AD/A-002 669

DAYTIME ATMOSPHERIC TRANSFER FUNCTION STUDY

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Lockheed Missiles and Space Company, Incorporated

Prepared for:

Defense Advanced Research Projects Agency
Rome Air Development Center

October 1974

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER RADC-TR-74-293	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER AD/A-002669
4. TITLE (and Subtitle) Daytime Atmospheric Transfer Function Study		5. TYPE OF REPORT & PERIOD COVERED Interim Report 15 Feb - 10 Sep 74
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Alan M. Title		8. CONTRACT OR GRANT NUMBER(s) F30602-74-C-0144
9. PERFORMING ORGANIZATION NAME AND ADDRESS Lockheed Missiles & Space Co., Inc. 3251 Hanover Street Palo Alto CA 94304		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 62301E 26460103
11. CONTROLLING OFFICE NAME AND ADDRESS Defense Advanced Research Projects Agency 1400 Wilson Blvd Arlington VA 22209		12. REPORT DATE October 1974
		13. NUMBER OF PAGES 19
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) Rome Air Development Center (OCSE) Griffiss AFB NY 13441		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE N/A

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

Same

18. SUPPLEMENTARY NOTES

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Griffiss AFB NY 13441
AC 315 330-3145

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Atmosphere
Imagery
Transfer function
Telescope

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

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DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

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Contractor: Lockheed Missiles & Space Co., Inc.
Contract Number: F30602-74-C-0144
Effective Date of Contract: 1 May 1974
Contract Expiration Date: 16 February 1975
Amount of Contract: $65,000.00
Program Code Number: 5E20
Period Covered - 15 Feb 74 - 10 Sep 74

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Approved for public release;
distribution unlimited.

This research was supported by the Defense Advanced Research Projects Agency of the Department of Defense and was monitored by Donald W. Hanson RADC (OCSE) GAFB NY 13441 under Contract F30602-74-C-0144, Job Order Number 26460103.

This report has been reviewed by the RADC Information Office (OI), and is releasable to the National Technical Information Service (NTIS).

This technical report has been reviewed and is approved.

Donald M. Hanson
RADC Project Engineer

ABSTRACT

It is of critical importance to know the temporal and spatial character of the isoplanatic patch, in order to access or design pre- or post-detection systems. Here we report on progress on a system that uses the edge of the sun as an extended target in order to determine the daytime spatial and temporal characteristics of the isoplanatic patch.

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INTRODUCTION

The central problems of visible space object identification are the elimination of the disturbances to a telescopic image introduced by the atmosphere and the achievement of diffraction limited performance.

In the mid-60s, John Goodman demonstrated that aperture plane correction could remove the effects of a random atmosphere if the atmosphere was sufficiently close to the telescope, (Goodman, J. W., "Restoration of Atmospherically Degraded Images, a Woods Hole Summer Study," July 1966). Since then, there has been a great deal of progress. A group at Itek has demonstrated an active aperture control system that can correct a random atmosphere created by a heat source, given a suitable reference signal. It is clear that the Itek technique can be extended to perform the aperture correction for a large telescope, and that if the random atmosphere satisfies the condition that it is sufficiently close to the aperture plane, diffraction-limited performance can be achieved.

The critical questions then reduce to the actual behavior of the atmosphere and the method of generating or the method of deriving a reference signal.

The diffraction-limited imaging program has two major requirements;

- To correct the atmospheric point spread function in real time, which requires real time detection of the atmospheric point spread function.
- To obtain and quantify the diffraction-limited images in a useful form, requiring detecting, recording, storing, and processing of the diffraction-limited images.

In order to attack requirement number one in an efficient manner, the effect of limitations placed upon the correction system by the atmosphere must be understood. Since the early '60s a large number of scientists have been analytically attacking the problem of propagation through a turbulent atmosphere. Mathematically, the general transfer problem is stated as

$$I'(\xi,\eta) = \int_A\int dxdy\ I(x,y)\ P(x,y,\xi,\eta) \qquad (1)$$

where $I'(\xi,\eta)$ is the image actually detected, $I(x,y)$ is the perfect image, $P(x,y,\xi,\eta)$ is the point spread function, and A is the area of the image. In general as indicated in equation (1), the PSF will vary from point to point in the image plane. If equation (1) is written in discrete form:

$$I'_{mn} = \sum_i^M \sum_j^M I_{ij}\ P_{ijmn}\ , \qquad (2)$$

where the real and detected images are described by an M x M matrix and the point spread function is described by M^4 matrix.

