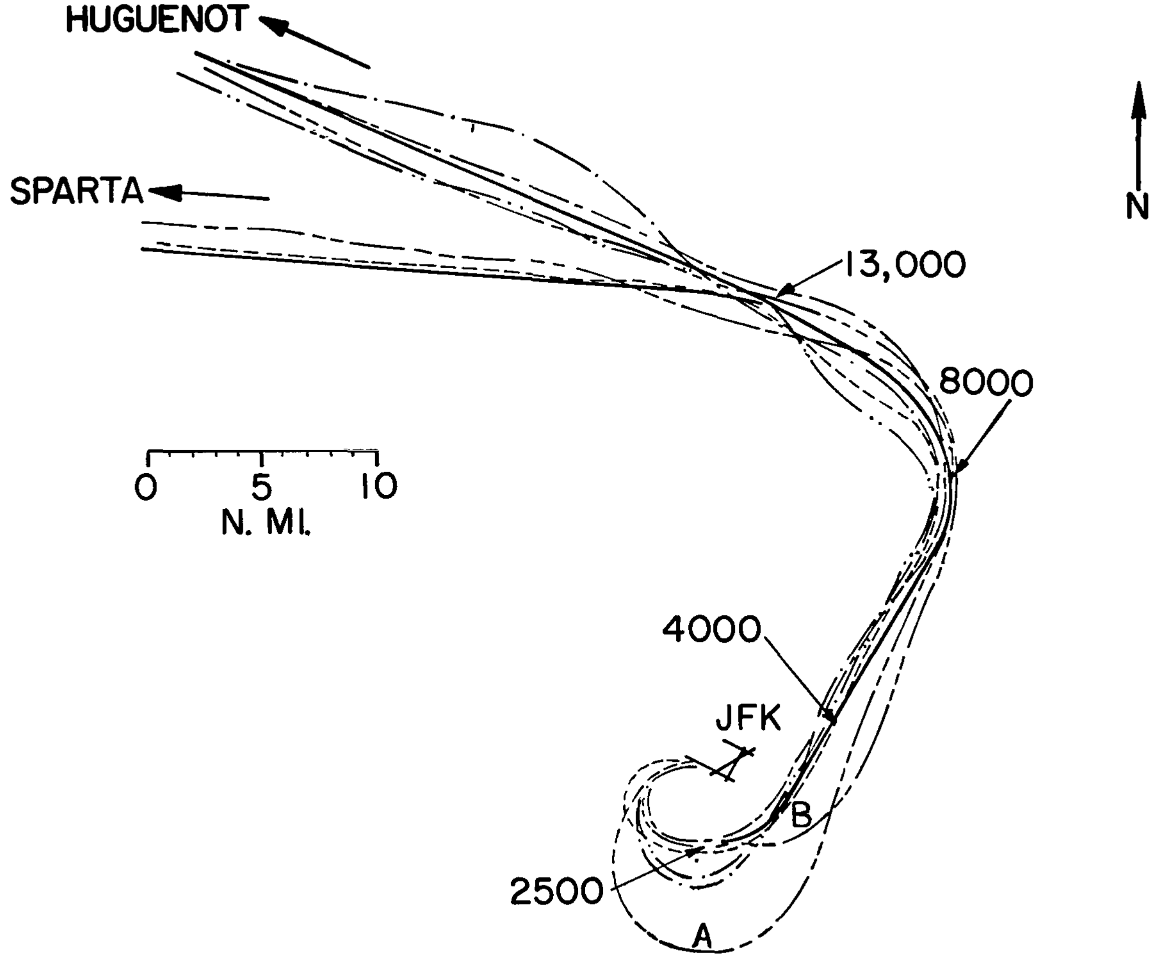


Figure 7.- Tracks of 6 departures to Huguenot Sparta; pictorial display routes are shown as solid lines. Map scale 5 n. mi. per inch (3.65 km per cm). Altitude restrictions shown are in feet.

