(NASA-CR-120600) CONDUCT OVERALL TEST OPERATIONS AND EVALUATE TWO DOPPLER SYSTEMS TO DETECT, TRACK AND MEASURE VELOCITIES IN AIRCRAFT WAKE VORTICES Final Report (Lockheed Missiles and Space Co.) 61 p

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CONDUCT OVERALL TEST OPERATIONS AND EVALUATE TWO DOPPLER SYSTEMS TO DETECT, TRACK AND MEASURE VELOCITIES IN AIRCRAFT WAKE VORTICES

FINAL REPORT

December 1974

Contract NAS8-30645

Prepared for National Aeronautics and Space Administration
Marshall Space Flight Center, Alabama 35812

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FOREWORD

This document was prepared by personnel in the Laser Systems Section of Lockheed Missiles & Space Company, Inc., Huntsville Research & Engineering Center.

The work described was accomplished under Contract NAS8-30645, "Conduct Overall Test Operations and Evaluate Two Doppler Systems to Detect, Track and Measure Velocities in Aircraft Wake Vortices." The NASA-MSFC technical monitor and alternate monitor for this contract were Mr. J. W. Bilbro and Mr. H. B. Jeffreys, respectively.

Completion of the work at Huntsville described herein would have not been possible without the help of many NASA-MSFC personnel. Aircraft test time was also provided by the U.S. Army, NASA-Langley, NASA-MSFC and FAA.

Graditude is expressed to NASA-MSFC personnel for their logistics assistance in moving the system to New York, to Lockheed Aircraft Service for use of their New York facilities, and to NAFEC personnel at the New York site for their assistance in establishing the test operation at Kennedy International Airport.

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Section 1
INTRODUCTION, SUMMARY AND CONCLUSIONS

1.1 BACKGROUND

The effort under the subject contract (NAS8-30645) began on 28 January 1974. The contract was awarded as a result of Request for Quotation 8-1-4-75-40013 issued by NASA on 23 November 1974, and a competitive proposal submitted by Lockheed on 26 December 1973.

Prior to initiation of the subject contractual effort, Lockheed, Raytheon and other suppliers had fabricated and delivered certain components of a Scanning Laser Doppler System (SLDS) to NASA-MSFC. These components had been loosely integrated at the MSFC test site by NASA, Lockheed and Raytheon personnel. The test site had been laid out as depicted in Fig. 1-1, and three sets of flyby tests had been conducted with a single-van SLDS configuration using NASA's Grumman Gulfstream aircraft. Program status at time of contract initiation is discussed in Section 2.1 of this report.

1.2 SUMMARY

Immediately after contract award, Lockheed personnel developed a program plan and performed a critical path review of events necessary for a successful program completion, i.e., a system checked out and packed for shipment to Kennedy International Airport (KIA), by early May 1974. The program plan, discussed briefly in Section 2.2, required completion of noise tests and wind tests (Section 3), large blower flowfield tests (Section 4), single SLDS unit (1-D) flyby tests and dual unit (2-D) flyby tests (Section 5) along with associated logistics preparation, equipment interface checkouts and data processing prior to program completion.

Unfortunately a key piece of test gear — the aircraft engine blower — could not be made available on schedule. Omission of this blower test helped

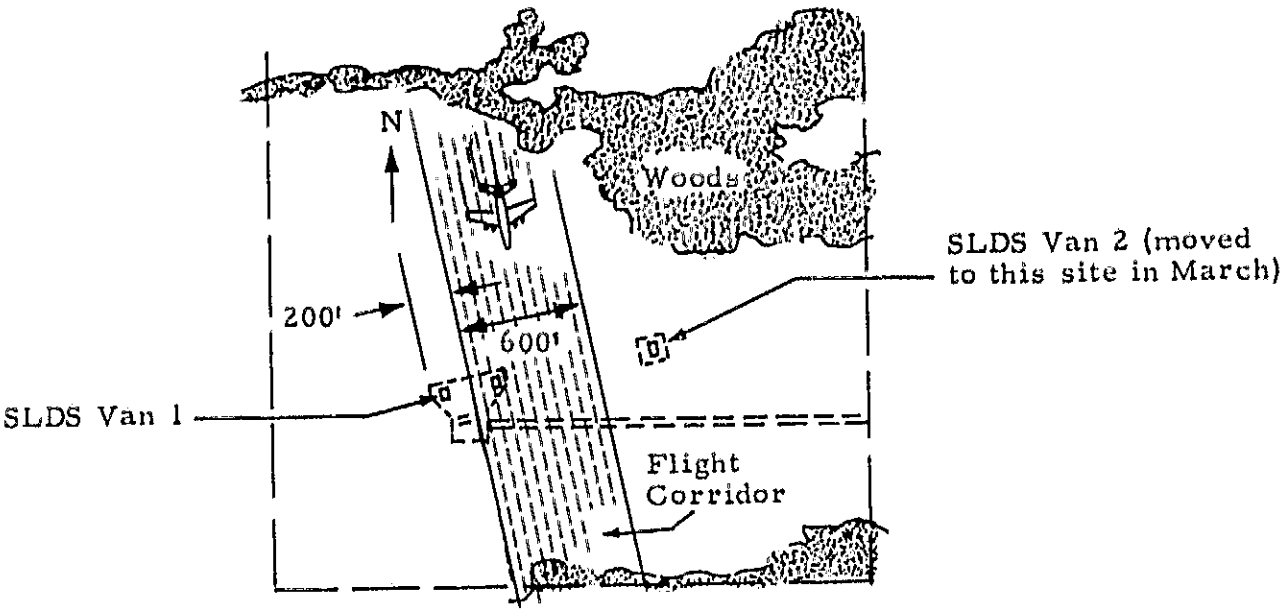

Fig. 1-1a - Plan View of MSFC SLDS Test Site

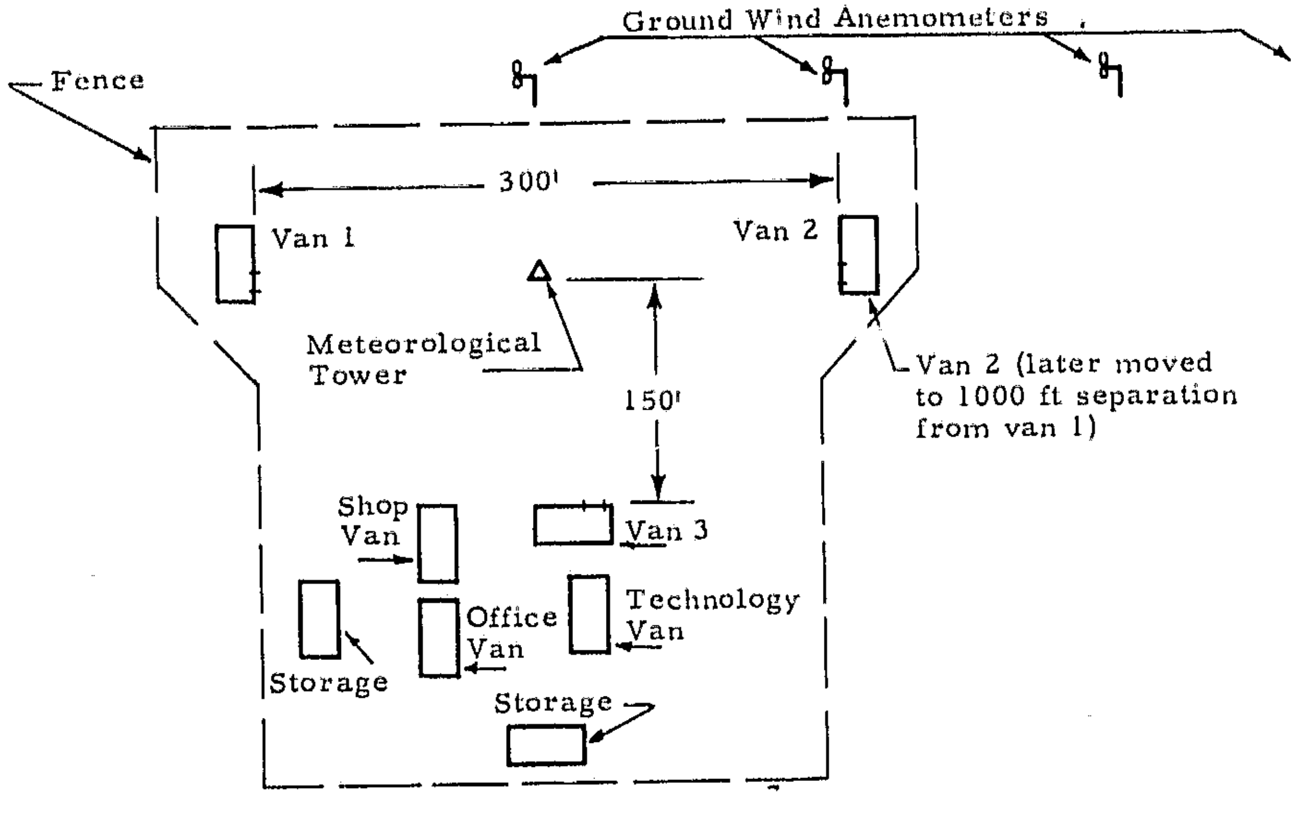

Fig. 1-1b - Enlarged Plan View of Enclosed Area of SLDS Test Site at MSFC to conceal a scale factor problem in the range scanner optics servo. The range scanner was scanning short and flyby tests in early April indicated that the SLDS – although capable of detecting vortices – was not ready for shipment to KIA. A decision was made by NASA and DOT management to perform additional SLDS testing at MSFC and the subject contract was extended and expanded to cover testing at Huntsville through the summer. The blower flowfield calibration tests were performed in late May and June. Additional flyby tests were performed in June and early July.

In July a decision was made to add a capability for on-line processing of data to provide vortex tracks of higher resolution in real time. Implementation of this capability had begun by early August when the final MSFC flybys were performed (see Fig. 1-2) prior to system shipment to KIA.

Lockheed personnel began SLDS assembly and checkout at KIA in late August and completed this task by mid September. This task, the final task of the subject contract, is discussed in Section 6 of this report.

1.3 CONCLUSION

In conclusion, the SLDS is capable of accurately tracking aircraft wake vortices from small aircraft or large aircraft and in almost any type of weather. The system was integrated, tested and somewhat optimized under the subject contract in a relatively short time frame for such a complex, state-of-the-art system. Equipment problems, although they appeared major at the time, have essentially all been resolved and were really – in retrospect – not very major at all. For a breadboard-type system, the equipment operates reliably with only minor maintenance requirements. Experienced personnel are now required to operate the system. However, the technology is available to develop a system which would be more or less self-operating.

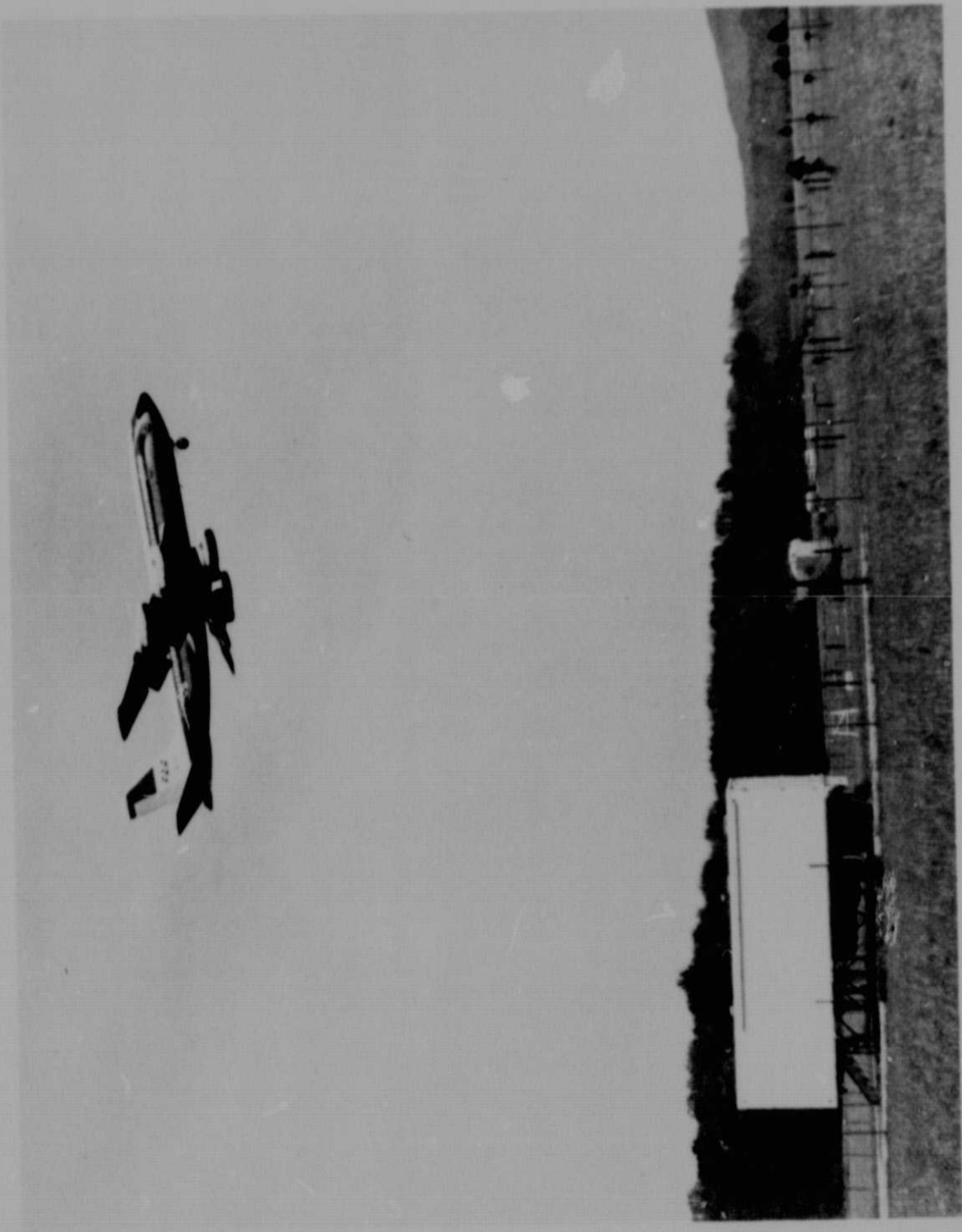

Fig. 1-2 - SLDS Flyby Tests at MSFC with FAA B-720 Aircraft on 9-10 April and 7-8 August 1974

Section 2
EARLY FLYBY TESTING AND PROGRAM PLAN

2.1 STATUS AT TIME OF CONTRACT AWARD

Lockheed began work under this test and evaluation contract on 25 January 1974. By the time of contract initiation, the two scanning laser Doppler system (SLDS) vans had been moved to the test site designated for system flyby evaluation at MSFC. Van 1 had been moved into position and flybys had been flown with Van 1 semi-operational on three separate occasions (28 November, 12 and 21 December 1973).

The 20 November flyby was essentially a dry run with the objective of familiarizing system operating personnel with conditions to be encountered during later scheduled flybys. The Grumman Gulfstream aircraft made 12 passes in front of Van 1 at ranges of 300 to 350 feet and altitudes of approximately 150 feet. The equipment status was semi-operational.

