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OBSERVATIONS OF CHEMICAL RELEASES FROM HIGH FLYING AIRCRAFT

Prepared by
John F. Bedinger

Prepared For
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
HEADQUARTERS
Washington, D.C.

FINAL REPORT
CONTRACT NO. NASW-2308

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GCA/TECHNOLOGY DIVISION
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OBSERVATIONS OF CHEMICAL RELEASES FROM HIGH FLYING AIRCRAFT

Final Report

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I

TABLE OF CONTENTS

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ABSTRACT

Barium and lithium vapors were released from sounding rockets in the thermosphere and observed from aboard the NASA Convair 990 at an altitude of 40,000 ft. The purpose of the releases were to (1) check out observational and operational procedures associated with the large high altitude barium release from a Scout rocket (BIC); (2) develop an all-weather technique for observing chemical releases; (3) evaluate methods of observing daytime releases, and (4) investigate the possibilities of observations from a manned satellite.

During evening twilight of 7 September and again during morning twilight of 16 September 1971 a trail of lithium and sodium vapor was released from 80 to 175 km and a cloud of barium was released at 175 km. All of the releases were observed from aboard the aircraft and the initial analysis indicates that the previous limitations on the usage of the vapor release method have been removed by the use of the aircraft and innovative photographic techniques. Methods of analysis and applications to the investigation of the thermosphere are discussed.

SECTION I

INTRODUCTION

There were four specific objectives of this contract, all of which required that observations of chemical releases be made from aboard the NASA Convair 990 instrumented aircraft. The releases were scheduled during the period when the aircraft was at Wallops Island in support of the high altitude ion cloud experiment (BIC) which utilized a Scout rocket. Low altitude barium releases from a Nike Apache rocket were used to offer an opportunity for real time check out of some observational equipment and procedures aboard the aircraft which were to be used during BIC. Lithium vapor was released in a trail from the same NIKE Apache rocket and was photographed from the aircraft in order to: (1) develop an all-weather technique for observing chemical releases, (2) evaluate methods of observing daytime releases, and (3) investigate the possibilities of observations from a manned satellite.

Nike Apache rockets were launched from Wallops Island, Virginia during evening twilight at 1857 EST on September 7, 1971 and during morning twilight at 0456 EST on September 16, 1971. Each rocket released a trail of lithium and sodium vapor from about 80 km to apogee at 175 km and a small cloud of barium vapor at apogee. The aircraft flight plan and the rocket launch were carefully coordinated in order that the high speed and versatility of the BIC triangulation cameras aboard the aircraft could be used to record the early expansion of the barium release. Additional wide angle cameras were installed to record the spreading and motion of the lithium trails. The chemical payloads, aircraft preparation, rocket launchings and data recording are discussed in sections II thru V of this report. All systems operated properly and good data on the expansion and motion of the releases were obtained. It now appears that the use of vapor trails for the measurement of thermospheric winds is no longer restricted by local weather conditions or logistic difficulties and may be used during the daytime. The results which lead to these conclusions are discussed in section VI and were reported briefly at the A.G.U. meeting in April 1972 and in the J. Atmos. & Terr. Physics, 35, 377-381, 1973. Section VII contains suggestions for the expanded use of the method.

SECTION II

CHEMICAL VAPOR PAYLOADS

Two chemical vapor payloads for Nike Apache vehicles were constructed in order to deposit a trail of lithium vapor from 80 km to rocket apogee at 175 km and release a barium cloud at apogee. The standard GCA alkali-metal vaporizers were used to eject the lithium vapor. These units contained a mixture of 6 kgs of thermite, 1 kg of sodium and 0.5 kg of lithium in a stainless container. The mixture is ignited by a completely redundant dual ignition sequence consisting of igniters, boosters, batteries, Raymond timers, baroswitches, and arming plugs. Ignition occurs at a preset time after arming by the baroswitch at an altitude of 70,000 ft. Lithium vapor is ejected through three nozzles which are flush with the payload shell, and equally spaced around the circumference of the shell. These payloads have been completely described in reports on previous contracts.(1)

The other part of the payload released a barium vapor cloud at rocket apogee. The complete barium module was purchased from the Astro-Met Division of Thiokol Chemical Corporation, Ogden, Utah. Each module contained 2 kg of barium-copper oxide thermite which vaporizes excess barium after ignition. These units also had dual ignition systems similar to the lithium canisters except that chargeable/dischargeable batteries were used. The barium vapor is ejected through two nozzles located on opposite sides of and flush with the payload shell. These nozzles are sealed with carefully calibrated burst diaphragms which release at the proper internal pressure.

The combined payload with an 11 dgreee nose cone weighed 43.6 kgs and measured 188 cm in length.

SECTION III

AIRCRAFT AND CAMERA PREPARATION

The NASA Convair 990 was instrumented primarily for observation during the BIC program. The low altitude releases were coordinated to utilize the BIC instrumentation, the aircraft support equipment, and allow the addition of other cameras on a non-interference basis. The BIC triangulation cameras without image intensifiers were used to observe the low altitude barium release. The small 13 degree field of view and high viewing angle of 58 degrees placed some constraints on the flight path at early times, but the speed, ease of operation, and versitility of the system provided good coverage of the initial expansion of the barium cloud. These cameras were located in the center of the aircraft and utilized stabilized mirror systems to view through the 60 degree windows (see Figures 1 and 2). The exposure number and time is recorded directly on each frame. The aircraft orientation and the stabilized mirror positions are recorded on a synchronized chart recorder and on the master tape which also records all aircraft position coordinates.

The lithium trail extended from 80 to 175 km and required a large angle of view in order to record its expansion and position. Four of the standard 70 mm cameras used for triangulation of vapor trails from ground sites were adopted for this purpose. The cameras were mounted to view through the 14 degree elevation window at an elevation angle of 45 degrees and could be adjusted in azimuth by $\pm 10^{\circ}$ from the normal to the aircraft pointing direction (see Figures 2 and 3). GCA designed and built the mount for one camera which was attached to a standard mounting platform in the aircraft. Three camera mounts were designed and built by the Airborne Science Laboratory, NASA Ames Research Center. These mounts were attached to the load bearing structures in the cabin walls around the windows. Both mounts allowed good coverage of the lithium trail. The 70 mm cameras were located at station nos. 508-527, 758-778, 797-816 and 1040-1059 (see Figure 1).

The 70 mm cameras were operated from synchronous timers which exposed a frame every 10 sec. The opening of the shutter was recorded on the chart recorder and on the master magnetic tape. Thus parameters of aircraft position, motion, and altitude could be obtained from the tape at the exact time of the exposures. The cameras were installed at Ames Research Center and tested on the ground and in flight before the plane departed for Wallops. A GCA technical photographer was present for the installation and testing.

Personnel associated with the Convair 990 operation supervised the cameras' installation, conducted interference testing, arranged recording systems, and generally supplied any necessary help and materials. The GCA program manager and technical photographer were briefed by aircraft crew and experimenters on all phases of the airborne operation during several test flights prior to the rocket launches. These flights were required during the preparation for BIC, but also accommodated check-out for the four 70 mm cameras to be used for the lithium trail photography.

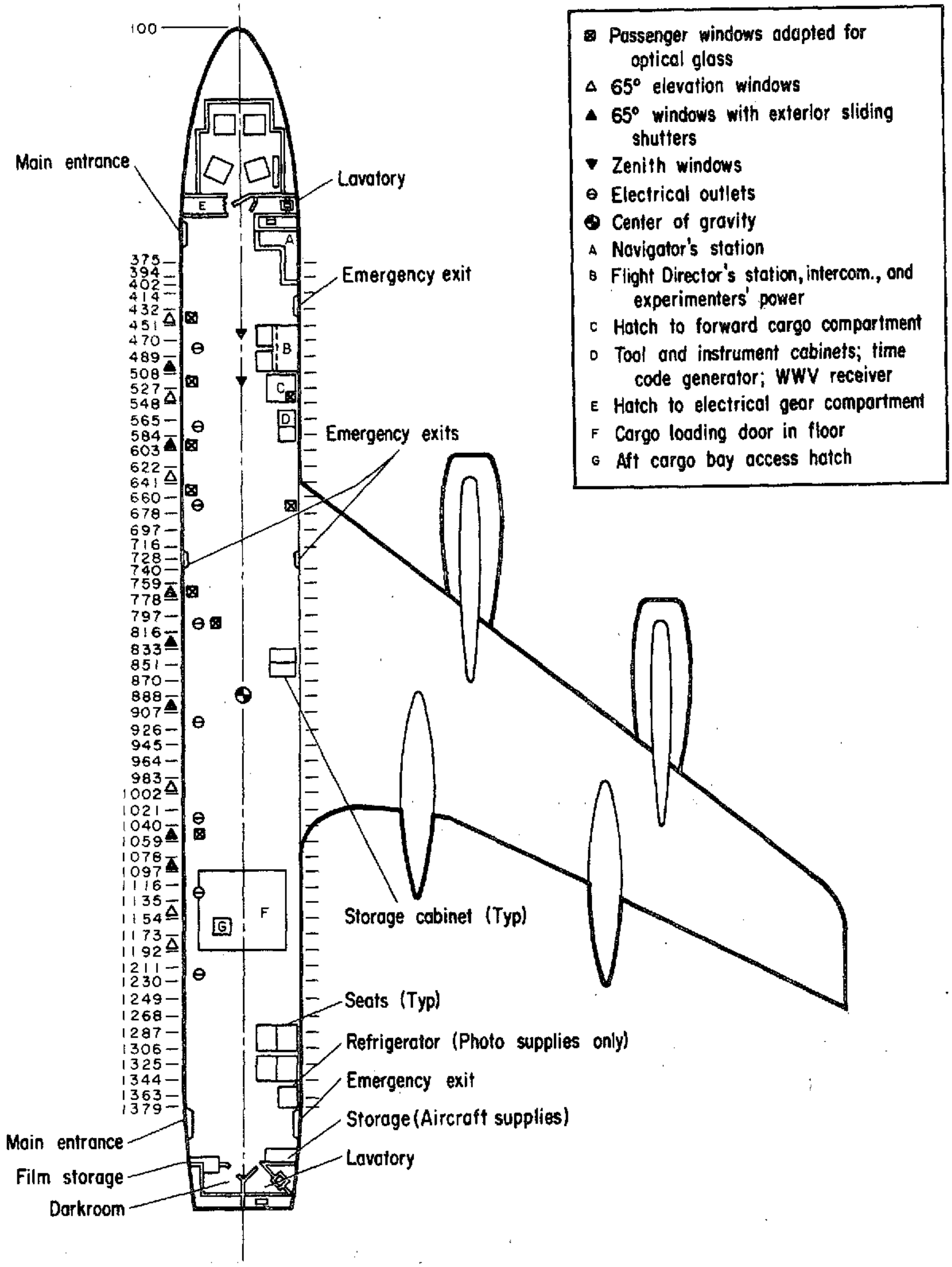


Figure 1. General cabin layout of the Convair 990 during the vapor release of September, 1971.

