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Apollo 16 Launch Measurements (U)

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Project Report

AOR-25

Apollo 16 ~~launch~~ Measurements

H. J. Bullwinkel
R. H. Ellis

(Title UNCLASSIFIED)

9 November 1972

Prepared for the Advanced Research Projects Agency
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Lincoln Laboratory

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

LEXINGTON, MASSACHUSETTS



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R. H. ELLIS
Group 52

PROJECT REPORT AOR-25
(ARPA Optics Research)

9 NOVEMBER 1972

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The work reported in this document was performed at Lincoln Laboratory, a center for research operated by Massachusetts Institute of Technology. This work was sponsored by the Advanced Research Projects Agency of the Department of Defense under Air Force Contract F19628-73-C-0002 (ARPA Order 600).

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ABSTRACT

(S) During mission ETR 1601, excellent long wave infrared [REDACTED] data [REDACTED] were obtained during the launch phase of Apollo 16 by the Lincoln Laboratory NKC-135 aircraft. Infrared hard body, core and plume measurements, primarily of Apollo 16 second stage (S-II) and early third stage (S-IVB) operation, were obtained during a seven minute continuous data coverage interval.

(S) The LWIR tracker-radiometer acquired the Apollo 16 second stage (S-II) [REDACTED] when the vehicle was at an altitude of [REDACTED] and a range of [REDACTED]

(S) Excellent second stage plume data were recorded by the LWIR tracker from [REDACTED]

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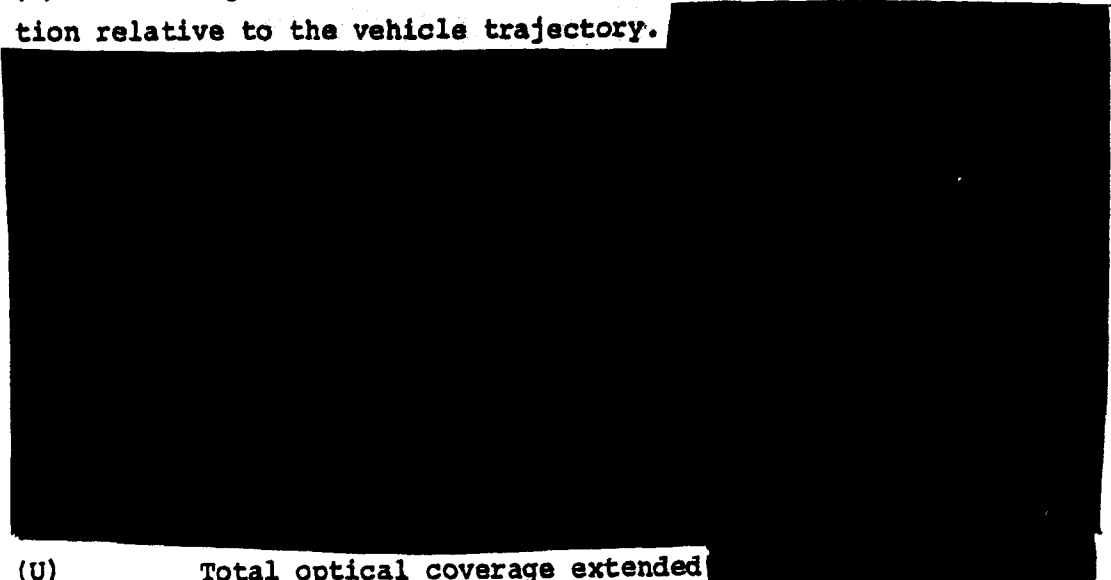
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TEST DESCRIPTION

(U) The Apollo 16 space vehicle, ETR 1601, was launched from complex 39A at the Kennedy Space Center, Florida, on 16 April 1972 at 17:54:00Z. The launch phase, which occurred during cloudless weather conditions, consisted of the complete burn of the S-1C and the S-II stages and a partial burn of the S-IVB stage of the Saturn V launch vehicle. OSD 3.3(b)(4)(b)

(U) Figure 2 shows the location of the airborne instrumentation relative to the vehicle trajectory.



(U) Total optical coverage extended [redacted] with data being obtained on the S-I^r and S-IVB stages. Characteristics of the data collecting instruments are listed in Appendix A. Metric data, which includes plots of the Apollo 16 nominal angle of attack, as well as the look angle and elevation angle measurements relative to the KC-135 aircraft, are presented in Appendix B.

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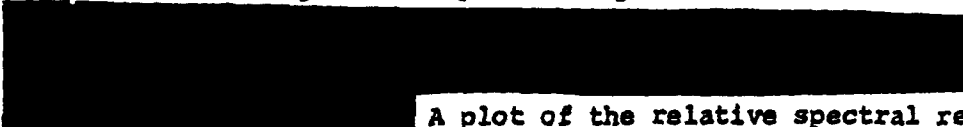
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INTRODUCTION

(S) This report deals primarily with infrared data obtained during the launch phase of Apollo 16 by the Lincoln Laboratory

 A plot of the relative spectral response of each of the instruments is presented in Fig. 1. A summary of the characteristics of both instruments is presented in Appendix A.

(S) The Apollo 16 S-II and S-IVB stages provided excellent targets for the study of infrared hard-body and plume radiation. Approximately 1300 samples of long wavelength data were obtained during the seven minutes of optical coverage. During this mission the prime objective of the instrumented NKC-135 aircraft was to obtain long wavelength optical data during second stage burn with the point of greatest interest occurring at second stage cut-off. This objective was successfully accomplished.

(U) The data presented in this report represents a sampling of the abundant data obtained during this mission. Several frames, selected at representative phases of the Apollo's plume history, have been presented in detail. Throughout this report, an expanded caption format is used to allow the reader to compare explanatory information with the accompanying illustrations.

(U) *The characteristics of the LWIR tracker-radiometer have been described at several Midcourse Measurement Meetings^{1,2,3} and in several previous AOR's^{5,6,7}.

(U) **Both instruments were described at the 1971 annual IRIS meeting.⁴

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~~157~~ A pictorial display of 96 representative frames, from the more than 1300 data frames collected by the LWIR instrument during this mission, are presented in the final portion of this report.

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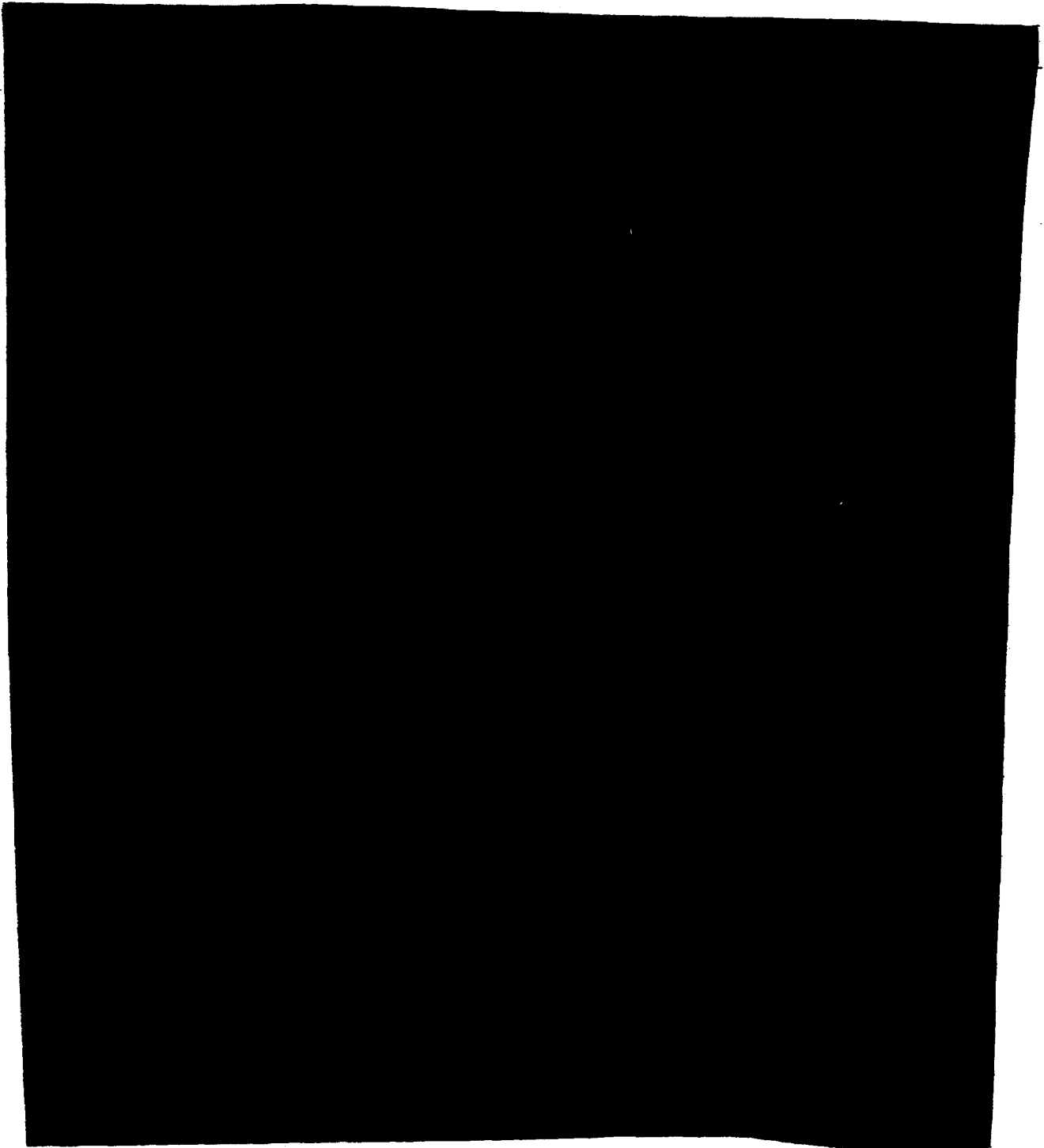


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FIGURE 3

(S) Figure 3 presents the Apollo 16 altitude and range to the aircraft as well as a brief event summary. The LWIR tracker-radiometer acquired the Apollo second stage (S-II) at an altitude of [REDACTED] and a range of [REDACTED]. The SWIR (1 μm -6 μm) spatial radiometer obtained data between TAL [REDACTED] and TAL [REDACTED]. Stage II thrust termination occurred at TAL [REDACTED] and third stage (S-IVB) ignition began at TAL [REDACTED].