The objectives of the 12 December flyby were the further development of flyby test procedures, further crew training, equipment checkout and a first attempt to detect a vortex with the SLDS. Seventeen flybys were made with the Gulfstream aircraft flying at 300 to 400 feet range from Van 1. (Van 2 was not yet in position.) Flight altitudes varied from 105 to 200 feet and airspeeds from 120 to 130 knots. Winds were approximately 1 knot cross and 8 knots head. Of the seventeen passes made, the first three were test passes for the flight crew, and an attempt was made to detect vortices with the SLDS on the remainder. Comments from the data sheets for these runs were:

Run	Comment	Run	Comment
4	Display showed vortex position	10	Fair data
5	Vortex spotted, not as good as run 4	11	Good data
6	Good run	12	Fair data
7	A lot like run 5	13	Nothing on LDV
8	A lot like run 5	14	Questionable
9	No signal apparent	15	Changed processor setting

In retrospect, a few blurs were recorded from the real time display which were considerably inferior to the vortex position or lifetime indications currently possible. However, the output of the spectrum analyzer after aircraft flyby did provide a signature representative of that expected from a wake vortex.

The 21 December flyby test with objectives similar to those of previous tests consisted of 13 Gulfstream passes. Again the first three were made for flight crew practice. All flights were made at ranges of approximately 300 feet from Van 1 (Van 2 was not yet operational) and altitudes of 100 to 200 feet. The headwinds and crosswinds were approximately 5 and 0 knots, respectively. The data sheets indicate the operators believed they saw vortices on very few of the passes. However, the additional objectives of developing test procedures, crew training and further check out of equipment components were met.

2.2 PROGRAM PLAN FOR SYSTEM EVALUATION

Immediately after contract award, Lockheed personnel performed a Critical Path Analysis of the events required for successful operation of the Two-Dimensional Scanning Laser Doppler System. Integrated systems testing required to meet system evaluation and optimization objectives were determined to include:

- Noise Tests (Performed 2-13, 3-1-74)
- Wind Test (Performed 3-1-74)
- Blower Flowfield Tests (Performed 3-29, 5-31, 6-6, 6-7, 6-11-74)

- 1-D Flight Test (Performed 3-7, 3-13, 3-14, 3-22-74)
- 2-D Flight Test (Performed 4-2, 4-9, 4-10, 6-17, 6-25, 7-2, 8-7, 8-8, 8-9-74)

Under ideal conditions, the testing would have been performed in the order listed with preliminary data analyses completed before progressing to the next test on the list. However, due to unavailability on schedule of the blower (aircraft engine) and requirements to perform flyby tests early in the series, flight tests were performed before the blower flowfield tests. In retrospect, if the blower tests had been performed as scheduled and the results processed on-line or via computer in a timely manner, range scanner scaling problems would have been discovered earlier and the system readied for shipment to Kennedy earlier.

In addition to the systems tests discussed above, component testing was performed simultaneously on various subsystems of the Scanning Laser Doppler System. Many of these tests, performed under separate contract, are discussed in Volume I of "Development and Testing of Laser Doppler System Components for Wake Vortex Monitoring," Lockheed Final Report for NAS8-29824, August 1974.

Section 3
NOISE TESTS AND WIND TESTS

3.1 NOISE TESTS

A series of tests was conducted on 13 February 1974, with the objective of determining and recording the noise characteristics of the Scanning Laser Doppler System (SLDS) as configured in Van 1. These were the first tests conducted with the SLDS under Contract NAS8-30645. The SAT detector, Raytheon interferometer, laser and processor and Lockheed telescope and scanners were configured into the system. A blackened wire was used to reduce secondary backscatter. The tape recorder was configured to record the following: time code, spectrum analyzer synchronization, raw LDV signal, PCM data, range, elevation and spectrum analyzer vertical output. The above items were recorded with the van window closed (i.e., telescope output blocked) for the conditions shown in Table 3-1 on the following page.

3.2 WIND TESTS

A series of measurements of winds was conducted on 1 March 1974 with the SLDS with the objective of determining the ability of the system to measure ambient wind under non-scanning and scanning conditions. Recordings of scanning and non-scanning data were analyzed to determine effects of the scanning elements and servo electronics on the recorded data. Time-on-target effects were also of interest. Parameter variations for these tests are listed in Table 3-2. Data recorded during these tests (Table 3-2) included time code, spectrum analyzer synchronization and vertical output, PCM, raw LDV signal, range and elevation. Analysis of these data indicated typical signal-to-noise ratios of better than 25 dB for the wind signal. The effects of scanning and integration time variations were as expected. The tests indicated the elevation scan rates were not sufficient to degrade the signal due to receiver aperture moving out of the transmitter field of view. Degradation of the signal due to scanning was minimal.

Table 3-1
NOISE TEST PARAMETERS

Run No.	Event No.	Integration Time (ms)	Range	Elevation
001	A	4	61 m	3.2^{o}
	B	4	↓	↓
	C	8		
	D	16		
	E	4	300 m	
	F	8	↓	
	G	16		
	H	4		33^{o}
	I	8		↓
	J	16	0.1 Hz (62-300 m)	
002	A	16	1.1 Hz (62-300 m)	33^{o}
	↓	↓	3.1	↓
			5.1	
			6.9	
	B		62 m	0.1 Hz ($3-33^{o}$)
	↓		↓	0.3
	C			0.5
	D		1.1 Hz (62-300 m)	0.5
	↓		5.1	↓
			6.9	

Table 3-2
WIND TEST PARAMETERS

Range			Elevation			Processor	Spectrum Analyzer
Max. (m)	Min. (m)	Freq. (Hz)	Max. (deg)	Min. (deg)	Freq. (Hz)	Integration Time (ms)	Band Width (kHz)
—	62	0	—	3.3	0	4, 8	100, 200
—	62	↓	—	33	↓	↓	↓
—	300	↓	—	3.3	↓	↓	↓
—	300	↓	—	33	↓	↓	↓
300	62	0.1	—	3.3	↓	↓	↓
↓	↓	0.1	—	33	↓	↓	↓
↓	↓	1	—	3.3	↓	↓	↓
↓	↓	1	—	33	↓	↓	↓
—	↓	0	33	3	0.1	↓	↓
—	300	↓	↓	↓	0.1	↓	↓
—	62	↓	↓	↓	0.3	↓	↓
—	300	↓	↓	↓	0.3	↓	↓
—	62	↓	↓	↓	0.5	↓	↓
—	300	↓	↓	↓	0.5	↓	↓
300	62	1	↓	↓	0.1	↓	↓
↓	↓	1	↓	↓	0.5	↓	↓
↓	↓	7	↓	↓	0.1	↓	↓
↓	↓	7	↓	↓	0.5	↓	↓

Section 4
BLOWER FLOW FIELD

Blower flowfield tests were planned with the objective of determining the capability of the SLDS to accurately measure calibrated flow fields which could be fixed in space and which would exhibit many of the properties of the dynamic aircraft wake vortex. An ideal target for calibration of the SLDS would have been a wake vortex fixed in space with a calibrated flow for static and dynamic probing with the SLDS. However, since a wake vortex is a property of lift, the large fixed, calibrated vortex is a difficult, if not impossible, phenomenon to produce. We thus decided upon an alternate type of spatially fixed flow field for calibration of the SLDS; this flow field consisted of the wake of a large engine driven blower.

Two types of blowers were located at MSFC as candidate sources for the flow fields for the calibration tests. The smaller blower consisted of a "squirrel cage" type fan with a turbine ~4 feet in diameter and 4 feet long and an exit duct of 3 by 5 feet. With a 30 hp motor, this blower (Fig. 4-1) would provide maximum flows of approximately 35 ft/sec. A larger and more appropriate blower was also located — a 3300 hp Allison aircraft engine with an approximately 14 foot diameter three bladed propeller (Fig. 4-2).

Both of the above blowers were moved to the MSFC test site. The small blower was moved in first because we were not sure of the availability of the larger blower. Lockheed personnel procured and installed a flow directing duct on the small blower to provide a less turbulent, more contained flow. Once the larger blower was moved to the site and preliminary tests were conducted, a decision was made to conduct all wind gradient tests with the larger aircraft engine blower instead of the smaller blower. A calibration of the large blower flow made by Mr. J. Bilbro, program COR, is presented in Fig. 4-3.

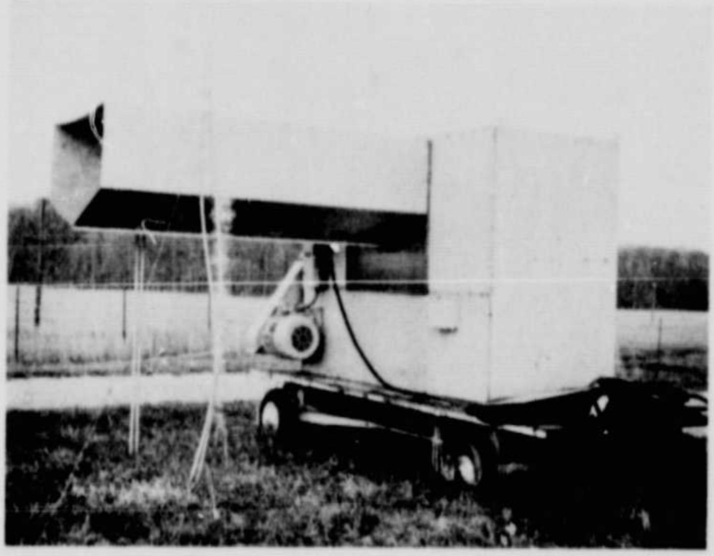

Fig. 4-1 - 30 hp Blower

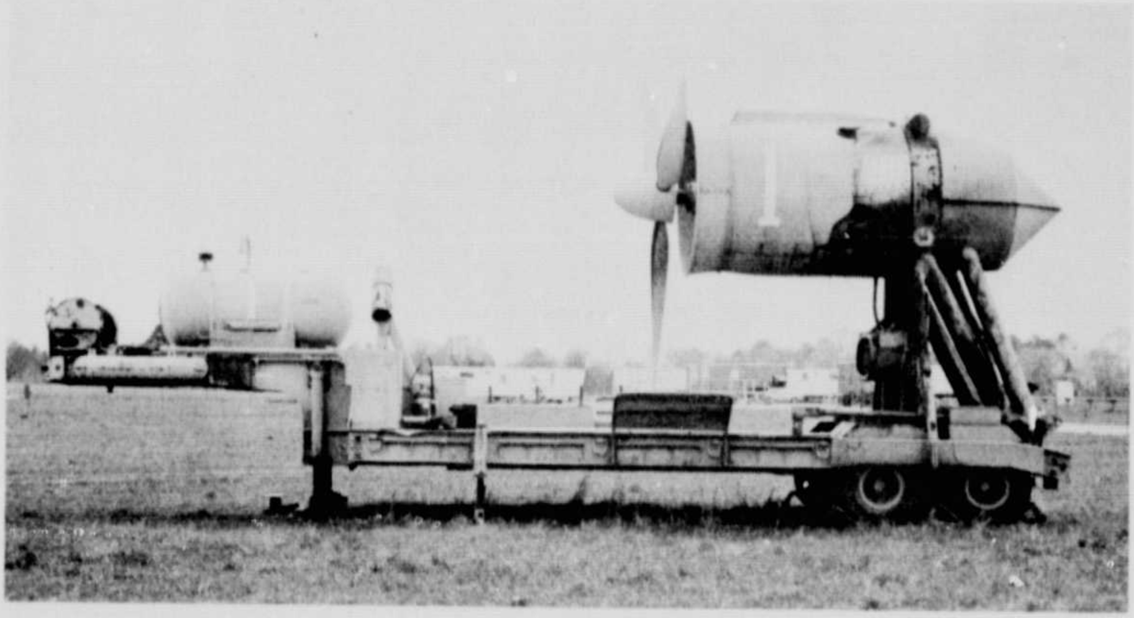

Fig. 4-2 - 3300 hp Blower Used to Generate Flow Field for Testing SLDS Capability to Accurately Locate Flowfield Discontinuities Within the Atmosphere. (Flow field from this blower was located at ranges of 250, 500 and 700 ft.)

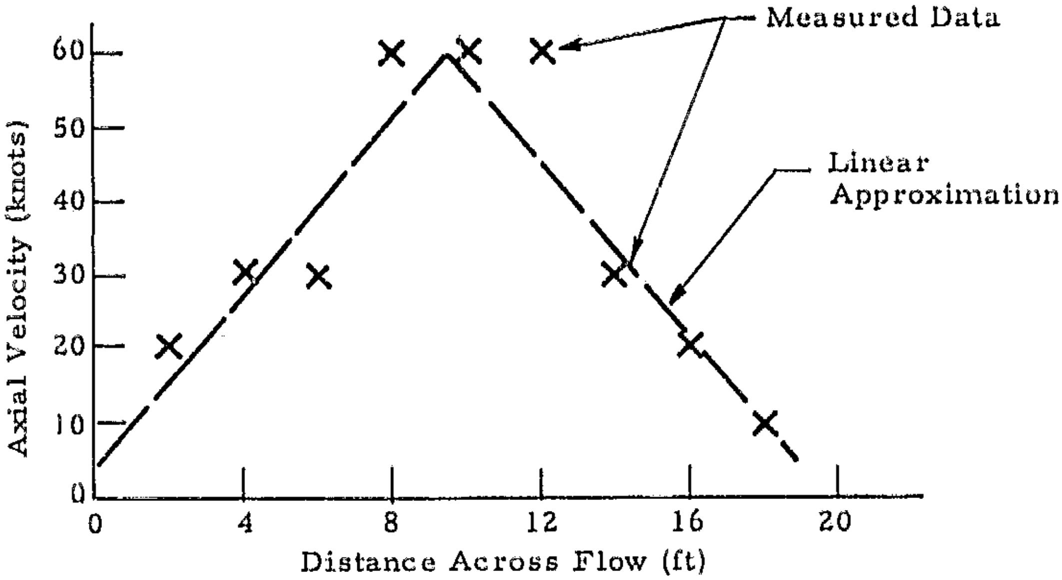

Fig. 4-3 - Calibration of Blower Flow Field of Fig. 4-2 (Velocity full scale of anemometer used for calibration was 60 knots.)

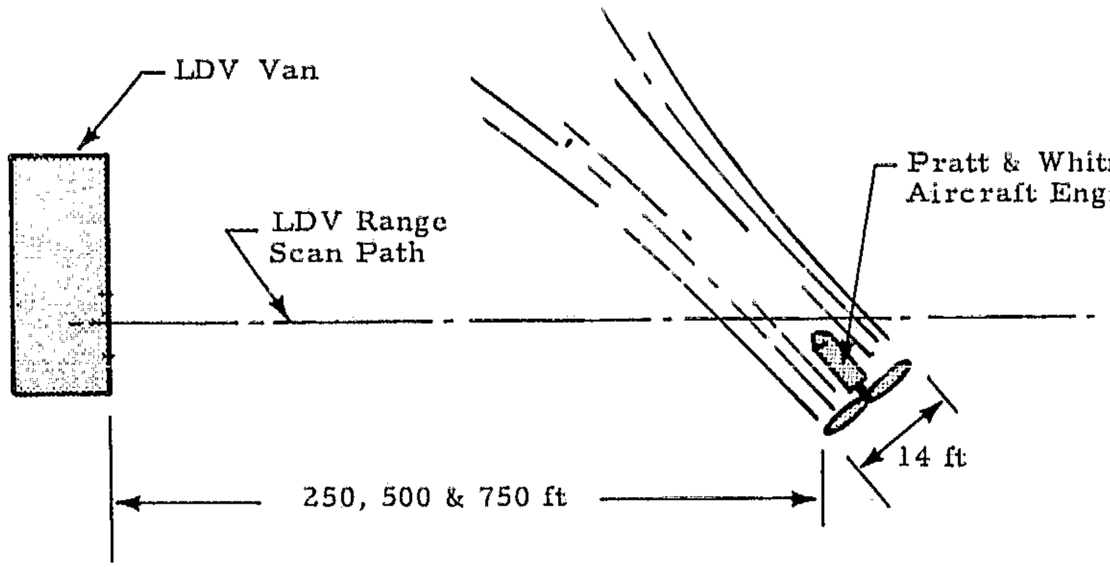

Fig. 4-4 - Schematic of Test Site Geometry for Blower Tests

4.1 INITIAL BLOWER FLOWFIELD TEST

For the initial blower flowfield test, the engine was set up at a distance of approximately 500 feet (137 m) from Van 1 and oriented at 45 deg to the line of sight of LDV 1 (see Fig.4-4). LDV 1 was aimed approximately one foot aft of the engine cowling.