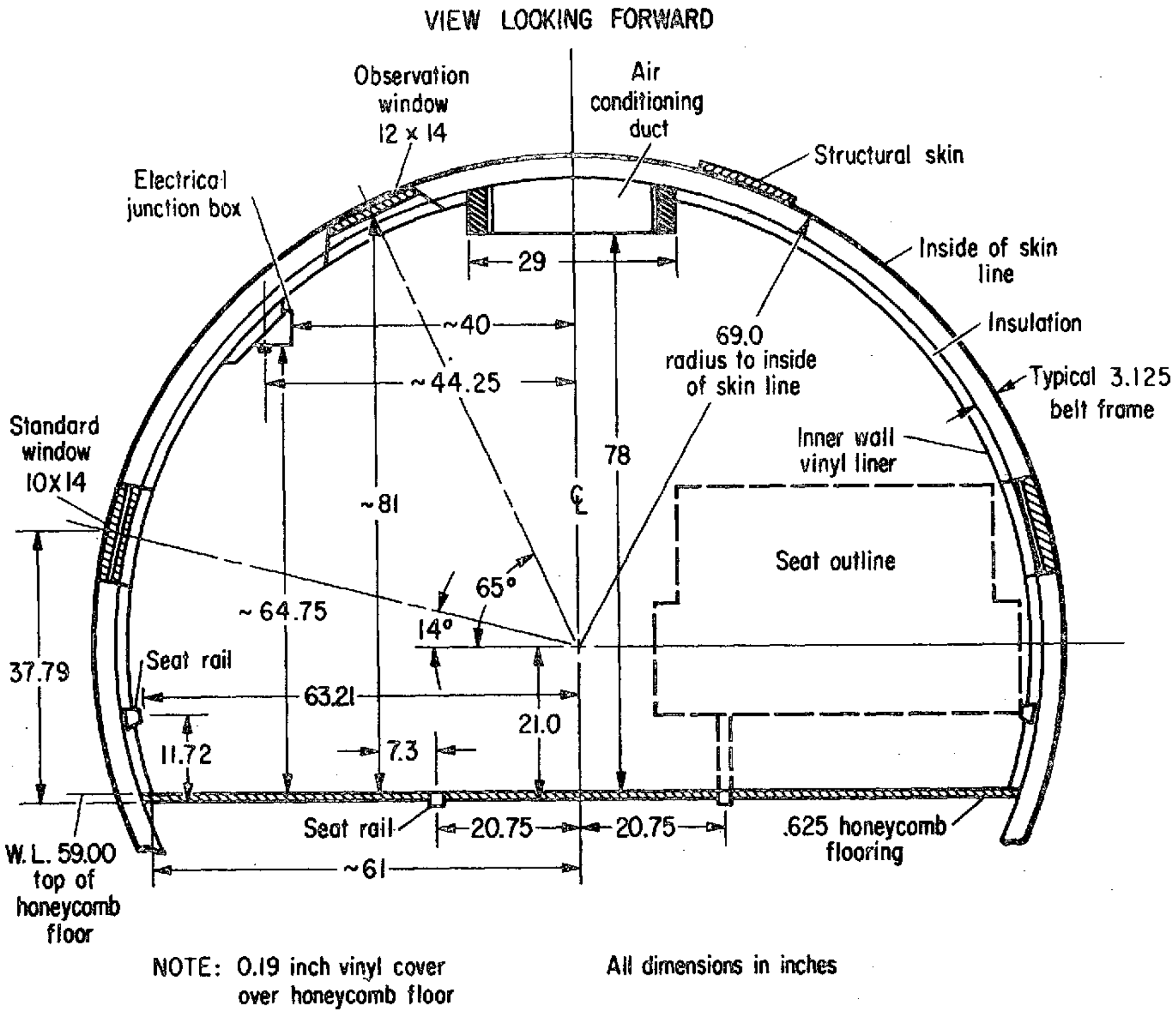


Figure 2. Cross section of cabin of the Convair 990 showing window placement.

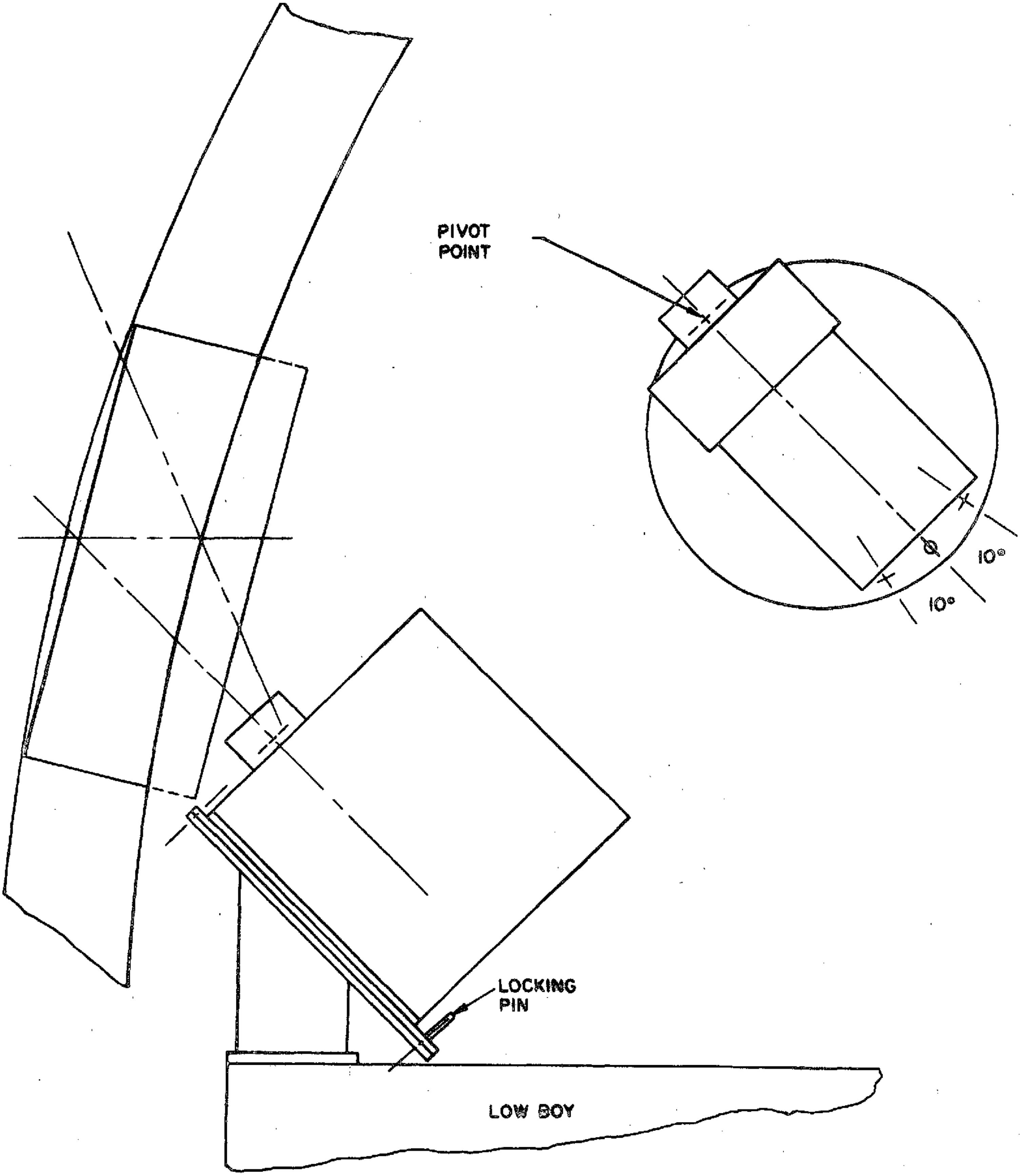


Figure 3. Schematic of 70 mm mount used in the Convair 990.

SECTION IV

PREFLIGHT PHOTOGRAPHIC TESTING AND PREPARATION

A large amount of testing and preparation was required in order to utilize the available equipment to meet the multiple objectives of the program. The different characteristics of the cameras and the variations in the desired data required that several schedules of exposures and filter combinations be prepared for each system. The BIC triangulation cameras were equipped with stabilized mirrors so that aircraft motion was not a major problem, but the small field angle and fixed viewing angle required that the pointing be controlled by aircraft heading. The 70 mm cameras had a large field angle and could be adjusted somewhat in azimuth but did not have stabilization. Thus, the exposure must be short enough to eliminate aircraft motion, but long enough to record star images and dim trail features. In addition, the sky brightness during twilight as viewed from the aircraft is not as precisely known as on the ground so that a series of exposures was used to insure complete coverage.

Exposure sequences for the late morning twilight when the sky background was very bright were the most critical and difficult to establish. Little experimental data were available and the use of narrow interference filters introduces problems concerning the useful field of view. These difficulties were overcome through conducting an extensive testing program from the aircraft during the daytime ferry flight from Moffet Field to Wallops Island, Virginia. During that flight many different exposures for various film and filter combinations were recorded with a 35 mm camera and the proper values for various conditions were selected.

Three different classes of filters were used in the cameras. During the evening twilight observations two of the 70 mm trail cameras used wide wratten filters which allowed a transmission band width of approximately 1000A. During the late morning twilight some cameras used interference filters with approximately 100A band width and two cameras had interference filters with approximately 10A band width. The specific exposures for each camera used during the evening and morning observations are given in Tables 1 and 2, respectively.

Table 1. Camera and exposure schedule for evening twilight observation of vapor release from aboard the NASA Convair 990. Rocket launch time 1857 EST, 7 September 1971.

Camera	Film	Exposure Rate	Exposure Time	F-stop	Filter	Primary Use
I. BIC Triangulation						Record early time expansion of Ba release
AC2	2485	5 sec intervals	1/10sec.	2.8	none	
AC4	2485			4-1st leg 1-2nd leg	none none	
II. 70 mm						Record expansion & motion of lithium trail
1	2475	6 sec intervals	1/5 sec.	2.8	Interference 10Å (6708)	
2	2475				Wratten W8	
3	2475				None	
4	2475				Wratten W15	
III. 35 mm	2475	Variable	1/10sec.	1.5	Interference 10Å (4554)	Record ion cloud motion

Table 2. Camera and exposure schedule for morning twilight observations of vapor releases from aboard the NASA Convair 990. Rocket launch time 0456 EST 16 September 1971.

Camera	Film	Exposure Rate	Exposure Time	F-Stop	Filter
I. BIC Triangulation					
AC2 AC4	Same as in Table #1 except that interference filters of approximately 100Å band width at λ 4554 and 5535 were added after T+13 minutes. Early time exposure rate was 1 second intervals increasing to 10 seconds at very late times.				
II. 70 mm					
1	2475	6 sec. intervals	1/10 sec	4	Interference 10Å (6708) for first 15 minutes Interference 10Å (4554) after 15 min.
2	2475	6 sec. intervals	1/2 sec	2.8	None for 1st 15 minutes Interference - 100Å (6708) after 15 min.
3	2475	6 sec. intervals	1/5 sec	2.8	same as above
4	2475	6 sec. intervals	1 sec	2.8	same as above
III. 35 mm					
1	2475	variable	1/10 sec	1.5	Interference 10Å (4554) for 1st 15 min. Interference 10Å (6708) after 15 min.
2	Color	variable	10 sec	1.5	Utilized stabilized mirror and recorded early time of barium release.