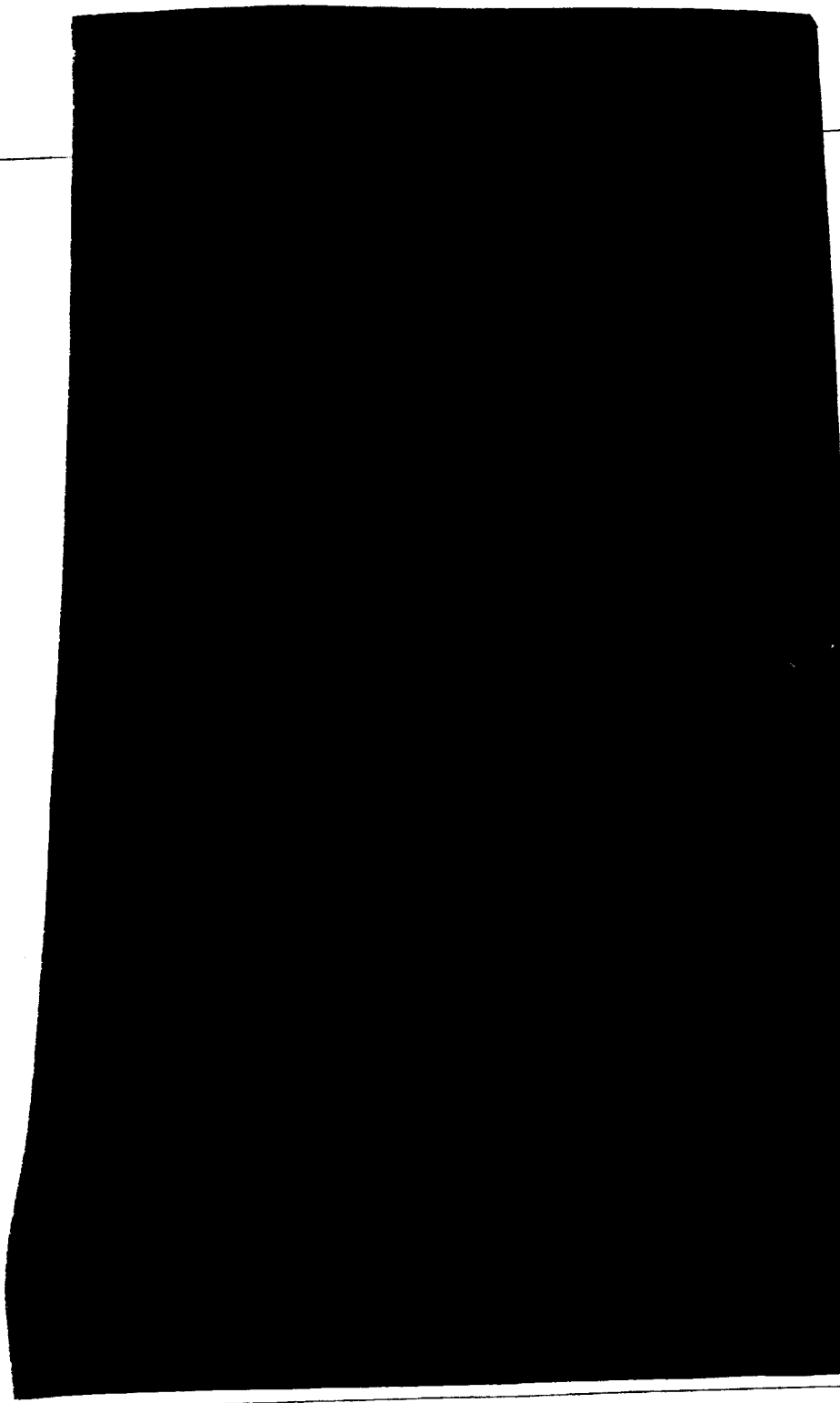
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FIGURE 4

~~(S)~~ Figure 4 presents an example of one of the more than 1300 data frames obtained by the 16mm film record of the LWIR C-scope display. The C-scope data is a "TV" type display of the serialized output of the scanned 176 cell array ($3.4^\circ \times 3.4^\circ$ FOV). The lower edge of the paraboloid-shaped bow-shock is the primary observable. The apparent high intensity of the lower portion of the plume is caused by the missile angle of attack and possibly the atmospheric density gradient. The apparent attitude of 45° is caused by a combination of gimballed mirror angles, look angle (34°) and angle of attack (18°). The striated structure of the plume, as yet unexplained, is of considerable interest to aerodynamicists.

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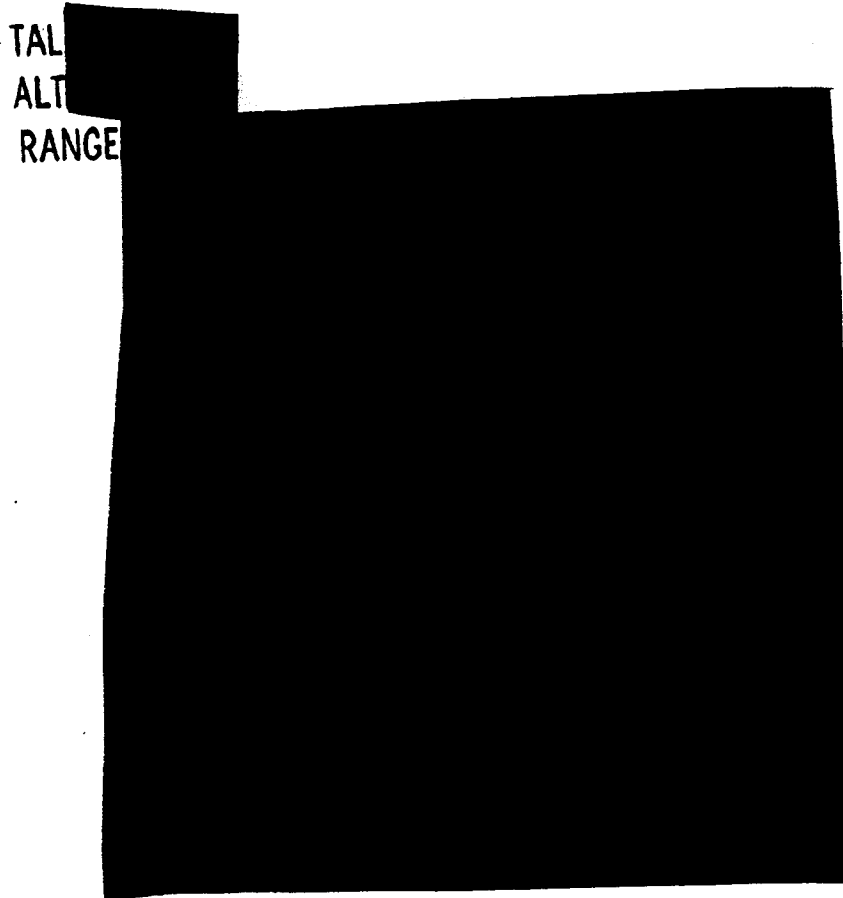


Figure 4

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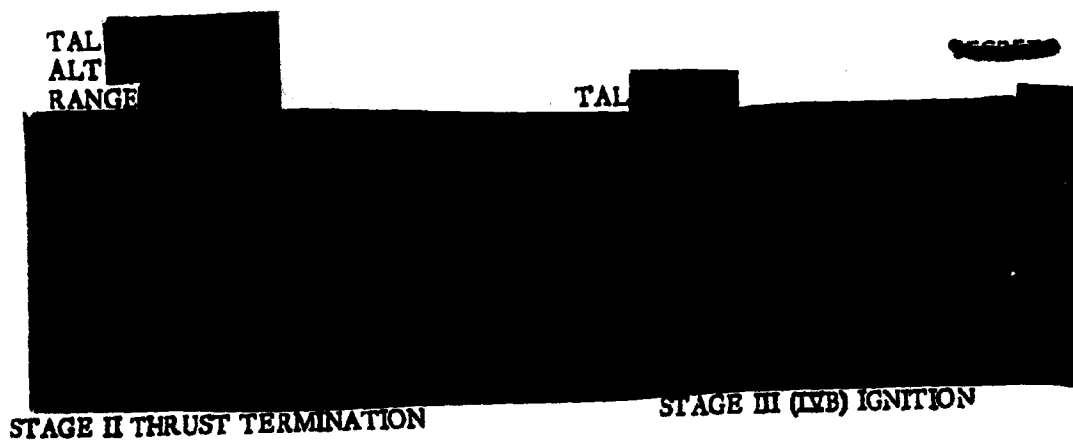
FIGURE 5

(S) Figure 5 presents two samples of LWIR C-scope data which show thrust termination of the S-II stage and ignition of the S-IVB stage. At thrust termination gaps appear in the missile plume structure indicating the loss of H_2O from the engine even though the bow-shock excitation remains available. The lack of persistence in the plume radiation is obvious, as compared with reentry trails.