On 29 March 1974, the first blower test was conducted. The test plan called for statically probing the flow field and recording data at 70, 104, 132, 150, 160, 170, 200, 248, 306 and 402 m. After statically probing the semi-steady state flow field, the range scanner would then scan through the flow at rates of from 0.1 to 6.9 Hz at integration times of 4, 8 and 64 ms. The effects of time on target and scanning through wind gradients would be determined from the recorded data. The engine would be run at idle (1000 rpm) and at 2200 rpm.

The test was conducted on 29 March as outlined. The system was calibrated initially on a wheel at 194 ft. However, two events did not occur which could have had considerable positive effect upon the program: (1) system operators did not notice during the test that the flow from the engine was not detected as it should have been, and (2) the data were not reduced via computer until many weeks after the test. In retrospect, either one of the above events could have possibly determined that the range scanner was scanning shorter than indicated by scanner controls and display.

4.2 BLOWER FLOWFIELD TESTING SUBSEQUENT TO SPRING FLYBY TEST SERIES

Subsequent to the spring flyby test program and the discovery and fix of the short range scan problem, a second series of blower flowfield tests was initiated. These tests began on 31 May and continued through 11 June 1974. The objectives of these tests were to:

- Determine the capability of the SLDS to locate a calibrated flow field which has many of the flow gradient properties of a wake vortex, and

- Verify the effects of time on target and integration time variations for laser Doppler monitoring of transient soft targets.

The summer blower flowfield tests series was conducted on 31 May and 4, 6, 7 and 11 June. The 31 May tests were rained out immediately after initial system noise calibration and before any blower data were recorded.

For the 6 June test, both Van 1 and Van 2 systems recorded data while both SLDS probed the blower flow field. First the two systems recorded a series of noise data runs at different scan rates. Next, recordings were made as both systems (a) range scanned, and (b) elevation scanned with sandpaper wheels used as hard calibration targets at 500 ft ranges. Finally data were taken with the blower flow field used as a soft target for each system at a range of approximately 500 ft (152 m). The blower flow field was initially probed in a non-scanning mode and data were taken at the following ranges while integration periods were varied between 4 and 16 ms: 127, 132, 137, 142, 147, 152, 157, 162, 167, 172 and 177 m. Next the blower was range scanned between 95 and 256 m at rates varying from 0.1 to 6.1 Hz. Also elevation scanning of the flow field without range scanning as well as simultaneous range and elevation scanning were conducted. All scanned data were recorded with both 4 and 16 ms integration. (Other integration periods would have been also used but were not available at the time because of hardware problems.)

The initial results of these blower data from strip chart recordings (see Figs. 2-20a, 2-20b, 2-21, 2-22 and 2-23 of Vol. I, Lockheed final report to NAS8-29824) indicated that the blower flow field could truly be resolved in range with the scanning laser Doppler system with some degree of accuracy and "repetition." Further analyses of digitized data indicated that hand plotting of the system output of signal intensity above the velocity threshold versus range will yield the blower position within the theoretical focal volume of the system (25 m) plus the flowfield diameter (5 m). Additional processing of the data by NASA indicated the flow field could be located with a variance of 3 m at a range of 152 m.

The initial large blower flowfield tests at 500 ft range were followed by additional tests at 250 and 750 ft ranges. The results from these tests were as expected. The range resolution at 250 ft allowed improved blower position resolution and the degraded resolution at 750 ft degraded position resolution.

Time-on-target and integration time variations were evaluated and found to have the effects expected. One of the effects observed in this test was that the scan-to-scan variance in the range location of the maximum signal from a given filter was condiserably smaller when a fast range scan was used compared to that obtained at slow scans. This verified that the short illumination periods characteristic of fast scans permitted a full excursion of the intensity pattern while the effective backscatter area remained essentially constant, while with slow range scans random fluctuation of the backscatter area can cause the maximum of the signal to appear at some time (range) other than that corresponding to the passage of the maximum illumination intensity through the frequency "cell" corresponding to the particular filter under observation. It was also noted that this property tends to disappear at long range, where the intensity pattern is itself much longer, and the power returned from a velocity cell considerably smaller. These effects tend to diminish the effectiveness of the signal-to-noise ratio increase which one usually expects to obtain from increased integration time, i.e., the number of statistically independent signal and noise samples is reduced, since several successive samples are highly correlated. What is happening is that a particular assemblage of particles, producing some net backscattered field, moves through the beam, and during the time required to make such a transit, the signal vector is at a given level, with very little fluctuation (it may, however, be very low due to phase cancellation of the individual backscattered fields). If, during this time, the intensity pattern moves rapidly in range, and this pattern has very small axial length, the resultant signal faithfully depicts the rise and fall of the illumination on that collection of particles, since the effective backscatter area is nearly constant; hence the peak signal return from any filter output (which represents the backscatter from a particular collection of particles all moving at the same velocity) occurs exactly at the time when the illumination peak is on the collection of particles, providing an accurate range measurement.

If the range scan is slow, or if the illumination density at a given point in space changes slowly because the illumination pattern has a large axial spread, the particle population of the region representing a given velocity (i.e., frequency) interval renews itself many times – the peak signal in time will not in general coincide with the time of most intense illumination of that region since a particularly good (i.e., giving high backscatter) collection of particles can easily occur considerably earlier or later – the signal scattered back at the time of most intense illumination may well be one of the smaller ones in the collection.

Since the transit time tends to be dominated by the elevation scan rate rather than by the particle velocity, and since the former effect gives a range-invariant transit time

$$\left[\tau = \frac{\text{beam width}}{\text{velocity}} = \frac{\lambda R/D}{\omega_e \cdot R} = \frac{\lambda}{\omega_e \cdot D}\right]$$

where λ = wavelength; R = range; D = aperture diameter; ω_e = elevation angular rate; and τ = particle transit time. The main item causing population renewal at a rate higher than the passage of the illumination pattern through the region will be the axial length of the illumination pattern itself, which increases as R^2.

The effect of the fluctuation due to population renewal on the signal detection is more complicated; for a given average power return, such fluctuation in signal power gives a higher detection probability that no fluctuation would, if the average signal power is low; if the average signal power is high, the fluctuation decreases the detection probability below that which would be obtained if the power were non-fluctuating (i.e., at the constant average value).

Section 5
FLYBY TESTING AT MSFC

Flyby testing of the SLDS under the subject contract is divided chronologically into two groups:

- Spring flyby tests prior to blower flowfield tests, and
- Summer flyby tests subsequent to the blower tests.

5.1 SPRING FLYBY TESTING

Flyby testing was initially planned to follow the blower flowfield testing calibration of the SLDS. However, due to unavailability of the blower on schedule and requirements for early flyby testing, these tests began in early March and continued through mid-April. Initial flyby testing in this series began with single van SLDS (1-D) testing, on 7, 13, 14 and 22 March and expanded to two van (2-D) tests on 2, 9 and 10 April. The objectives of these tests were to:

- Further develop test plans and procedures for 1-D (single van) operation of the SLDS and expand these for 2-D (two van) operations
- Further train crews for operating the SLDS in 1-D and 2-D modes
- Continue component check out and provide minor modifications to improve system reliability, and
- Detect aircraft wake vortices in 1-D and 2-D modes of operation.

5.1.1 1-D Flyby Testing

5.1.1.1 Flight Testing with C-47 on 7 March

The first flight test of this series began with preparations many days prior to the actual test. Actual aircraft overflights began at 7:53 a.m. near dawn* and continued to 8:40 a.m. after 13 passes over the test area. The wind was perpendicular to the flight path at 4 to 10 knots (200 to 600 kHz Doppler) and the temperature was 65°F. The laser power varied from 16 W at test initiation to 14.7 W at the end of the test. Signal-to-noise ratios were measured to be 65 dB of the wheel at a 210-foot range and 25 dB off the atmosphere. Comments during the test were:

Run	A/C Range (ft)	Comment	Run	A/C Range (ft)	Comment
1	325	Good data	7	350	No data
2	200	Plane too close	8	—	Questionable
3		Questionable	9	400	No data
4	500	Questionable	10	—	Wind calibration
5	350	Very good data	11	330	Change tape
6	350	No data	12	330	No data
			13	—	Very good data

During all runs the aircraft altitude at time of overflight varied from 150 to 200 ft. The scanner was set to range scan at 5 Hz from 62 to 200 m for the first six runs. For the remainder of runs the minimum range was not changed and the maximum range was varied between 160 and 180 m. Elevation scanning was between 3 and 33 deg at 1/10 Hz. Following the flight tests a number of

*Near-dawn test period was chosen for stable atmospheric conditions.

runs of wind data at different scan rates were recorded plus one run of noise data. Integration time was unchanged at 4 ms during the tests.

5.1.1.2 Helicopter Flyby Tests of 13 March

A helicopter was made available on short notice on 13 March, for a total flyby test period of less than 8 min. During this period the helicopter made nine passes at short range and in rapid succession. Little control of the helicopter flight path or pass time could be exercised from the test site. Thus the time between passes was not sufficient for complete system set up between runs, and data gathered were not as valuable as would have been possible from a more "controlled" experiment. However, data were recorded and the wake vortices of the helicopter were seen by system operators after several of the overpasses.

5.1.1.3 C-47 Flyby Tests of 14 March

Sixteen data runs were conducted with the Army C-47 aircraft beginning at 7:14 a.m. and continuing through 8:19 a.m. on 14 March. Aircraft altitude was generally 100 to 150 ft and range was 150 to 250 ft. Comments indicate good data on most passes. Laser power output varied from 13.5 to 10.7 W during the test period. Signal-to-noise ratio remained at 75 dB off the sand-paper wheel target at 210 ft and 25 dB off the atmosphere during the test. The secondary (backscatter) local oscillator source was used. Range scanning was varied between 2 and 5 Hz between ranges of 32 and 130 m. Elevation was scanned between 3 and 40 deg at rates varying from 0.1 to 0.3 Hz. Integration times were varied on the processor starting with 4 ms during the first four runs then changing to 1 ms and to 1/2 ms during the last 3 runs. Strip chart recordings of ground wind anemometers set up to monitor vortex paths indicated very low cross winds (below anemometer threshold — except in the presence of the vortex) during most of the runs with winds increasing somewhat during the last runs.

5.1.1.4 C-47 Flyby Tests on 22 March

The objective stated for this test was "continue to optimize LDV settings for flight test for off-line data analysis." Fifteen flybys were performed between 7:16 and 8:21 a.m. with most remarks on the data sheets indicating "good runs." The aircraft flew at ranges of 150 to 400 ft from the LDV and at approximately 100 ft altitudes. No data were seen at ranges beyond 300 ft. (The fact that the range scanner was not covering longer ranges was unknown during these tests.) Laser power measured at the secondary varied from 14 to 13 W. Signal-to-noise ratio measurements were 75 dB for the 210 ft wheel target and 25 dB for the atmosphere. Backscatter (secondary) local oscillator power was used in the optical configuration. Range scan was typically set for 4 Hz from 32 to 130 m for shorter range flybys and 32 to 190 m for the 400 ft range flybys. Processor integration periods of 1, 2, 4 and 8 ms were attempted. Vortex signatures were also recorded in strip chart fashion from the propeller anemometers.

A wind velocity profile was recorded one hour after the test with winds varying from approximately 15 ft/s on the ground to approximately 20 ft/s at an indicated altitude of 300 ft.

5.1.1.5 Summary of 1-D Testing

This series of one-dimensional tests was conducted primarily with C-47 Army aircraft flying at ranges from 150 to 400 ft. Vortices were normally seen at the shorter ranges, but were often missed at the longer ranges because of the scale factor problem with the range scanner. Data were normally taken as soon after dawn as visibility was sufficient for flight crews, to take advantage of stable atmospheric conditions. This necessitated test crew arrival at the test site at 3 to 4 a.m.

5.1.2 2-D Flyby Testing

5.1.2.1 Flight Tests with Caribou on 2 April

The SLDS units in Vans 1 and 2 were operated simultaneously during flybys for the first time for the Caribou tests on 2 April 1974. These tests were conducted in the early afternoon and therefore did not have the stable atmospheric advantages of earlier flyby tests. However, the cross wind component was light.

The tests were conducted such that the plane flew near Van 2 for the first flight, near Van 1 for the second, etc. The comments from the operators for each system along with the range scanner settings are depicted in Table 5-1. Aircraft position during flyby can be inferred above from the range scan settings. The comments from each unit's operators, in general, indicate the systems were detecting the vortices when the flight path came near the van. In light of current knowledge about range scanner scale factor problems during these flights, this detection problem for long range (beyond 150 m) flybys is understandable.

For the above tests, optical system data were as follows:

Parameter	Van 1		Van 2	
	Initial	Final	Initial	Final
Laser Power at Secondary	15 W	13.2 W	12.5 W	10.5 W
Signal/Noise - 200' Wheel	75 dB	74.5 dB	75 dB	70 dB
Signal/Noise - Atmosphere	25 dB	25 dB	25 dB	
Type Local Oscillator	Separate L.O.		Backscatter	

Integration times for the processors remained 4 ms during the tests.

Table 5-1
FLYBY DATA WITH OPERATOR COMMENTS

Run	Van 1				Van 2			
	Range Scanner Setting			Comment	Range Scanner Setting			Comment
	Min. (m)	Max. (m)	Freq. (Hz)		Min. (m)	Max. (m)	Freq. (Hz)	
1	300	–	–	Calib.	300	–	–	Calib.
2	64	–	–	↓	62	–	–	↓
3	180	–	–	↓	175	–	–	↓
4	300	64	2	Tele. blocked	300	62	4.1	↓
5	300	200	4		132	32	↓	One hit
6	132	32	4	Elevation scan set between 0.3 & 3 deg instead of 3 & 33 deg	300	200	↓	No time
7	300	150	4		132	32	↓	Too close
8	300	150	4		132	32	↓	Too close
9	130	50	0.1		300	200	↓	Nothing
10	130	50	0.1	↓	↓	150	↓	?
11	132	32	0.9	↓	↓	170	↓	?
12	130	50	0.1	Sig. here	↓	170	↓	Maybe
13	200	150	4	No sig.	160	70	↓	Good
14	200	150	↓		160	70	↓	Good
15	160	70	↓	Good Sig.	200	150	↓	Saw something
16	160	70	↓	Good run	↓	150	↓	Nothing
17	250	90	↓	Possible	↓	100	↓	
18	250	90	↓	Good run	250	60	↓	
19	220	90	↓	Nothing	220	90	↓	
20	220	90	↓	Maybe			↓	
21	220	100	↓	Good	220	90	0.1	?
22	220	90	↓	Low alt. data	220	90	4.1	
23	220	90	↓	Noise calib.				