SECTION V

ROCKET FIRINGS AND OBSERVATIONS

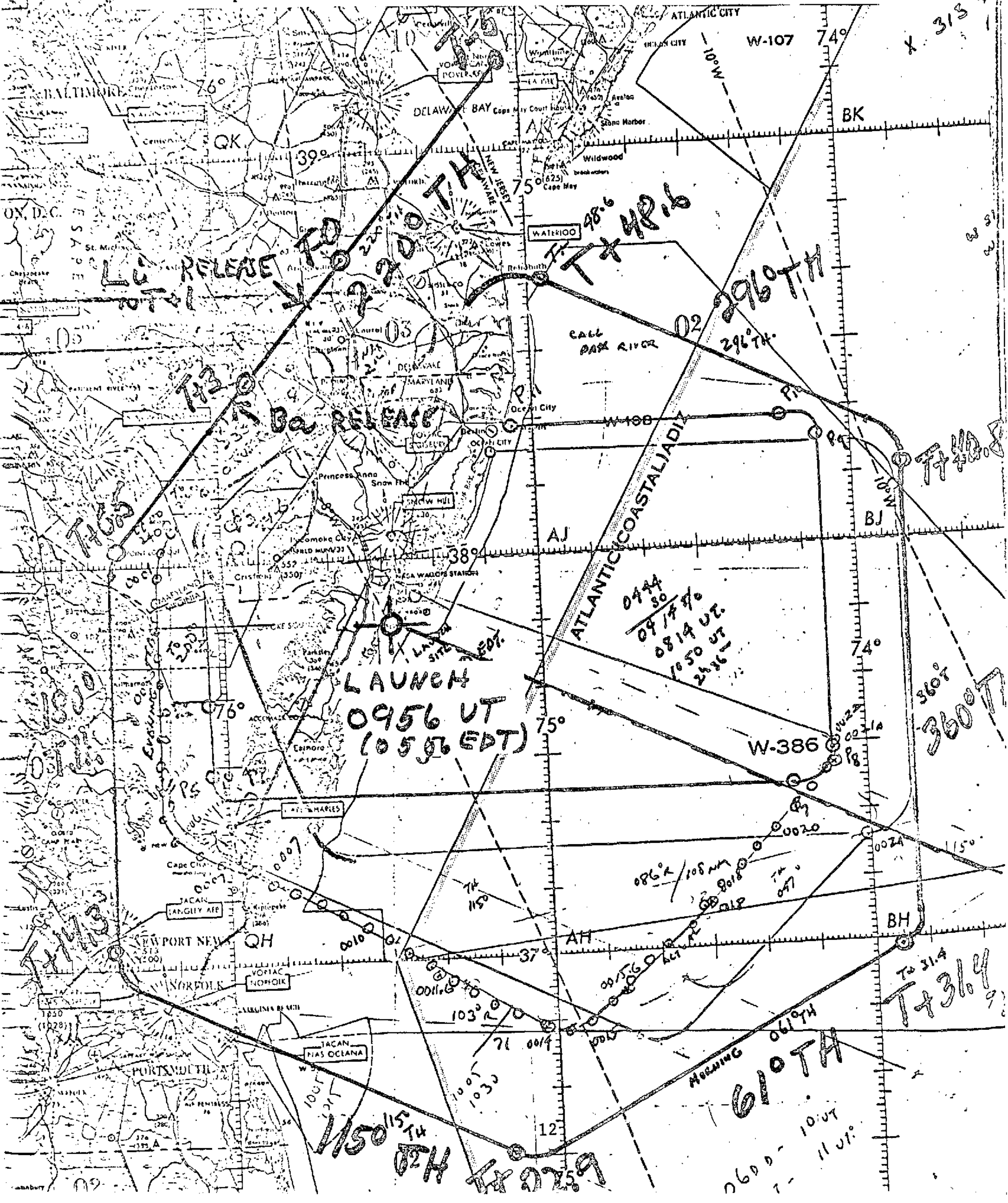
The first Nike Apache rocket of this series was fired during evening twilight at 1857EST on 7 September 1971. The second rocket was fired during morning twilight at 0456EST on 16 September 1971. Each rocket released a trail of lithium and sodium vapor from approximately 80 km to rocket apogee at 175 km and a single cloud of barium vapor at 175 km. Rockets and payloads performed as predicted on both flights.

The first firing on the evening of 7 September coincided with the arrival of the Convair 990 at Wallops Island, Virginia. The aircraft departed Moffet Field, California on a course so as to arrive at Wallops Island in position and on time to fly a prescribed pattern for observation of the vapor releases. This arrangement required less than an hour additional flight time for the aircraft and provided the first opportunity for the use of the aircraft. The aircraft arrived on schedule and performed the required flight path for the observations. Radar at Wallops Island tracked the aircraft at all times in the vicinity of Wallops Island, and verified the accuracy of the aircraft navigational systems. The flight path for observation of the evening releases is shown in Figure 4 as the inner path with the many small circles. The major triangulation data were obtained in the first three legs of the path between T-0 and T+14 minutes. The dark outer path is the pattern which was used for the morning observations. The major triangulation data were obtained between T-0 and T+14 minutes and the filter photography with bright sky background was in progress from about T+15 to T+48 minutes.

The filters, exposures and cameras which were used for this observation were contained in Tables 1 and 2 of the preceding section of this report.

During the period of the morning observations, the sky brightness changed by a factor of about 10^4. The rocket was launched at a solar depression angle of 10 degrees which allowed the major triangulation path to be completed (T+14 minutes) at a solar depression angle of 7 degrees. This was necessary to insure that star images, which are required for accurate direction determination in the data reduction were recorded on the photographs. After 14 minutes, the flight path was directed towards the East in order to provide a brighter sky background. Due to this effect and the altitude (40,000 ft.), sunrise occurred at the aircraft at about T+25 minutes. Ground sunrise at Wallops Island occurred at T+48 minutes. At that time the sun was more than three degrees above the horizon as viewed from the aircraft and thus, the sky brightness at that altitude was approaching that of the full daylight sky.

Figure 4. Flight path of the NASA Convair 990 during the vapor trail observations. The inner path with numerous small circles was the path for the evening launch of 7 September 1971. The longer outer path was flown during the morning of 16 September 1971.



SECTION VI

DISCUSSION OF RESULTS

A. REAL TIME CHECKOUT FOR CONVAIR 990 INSTRUMENTATION

The chemical releases from thw two Nike Apache rockets were scheduled during the period when the NASA Ames Research Center Convair 990 instrumented aircraft was at Wallops Island, Virginia in support of the high altitude barium cloud experiment (BIC). One of the objectives of the low altitude barium release was to offer an opportunity for real time check-out of some observational equipment and procedures aboard the aircraft. The equipment and procedures used during these tests are described in the previous sections of this report. The BIC triangulation cameras were positioned and programmed to record the early time expansion of the barium release. A sample of the results is shown in Figures 5 and 6. The frames in Figure 5 were taken at 1,2,3, and 4 seconds after barium release. The frames in Figure 6 were taken at 5,10,15 and 20 seconds after barium release. After a few minutes the barium clouds were not identifiable in the black and white photographs, because the much brighter lithium trail effectively masked the dim barium cloud. The solution to this problem was furnished by the 35 mm camera with color film which is listed in Table 2 of Section IV. The stabilized mirror system allowed sufficient exposure for color film and the color difference of the various releases allows observation of the individual clouds for much longer periods. Good color photographs were obtained also from the ground at Wallops Island.

B. EXPANDED CAPABILITY AND APPLICATION OF THE VAPOR TRAIL METHOD

1. Background

The vapor trail method has been widely used for the measurement of upper atmospheric winds and to a lesser degree for the measurement of temperature, diffusion, turbulence and correlation with other measurements. The method has been proven to be consistently reliable in producing the desired observations. However, there have been basic limitations to the method. Two of these are obvious to anyone acquainted with the method and the other becomes apparent during some applications. The obvious limitations are the requirement for clear skies at observing sites and the fact that the method could not be used during the daytime. The not so obvious difficulty occurs when several observation sites are being established and operated in remote or inaccessible areas such as the Arctic, or in foregin countries. The investigation and development of methods to overcome these restrictions was a major objective of this program. The basic requirement for the proposed methods was the capability of obtaining a wind measurement utilizing the Convair 990 as the only observational platform. Observational data which clearly indicate ways of overcoming all three of the basic restrictions on the vapor trail measurements were obtained. These data and the analytical methods are discussed in this section.

