Technical Memorandum 83915

A PLAN FOR THE CHARACTERIZATION, CALIBRATION, AND EVALUATION OF LAPR-II

J. R. Irons, J. C. Smith, L. R. Blaine, and M. W. Finkel

MARCH 1982

National Aeronautics and
Space Administration

Goddard Space Flight Center
Greenbelt, Maryland 20771

A PLAN FOR THE CHARACTERIZATION, CALIBRATION, AND EVALUATION OF LAPR-II

J. R. Irons
Earth Resources Branch – Code 923
J. C. Smith and L. R. Blaine
Experiment Engineering Branch – Code 973
M. W. Finkel
Sensor Evaluation Branch – Code 972

March 1982

GODDARD SPACE FLIGHT CENTER
Greenbelt, Maryland 20771

A PLAN FOR THE CHARACTERIZATION, CALIBRATION, AND EVALUATION OF LAPR-II

J. R. Irons

Earth Resources Branch – Code 923

J. C. Smith and L. R. Blaine

Experiment Engineering Branch – Code 973

M. W. Finkel

Sensor Evaluation Branch – Code 972

ABSTRACT

A new, airborne Linear Array Pushbroom Radiometer (LAPR-II) is being built. LAPR-II will use linear arrays of silicon detectors to acquire four channels of digital image data for spectral bands within the visible and near-infrared portions of the spectrum (0.4 - 1.0 μm). The data will be quantized to 10 bits, and spectral filters for each channel will be changeable in flight. The instrument will initially be flown aboard a NASA/Wallops' aircraft, and off-nadir pointing of LAPR-II will be possible. Together, the instrument and its platform will provide a flexible readily available source of digital image data for scientific experiments.

If LAPR-II is to serve as a precise scientific instrument, the instrument's characteristics must be quantitatively described and the data must be calibrated with respect to absolute radiometric units. This plan describes LAPR-II and outlines the work required to characterize the instrument's spectral response, radiometric response, and spatial resolution and to calibrate the response from the many detectors per array. The results of this work will be presented in a subsequent Technical Memorandum.

PRECEDING PAGE BLANK NOT FILMED

CONTENTS

Page

ABSTRACT iii

INTRODUCTION 1

BACKGROUND 1

CHARACTERIZATION, CALIBRATION, AND EVALUATION 5

Task 1: Instrument Set-Up 5

Task 2: Determination of Optical Characteristics and Angular Field-of-View 6

Task 3: Determination of Spatial Resolving Power 6

Task 4: Calibration and Determination of Radiometric Characteristics 7

REVIEW AND REPORTING 9

REFERENCES 11

LIST OF TABLES

Table *Page*

1 Spectral Filters for LAPR-II 3

LIST OF FIGURES

Figure *Page*

1 LAPR-II Calibration, Characterization, and Fabrication Schedule 12

A PLAN FOR THE CHARACTERIZATION, CALIBRATION, AND EVALUATION OF LAPR-II

INTRODUCTION

Personnel of Goddard Space Flight Center's (GSFC's) Experiment Engineering Branch (Code 973) have designed a second Linear Array Pushbroom Radiometer (LAPR-II). Their first linear array instrument (LAPR-I) demonstrated the ability to acquire useful multispectral digital image data using airborne multispectral linear array technology (Wharton et al., 1981). The new sensor will augment airborne data acquisition capabilities and will serve as a scientific instrument in support of GSFC's Multispectral Linear Array (MLA) development program. Fabrication and testing of LAPR-II is scheduled for completion by the early spring of 1983.

If LAPR-II is to serve as a precise scientific instrument, the spectral, spatial, and radiometric characteristics of the instrument must be quantitatively described, and the sensor's response must be accurately calibrated with respect to absolute radiometric units. This document describes the work required to characterize the instrument's attributes, calibrate the sensor's response, and evaluate the results.