5.1.2.2 Flyby Testing with C-47 in Preparation for B-720 Tests

On 9 April 1974, a set of "preliminary" flyby tests was planned for the Army C-47 aircraft in preparation for the major test series with FAA's B-720 aircraft on 10 and 11 April. Unfortunately the weather did not cooperate since the winds were high, turbulence was severe and the pilot could not fly below 250 ft altitude because of terrain hazards surrounding the test site. Only four passes were made and no detected hits were indicated by the system operators. In retrospect, the scale factor problem of the range scanner prevented the SLDS from interrogating the ranges of the aircraft at time of vortex generation. The vortices also likely degenerated very rapidly because of the high wind and turbulence conditions.

5.1.2.3 April 10 and 11 Flyby Tests with FAA's B-720 Aircraft

The B-720 flyby tests were planned to present a final demonstration to DOT/FAA, DOT/TSC, NASA Hq and NASA-MSFC management personnel the capabilities of the SLDS to detect wake vortices. According to schedule plans, successful completion of this test series would be prerequisite for shipment of the system to KIA in mid-May. The basic objective of detecting vortices with the SLDS was met. Vortices were detected during 70% of the total 35 passes of the B-720 aircraft during the two days. However, the resolution of the vortex tracks from the system was of poor quality. A review of the system status at this time indicates the poor quality was attributable to two factors: (1) the range scanner scale factor problem was such that the vortices were actually beyond the focal volumes of the systems in each van, and (2) data reduction techniques for the system were in their infancy. The actual detection of the vortices was accomplished by increasing system sensitivity to such extent that the systems were detecting the high velocities beyond the focal volume of each sensor.

The B-720 tests were flown in three sets. The first flybys began at 1:37 p.m. on 10 April and lasted until 2:23 p.m. The second set began at 5:56 p.m. of the same day and ended at 7:14 p.m. The third set began at

7:34 a.m. of 11 April and ended at 8:24 a.m. Preparation began several days before the tests, was intensive normally for two hours prior to the flybys, and continued for approximately one hour after each flyby set for recording of final calibrations.

Optical subsystem data for the three sets of flybys are listed in Table 5-2.

Table 5-2
OPTICAL SUBSYSTEM DATA

Parameter / Test and System	Laser Power at Secondary		Signal-to-Noise Ratio			
			200 ft Wheel		Atmosphere	
	Initial (W)	Final (W)	Initial (dB)	Final (dB)	Initial (dB)	Final (dB)
10 April; 1:30 p.m. Tests						
Van 1	10.5	9.3	73.5	73	25	20
Van 2	12	11	70	72	25	25
10 April; 6:00 p.m. Tests						
Van 1	15	13.5	75	74.5	25	25
Van 2	10.5	9.5	73	71	25	25
11 April; 7:30 a.m. Tests						
Van 1	14.2	13.4	74	74	25	25
Van 2	11.5	—	71	66.5	25	22

The optical packages for both systems were aligned in separate local oscillator modes with the backscattered radiation from the secondary blocked via blackened wires.

For the first of the three sets of tests, the aircraft made seven passes through the test region during a 45 min test period. The crosswind was approximately 7 ft/s and blowing toward Van 1. After three passes down the middle – i.e., approximately 500 ft from either van – the aircraft flew nearer to Van 2 and the vortices blew toward Van 1. Van 1 data indicated good detection during the first five passes and poor data during the last two. Van 1 indicated detection for 10 to 20 sec for the first five passes and 7 sec for the seventh pass. Van 2 recorded no vortex hits during this initial test set.

For the second of the three sets of tests, the B-720 made 17 passes between 5:56 p.m. and 7:20 p.m. The wind had calmed and vortex detection was very good with both vans. Detections were recorded for up to 30 sec from Van 1 and for significant periods of time from Van 2. The low wind condition, lower threshold settings on the processor, and the repumping of the Van 1 laser between the tests for increased output power were all significant in improvement of results for this test series.

During the third series of tests – 7:30 a.m. of 11 April – numerous hits were recorded with Van 1 for up to 50 sec after the initial hit and for similar periods of time with Van 2.

Processor settings during these tests were as follows:

Table 5-3
PROCESSOR SETTINGS

Parameter / Test and System	Input Levels	Ampli. Thres-hold	Integ. Period (ms)	Velocity Thres-hold	Width Integ.
10 April; 1:30 p.m. Tests					
Van 1	5.8	19	4	10-15	2
Van 2	9.5	27-28	4	10-15	2
10 April; 6:00 p.m. Tests					
Van 1	6.1	20	4	10-17	2
Van 2	10	21-26	4	11-21	2
11 April; 7:30 a.m. Tests					
Van 1	6.1	18-21	4	13-16	2
Van 2	10	23-26	4-16	14-17	2

The decreased amplitude threshold and input level increase of the Van 2 system for the 6 p.m., 11 April tests appeared to improve the detection capability of this system.

Scanner settings for these tests were typically 4 Hz for range scanning and 0.1 or 0.2 for elevation scanning. Spans were typically set for 3 to 33 deg for elevation and 90 to 220 m for range. The following chart (Chart 5-1) was typical of the set-up planning data for these tests.

5.1.2.4 Summary of Spring 2-D Flyby Tests

Spring flyby tests demonstrated that the SLDS could definitely detect aircraft wake vortices. These tests also demonstrated some capability to resolve the elevation (angle) of the vortices as viewed from the van (see Fig. 5-1). However, the range resolution capability for tracking the vortices was – at this time – thought to be very poor.

The decision was made to perform additional range resolution measurements with both hard (spinning wheel) and soft (blower flow field) targets and also to concentrate on data reduction techniques for improving data resolution. These efforts paid off as discussed in the section on blower tests and in the following section discussing summer flyby testing.

5.2 SUMMER FLYBY TESTING – FINAL MSFC SLDS TESTS

When the blower test series was completed and all apparent hardware problems with the SLDS were solved, a final set of flyby tests was scheduled for MSFC. Flight tests were scheduled for 17 and 25 June with small aircraft and for 2 July with the NASA/FAA B-737 aircraft. A later test was scheduled for 8 and 9 August with the FAA's B-720 aircraft as the last MSFC test prior to shipment of the system to KIA. Discussions of these tests follow:

Chart 5-1

LASER DOPPLER VELOCIMETER PREFLIGHT SETTING SUMMARY

Configuration Nomenclature	LDV No. 1													LDV No. 2											Notes
	Scanner						Processor			A/C Position				Scanner						Processor			A/C Position		
	Range			Elevation										Range			Elevation								
	Max.	Min.	Rate	Max.	Min.	Rate	Integ. Time	V Width	Mode	Altitude	Range from LDV 1	θ	R	Max.	Min.	Rate	Max.	Min.	Rate	Integ. Time	V Width	Mode	θ	R	
G	230	90	4	23	3	0.1	4	2	lin	200'	500'	22°	540	220	90	4	33	3	0.1	4	2	lin	22°	540'	Low Wind
H_1				40	5												30	3							Wind from East
H_2				30	3												40	5							Wind from West
I			0.1	33	3	0.5										0.1	33	3	0.5						Arc Scan with Slow Range Scan
F_1	200	70	4	40	5	0.1				200	400	26	450	250	120		30	3	0.1				18	630	Aircraft moved toward Van 1
F_2	250	100		30	3					200	600	18	630	200	70		40	5					26	450	Aircraft moved toward Van 2
E_1	150	150	0	33	3	0.5				200	500	22	540	150	150	0	33	3	0.5				22	540	Pure Arc Scan
E_2							16			200	500	22	540							16					Pure Arc Scan, Long Integration
G_2	220	90	4			0.1	16							220	90	4			0.1	16					Std. with Long Integration
G_1							1													1					Std. with Short Integration

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Note: Elevation Scan 3 to 30° at 0.2 Hz

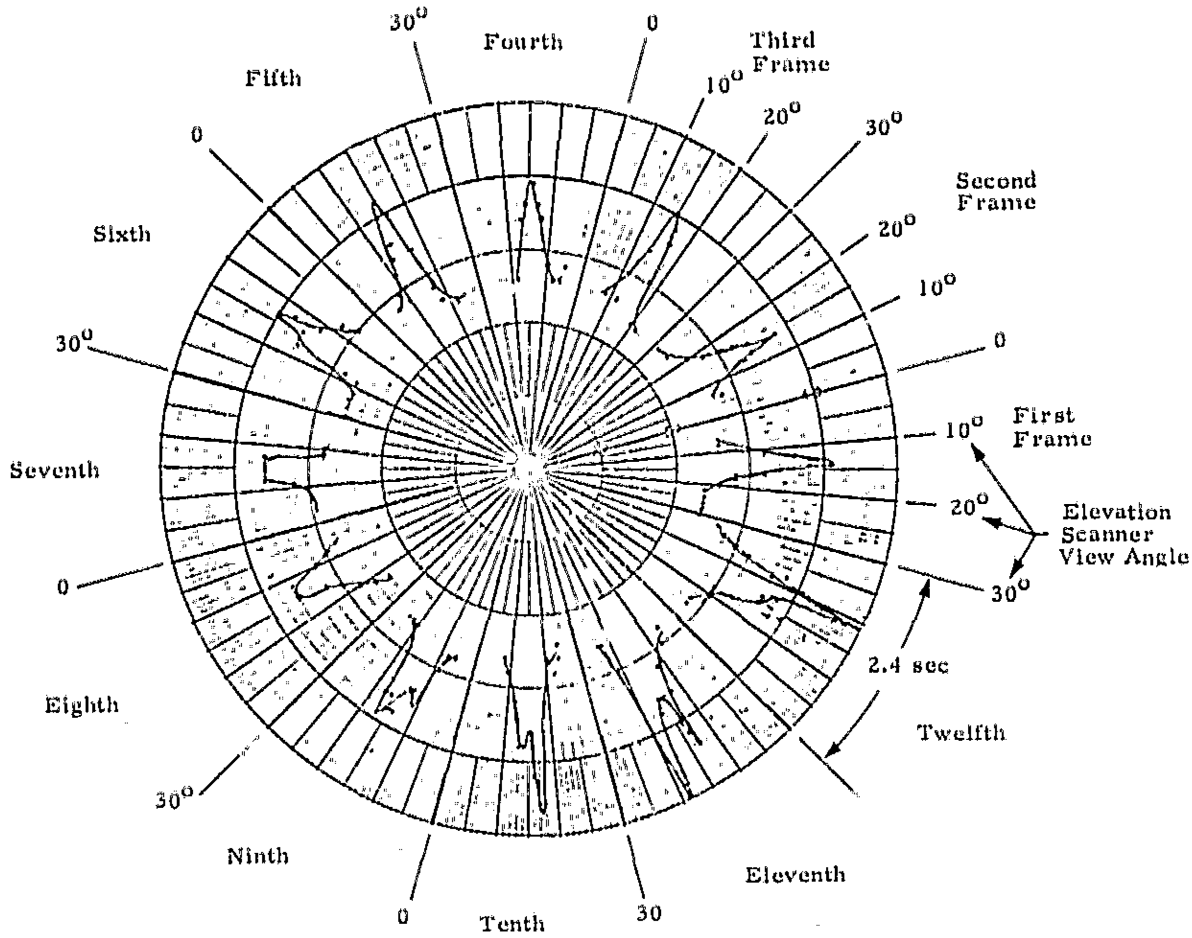

Fig. 5-1 - Polar Plot of Relative Maximum Signal Strength of Signal Which was above Operator Set Velocity Threshold During Elevation Scans Through B-720 Wake from Run 921 of 10 April 1974 Flyby Tests

5.2.1 Tests of 17 and 25 June with Gulfstream Aircraft

Fifteen flyby passes were made with the Gulfstream aircraft between 6:14 and 6:57 p.m. on 17 June 1974. Both LDVs were used to scan for the vortices with success. Scanners were operating typically from 63 to 229 meters in range at 4 Hz and 0 to 30 in elevation at 0.1 to 0.2 Hz. Processors* were typically set up for 4 msec integration time, and velocity thresholds of 5 to 7. A typical display hard copy record from these tests is depicted in Fig. 5-2.

A short flyby test was held on 25 June between 1:39 p.m. and 1:52 p.m. Only three passes were recorded.

5.2.2 Flyby Tests with the NASA/FAA B-737 on 2 July

On 2 July 1974, a flyby test series was performed with the NASA/FAA B-737 aircraft performing 20 passes over the MSFC test site. The test results indicated the two SLDS units were capable of tracking vortices of the B-737 type aircraft at ranges of over 500 feet with consistency.

Surveyed aircraft positions, scan parameters, and processor parameters are listed in Table 5-4. In general the test proceeded smoothly. However, a stability problem with the laser in Van 2 led operators to change the output aperture from 7.5 mm to 6.5 mm. Optical parameters for the two systems are shown on page 5-16.

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*Processors had been modified for log amplifier front ends.