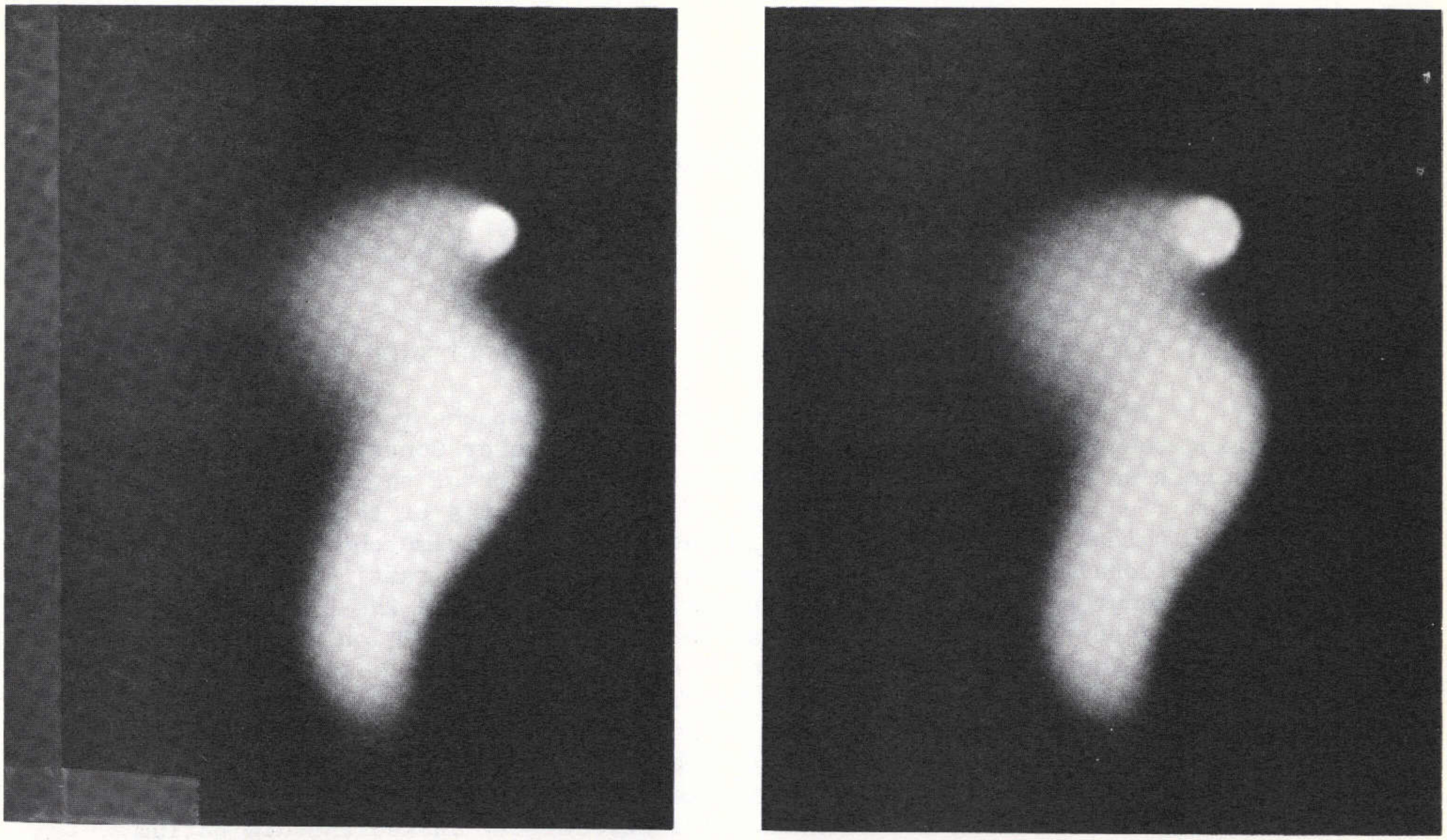
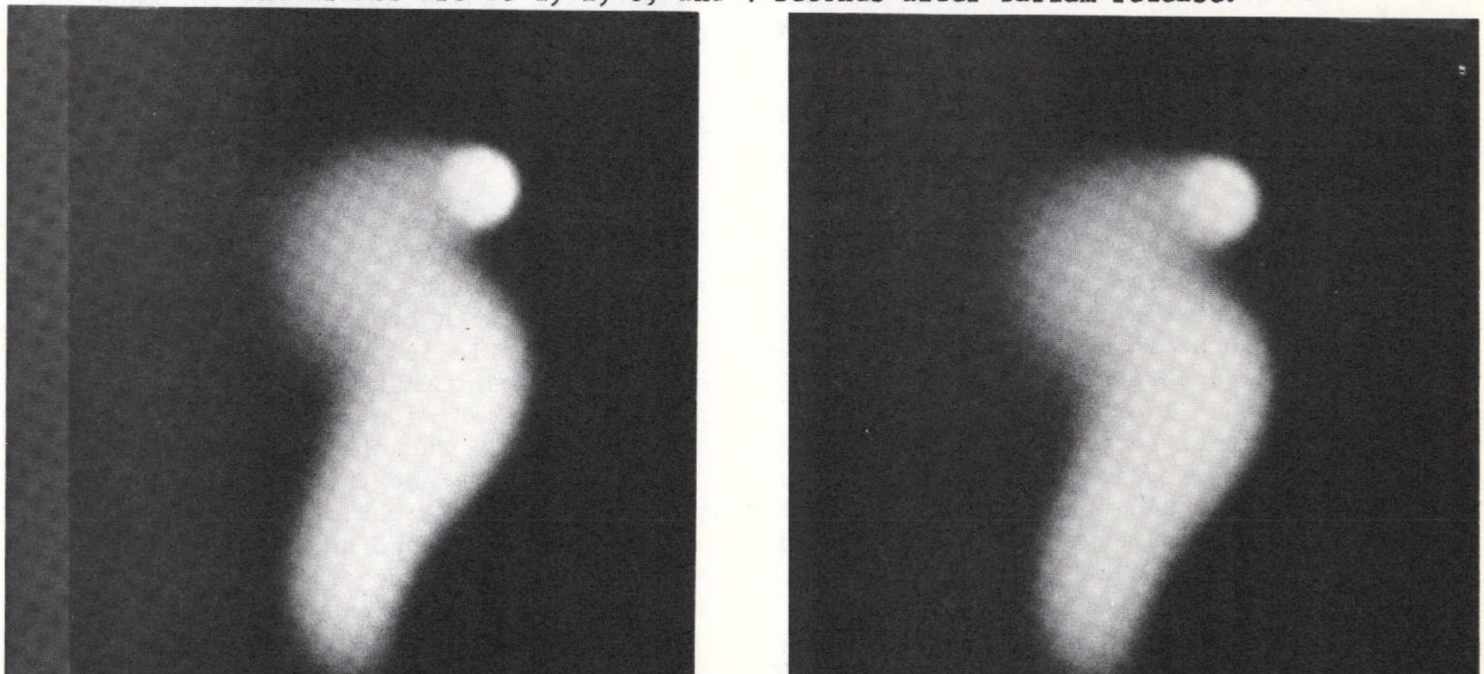


Figure 5. Photographs of the barium release of 16 September taken with the BIC triangulation cameras aboard the NASA Convair 990. The exposures are 1/10 sec at F/4 on Kodak 2485 film at a rate of one per second. The frames are at 1, 2, 3, and 4 seconds after barium release.



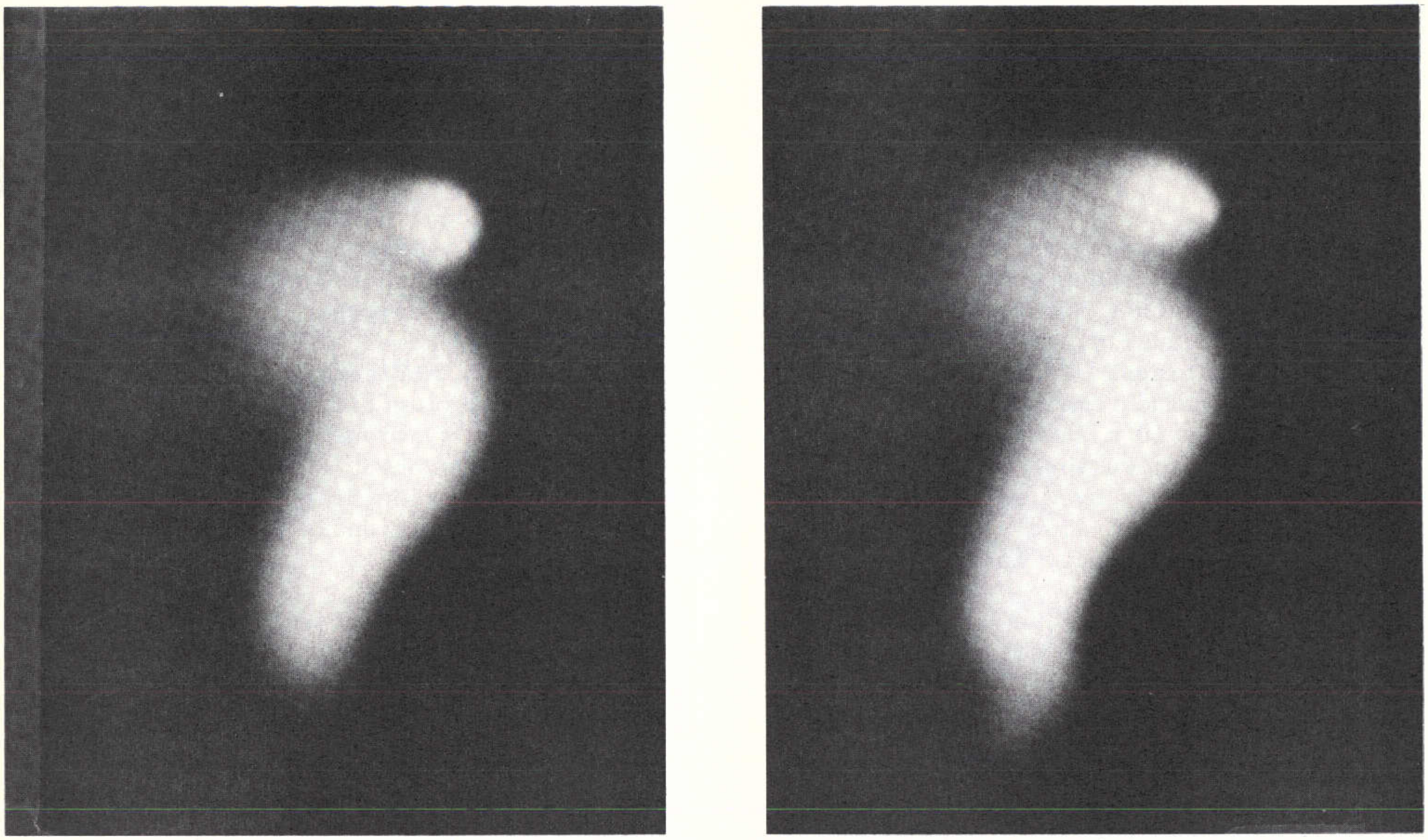
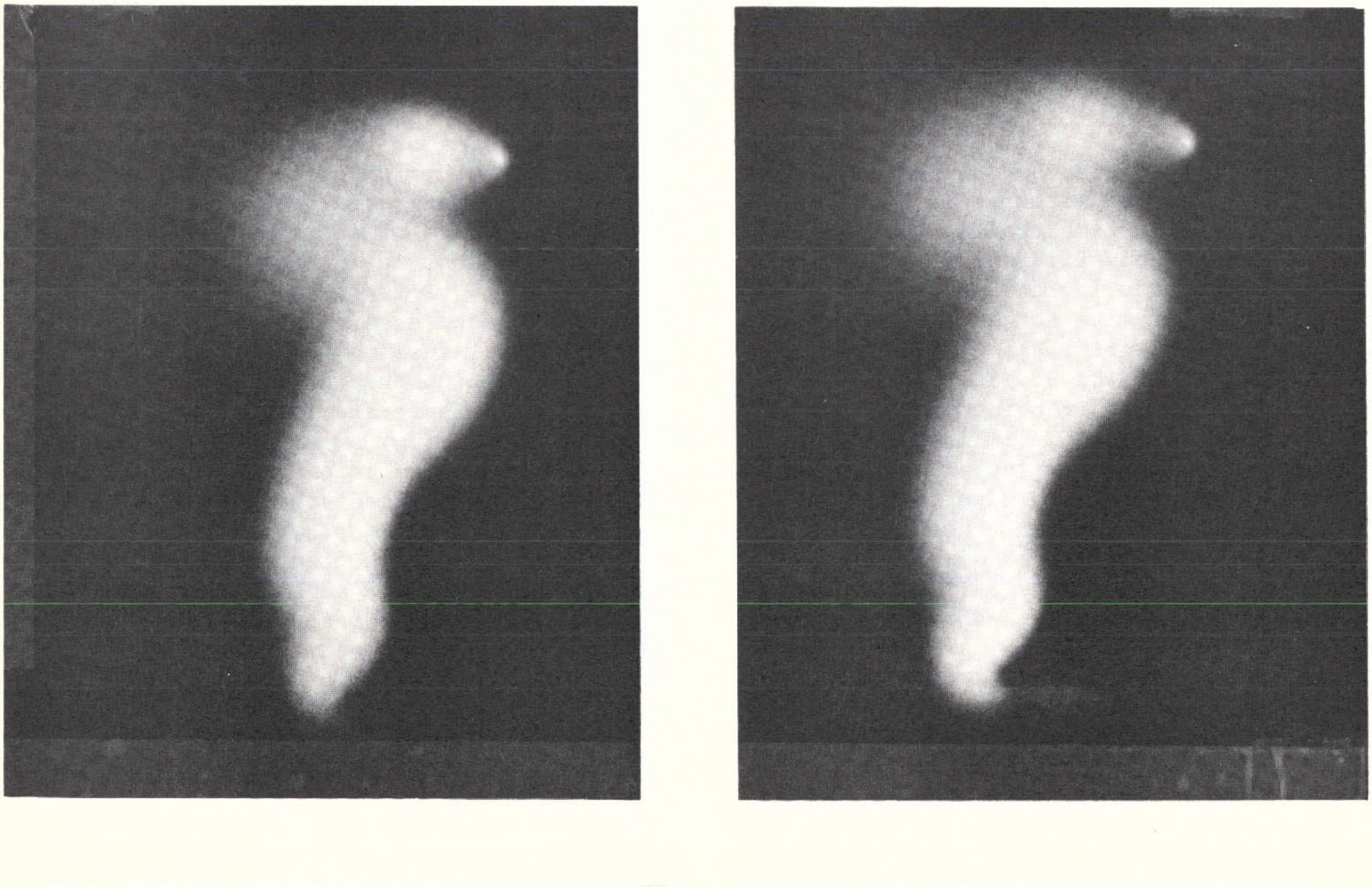