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LWIR C-SCOPE IMAGES

Figure 5

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FIGURE 6

(S) Figure 6 presents another sample of the LWIR C-scope display, showing the Stage III (S-IVB) plume and the spent Stage II plume. [REDACTED] The more intense portion of Stage III [REDACTED] The striated S-II plume structure, seen in Fig. 3, was not observed in the S-IV plume.

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TAL
ALT
RANGE



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FIGURE 7

(S) Figure 7 presents a composite of three modes of LWIR data obtained on the S-II and S-IVB stages at three selected times. Plume radiant intensities are presented in each of the three samplings. Calibrated peak detector outputs, are shown on the top row, whereas calibrated iso-radiance contours and C-scope display photographs are shown in the two lower rows. All calibrated levels were determined from digitally recorded star and planet data.

(U) The peak detector levels represent the maximum intensity of each resolution element in the azimuth scan and correspond to the ridge peak values of the contour map directly below. The C-scope photographs shown in the bottom row, represent a "TV" type display of the serialized output of the scanned 176 cell array (3.4° x 3.4° FOV).

(S) The more intense lower edge of the paraboloid shaped plume, which is evidenced in each of the data frames, is attributed to the vehicle's angle of attack and possibly the atmospheric density gradient.

(S) Radiant intensity values for both the S-II and S-IVB were obtained by integrating over the entire radiation within the field-of-view at each of the three selected intervals. Stage II



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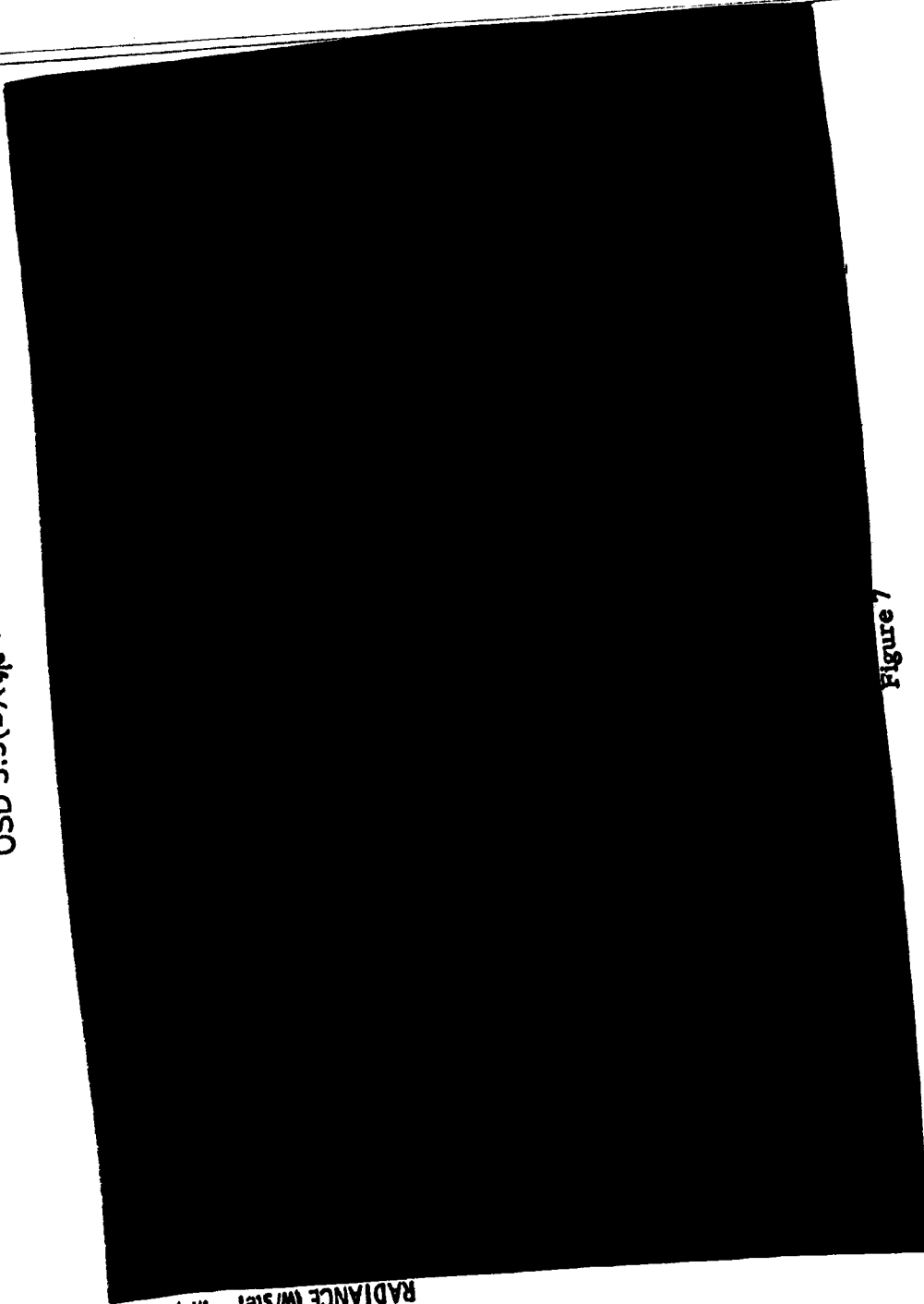


Figure 7

RADIANCE (w/ster - m²)

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FIGURE 8

(S) Figure 8 presents the LWIR radiant intensity histories of the unresolved S-II and S-IVB stage cores and the spent S-II hard body. The intensities were determined from the peak detected output. All values were computed from the instruments' signal to noise ratios based on irradiance from Jupiter, Mars, Mercury, Venus and the star α -Orion. The period over which the core radiation was saturated should be noted. No data are presented after [REDACTED] due to uncertainties introduced by superimposed plume radiation.

(S) As the data illustrate, core radiation of the S-II,
[REDACTED]

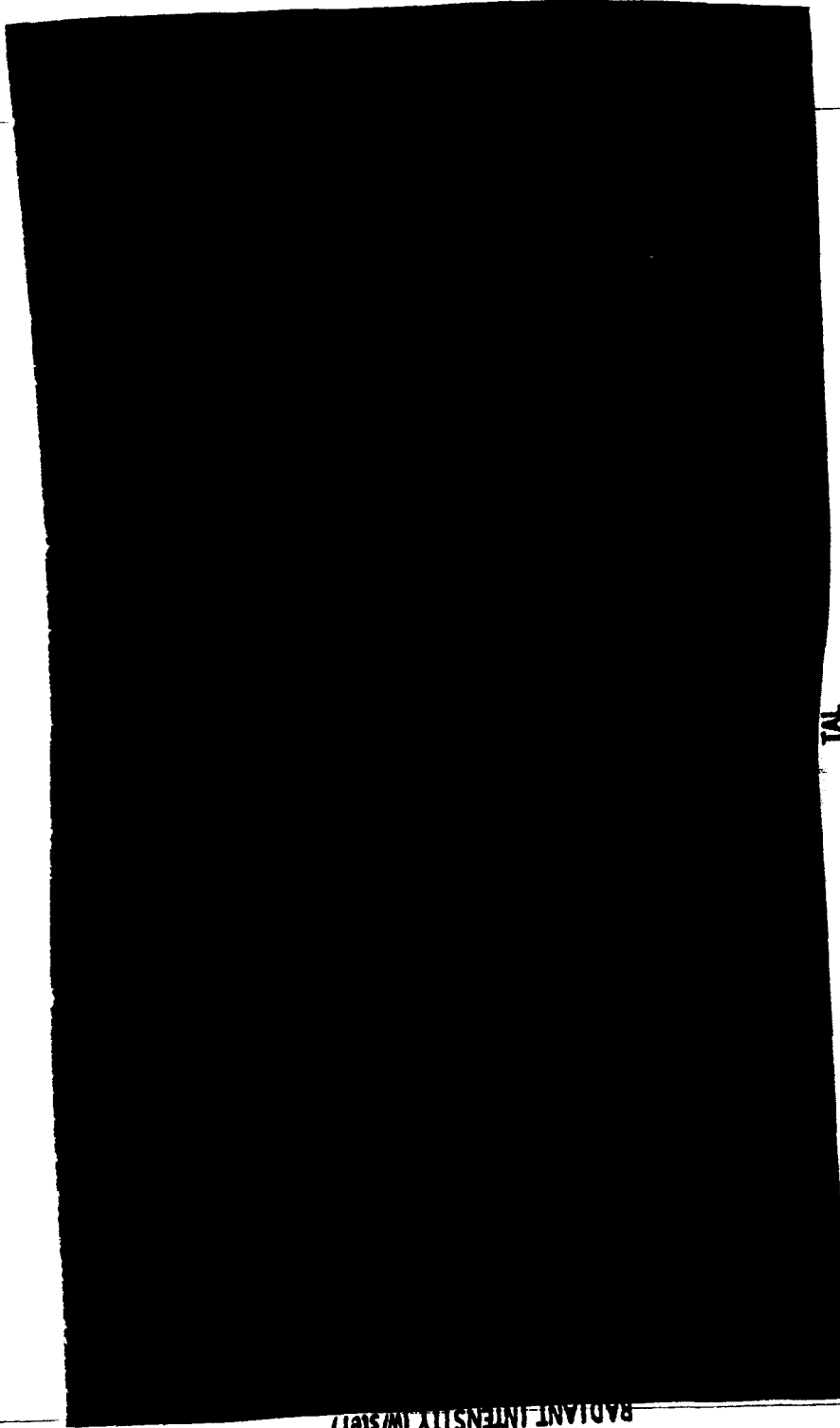
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TAL

RADIANT INTENSITY HISTORIES

Figure 8

RADIANT INTENSITY (w/ster)

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FIGURE 9

Figure 9 presents a plot of S-II stage peak plume radiance as a function of velocity. The intensities were derived from peak detector measurements obtained between TAL [REDACTED] and TAL [REDACTED].