Computationally, the general problem is extremely difficult to solve and most efforts in image transfer problems have attacked

$$I'(\xi,\eta) = \int_A\int dxdy\ I(x,y)\ P(x-\xi\ ,\ y-\eta) \qquad (3)$$

The point spread function indicated in equation (3) retains its analytic form over the entire image. It is called the spatially invariant point spread function (SIPSF). If the transfer problem is the atmospheric transfer problem, the area, A, over which equation (3) is valid is called the isoplanatic patch.

A great deal of mathematical expertise on propagation through a random medium has been built up; unfortunately, however, an equally impressive amount of experimental results are not available. In particular it is not known over how large an angle in the sky the atmospheric transfer function is the same, that is, the size of the object, and hence the image, over which the short term point spread function is space invariant (STSIPSF). Further, since the STSIPSF region size is not known, the time over which a single realization of the STSIPSF exists is not known precisely. However, it is known that the time scale is not much longer than 1/50 second and the angular scale is not much smaller than 2 arc seconds. At present, work is underway to attempt to determine the size of the STSIPSF for horizontal paths during day and night.

The work we are doing attempts to measure the size of the isoplanatic patch by studying the difference between the intensities recorded from pairs of detectors alligned using solar radii at positions that cross the limb. By varying the angle between the radii isoplanatic angles up to 32 minutes of arc can be compared. Exposures can be recorded and repeated within 3×10^{-4} seconds. The detectors are 256 element linear diode arrays. Hence, the detector geometry is fixed. At present, we plan to start taking data in early November. In the sections below, the optical system and the electronics is described.

Optical Instrumentation

The telescope designed and constructed for this study is a 12-inch folded refractor. The 12-inch diameter objective lens has a focal length of 168 inches. In order to achieve defraction limited results the surfaces of the BK-7 Schlieren quality Grade A glass, are aspheric. In order to minimize temperature induced focus shifts and obtain the highest image contrast, it was decided to use a single lens objective. Since a single lens objective is uncorrected for chromatic aberration, that is to say all colors do not come to the same focus, a monochromatic image will be obtained with a <50 angstrom half bandwidth filter. The telescope's primary focal length of 168 inches produces a solar image of approximately 1.6 inches which can be increased as much as 5 times with secondary enlarging optics.

Figure 1 is a photograph of the 12-inch telescope taken during fabrication.

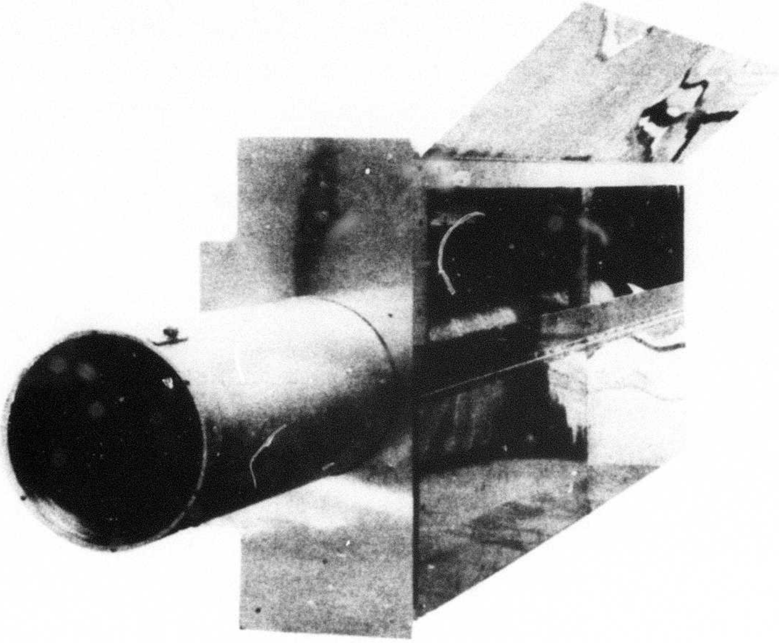

Figure 1. Photograph of 12-inch telescope housing.