Figure 6. Photographs of the release in Figure 4 taken at 5, 10, 15, and 20 seconds after barium release.



2. Analytical Method and Wind Data

The triangulation procedure for data acquired from the aircraft is necessarily different from that used with data from fixed, ground-based sites. The ground sites allow data acquisition simultaneously from several accurately located positions. On the other hand, the aircraft is moving continually, and thus data are obtained at different times and from different locations. Consequently it must be assumed that the horizontal velocity of the wind remains unchanged during the required observing time, which was about 10 minutes during recent tests. Previous observations of vapor trails have shown that the most careful observations do not detect a variation in the winds over such a short period. Thus, the assumption of a constant horizontal wind velocity during the interval of observation is not a source of uncertainty in the wind measurement.

The basic triangulation procedure requires that the trail be observed from different directions. The aircraft obtains the different perspectives by flying around the trail. The aircraft flight paths used in September 1971 are shown in Figure 4. The light inner path with many small circles is the flight path for the evening twilight trail on 7 September 1971. The dark outer path was used for the morning twilight on 16 September 1971. The triangulation data were obtained on the two portions of the flight path between the lithium release at T+1 minutes and the second turn at T+14 minutes. The different perspectives of the trail as seen from the different positions are shown in Figures 7 and 8 . Figure 7 was taken at about T+14 on the first part of the triangulation path. Stars shown in the upper right are in the familiar constellation, Orion. Figure 8 taken at T+8.5 on the second part of the path shows the different perspective which allows the triangulation. The trail left by the downward traveling rocket is shown also.

The basic data are photographic records of the trail. These are calibrated by well-known methods making use of photographic images of stars on the photographic records. Calibrated fiducial marks are used in the case of daytime trails. On a photographic plate the image of a trail is a continuous filament. Points are chosen on this filament in such a way as to divide it into arcs of approximately equal length. For a photograph taken from site A these points are sequentially designated as $A_1, A_2, \ldots, A_M, \ldots$ Similarly, $B_1, B_2, \ldots, B_N, \ldots$ are the sequential designations of points from site B. For each such point A_M, the calibration procedure supplies a set of direction cosines with respect to site A. These are labelled $C_i(A_M)$, $i = 1,2,3$. Similarly, a set of direction cosines $C_i(B_N)$, $i = 1,2,3$, is established for each point B_N from site B. The triangulation procedure is contained in a set of equations which are explained by the schematic representation of the pertinent geometry shown in Figures 9 a,b. (For simplicity, a two-dimensional situation is depicted in these figures. Further, the curvature of the earth, which can be accounted for by a straightforward elaboration, has been neglected.) In both figures, O_X, O_A and O_B are the origins of the reference system, site A, and site B, respectively. $\vec{S}(A)$ and $\vec{S}(B)$ are the vectorial coordinates of sites A and B, respectively, with respect to the reference. A vector from the reference to a point on the trail is represented by $\vec{X}$; whereas a vector from a site to a point on the trail is

Figure 7. Photograph of the lithium trail taken with 70 mm cameras from the 14° side windows of the Convair 990. The exposure is 1/10 second at F/2.5 on Kodak 2475. The time is 4.5 minutes after launch of the rocket.

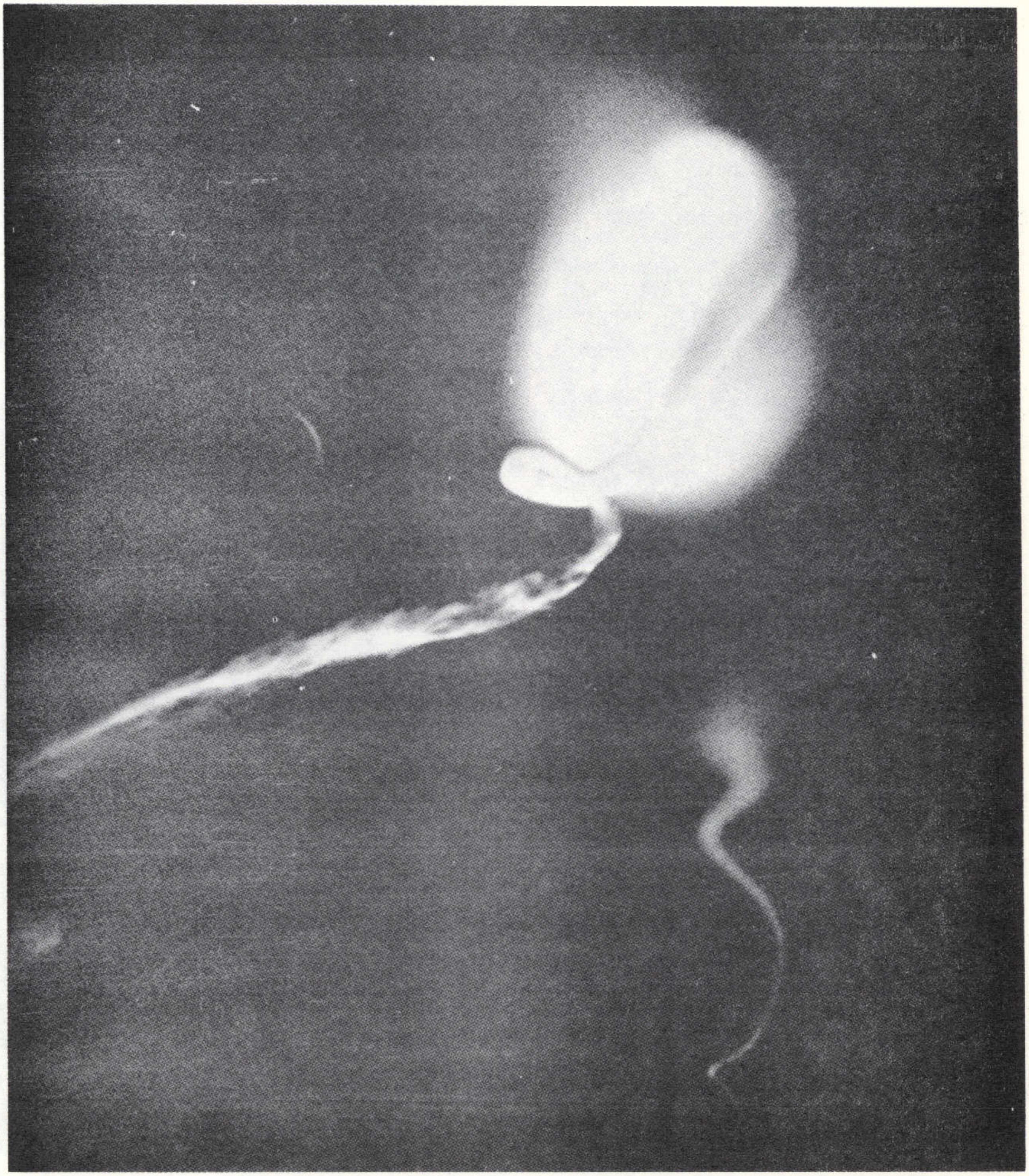


Figure 8 . The lithium trail in Figure 7 taken from the 990 after a change of direction of the flight path at 8.5 minutes. The different orientation of the trail allows triangulation with Figure 7 .

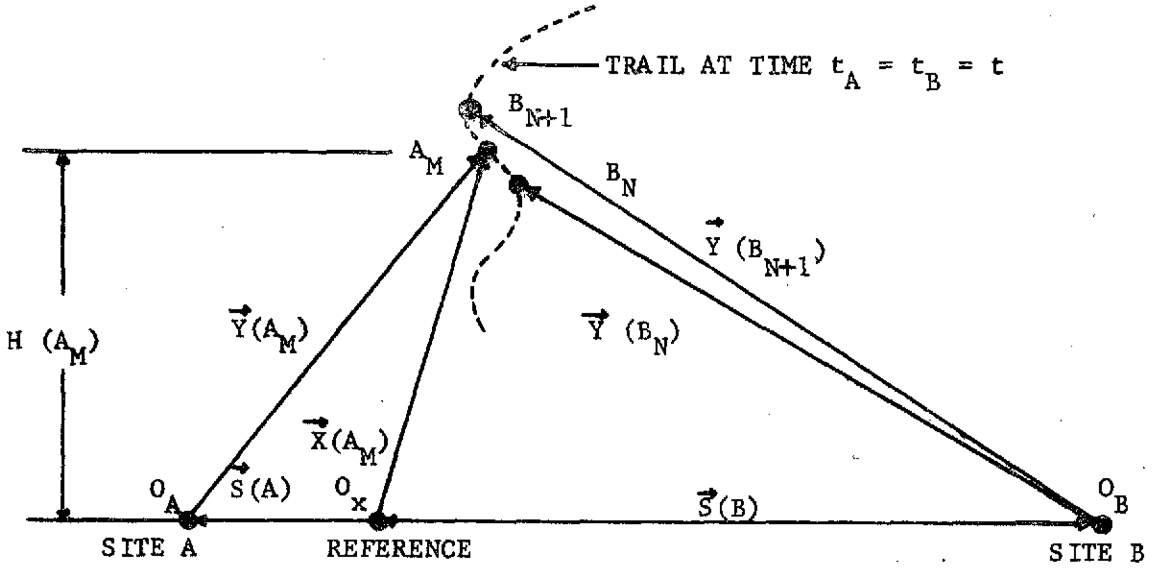


Figure 9a. Schematic representation of geometry involved in simultaneous triangulation.