BACKGROUND

Future sensor systems will utilize multispectral linear arrays for earth resources observations. Linear array radiometers operated in a pushbroom mode will offer several advantages over multispectral scanners. The "pushbroom mode" refers to the use of a sensor platform's forward motion to sweep a linear array of detectors, oriented perpendicular to the vector of motion, across a scene. The platform motion will provide one direction of scan while electronic sampling of the detectors will provide the orthogonal component to form a digital image. This mode of operation will eliminate the need for oscillating or rotating scan mechanisms and thus will present the following advantages: (1) the geometry of the optics relative to the detectors will remain fixed, allowing greater cartographic precision; (2) the optics will be compact, enabling a pointable field-of-view;

and (3) longer detector dwell times will be possible, reducing noise-equivalent-signals and enhancing signal-to-noise ratios. These improvements will lead to MLA instruments with finer radiometric, spectral, or spatial resolutions than current multispectral scanners. Pushbroom radiometers for earth observations have not yet been flown aboard spacecraft, but GSFC is conducting a program to provide the technology necessary for future spaceborne MLA systems.

The GSFC program consists of both scientific studies and technology development. The scientific studies will establish objectives for earth resource observation missions and will translate these objectives into required MLA sensor parameters. Development efforts will insure the existence of reliable linear array hardware to meet the scientific requirements. In particular, the development and evaluation of focal plane linear arrays for sensing in the visible and short-wave infrared portions of the spectrum will be emphasized.

GSFC's first Linear Array Pushbroom Radiometer (LAPR-I) was built to demonstrate the capability to acquire multispectral digital image data for the visible and near infrared (VIS/NIR) portions of the spectrum (0.4 to 1.0 μm) using an airborne MLA system. LAPR-I used three Reticon RL5-12C* linear arrays, each array consisting of 512 silicon photodiodes located on 2.5 μm centers. Each array viewed the surface through a structurally independent optical system which provided an instantaneous field-of-view (IFOV) of 2.5 milliradians for the nadir detector and a total field-of-view of 1.12 radians (64.2°) across the array. The optical systems were aligned so that each array imaged approximately the same scene and the signals from the three arrays were simultaneously amplified, converted to digital values (eight bit data), and stored on magnetic tape. Spectral filters were mounted in front of each array, and the spectral bands were altered between flights by changing filters. Useful false color images and thematic maps were derived from LAPR-I digital image data (Wharton et al., 1981).

In order to conduct scientific field experiments, a second linear array radiometer (LAPR-II) has been designed to enhance data acquisition capabilities. LAPR-II will employ four 512 element

*Trade names are given for description purposes only and do not imply endorsement by NASA.

silicon monolithic Westinghouse* arrays to simultaneously acquire four data channels for visible and near infrared spectral bands. Each array will view the Earth's surface through a separate Schneider Cinegon* 1.8/10 lens set at an f-stop of 2.5. This optical system will provide a total field-of-view of 0.74 radians (42.5°) and an IFOV of 1.54 milliradians for the nadir detectors.

A filter wheel with seven positions will be located between each lens and linear array within LAPR-II. One position will serve as a shutter and thus, six different spectral filters can be placed in front of each array. The wheels will allow filter changes in flight. Table 1 lists the bandwidths of the filters presently available for LAPR-II, but other filters could be obtained and mounted in the wheels at the request of a user.

Table 1. Spectral Filters for LAPR-II

Bandwidth (μm) at Full-Width-Half-Maximum	Centroid Wavelength (λ_o)
0.020 ± 0.004	0.410 ± 0.004
0.070 ± 0.014	0.485 ± 0.014
0.020 ± 0.004	0.500 ± 0.004
0.020 ± 0.004	0.550 ± 0.004
0.080 ± 0.016	0.560 ± 0.016
0.020 ± 0.004	0.680 ± 0.004
0.060 ± 0.012	0.660 ± 0.012
0.020 ± 0.004	0.720 ± 0.004
0.020 ± 0.004	0.740 ± 0.004
0.020 ± 0.004	0.790 ± 0.004
0.140 ± 0.028	0.830 ± 0.028
0.020 ± 0.004	0.850 ± 0.004
0.020 ± 0.004	0.890 ± 0.004
0.020 ± 0.004	0.940 ± 0.004