The data shows a gradual increase in intensity from [REDACTED] to a maximum value of [REDACTED] at termination of Stage II thrust at [REDACTED].

Although the data appear to fit a v^2 dependence, it should be noted that the data have not been corrected for atmospheric absorption. At early acquisition, when the target was at a range of [REDACTED] from the aircraft, the effects of an increase in background due to atmospheric radiation as well as signal absorption would be quite severe.

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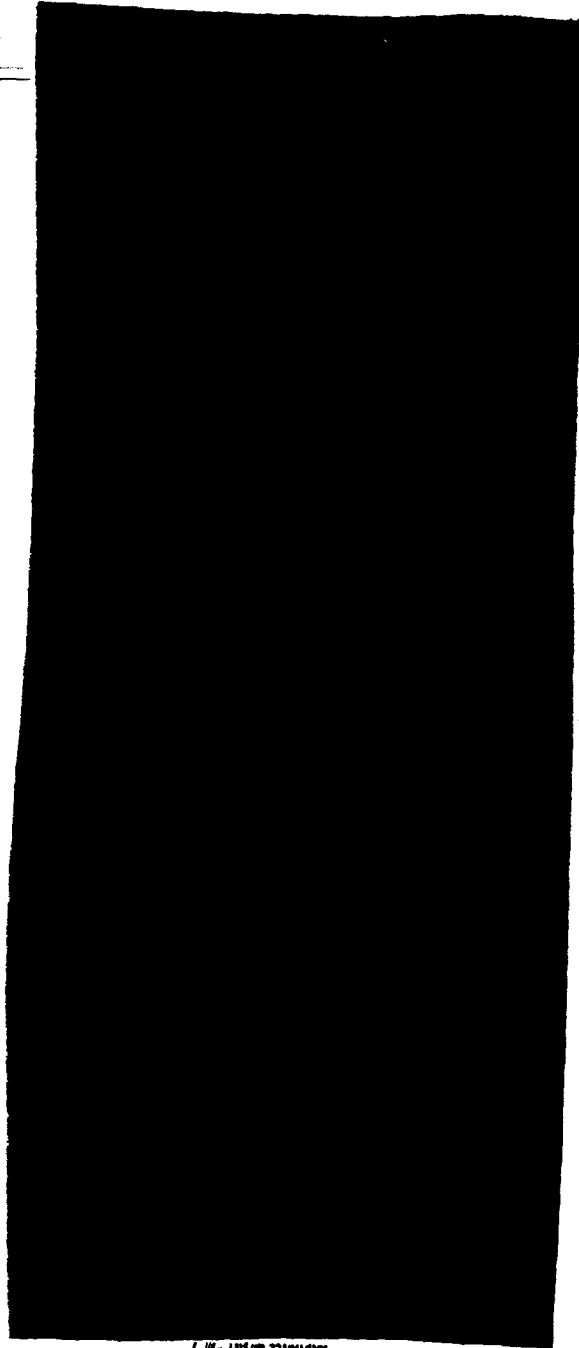


Figure 9

RADIANCE $\text{m}^2/\text{sr} \cdot \text{m}^2$

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FIGURE 10

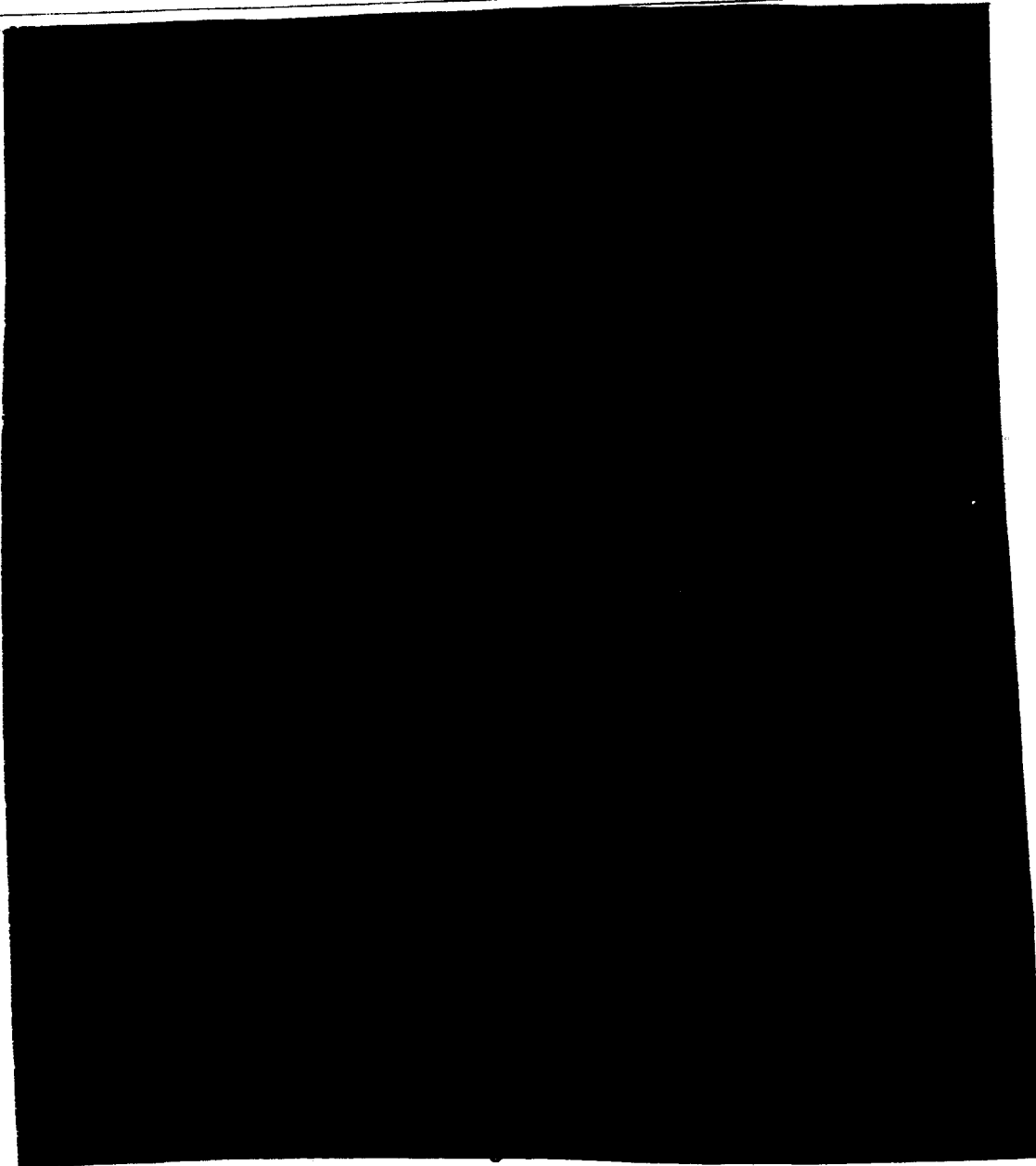
~~(S)~~ Figures 10 through 17 present additional samples of the 16 mm film record of the C-scope display of the LWIR tracker-radiometer data. These are presented in order to give the reader a pictorial history of the S-II and S-IVB stage events as they occurred during the data coverage period. The C-scope display pictures also provide the only LWIR data when the quantitative data are saturated.

~~(S)~~ A composite of twelve frames of the C-scope display, representative of the first minute of data coverage, are presented in Fig. 10. These data show the steady intensity increase of Stage II and the gradual development of the striated structure of the plume.

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FIGURE 11

(S) Figure 11 presents twelve representative C-scope frames showing the continued development of the Stage II [REDACTED] Evidence of electronic overshoot, which has characteristically been associated with the LWIR tracker-radiometer, is present throughout this sequence.