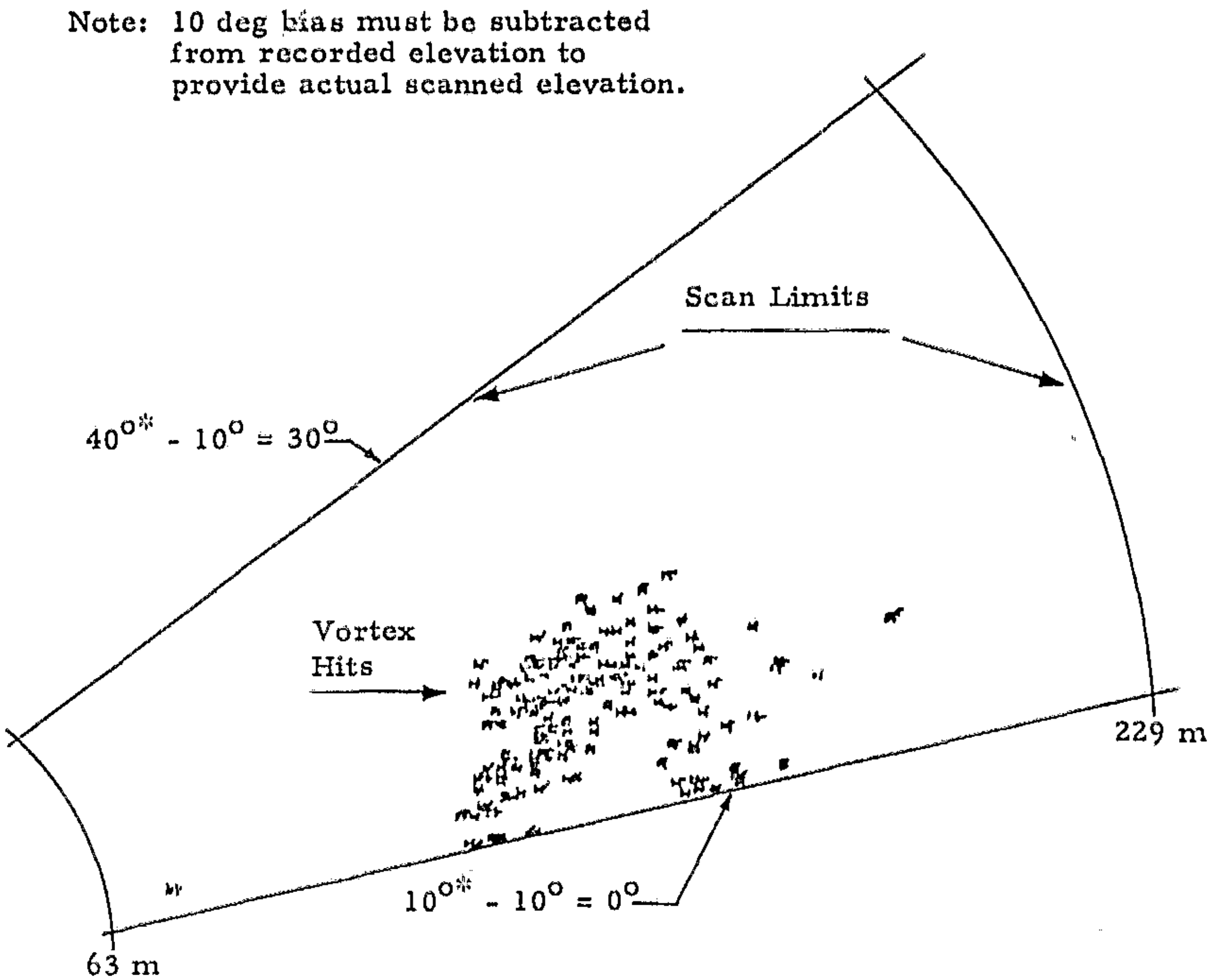

Fig. 5-2 - Display Hard Copy from Run 23 of Flyby Test of 17 June 1974

Table 5-4

PARAMETERS FOR B-737 FLYBY OF 2 JULY 1974

Test Number	Aircraft Parameters		Van 1							Van 2						
			Scanner				Processor			Scanner				Processor		
			Range		Elevation					Range		Elevation				
	Van 1 Distance* (ft)	Height Above Ground (ft)	Limits (m)	Rate (Hz)	Limits (deg)	Rate (Hz)	Amp. Thresh.	Velocity Thresh.	Width Integ.	Limits (m)	Rates (Hz)	Limits (m)	Rates (Hz)	Amp. Thresh.	Velocity Thresh.	Width Integ.
12			64-256	4	3-30	0.2	60	10	1							
13	485	172	100-300		3-25		70	12		63-224	4	3-35	0.2	26	13	1
14	438	177					80					3-35		30-37	13	
15	491	190					90					3-35		40	13	
16	487	212					85					3-25		40-30	13	
17	219	150	64-**		-30		85							30-39	10	
18	254	156					80			-256				40	12	
19	270	263					80							40	15	
20	289	229					80		4			3-35		40-43	12	4
21	312	215					80	10	6			8-28		43-30	8	6
22	221	214					80	10	4					40-33	8	4
23	212	216					76	10						30-31	7	
24	222	235						7						31	7-6	
25	414	184	100-	6				7				5-30		31	12	
26	506	204			-25			10				5-35		31	12	
27	372	209			-25			8	NA			5-35		31-21	8	
28	372	209			-25		66	10	NA			5-35		21-31	7	
29	506	137			-17		75	11	4	-224		3-23		31	8	
30	497	126			-17		75	10	4	-224		3-23		31-37	9	
31	211	144	64-	4	-18		79	12	4	-256		3-28		37-27	10	
32			64-	4	-18					-256		3-28				

*Horizontal from Van 1 (Van 1 and 2 separated by 1000 ft).

**A setting of 64 m provided a limit of 96 m during the test. This truncation has since been eliminated by the addition of higher level logic to the scan controller.

Time	9:30	10:20	10:38	10:50*	11:40	12:50	15:14
Van 1 Parameters							
Laser Power (W)	14.5				14	12.6	10
Wheel** S/N (dB)	70				69	72	
Atm. S/N (dB)	20				20	20	
Van 2 Parameters							
Laser Power (W)		12	11.5	11.5	8.5		6.0
Wheel** S/N (dB)		68	68	61	69		63
Atm. S/N (dB)		20	20		20		

*Aperture changed from 7.5 to 6.5 mm.
**Distance to wheel: 250 ft.

Vortex tracks were generated by the displays of both SLDS units during these tests. Hard copies of the displays from the two SLDS units for a typical flyby (Run 23) are depicted in Figs. 5-3 and 5-4. For this particular flyby, the scanner of SLDS 1 was set to scan between 3 and 30 deg at 0.2 Hz and between 64 and 300 m at 4 Hz. Because of logic truncation limits in the scan controller, SLDS 1 was actually scanning between 6.4 and 28.8 deg and between 96 and 282 m. Likewise the scanner of SLDS 2 was scanning between 9.6 and 25.6 deg and between 63 and 256 m. Scales have been typed on the display copies to indicate scan boundaries.

In Fig. 5-5 the above display hard copy from SLDS 1 has been inverted and overlayed on the hard copy from SLDS 2. The angles and range scales have been matched according to the test site geometry. As can be readily seen, the vortex tracks recorded by the two displays spatially coincide. As the data were taken in real time, equipment observers could see the two

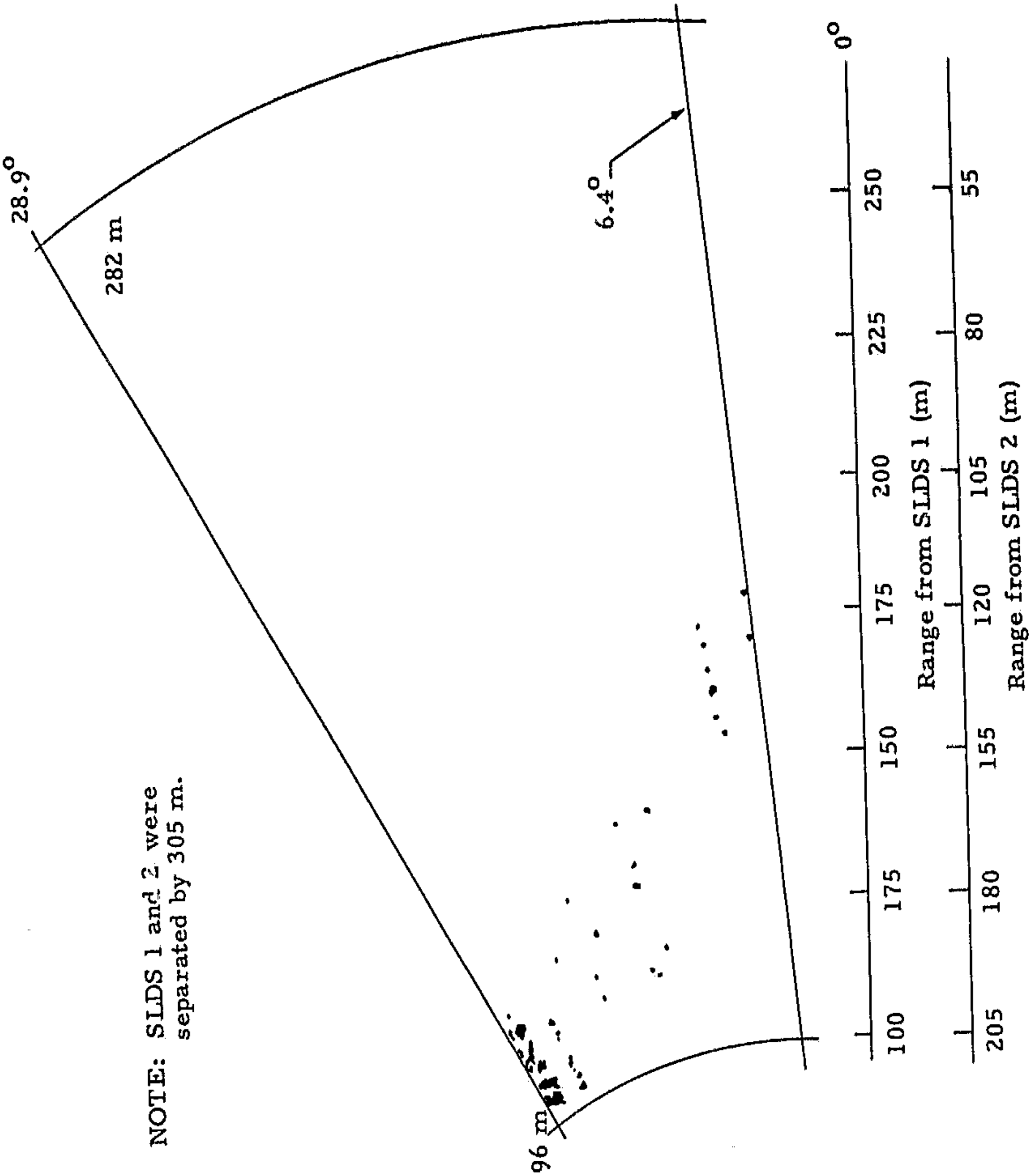

Fig. 5-3 - Hard Copy from SLDS 1 Display of Vortex Track from Run 23

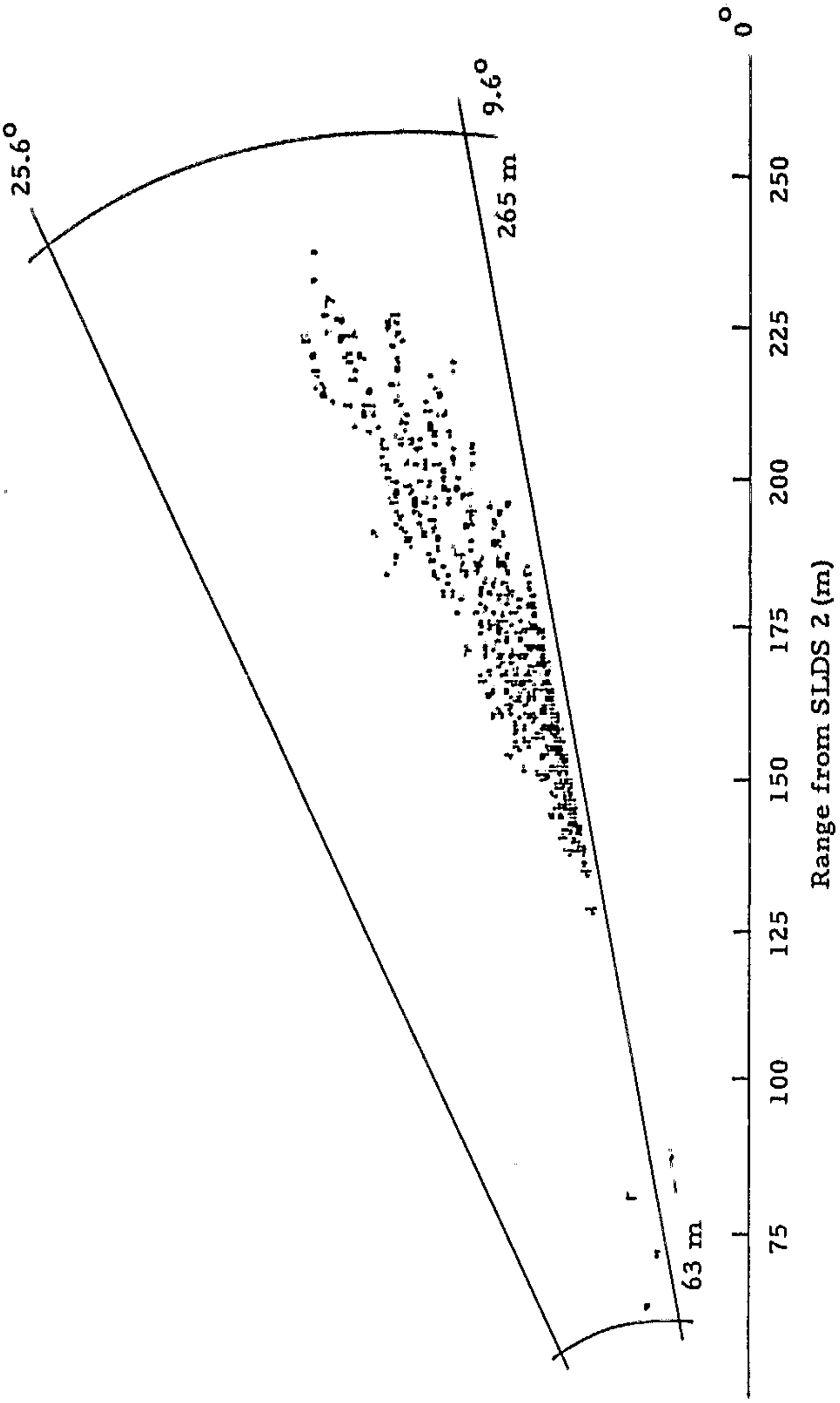

Fig. 5-4 - Hard Copy from SLDS 2 Display of Vortex Track from Run 23

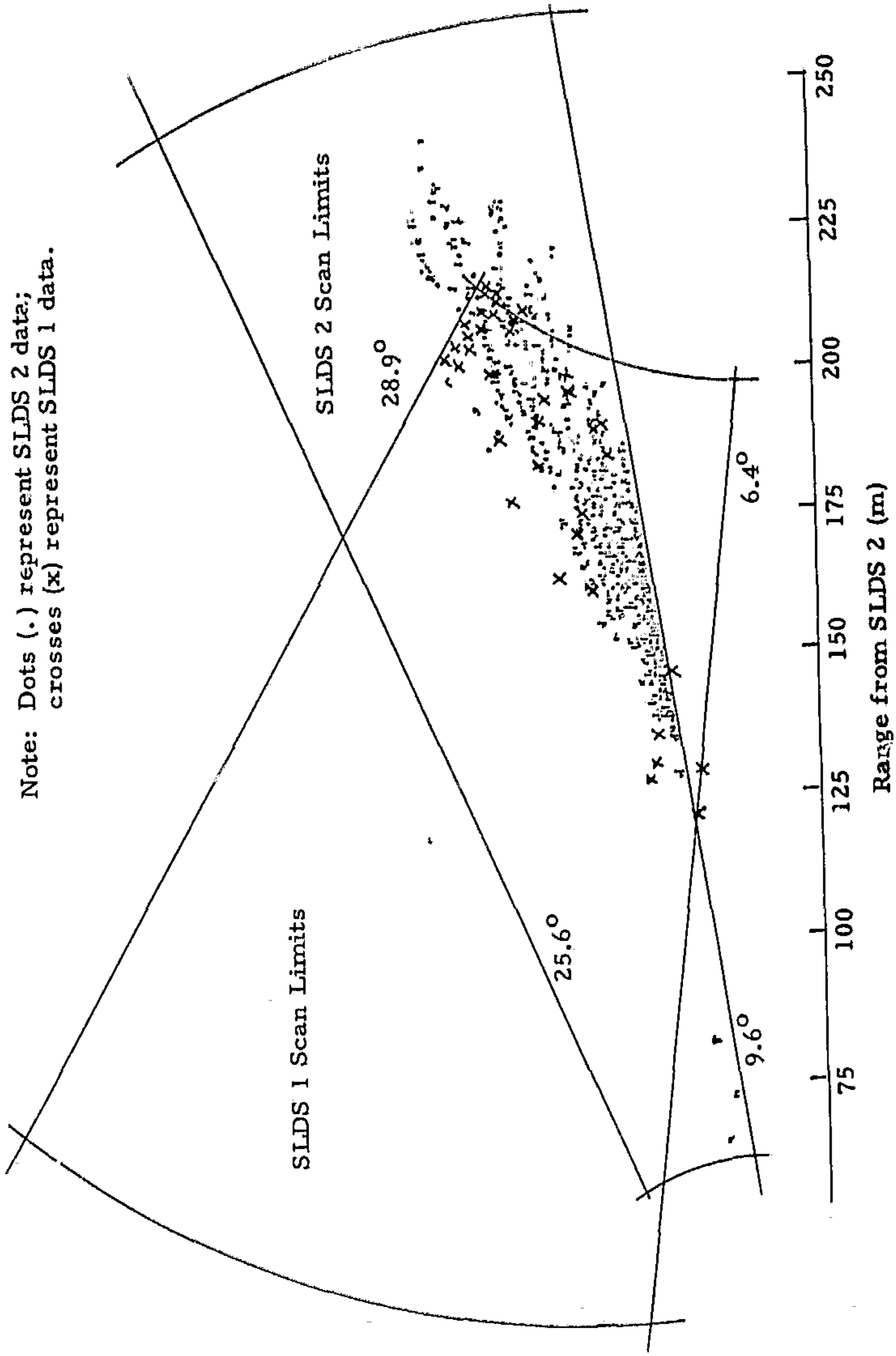

Fig. 5-5 - Overlay and Matching of Hard Copies from Displays of SLDS 1 and 2 for Run 23 vortices detected separately. However, the recording methods used in these early tests tended to smear the data such that identification of the separate vortices from the hard copy records is difficult and in many cases impossible.