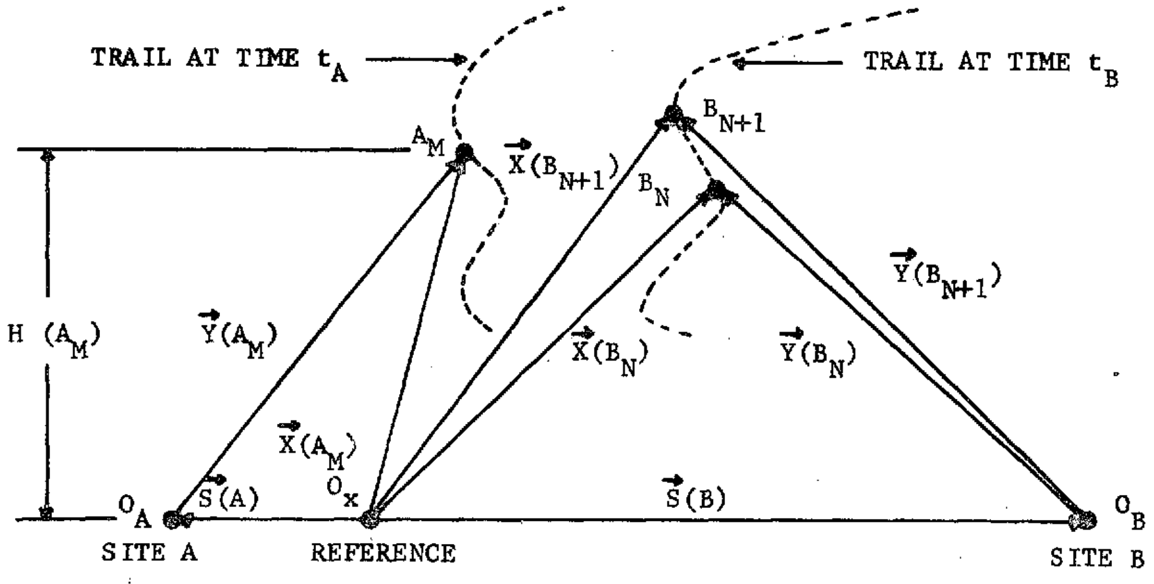


Figure 9b. Schematic representation of geometry involved in non-simultaneous triangulation.

represented by $\vec{Y}$. From Figure 9, it is evident that

$$\vec{X}\ (A_M) = \vec{S}(A) + \vec{Y}(A_M) = \vec{S}(A) + R(A_M)\ \vec{C}(A_M) \tag{1}$$

$$\vec{X}\ (B_N) = \vec{S}(B) + \vec{Y}(B_N) = \vec{S}(B) + R(B_N)\ \vec{C}(B_N) \tag{2}$$

$$X\ (B_{N+1}) = \vec{S}(B) + \vec{Y}(B_{N+1}) = \vec{S}(B) + R(B_{N+1})\ \vec{C}(B_{N+1}) \tag{3}$$

where $R(A_M)$ is the distance (range) from site A to the point A_M, and $\vec{C}(A_M)$ are the known direction cosines of the point A_M. Corresponding definitions apply to the symbols pertaining to site B.

Consider first the case of simultaneous triangulation depicted in Figure 9a. If the points A_M and B_N coincide, then

$$\vec{X}(A_M) = \vec{X}(B_N) \tag{4}$$

and hence

$$\vec{S}(A) + R(A_M)\ \vec{C}(A_M) = \vec{S}(B) + R(B_N)\ \vec{C}(B_N). \tag{5}$$

The two unknowns, $R(A_M)$ and $R(B_N)$, are determined from any two of the three scalar equations contained in the vector equation (5). From $R(A_M)$ and equation (1) the vector $\vec{X}(A_M)$ is determined. Corresponding to the altitude $H(A_M) = X_3(A_M)$, there is a release time (of the vapor from the rocket) $t_R(A_M)$ and release coordinates $\vec{X}_R(A_M)$. The horizontal velocity $\vec{V}$ is then obtained from

$$V_i(A_M) = \left[X_i(A_M) - X_{Ri}(A_M)\right] / \left[t_A - t_R(A_M)\right]\ i = 1,2 \tag{6}$$

where t_A is the time of the photograph from site A.

In practice, the set of points A_M do not coincide with the set of points B_N. Thus, in general, one determines two parameters, $d(A_M, B_N)$ and $d(A_M, B_{NM})$, which are proportional to the perpendicular distance between

$$\vec{Y}(A_M) \text{ and } \vec{Y}(B_N), \text{ and } \vec{Y}(A_M) \text{ and } \vec{Y}(B_{N+1})$$

respectively. An interpolation parameter λ is determined from these distances, and equation (4) is replaced by

$$\vec{X}(A_M) = (1-\lambda)\ \vec{X}(B_N) + \lambda\vec{X}(B_{N+1}) \tag{7}$$

The remaining steps are identical to the steps followed for exact correspondence between A_M and B_N.

The case of non-simultaneous triangulation, depicted in Figure 12b, is more complicated, owing to the fact that the photographs from sites A and B were taken at the distinct times t_A and t_B. Even if A_M and B_N represent the same point on the trail, this point has moved from $\vec{X}(A_M)$ to $\vec{X}(B_N)$ in the time $(t_B - t_A)$ between photographs. Thus, in addition to equations (1), (2), (3), the following equations, expressing the motion of the trail from the time of release (from the rocket) to the time of observation, are required:

$$\vec{X}(A_M) = \vec{X}_R(H_M) + \left[t_A - t(H_M)\right] \vec{V}(H_M) \tag{8}$$

$$\vec{X}(B_N) = \vec{X}_R(H_N) + \left[t_B - t(H_N)\right] \vec{V}(H_N) \tag{9}$$

$$\vec{X}(B_{NH}) = \vec{X}_R(H_{NH}) + \left[t_B - t\ (H_{N+1})\right] \vec{V}(H_{N+1}) \tag{10}$$

It is assumed that vertical motion is negligible, so that (8), (9), and (10) pertain to the horizontal components. The release time $t_R(H_N)$ and the release coordinates $\vec{X}_R(H_N)$ can be represented as simple analytic functions of the altitude H_N.

It can be shown that the case of exact coincidence between A_M and B_N (see Figure 12b) results in a set of 9 simultaneous equations in 8 unknowns. A deterministic solution is not possible, however, because data errors smaller than those encountered in practice are sufficient to product spurious results. The procedure adopted instead utilizes an iterative technique in conjunction with a high-speed computer to improve an initial rough guess. The rough guess consists of two tables, the first of which establishes a correspondence between points from different sites, to within a specified tolerance, and the second of which establishes a correspondence, to within another tolerance, of one of the length (or distance) parameters. Thus formulated, the procedure incorporates an interpolation algorithm. The speed of convergence of the iteration depends on the goodness of the initial rough guess. With a moderately good guess, a trail extending from 90 to 160 kilometers was reduced in less than 10 minutes on a CDC 6400 computer. The accuracy of the results was approximately ± 3 meters/second for the velocity and 0.25 km (in the lower region) to 1.00 km (in the upper region) for the altitude.

The results for flight NASA 14.494 are given in tabular form in Table 3. Figures 10 and 11 present the eastward and northward velocity components, respectively, in graphical form. Figure 12 gives the same results in the form of a hodograph.

Table 3. Winds During the Morning Twilight of 16 September 1971

Height km	V_x* m/s	V_y** m/s
92	80	41
92.5	75	44
93	74	47
94	72	52
95.5	72	54
97.5	74	58
99	72	57
99.5	69	56
99.8	65	53
100.0	62	50
100.5	55	44
101.0	51	39
101.5	43	28
101.6	37	18
101.7	33	9
101.8	30	3
102	27	-3
102.4	23	-9
102.6	18	-13
102.8	16	-18
103	14	-23
103.5	12	-26
105	5	-36
106.5	-3	-36
107.7	-5	-34
109	-10	-23
109.5	-3	-24
110.2	-2	-29
110.7	-6	-38
111.5	-11	-41
112.2	-22	-44
113.5	-32	-47
114	-38	-49
114.2	-44	-50
114.7	-51	-52
115.9	-54	-52
116.1	-59	-51
116.3	-57	-47
116.5	-68	-39
117	-67	-37
118.5	-57	-46
120	-58	-49

Table 3. (continued)

Height km	V_x* m/s	V_y** m/s
120.5	-60	-45
123	-54	-43
130	-43	-43
135	-31	-43
142	-17	-43
152	15	-48
163	27	-56
175	35	-65

* V_x is the Eastward Component

** V_y is the Northward Component

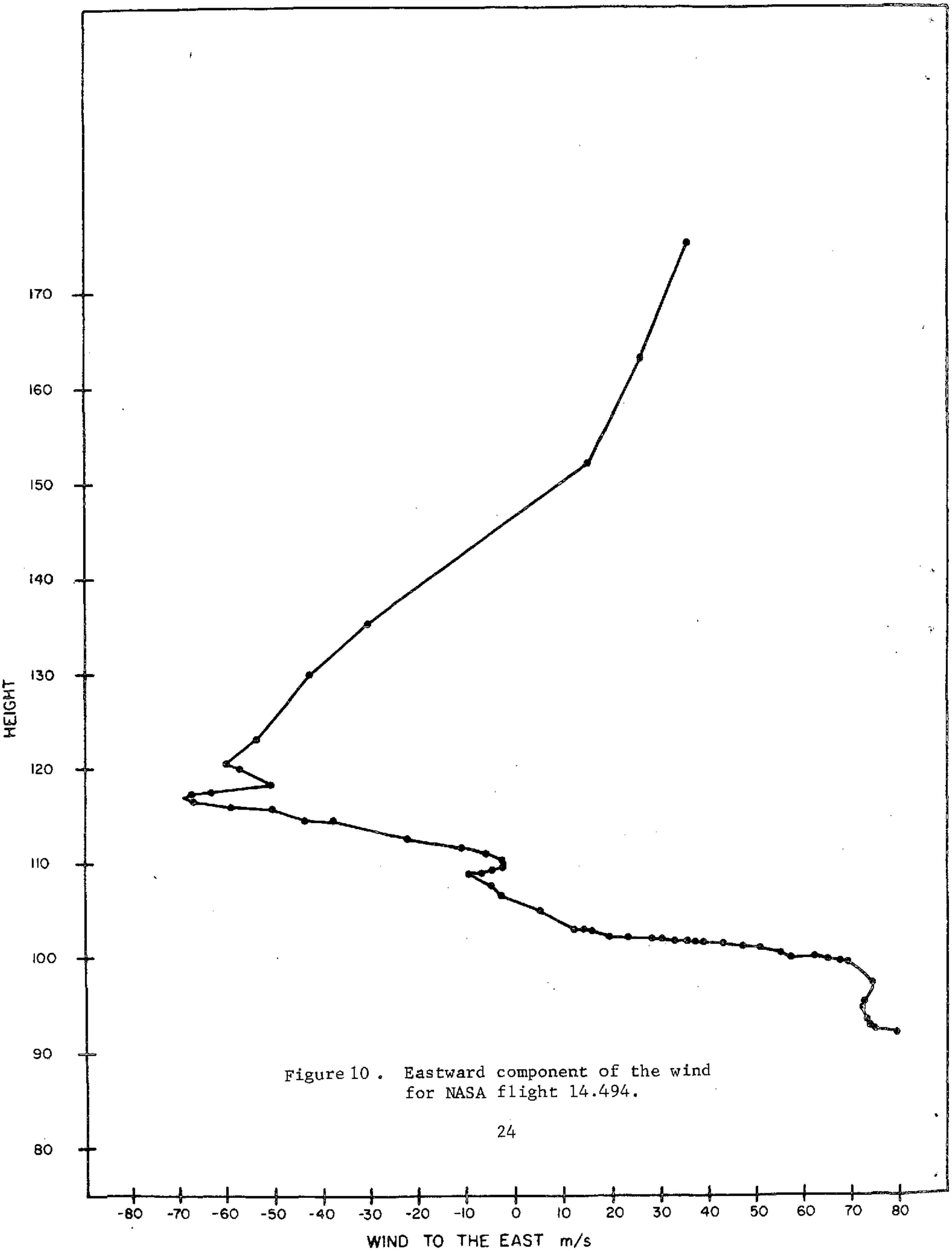


Figure 10. Eastward component of the wind for NASA flight 14.494.