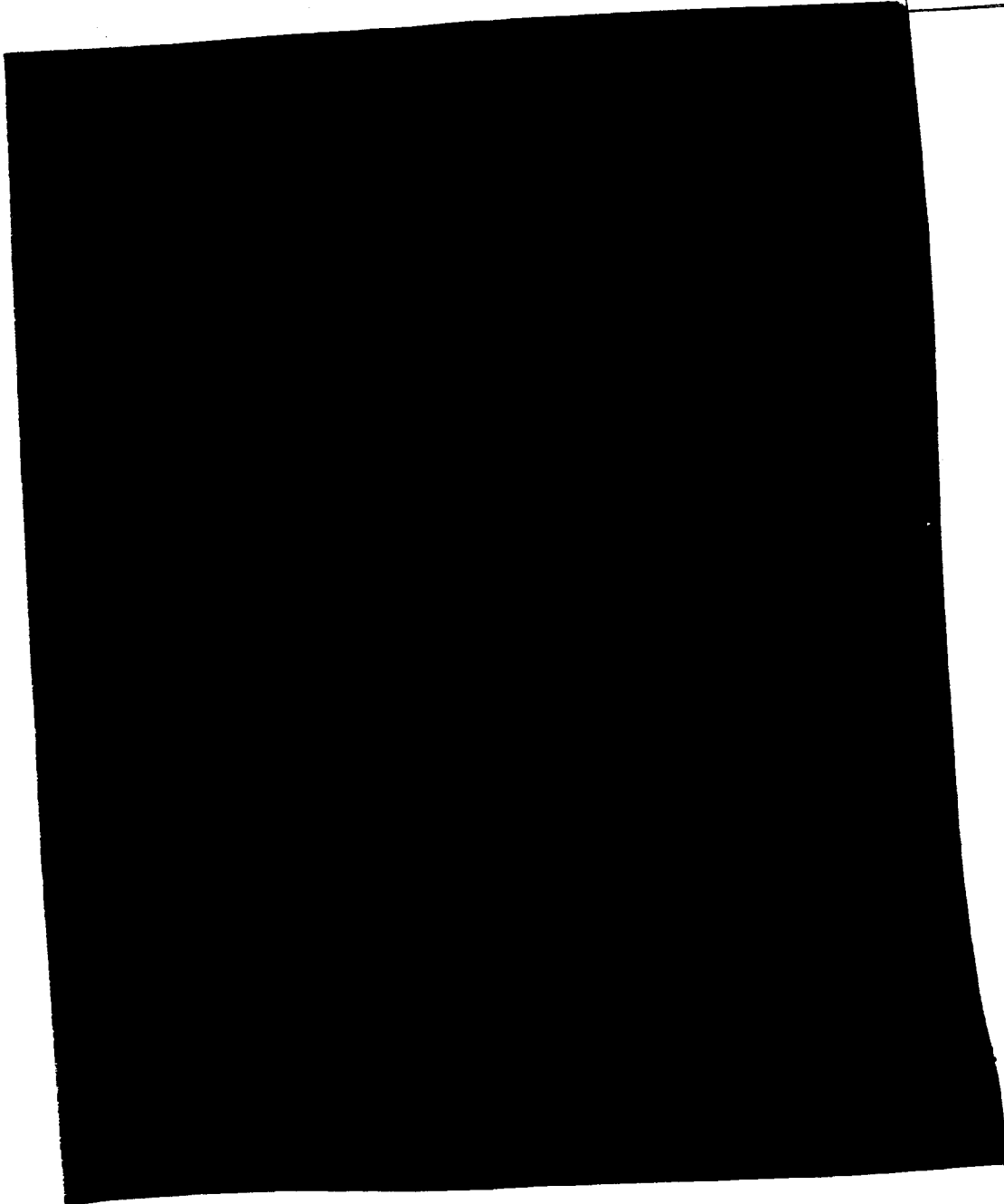
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FIGURE 12

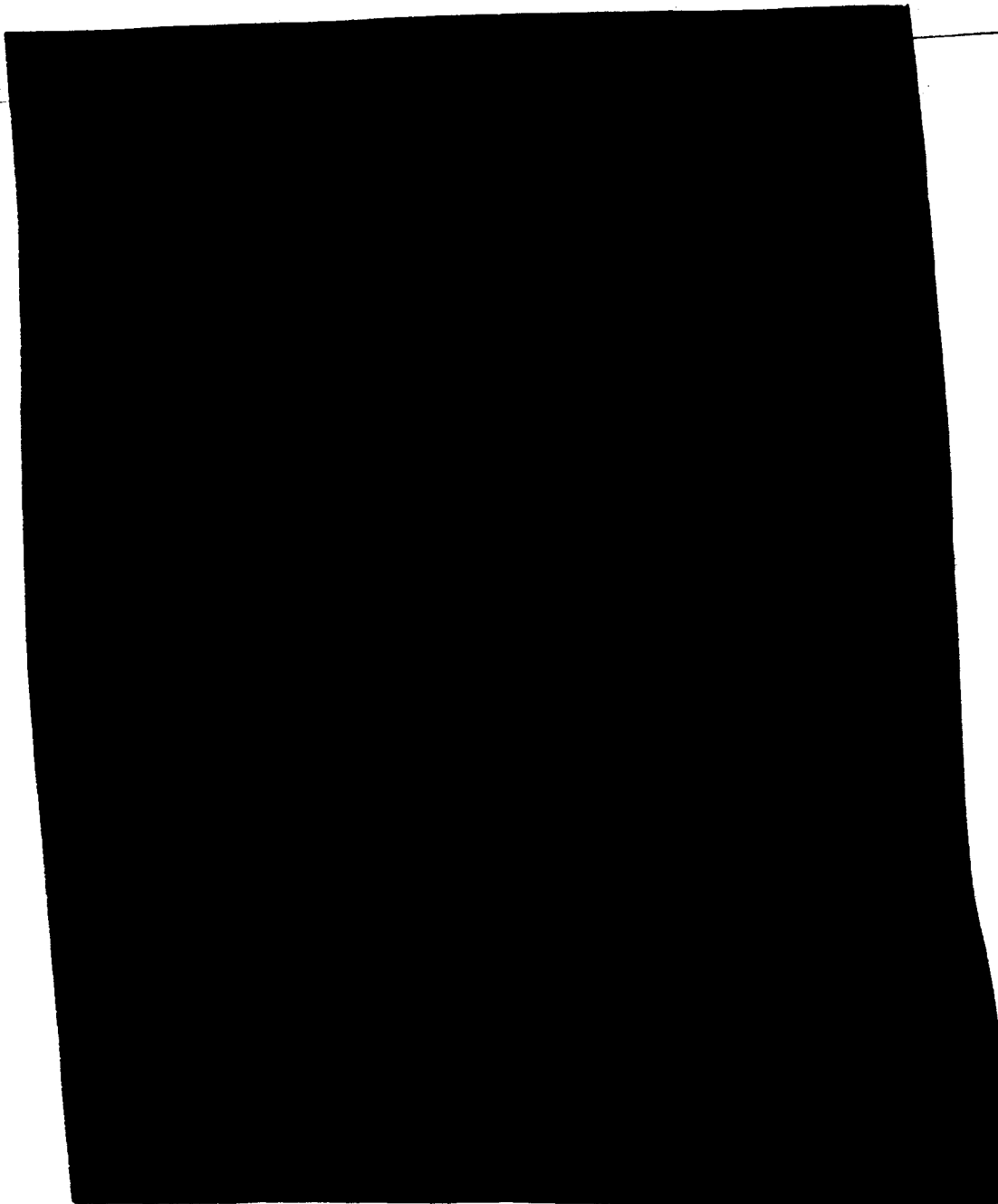
~~12~~ Figure 12 presents a sequence of twelve successive C-scope frames showing the LWIR history of Stage II just prior to Stage III ignition. The plume is now shown enveloping the vehicle on all sides. Variations of the location of the data in the data frames are due to aircraft maneuvering at this time.

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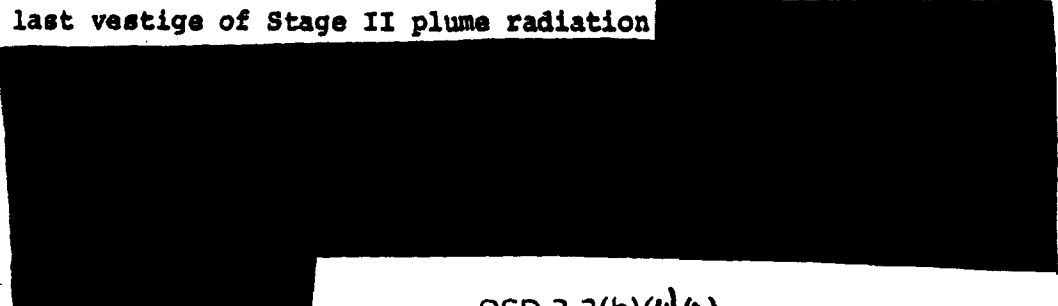
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FIGURE 13

(S) Figure 13 presents a sequence of C-scope frames showing Stage II plume radiation demise and Stage III ignition. The last vestige of Stage II plume radiation