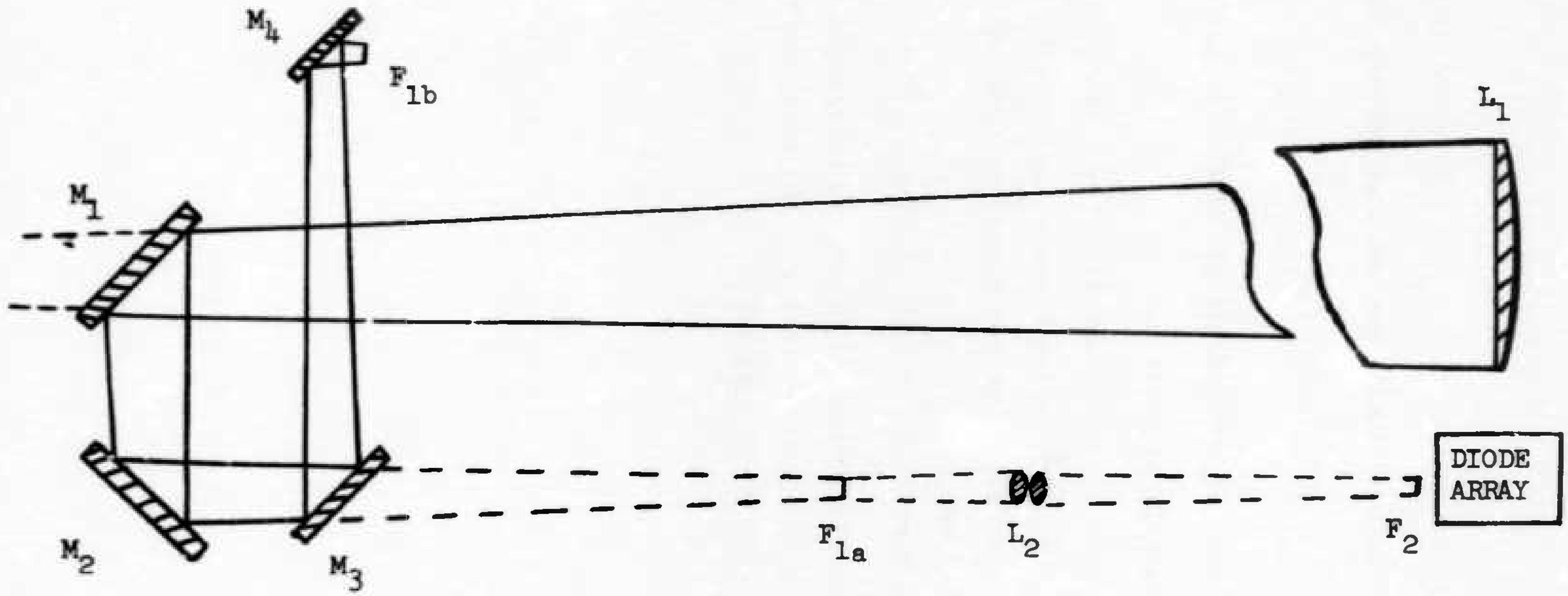

Figure 2. Optical Schematic of 12-inch Refracting Telescope 1/10 Scale - Explanation of notations will be found in Table 1.

TABLE 1. EXPLANATION OF NOTATIONS IN FIGURE 1

L_1	12-inch diameter objective lens with a 168 inch focal length
L_2	Enlarging lens 6-inch focal length can enlarge primary image 2 to 5 times
F_{1a}	Primary focus position
F_2	Enlarged image position at which diode array will be placed
F_{1b}	Auxiliary beam primary focus position
M_1	First beam folding flat mirror 8-inch diameter. Front surface has dielectric coating which reflects useful wavelengths and allows much of the non-useful radiant energy to pass out through the back of the telescope.
M_2	Second beam folding flat mirror 8-inch diameter.
M_3	Third beam folding mirror, 6-inch diameter, can be flipped 45° in order to either allow beam to reach F_{1a} and thus the diode array, or F_{1b} auxiliary focus position.