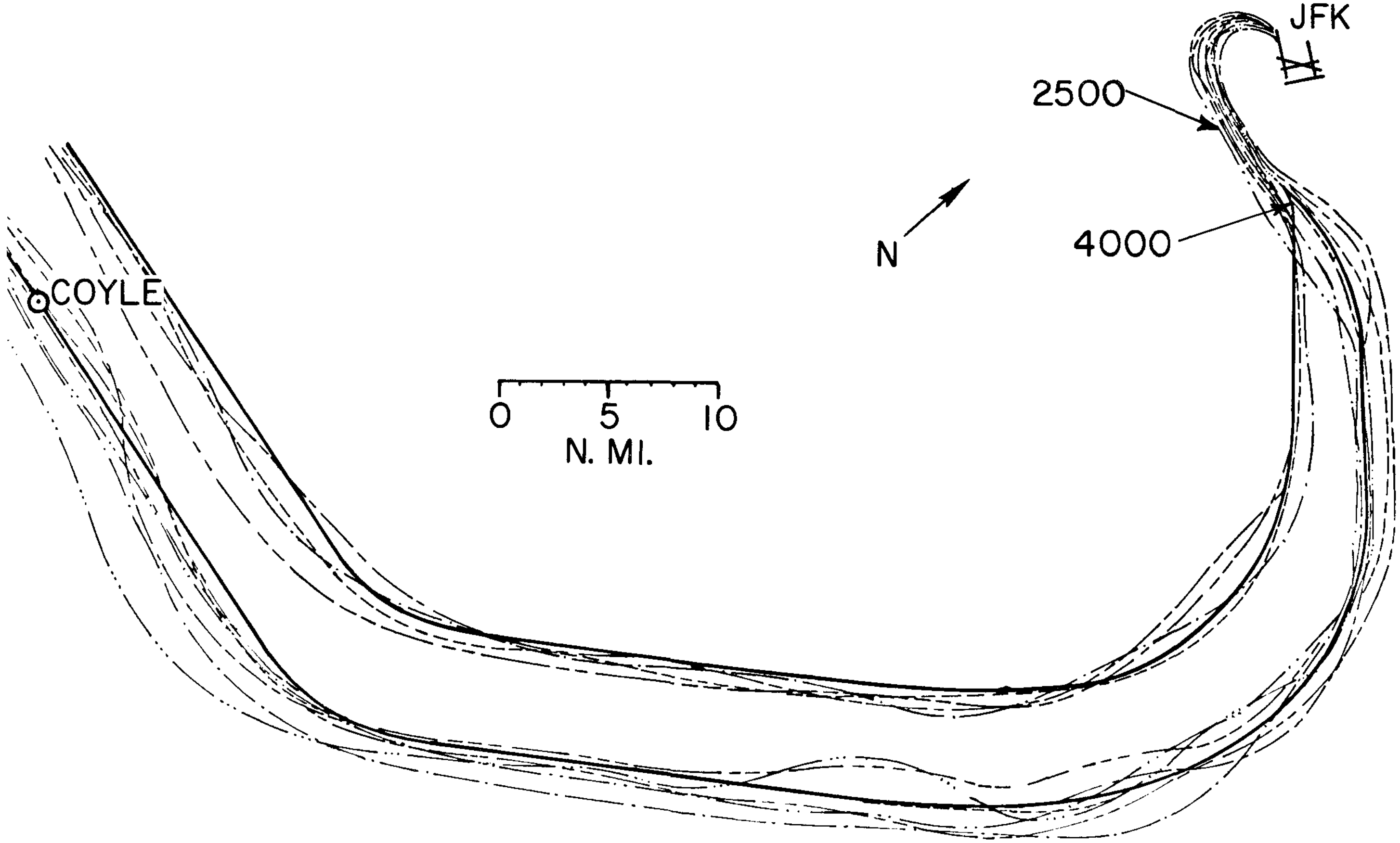


Figure 8.- Tracks of 11 departures to Coyle (CYN); pictorial display routes are shown as solid lines. Map scale 5 n. mi. per inch (3.65 km per cm). Altitude restrictions shown are in feet.