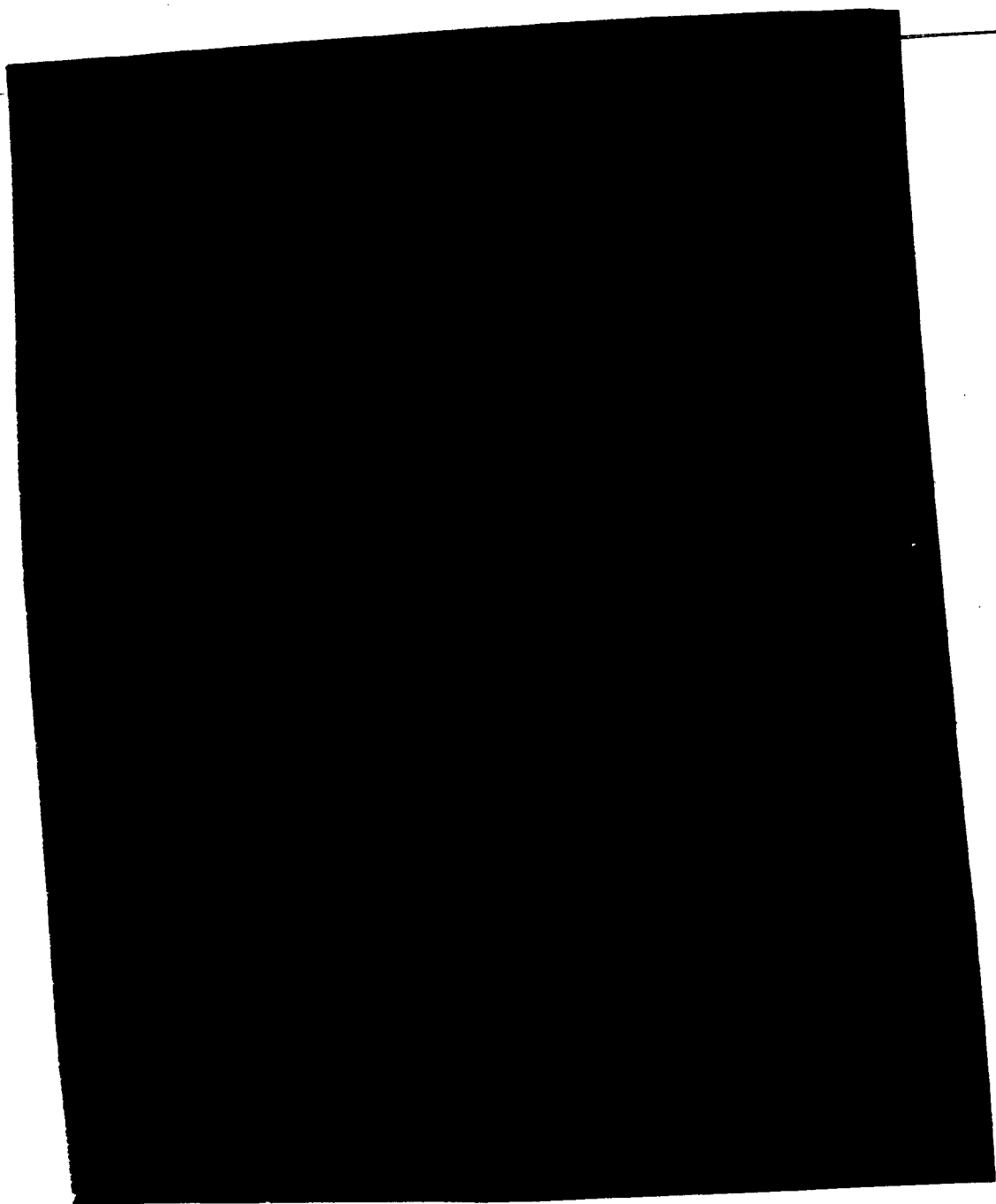
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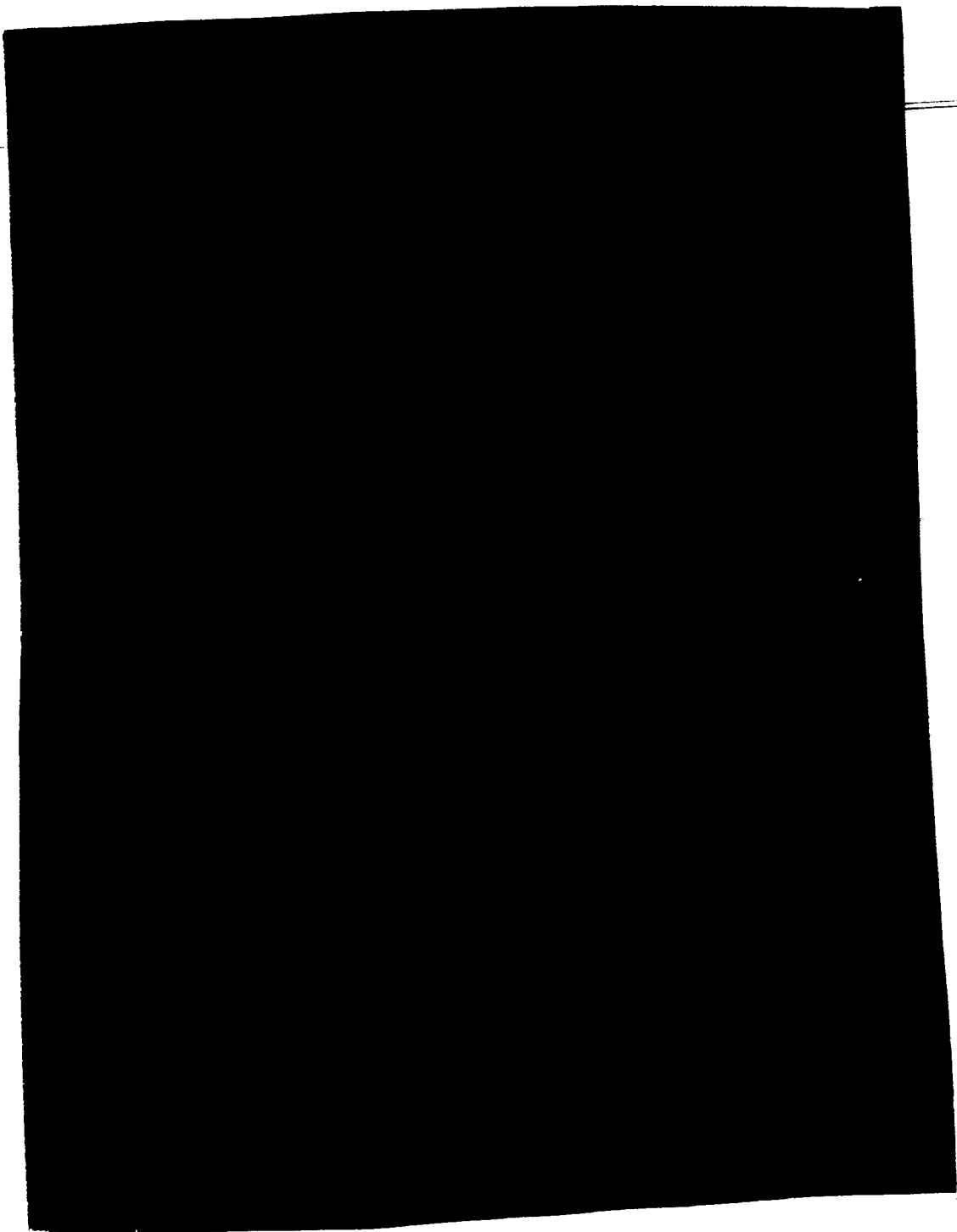
FIGURE 14

~~(S)~~ Figure 14 presents a series of twelve C-scope display frames showing Stage III hard body and plume radiation as well as the spent Stage II vehicle falling behind.

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FIGURE 15

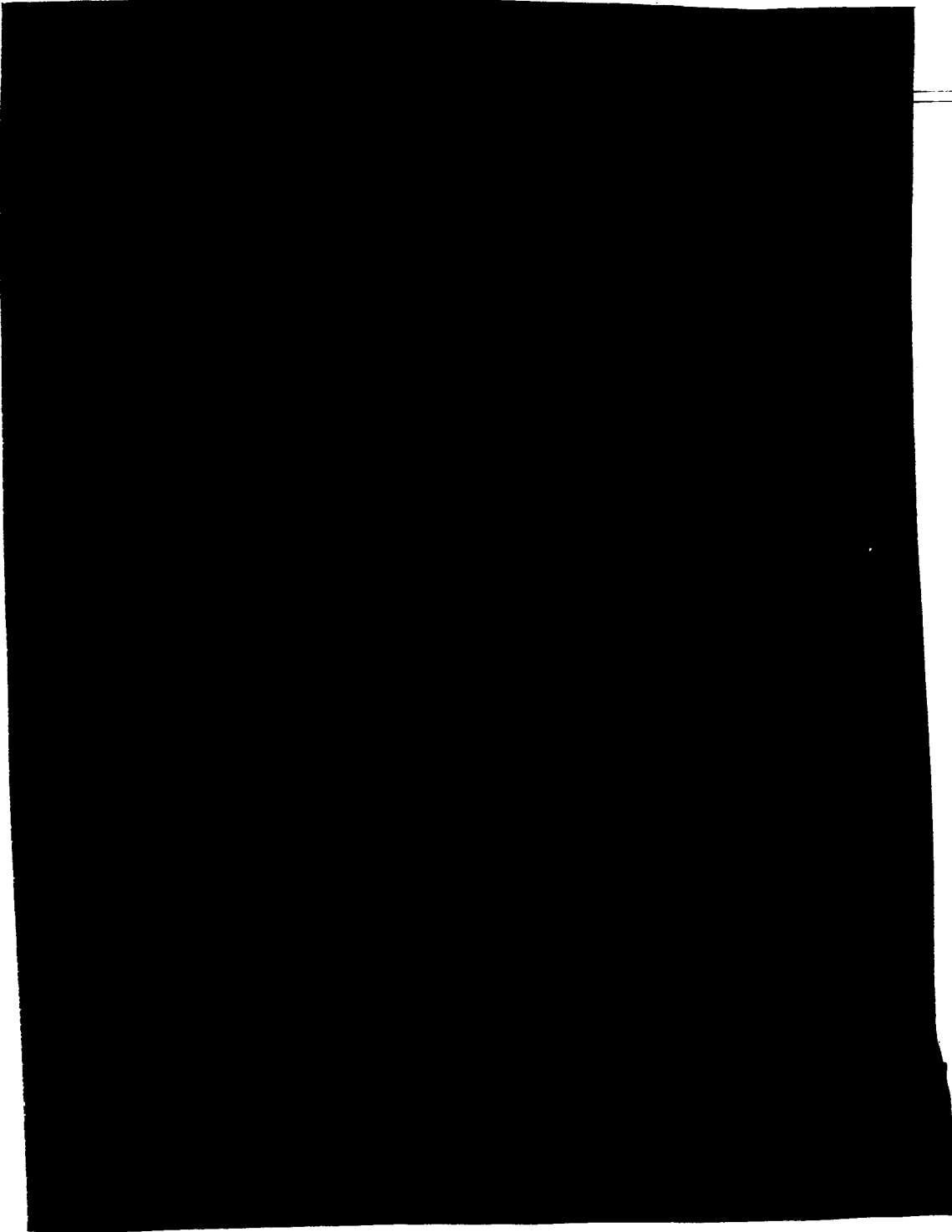
Figure 15 shows a continuation of the Stage II and Stage III C-scope data obtained between [REDACTED] [REDACTED] Throughout this interval, the LWIR radiation intensity levels of both the Stage III hard body and plume as well as the receding spent Stage II, remain relatively constant.