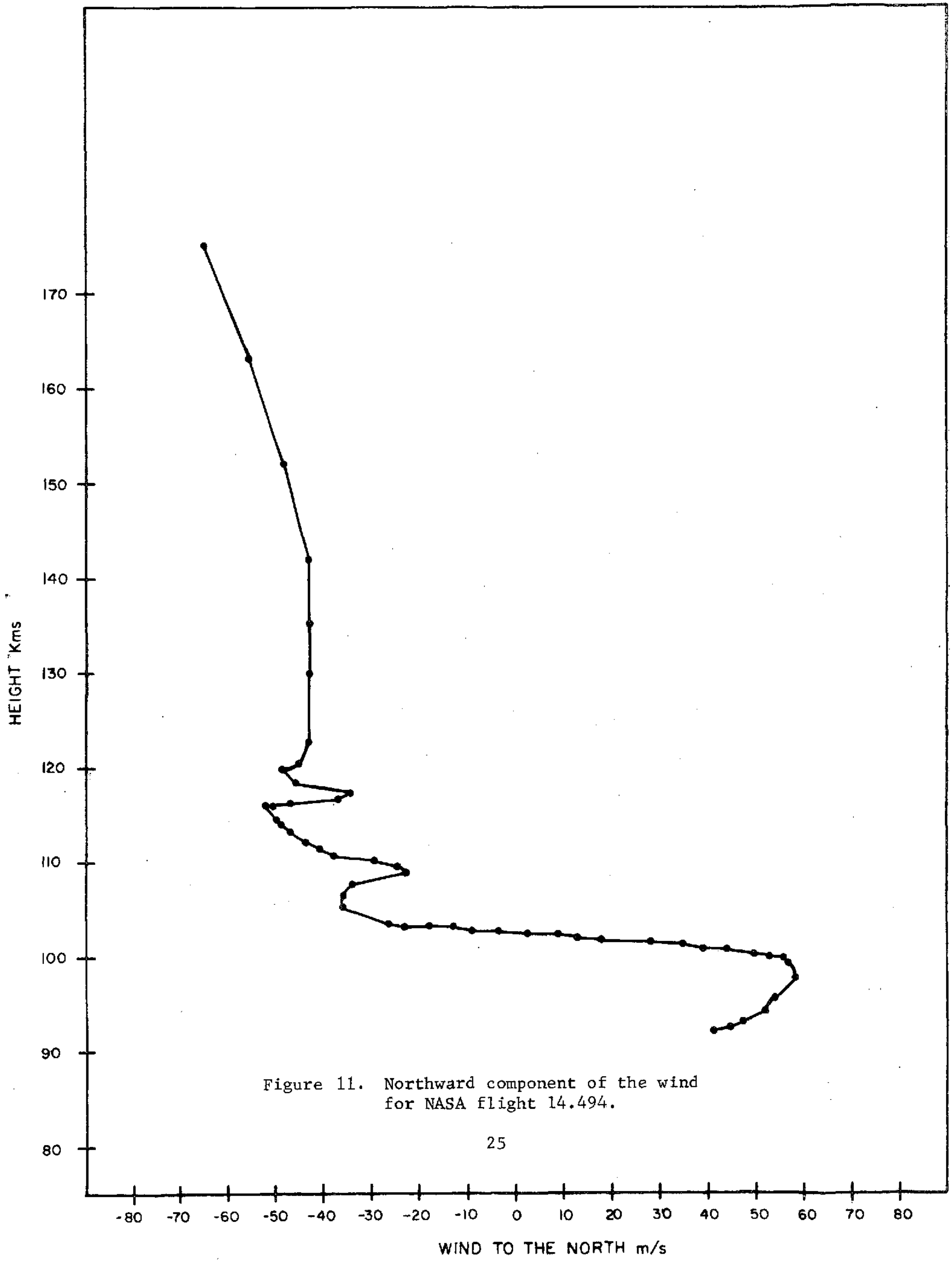


Figure 11. Northward component of the wind for NASA flight 14.494.

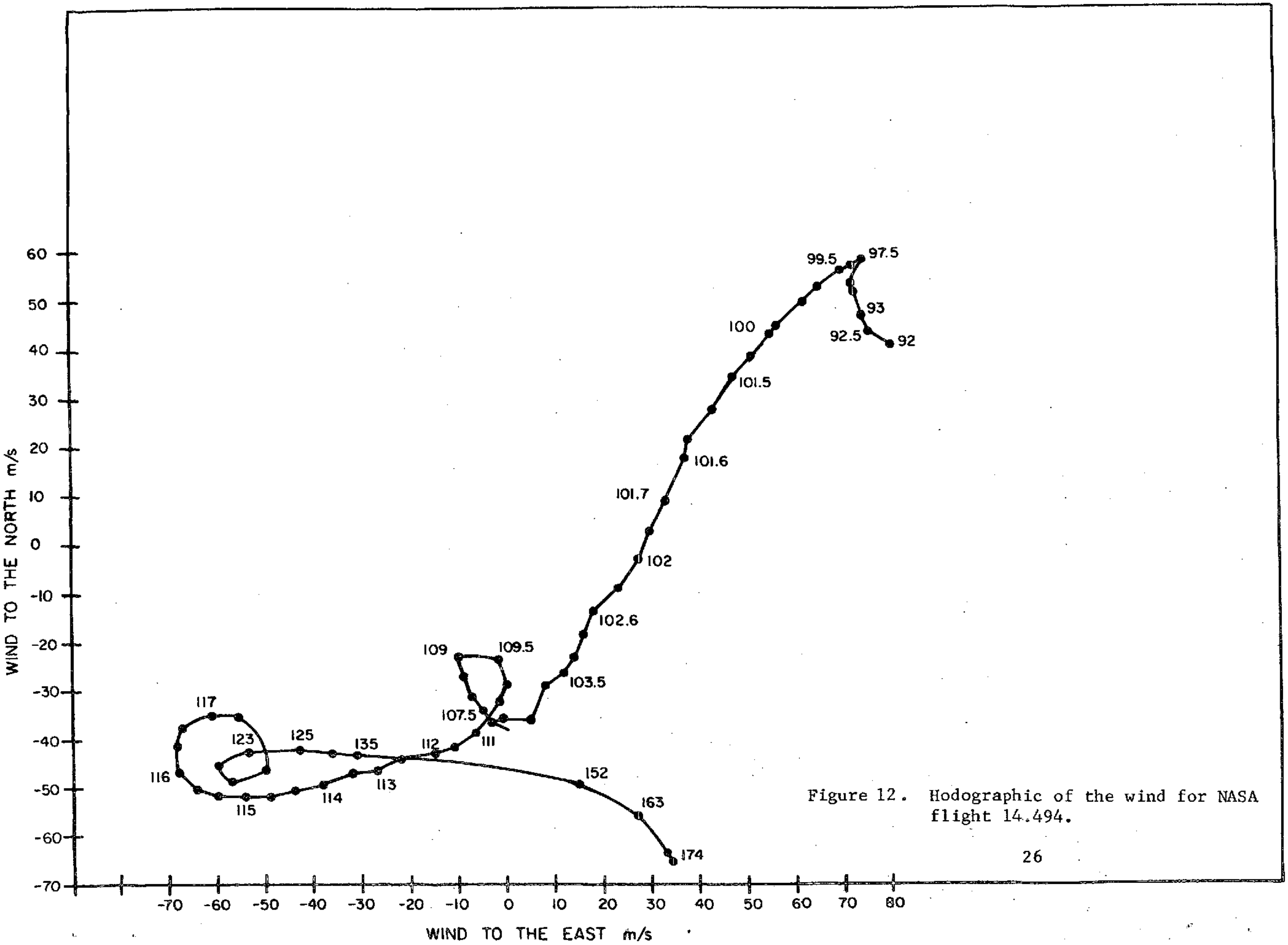


Figure 12. Hodographic of the wind for NASA flight 14.494.

3. Weather Independence

The requirement for clear skies at several widely spaced observing sites has caused costly delays in programs utilizing vapor trails and has resulted in failure to participate in many special programs such as eclipses, PCA's or closely coordinated international programs. Observing from above the clouds has overcome this restriction. The two vapor trails were photographed over Wallops Island, Virginia from the NASA Convair 990 with the clarity and precision to obtain a wind measurement and thus such measurements can be obtained in all but the most adverse weather conditions such as storms which prevent the rocket launch, or where clouds are above 40,000 feet.

4. Logistic Independence

The establishment and maintenance of observing sites in remote locations often are difficult, expensive, and sometimes dangerous. For instance, at Ft. Churchill during the Arctic winter, all personnel and supplies are furnished to remote sites by helicopter. Often the weather is too bad for flying and sites can be cut off for several days. The cost of maintaining such sites for long periods is more than the cost of "flying by" in the NASA Convair 990. The feasibility of a "fly by" from a long distance was demonstrated during the September 1971 vapor trail firings at Wallops Island, Virginia. The Convair 990 departed Moffet Field, California on a flight plan to arrive at Wallops Island, Virginia on a very close schedule with an evening twilight vapor trail release. The aircraft arrived on course and on time. It flew the required pattern and trail observations were obtained. The accuracy of the flight pattern was verified by a radar track from Wallops Island. Thus, it has been demonstrated that the Convair 990 provides a suitable observing platform at remote sites and ground-based sites at such locations would not be required. Observations can be made over water also, and vapor trails may be scheduled for special events with confidence.