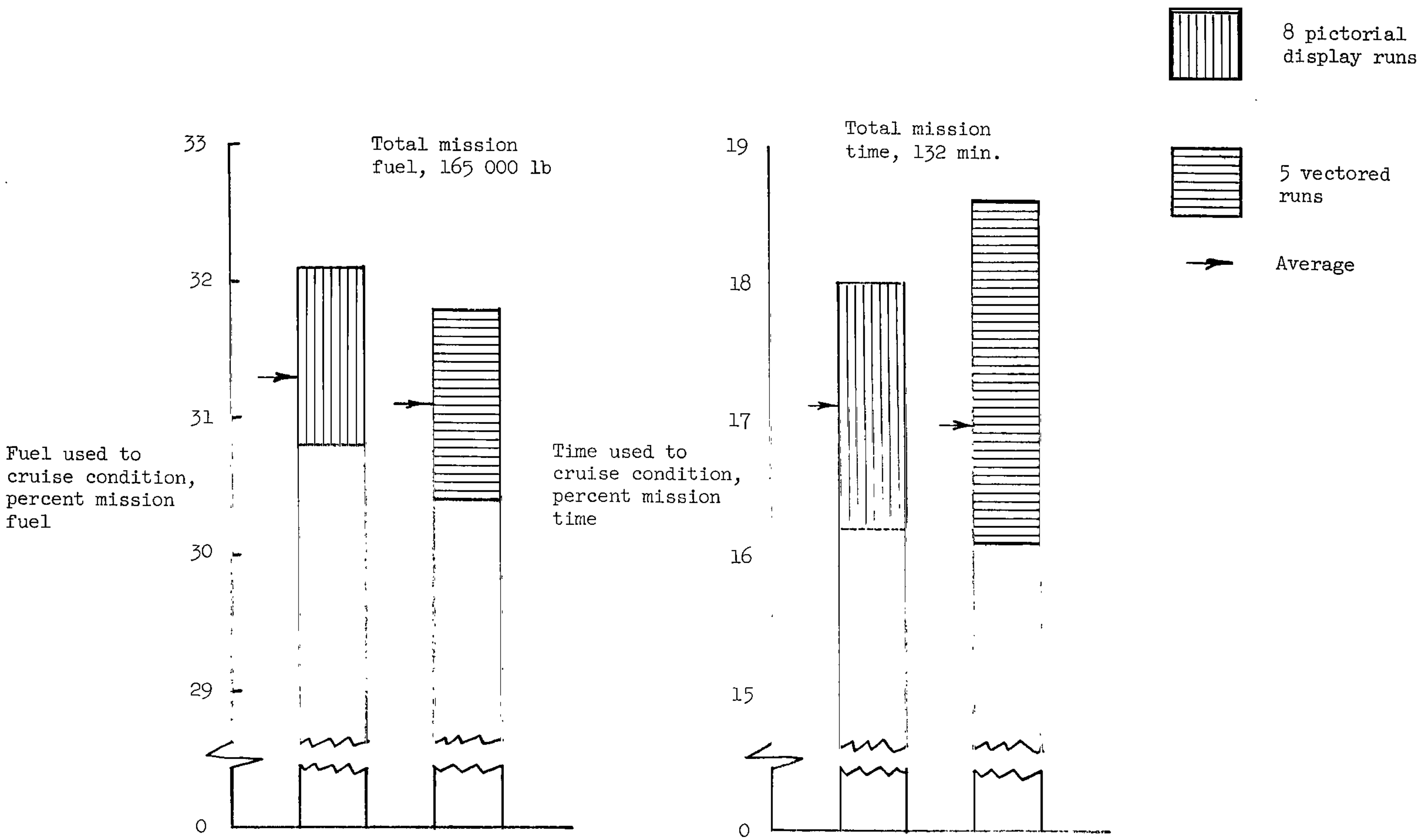


Figure 9.- Comparison of time and fuel for pictorial display and vectored test runs.

NASA-Langley, 1967 — 21 L-5321

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