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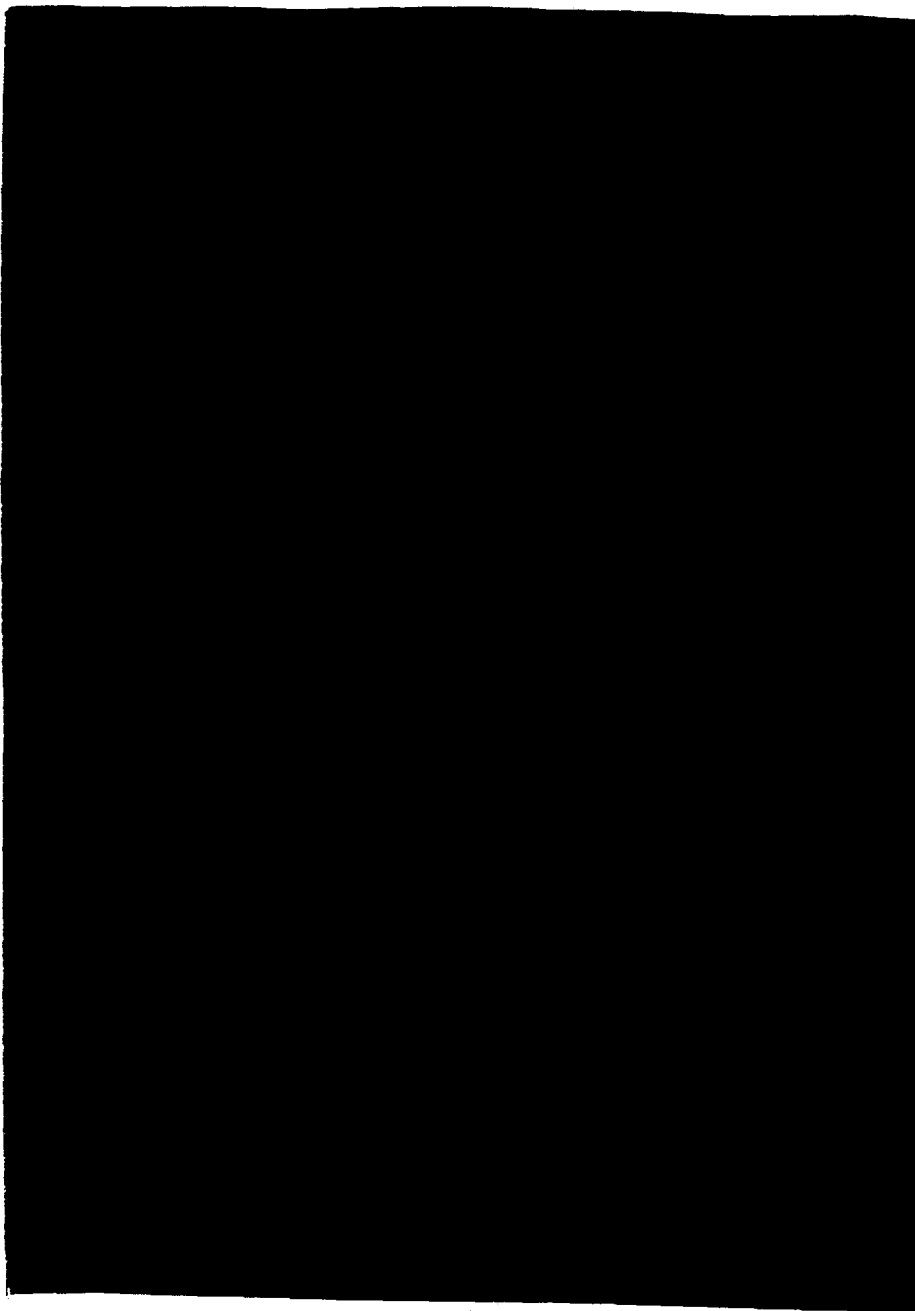
FIGURE 16

(S) Figure 16 presents additional frames of the Stage II and Stage III C-scope display data obtained between [REDACTED]. During this coverage interval, the LWIR adiation of Stage II is rapidly decreasing in intensity and Stage III radiation is largely confined to the paraboloid shaped bow shock region of the vehicle. Extensive Stage III plume radiation is no longer apparent.

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FIGURE 17

(S) Figure 17 presents the final sequence of C-scope display data, showing the decreasing LWIR radiation intensity signatures of both Stage II and Stage III from [REDACTED]. Lack of additional camera film presented further coverage of the C-scope display of the LWIR tracker data.

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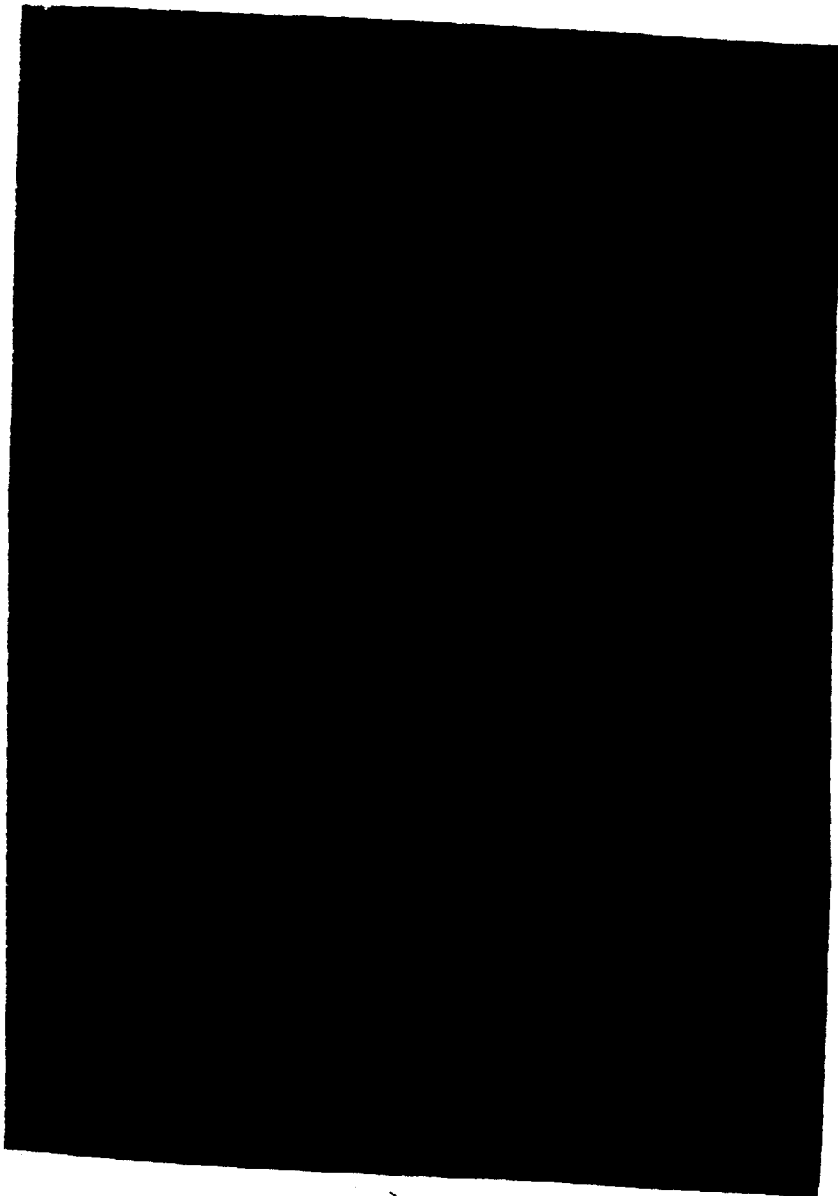
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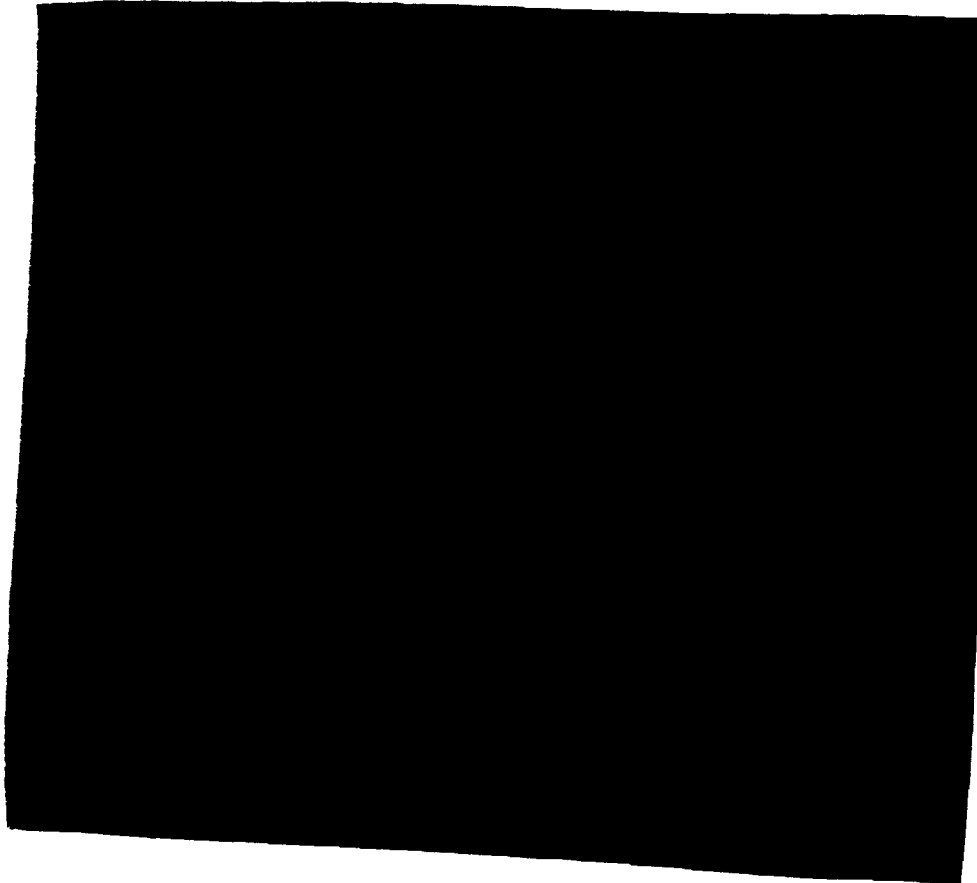