Following these B-737 tests, NASA and FAA officials made the decision to proceed with the procurement and in-house development of an on-line data graphics system for the SLDS. The graphics system would be designed to improve vortex track definition with an objective of providing real time tracks from both SLDS units of each of the two vortices generated by a passing aircraft. The system would provide a real time display and hard copy capability.

5.2.3 Final B-720 Flyby Test Series at MSFC on 8, 9 August 1974

Following a practice flyby test on 7 August 1974 with 12 passes of the NASA Grumman Gulfstream aircraft, a final flyby test series was held with the FAA's B-720 aircraft. The test series was divided into three groups of approximately 12 flybys each. The first two groups of flybys were scheduled for 12 noon and 3:30 p.m. on 8 August with the final group scheduled for 12 noon on 9 August. The objective of these tests was to demonstrate the readiness of the SLDS for delivery to KIA. The test plan called for taking data during the first test group, demonstrating an essentially hands-off operation capability for the second test group, and recording more data during the third test group. Equipment calibrations would be checked and compared for the two systems between test runs.

Optical subsystem data for the test series is listed on the table on the following page. During the first test group, a fuse was blown in the Van 1 laser. This had never occurred before and five aircraft passes were missed before the problem was solved. Otherwise the tests proceeded smoothly.

Test and System \ Parameter	Laser Power at Secondary (W)	Signal-to-Noise Ratio* (dB)	
		250 ft Wheel	Atmosphere
8 August 12 noon			
Van 1	15	62	18
Van 2	12	68	20
8 August 3:30 p.m.			
Van 1	Demonstration only; optical data not recorded.		
Van 2			
9 August 12 noon			
Van 1	15	65	20
Van 2	15	70	20

*Signal-to-noise ratio measured via spectrum analyzer.

For these tests the aircraft was directed to fly half way between the two vans at an altitude of 200 ft. The scanners were set up to scan continuously between approximately 62 and 250 m at 5 hertz and between 3 and 33 deg at 0.2 Hz. This condition remained essentially unchanged during all three test groups.

The processor settings for the tests were as shown in Table 5-5.

The test proceeded smoothly and data were recorded via tape and display hard copy. The visual demonstration of the system during the flyby test plus presentations discussing the on-line data graphics package to be shortly installed in the system convinced NASA and DOT management personnel that the system was ready for shipment to Kennedy International Airport. Dismantling, refurblishment and packing of the system began shortly after this test series ended.

Table 5-5

PROCESSOR SETTINGS FOR FINAL MSFC B-720 FLYBY TESTS

Run No.	8 August, 12 noon*				8 August 3:30 p.m.*				9 August, 12 noon*			
	SLDS 1		SLDS 2		SLDS 1		SLDS 2		SLDS 1		SLDS 2	
	Amp. Thresh.	Velocity Thresh.	Amp. Thresh.	Velocity Thresh.	Amp. Thresh.	Velocity Thresh.	Amp. Thresh.	Velocity Thresh.	Amp. Thresh.	Velocity Thresh.	Amp. Thresh.	Velocity Thresh.
1	47	6	42	7	42	15	53	15	43	14	~43	~17
2	43-62	7	42-82		42				40	15		
3	65	8	62		48				37	15		
4	75-65	8	60						37	15		
5	65	9	60-80						37	16		
6	Blown fuse		70-80						40	17		
7	Blown fuse		70									
8	Blown fuse		40	15		17						
9	64	10	44	15	40	19						
10	64	10	48	17	48	17			38			
11	70	10		19-13	48	17	48	17-15	41			
12	50	17		17-15	48	17	48	17-15	36			
13	49	15		17-13								
14	45	16		16-13								

*Integration time remained at 2 msec; width integration at 1 for these tests.

5.3 Concluding Remarks for MSFC Flyby Testing

The MSFC flight test program began with two sets of SLDS components which had been loosely integrated and ended with a properly functioning system ready for shipment to KIA. During the test program a number of unexpected problems arose. These problems thus had to be solved, explained or understood to proceed to a satisfactory program phase completion. At the time of shipment to KIA, most of the problems had been solved with the exception of: (1) the frequency translator which is being worked today, and (2) the on-line data processor which was delivered to KIA and satisfactorily installed and operated shortly after SLDS installation at KIA.

Section 6

SYSTEM ASSEMBLY AND CHECK OUT AT KENNEDY INTERNATIONAL AIRPORT

The two vans of the SLDS were hauled by tractor and arrived at Lockheed Aircraft Service (LAS) at Kennedy International Airport (KIA) by 26 August 1974. Lockheed-Huntsville technical personnel arrived at KIA on August 26 and began system set up.

Pads of aluminum had been assembled at the site for SLDS trailer bases by NAFEC personnel prior to system arrival. Power transformers had also been installed near each pad (Figs. 6-1 and 6-2): Van 1 was driven to the site by subcontracted riggers with relative ease and leveled and blocked in place (Fig. 6-3). However, due to terrain conditions, Van 2 required heavy equipment for installation (Figs. 6-4 and 6-5).

Figures 6-6 and 6-7 depict Lockheed crews performing interface operations at KIA. Cables were run between vans for communications and computer data. All cables were buried to prevent lightning damage to equipment or rodent gnawing of insulation.

Calibration towers were erected between the vans to carry spinning wheels and warning lights. A corridor was also marked "Caution Laser" and cordoned off between the vans for safety purposes (Figs. 6-8 and 6-9). Site external geometry is depicted in Fig. 6-10.

Most of the van instrumentation was flown to KIA aboard the NASA Gulfstream aircraft. The equipment was received at LAS and carried to the site via the NASA four-wheel drive truck. Figures 6-11 through 6-16 depict photographs of instrumentation and equipment within the vans.

System installation and check-out at KIA, in general, ran rather smoothly with several unexpected problems which were eventually solved. Initial problems involved requirements for a crane to place one of the vans in position due to rugged terrain and soft surfaces from recent rains. Another initial unexpected problem involved requirements for unloading the four-wheel drive vehicle which had been packed rather tightly (via crane) on a "low boy" in Huntsville. Other problems involved handling of heavy instrumentation items at the remote location, establishing adequate telephone communications with Huntsville, developing a proper earth electrical ground and establishing good vendor sources in the New York area.

The two units of the SLDS were set-up and operating satisfactorily by mid October. Operation was interrupted shortly for installation of the online graphics procession unit. System operation then proceeded under contract NAS8-30971.

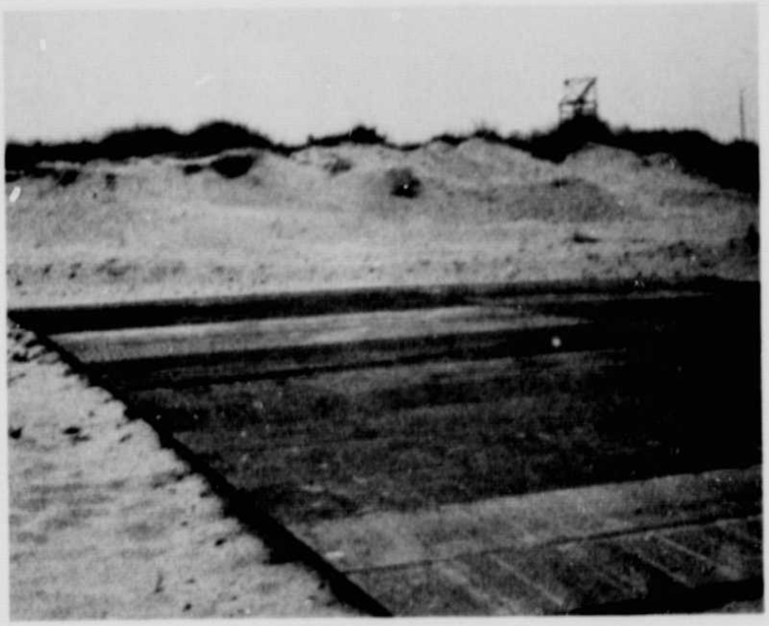

Fig. 6-1 - Aluminum Pad for SLDS No. 2 Unit

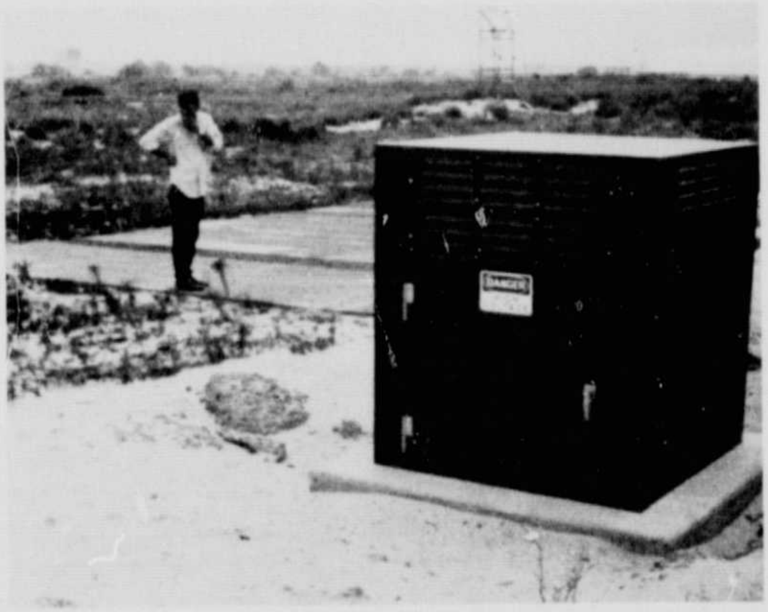

Fig. 6-2 - Pad and Power Transformer for the No. 1 SLDS Unit

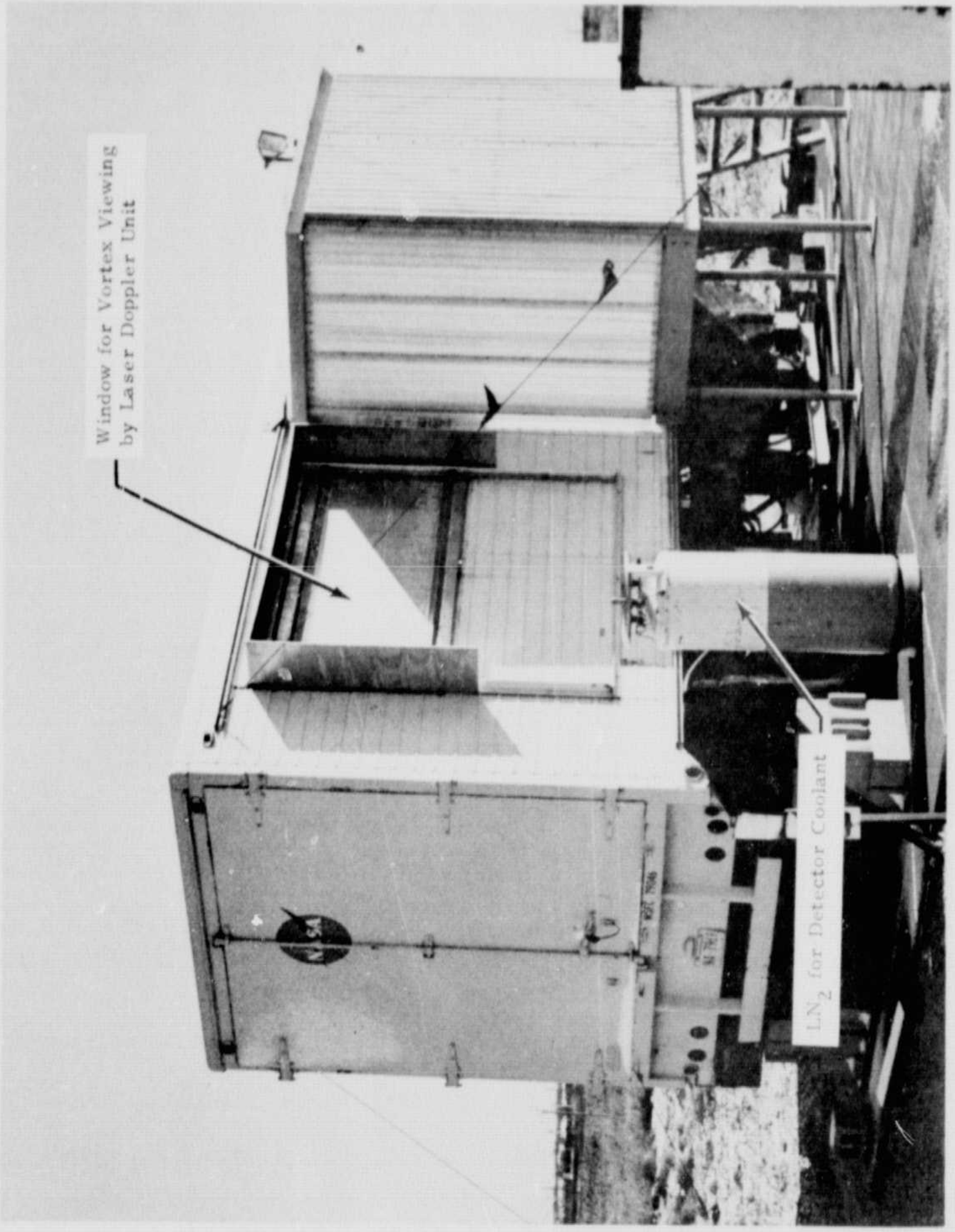

Fig. 6-3 - SLDS Van 1 Leveled and Blocked in Place

Fig. 6-4 - Lifting Van 2 in Place at KIA (28 August 1974)

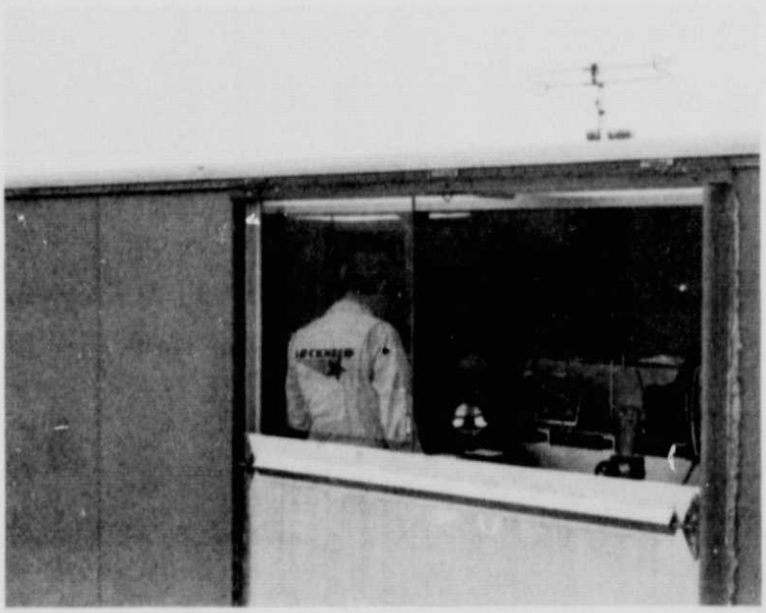

Fig. 6-5 - Van 2 in Place and Operating at KIA

Fig. 6-6 - Off-Loading and Interface of Rotary Converter for Conversion of Single Phase to Three-Phase Power for Air Conditioners