Four doors, two of which are open in the photograph, give complete accessibility to the interior of the telescope.

Figure 2 is an optical schematic of the 12-inch telescope. Table 1 is a complete explanation of notations in Figure 2. In order to keep the length of the telescope manageable, the optical path is folded by two 8-inch mirrors, designated M_1 and M_2. Folding the telescope decreases its total length from nearly 18 feet to a far more manageable 10.5 feet. The main optical beam can be further diverted by mirrors M_3 and M_4 to an auxiliary position. The auxiliary position increases the flexibility of the system by providing a possible test bed for experimentation and instrumentation development.

The main body of the telescope is aluminum plate, the outside of which will be coated with a paint containing a high proportion of white titanium dioxide pigment for maximum reflection of incident sunlight. This paint helps to minimize internal telescope heating which can deteriorate optical performance. It can be seen by the nature of this experiment that negligible seeing effects inside the telescope housing must be maintained.

All interior surfaces will be lined with polyurethane insulation and the 30-inch snout, projecting from the front of the main body, which contains the objective lens, is further insulated on its outside surface.

The front of the main body is shielded from direct sunlight by a thin sheet of aluminum mounted on 2-inch plastic standoffs.

Since a major source of image distortion is the hot solar beam itself, a large portion of this radiant energy will be passed right through the telescope by means of a dielectric coating on the first mirror (M_1). Useful wavelengths will be reflected to the diode array and as much unwanted radiation as possible will pass through M_1 and out the back of the telescope.

Telescope Optical Characteristics

Some of the basic telescope optical characteristics are given in Table 2, along with the image scale and effective focal ratio obtained with image magnification ranging from 1 to 5. Since several diode arrays, consisting of 256 individual silicon elements each approximately 0.001-inch square, will be used in this study, image scale in Table 2 is given in seconds of arc per 0.001 inch.

TABLE 2

Telescope Objective: 12-inch Diameter Aspheric Singlet
Focal Length: 168.5 inches
Focal Ratio: f/14
Primary image scale: 1224 seconds of arc per inch

Magnification of Prime Image	Effective Focal Ratio	Image Scale in Second of Arc per Diode Array Element *
1.0	14	1.22
1.5	21	0.82
2.0	28	0.61
2.5	35	0.49
3.0	42	0.41
3.5	49	0.35
4.0	56	0.31
4.5	63	0.27
5.0	70	0.24

* .001 inch

Electronic Instrumentation

The instrumentation for this experiment can be conveniently viewed as consisting of four parts: (1) sensor, (2) signal processor,(3) control logic, and (4) interface. Figure 3 is a block diagram of the electronic instrumentation.

There are two sensors, each consisting of a 256 element photodiode array, associated drive circuitry and output amplifiers mounted on a single small printed circuit board. Fabrication of these circuit boards is nearly complete. The output of each sensor is a series of analog pulses which is fed into the signal processor.

In the signal processor each pulse is sampled at its beginning and at its peak by very high speed sample and holds. The outputs of these sample and holds are fed into differential amplifiers and thus produce an analog signal proportional to the amplitude of the pulses but relatively insensitive to noise at the input. The last stage of the signal processor consists of a pair of high speed analog to digital converters which convert the analog data into 10 bit words. The design of this part of the system is complete and fabrication awaits only the delivery of the A/D converters from the manufacturer.

The control logic provides the proper timing signals to the other parts of the systems. This circuitry consists of a mixture of ordinary and high-speed t^2L logic and will be fabricated in conjunction with the signal processor. The design of this circuitry is essentially complete.

The output of each A/D converter is a 10 bit parallel word which is converted by the interface circuitry into serial data and transmitted via coaxial cable from the telescope to a PDP 11-45 computer. At the computer the data is converted back into parallel form and fed directly into memory via a DR-11B computer interface. Design of the interface circuitry is complete and fabrication is in process.