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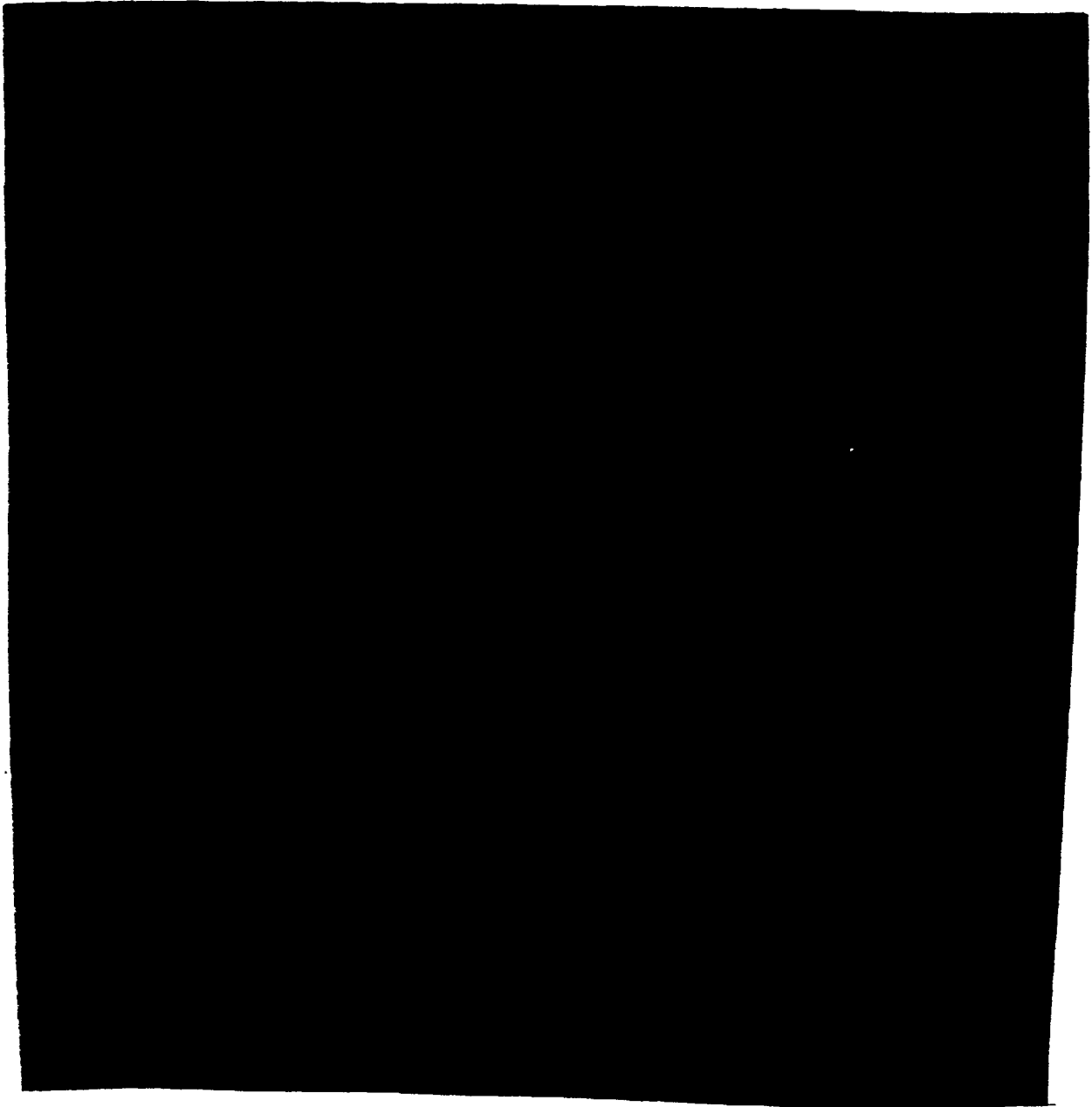
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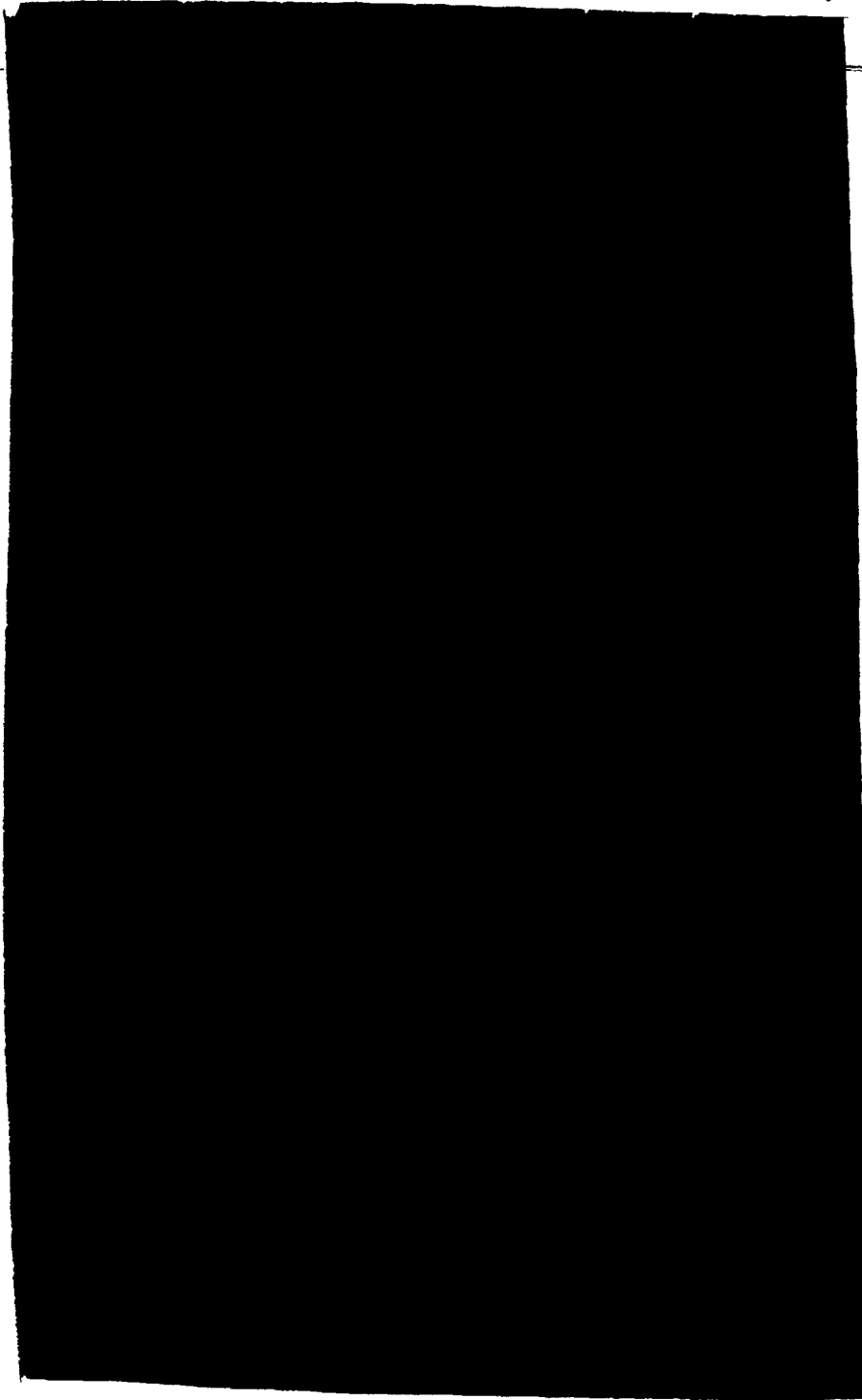


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