5. Daytime Measurements

The possibility of the daytime use of the vapor trail method was realized about 2 years ago when very narrow band interference filters became available. It was demonstrated by Bedinger(2) and also by Best(3) that a differential radiometer employing a 2Å interference filter could track a lithium trail in the daytime. This method requires more specialized and expensive equipment than has previously been required for the vapor trail observations, and to date no operational system is available. The scanning photometer method is necessary because the narrow band interference filter required to isolate the lithium trail against the bright day sky has a small usable field of view.

The effective field angle for various filters was investigated under Contract NASW-2147 in connection with daytime photography. The angular field of view, 2θ, for filters at λ 6708Å with spacer of zinc sulfide and varying band widths, $\Delta\lambda$ are given in Table 4.

Table 4. Angular field of view of interference filter peak transmission at $\lambda = 6708\text{Å}$; $\mu = 2$

$\Delta\lambda$	2θ
2	5°
5	9°
10	13°
15	16°
20	18°

It is apparent from Table 4 that the narrow (< 2Å) bandwidth required to isolate the lithium radiation from the ground in the daytime would allow only a small portion of a vapor trail to be photographed. Even if a group of carefully oriented cameras were used, it would require at least 16 cameras (4 x 4) to cover a 20 x 20 degree field of view which is the minimum field size required to photograph a complete lithium trail. The formation of a mosaic-type photograph of a vapor trail from such a bank of cameras would require careful alignment and precise angular calibration of the fields of view as well as skillful preparation and control of the filters. However, both the photographic and photometric methods, if used on the ground, are restricted by weather and logistics. These restrictions may be removed by observations from an aircraft as discussed previously. The scanning radiometer method is complicated by the rapid motion of the aircraft and the time required for the scan. This could result in a serious degrading of the data. On the other hand, the use of the aircraft greatly improves the photographic method. The background sky brightness at an altitude of 40,000 feet is reduced by an order of magnitude as compared to the ground values. Thus, the bandwidth of the filter can be increased to 10 or 20Å, which decreases the number of cameras required to no more than four and possibly only two.

The exact arrangement which is chosen for the multiple camera and filter assembly in order to record the entire trail may vary depending on program objectives or other limitations. However, the efficiency of the system will depend on how well the orientation of the aircraft is directed so that the camera assembly views the appropriate direction. An accurate direction for viewing the trail with respect to the heading of the aircraft may not be predetermined due to the variability of sounding rocket trajectories, the unpredictability of the thermospheric wind profile, and the unknown drift angle of the aircraft due to the local wind. These effects may cause variations of several degrees in the viewing directions which have required corrective pointing even for trails during the twilight when unfiltered cameras having 40° field angles were used. The problem is acute for daytime trails where the filtered cameras have useful field angles of less than 15°. Fortunately, there is a relatively straightforward solution for this problem which was employed during the B.I.C operation. The method consists of a simple TV camera which is viewing the same field as the data cameras and which has a monitor in

Figure 13. Photograph of the lithium trail of 16 September taken from the Convair 990 with the same film, filter and exposure as Figure 8. The useable field for the interference filter is only 7° for the lithium resonance line at 6708Å, and thus, only a portion of the trail is recorded.

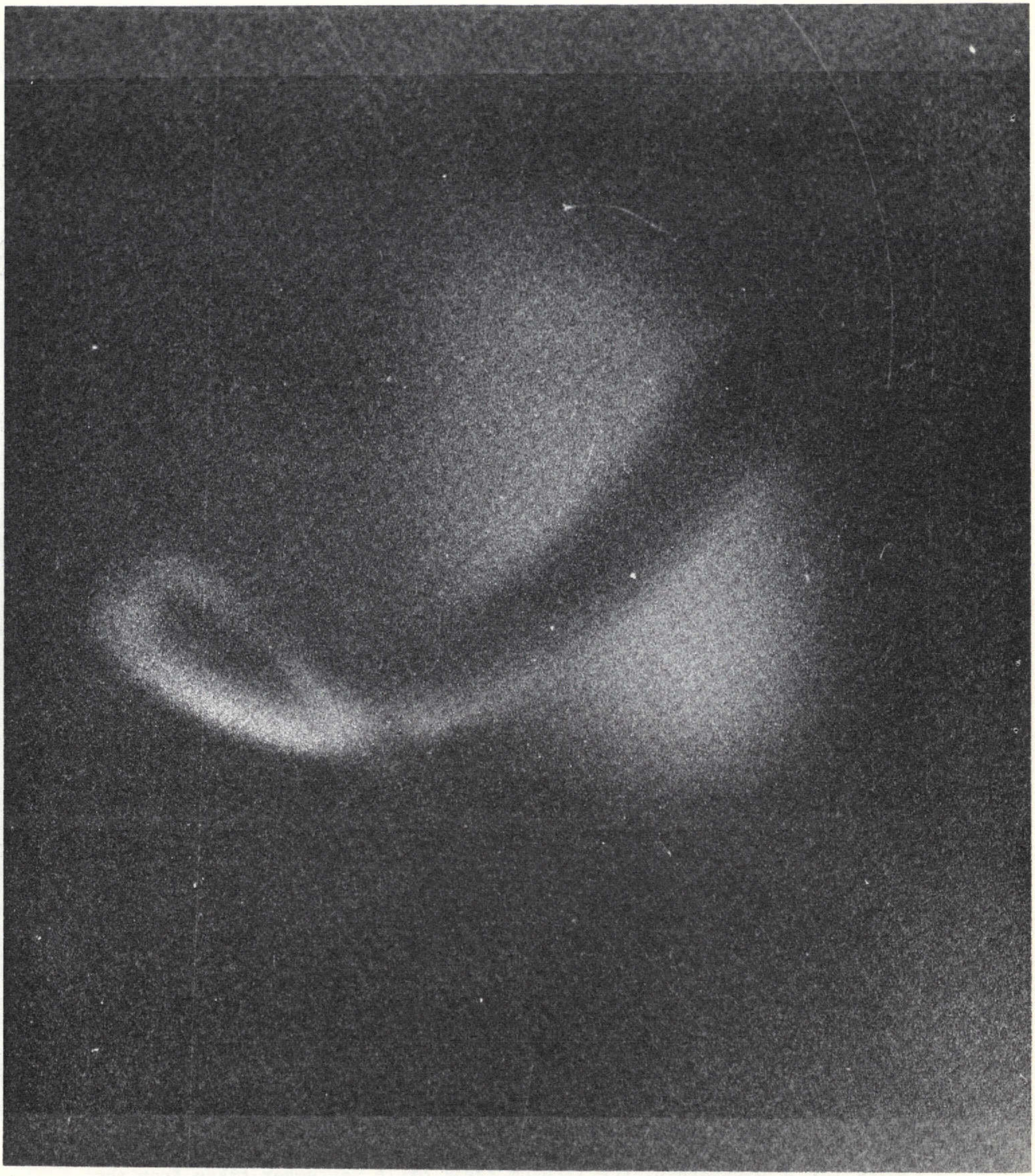


Figure 14. Photograph of the lithium trail taken in exactly the same way as Figure 7, but at a later time.

Figure 15. Photograph of the lithium trail on 16 September 1971 taken from the Convair 990 at T+34 minutes. The time was 10 minutes before ground sunrise, but 9 minutes after sunrise at the altitude of the aircraft.

the cockpit allowing the pilot to fly the aircraft so as to keep the vapor trail centered in the field of view. During the daytime, the TV camera must be filtered in the same manner as the data cameras.

The calculations in Table 1 were verified by photographing the September 1971 vapor trails with an 11Å filter centered on the lithium wavelength 6708Å. The maximum angular field for a particular transmitted wavelength, λ, is obtained by designing the filter passband such that the peak transmission for normally incident light is a wavelength which is given by $\lambda_1 + 1/2\ \Delta\lambda$. For light incident at angles other than normal, the passband of the filter is shifted to lower wavelengths. For light entering at the maximum usable field angle, θ, the passband has shifted so that normally incident light is transmitted at $\lambda_1 - 1/2\ \Delta\lambda$. Thus, the transmission of the desired wavelength, λ_1, is at least 50 percent of the maximum transmission over the field angle, 2θ. The filter used in the September 1971 observations was not designed for the maximum field angle because there was insufficient time to allow for special preparations. The spacer layer was crolite ($\mu = 1.35$) and the maximum transmission was located at 6709Å. Thus, although the filter passband was 11Å, the available $\Delta\lambda$ was only 6.5Å and the field angle for 6708Å is computed to be 6.8°. The largest image of a portion of the trail which was recorded is shown in Figure 13. The trail image subtends an angle of about 7°, which confirms the computation in Table 1. Another view is shown in Figure 14.

Figure 13 was taken from the aircraft at an altitude of 40,000 feet on Kodak 2475 film using an exposure of 1/10 sec at f/4. Numerous photographs of the day sky taken from the aircraft with the narrow band filter confirmed that the same exposure used in Figure 13 produces a useful density due to the day sky light. More conclusive evidence that the lithium vapor trail may be photographed in this manner is shown in Figure 15. The photograph in Figure 15 was obtained from the aircraft with the 11Å filter on the morning trail when the trail was 34 minutes old and reduced in brightness by diffusion. This portion of the trail is easily identified as the loop shown in Figure 15. The time was 9 minutes after sunrise at the altitude and position of the aircraft. Photographs were obtained up to T + 45 minutes, but showed only small portions of the trail and were not suitable for reproduction in a report.

SECTION VII

SUGGESTIONS FOR THE EXPANDED USE OF THE METHOD

The observational and analytical results of this program have demonstrated conclusively that the aircraft method is a practical and reliable method of measuring winds. This section of the report suggests certain further developments in the method and applications for investigation in the thermosphere.

A. CONTINUED DEVELOPMENT OF THE METHOD

It is suggested that the use of the method may be expanded in two ways. One is by the simplification of the technique so that it may be utilized more easily on a routine basis. This entails standardization and complete automation of the data reduction procedure and investigation of improvements in the data acquisition system such as increased field angles and direction measuring methods.

The other suggestion is the opposite of standardization and involves investigating by means of adapting the method for use with observations obtained from an earth orbiting vehicle. The orientation of the trail and rate of change of orientation is very different from that observed from the aircraft and thus different fitting and smoothing procedures will be required. The ability to observe a large geographic region in a short time period would allow separation of temporal and spatial components of the winds and thus contribute greatly toward development of a global wind model.

B. INVESTIGATIONS IN THE THERMOSPHERE

The new technique which is weather independent makes feasible the use of the vapor trail method of wind measurement in coordinated programs and in conjunction with such events as satellite passage or special atmospheric conditions. This daytime capability, when developed, will aid in the formulation of a realistic tidal model and also allow the investigation of S_q and daytime E_s. These studies require the simultaneous measurement of electron density and magnetic or electric fields.

REFERENCES

1. GCA Technical Report TR-67-11-N, Final Report, NASA Contract No. NASW-1083, June 1967.

2. Bedinger, J.F., Rev. Sci. Instr., 41, No. 8, 1234 (1970).

3. Best, G.T., J. Atmospheric Sci., 27, 979 (1970).