Fig. 6-7 - Modern Ditching Technique for Cable Interfacing Between Vans 1 and 2

Fig. 6-8 - Erection of Calibration Target Tower

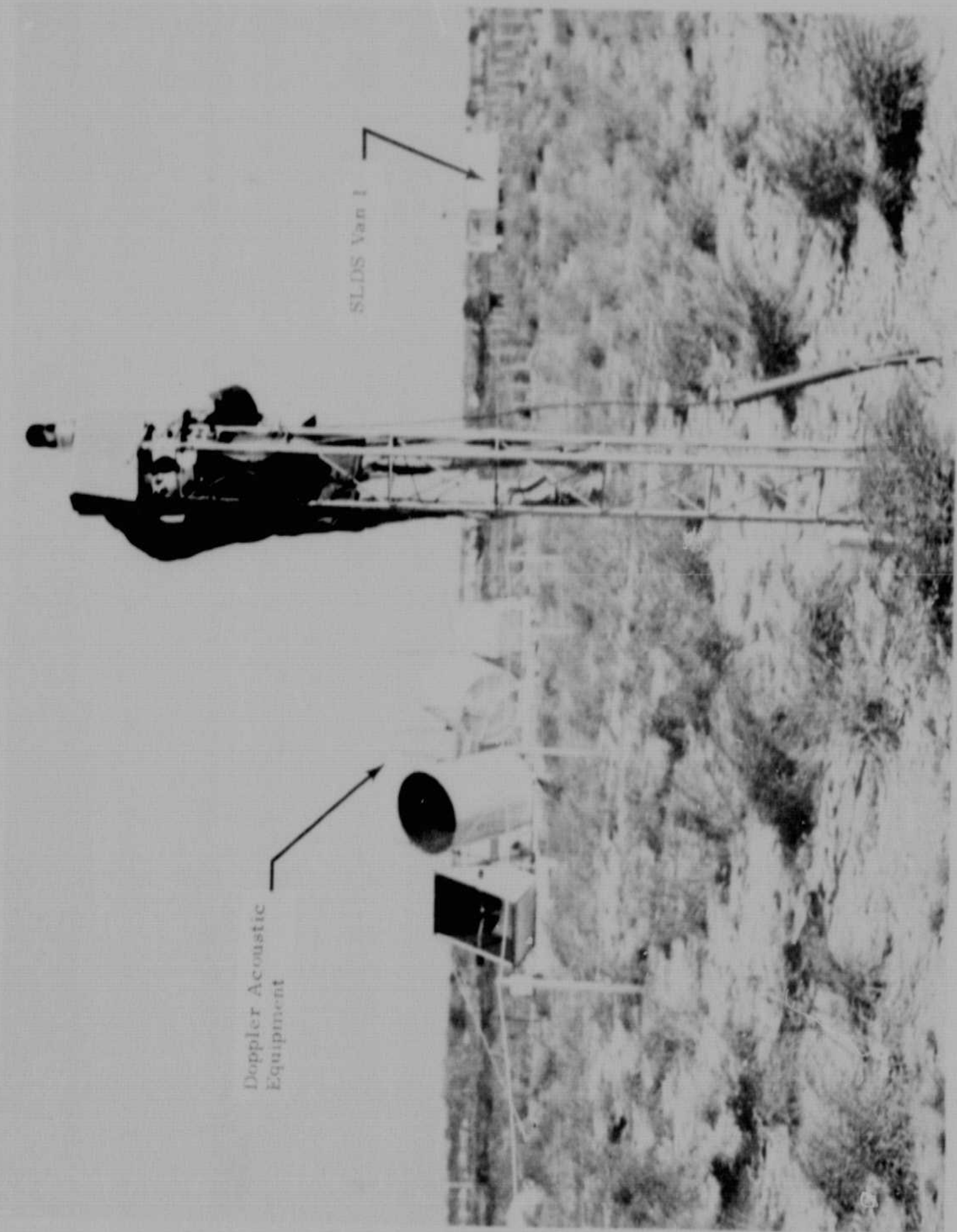

Fig. 6-9 - Adjustment of Target on Calibration Tower

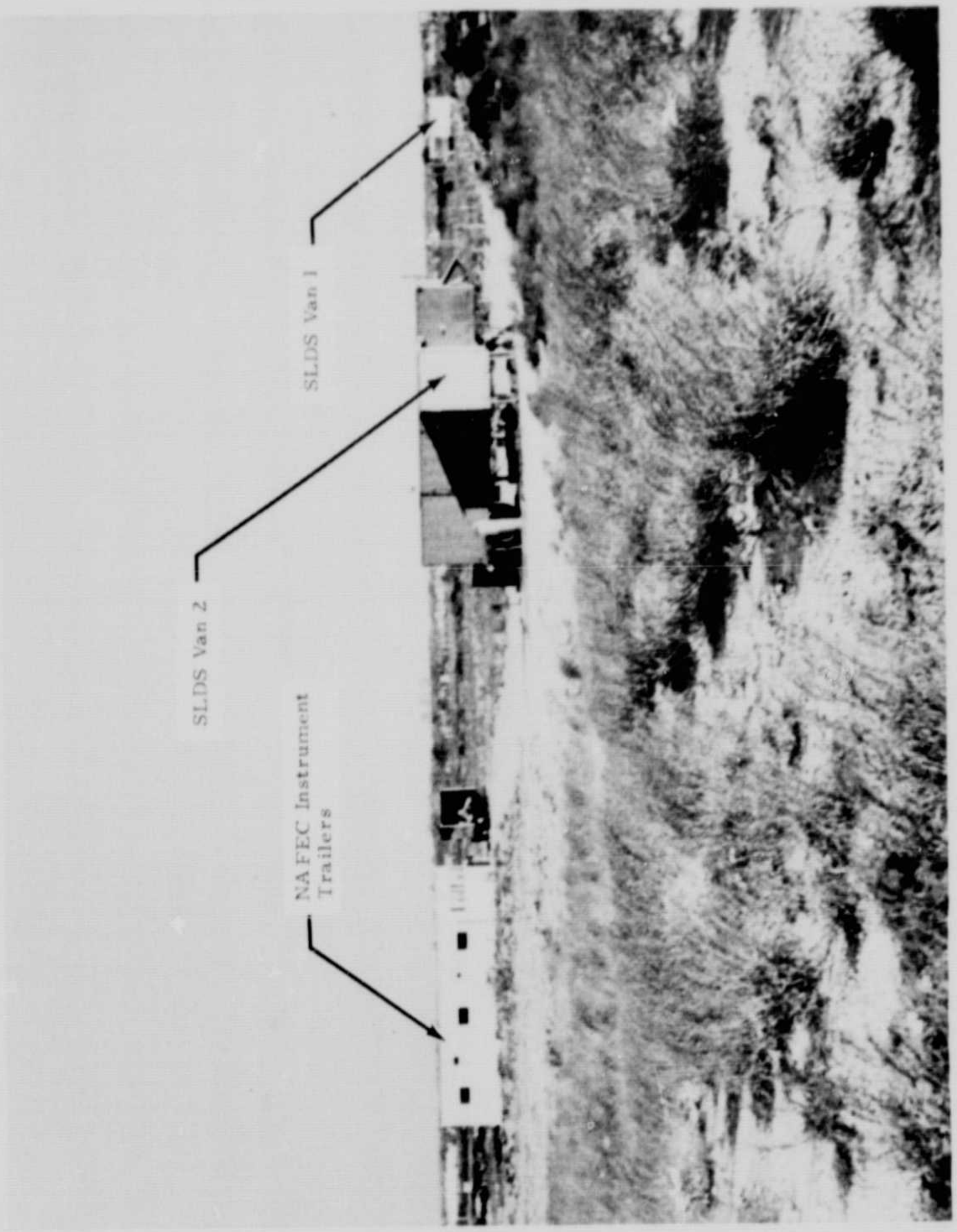

Fig. 6-10 - Site External Geometry

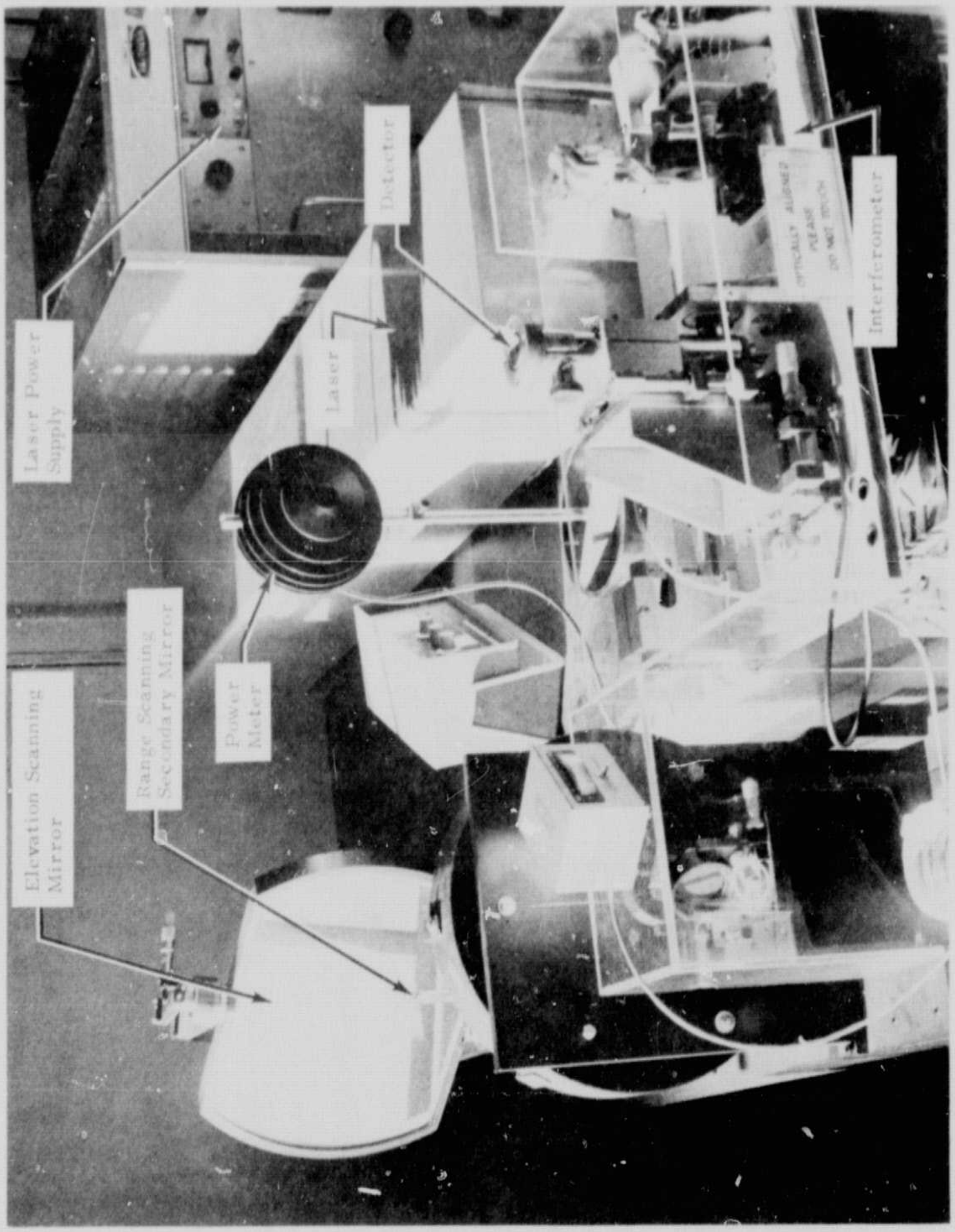

Fig. 6-11 - Optical Equipment Within Van 1