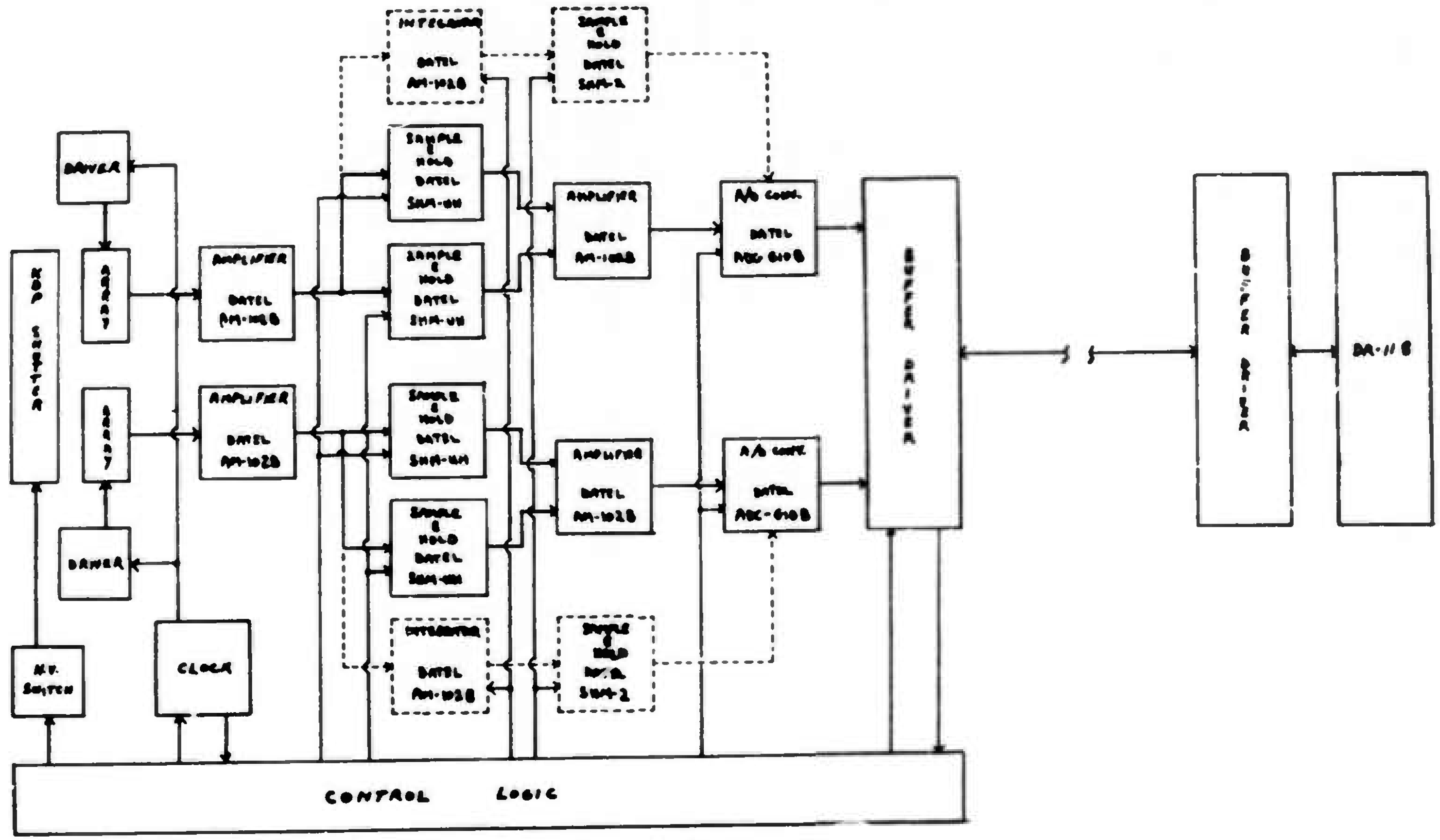

Figure 3. Block Diagram of Electronic Instrumentation

The design of this system includes provision for the use of a second type of signal processing should this prove necessary. This second type of processing involves integrating each analog pulse before it is sampled.

The overall speed of the system is such that data is produced as fast as it can be transferred into memory (approximately 1 MHz word rate). Provision is also being made for using 8 bit instead of 10 bit words. This would effectively double the speed of the system at some cost of accuracy.

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Source AFSCR 23-50, 11 May 70