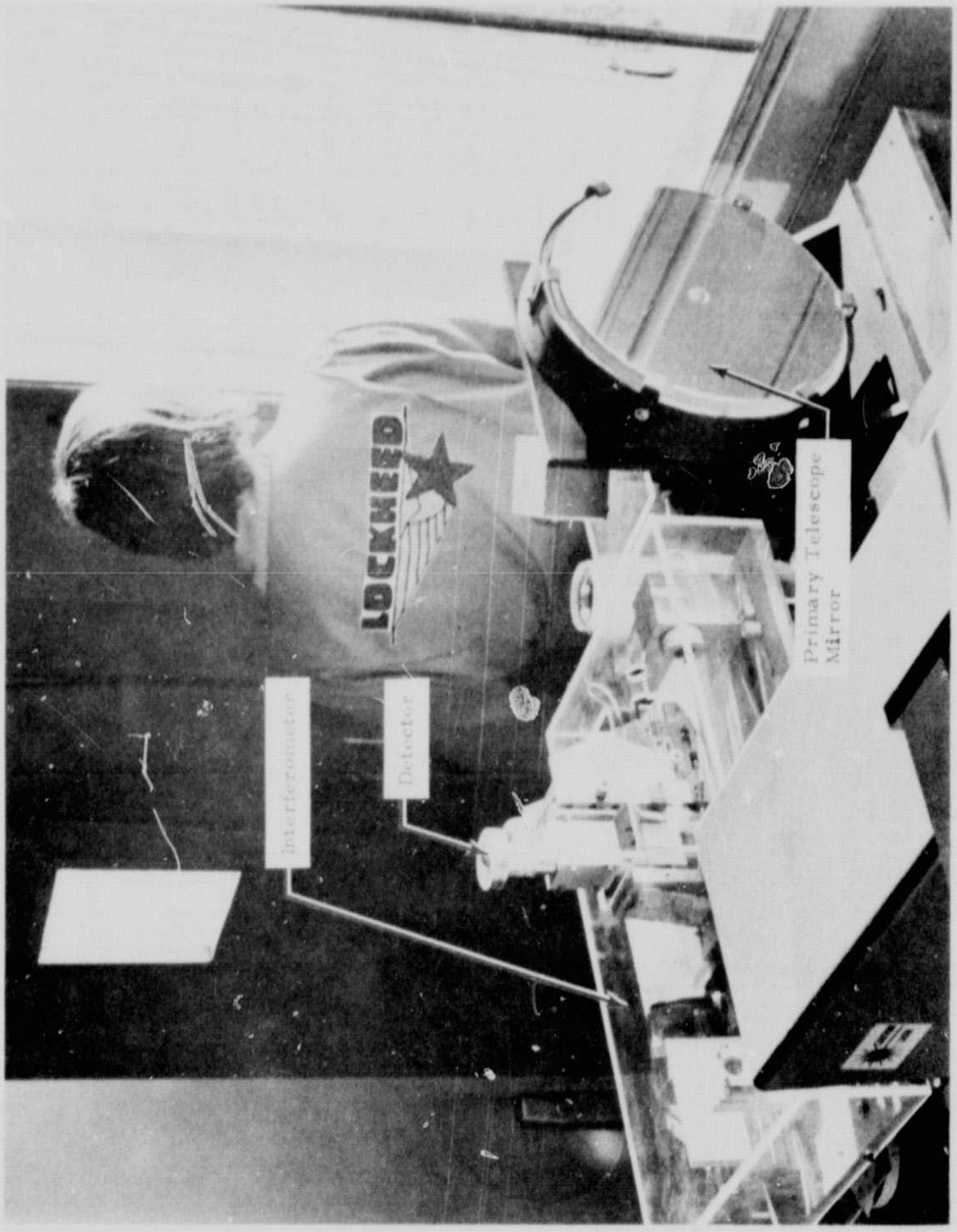

Fig. 6-12 - View of Van 1 Optical Equipment from Opposite Direction

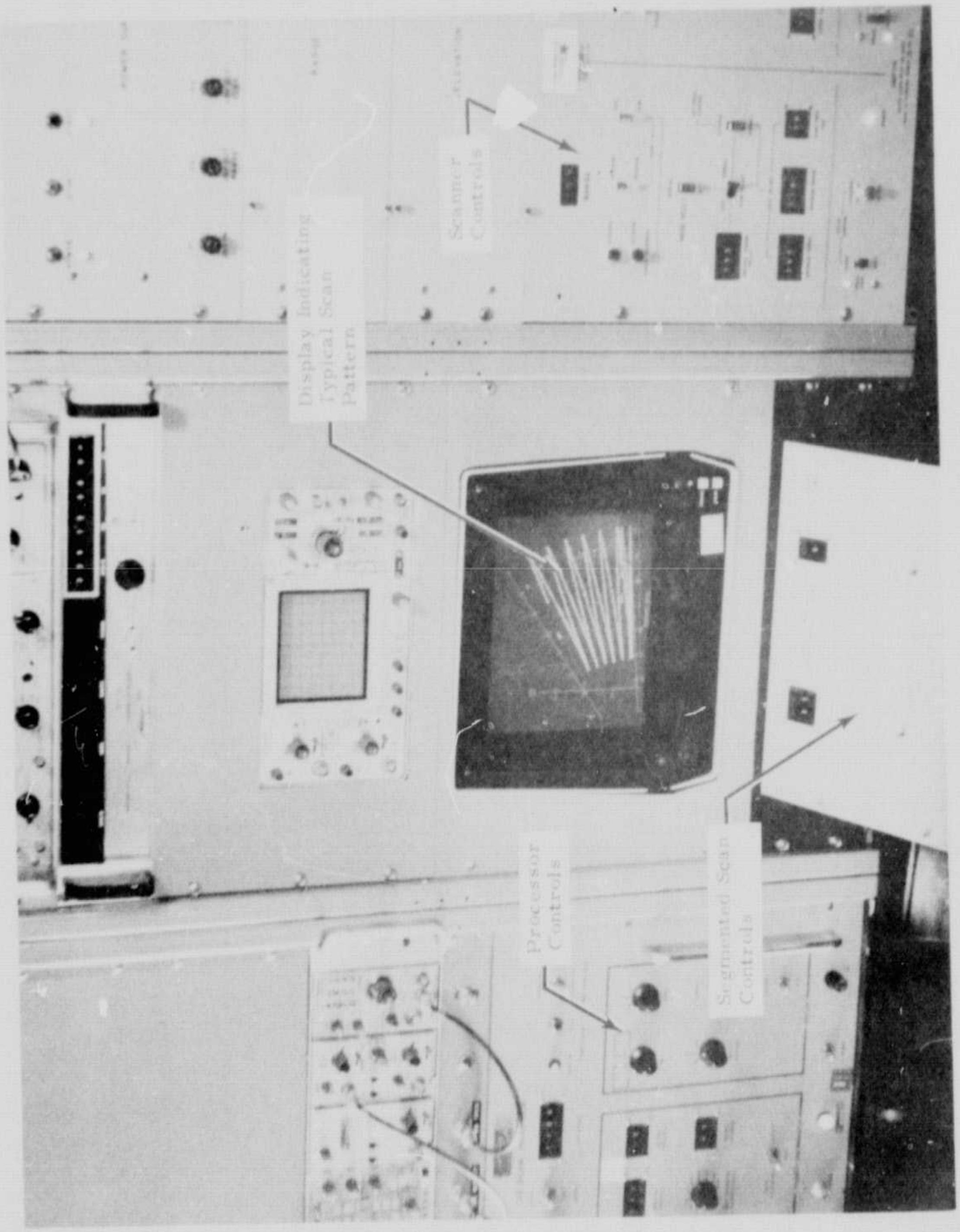

Fig. 6-13 - Van 1 Control Panel

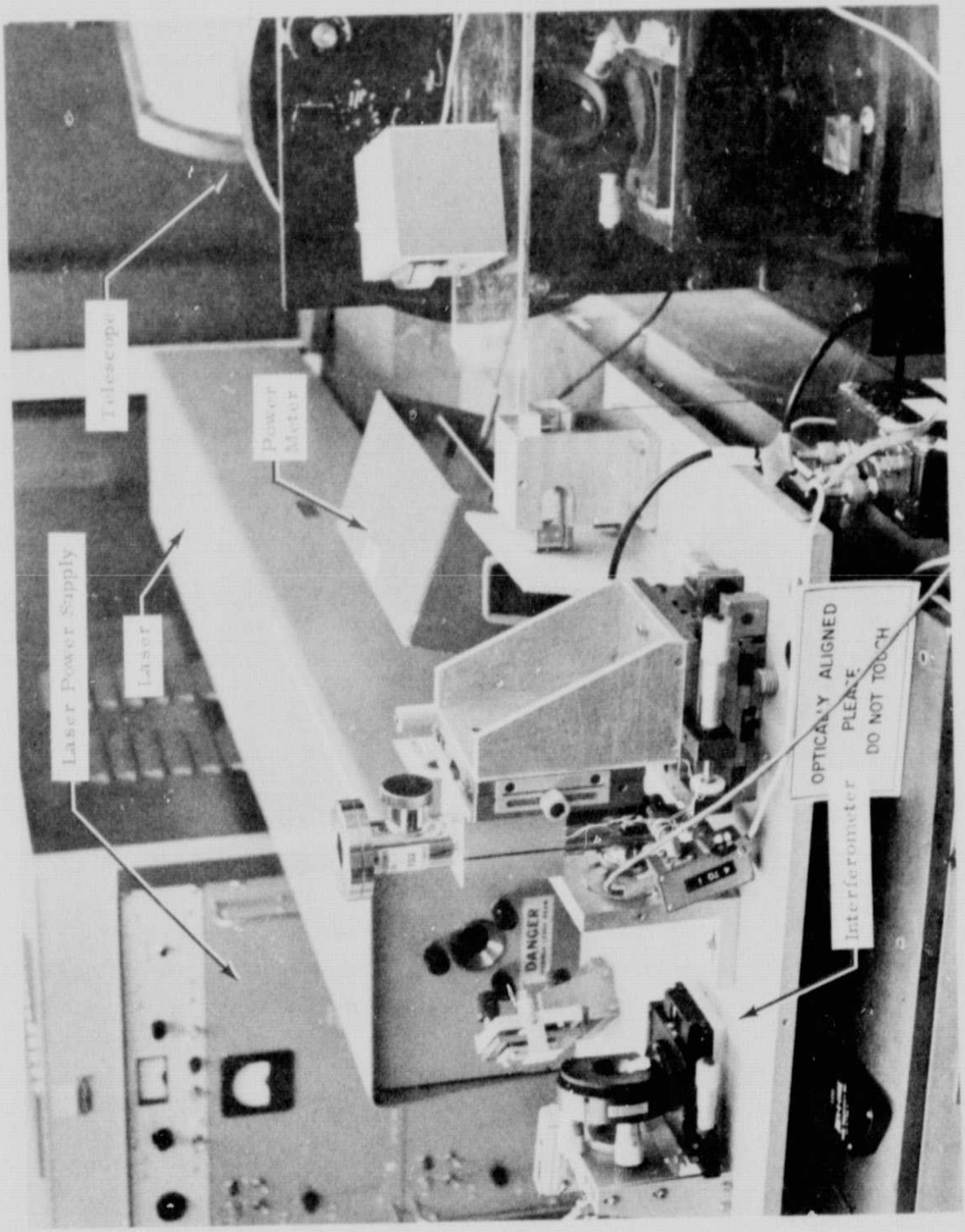

Fig. 6-14 - Van 2 Optical Equipment

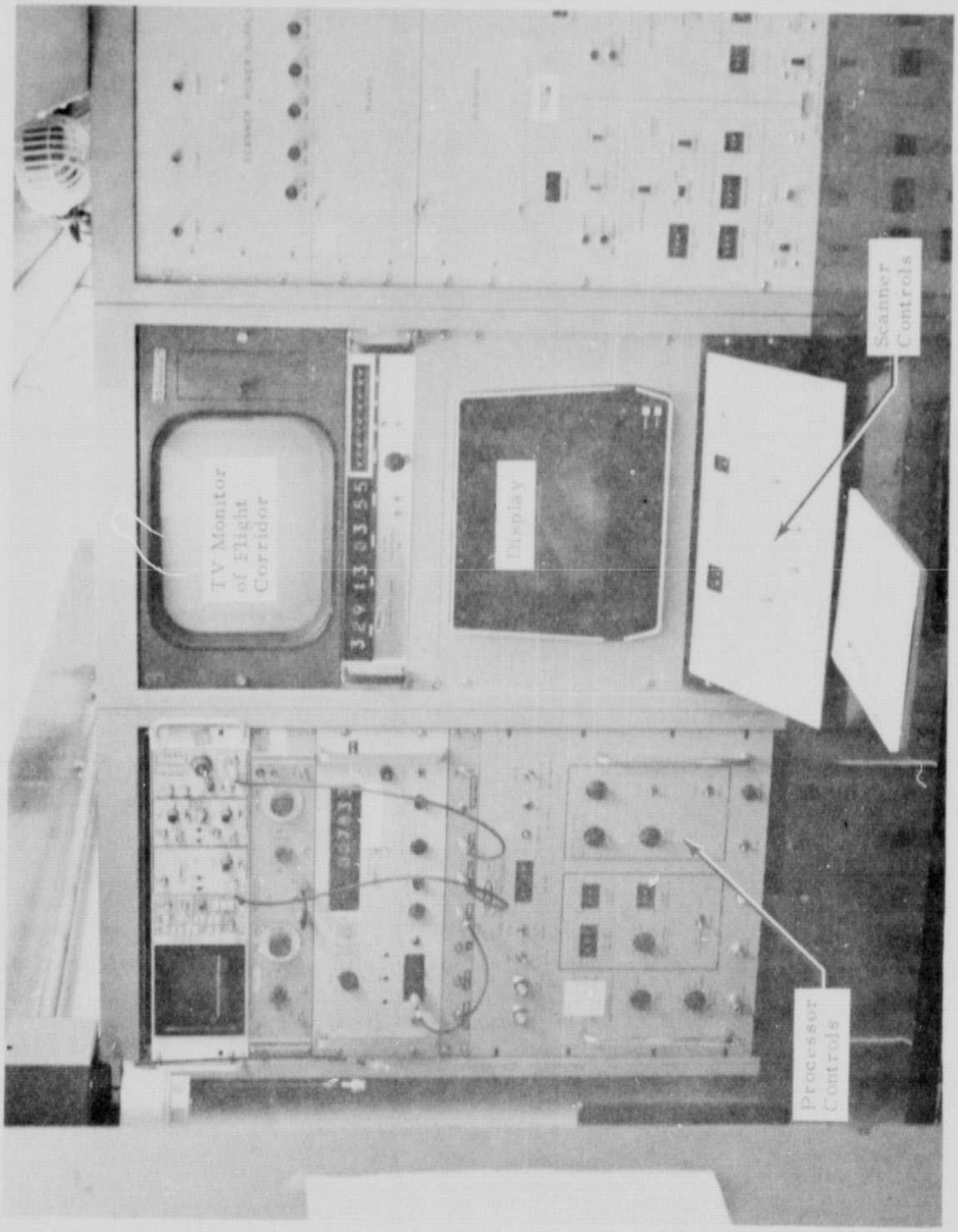

Fig. 6-15 - Van 2 Control Panel

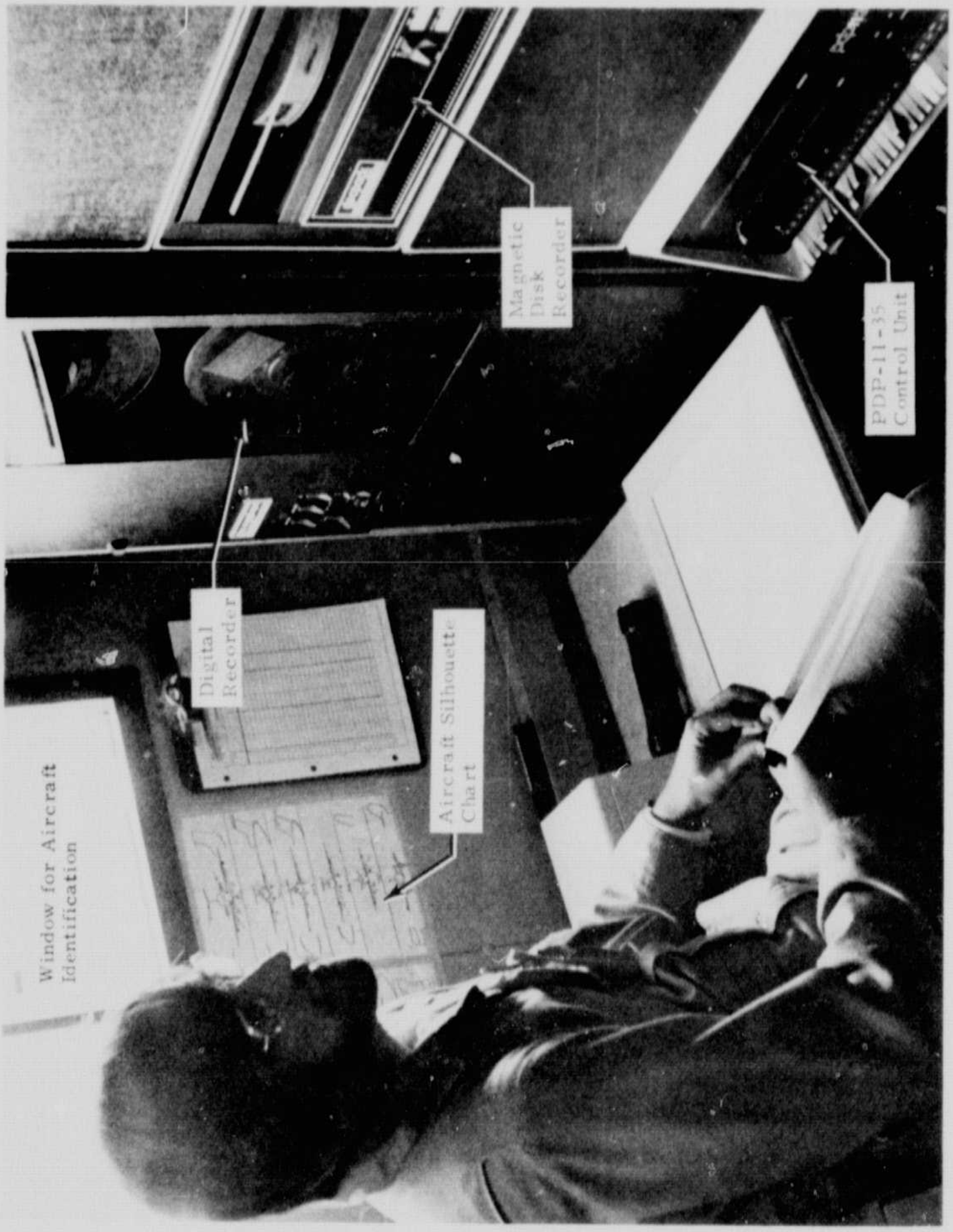

Fig. 6-16 - Graphics Processor Unit of Van 1