LAPR-II's data system will record the signals from the detector arrays in digital image format. Each array will contain its own analog-to-digital (A/D) converter which will digitize each detector's signal to 10 bits. This corresponds to 1024 digital counts for a full scale 10-volt input and a signal-to-count ratio of approximately 10-millivolts per count. The data system will then accept four channels of data, each consisting of 10-bit parallel data. The data system will also collect 152 bits of pertinent instrument and aircraft information during the data collection sequence for each scan

*Trade names are given for description purposes only and do not imply an endorsement by NASA.

line. This "housekeeping" data will include aircraft altitude and velocity, scan and integration times, filter and electronic gain selection, time code, aircraft roll position, and several timing signals that will allow proper data transfer between the sensor and the data system. The data system will then output four pulse-code-modulated (PCM) data streams (one per array) to a 14-channel analog tape recorder. The PCM bit rate may vary from 178 kilobits-per-second to 36 kilobits per second which corresponds to scan rates of approximately 30 milliseconds to 150 milliseconds. The data system will also output serial time code to the tape recorder on a separate channel. The time code will be used when the analog tape is converted to a computer compatible tape in a digital format. The code will identify the PCM bit rate used for data acquisition so that the PCM data can be correctly converted to digital data.

LAPR-II will initially be flown aboard a Skyvan aircraft from NASA's Wallops Island Installation. The instrument will be flown at altitudes between 1,000 and 12,000 ft., and the electronic scan rate for the linear arrays will be selectable inflight to insure that contiguous scans of the surface can be obtained at different velocities and altitudes. The sensor's aircraft mounting will enable off-nadir pointing. Both fore-and-aft pointing (±50° from nadir) and side-to-side pointing (±50° from nadir) will be selectable inflight at five degree increments. The Skyvan provides a flexible, readily available, and relatively inexpensive sensor platform.

The scientific studies within GSFC's MLA development program will take full advantage of LAPR-II capabilities. The ability to rapidly switch spectral filters will be utilized in studies which assess the relative utility and information content of data from different spectral bands. The sensor's aircraft mounting will facilitate an investigation into the radiometric and geometric effects of off-nadir viewing. Studies addressing spatial resolution and atmospheric effects will benefit from the capability to acquire data at varying altitudes. The general goal of these research efforts is to select and justify the instrument parameters required for an effective spaceborne MLA sensor system dedicated to earth resource observations. LAPR-II will serve as a valuable tool in this effort given a quantitative characterization of the sensor's attributes and an accurate absolute calibration of its data.

CHARACTERIZATION, CALIBRATION, AND EVALUATION

The work required to insure LAPR-II's utility as a scientific instrument is herein divided into four tasks. The tasks involve the quantitative specification or determination of the sensor's radiometric, spectral, and spatial characteristics as well as the calibration of the sensor's response. The task descriptions are accompanied by a schedule (Figure 1).

Task 1: Instrument Set-Up

The first task will require a review of potential LAPR-II applications and a subsequent evaluation of the environmental conditions (e.g., sun angles, atmospheric conditions, altitudes, target reflectivities) under which LAPR-II will acquire data. This review and evaluation will enable a selection of useful spectral band combinations and a prediction of the range of spectral radiances which will impinge upon the apertures of the radiometer. Thus, the first task consists of specifying the arrangement of available spectral filters on the filter wheels and setting the electronic gains for each linear array.

Scientists involved in the MLA development program (i.e., the MLA Science Team headed by Dr. P. Cressy) will meet with the engineer building LAPR-II (Mr. J. Smith of the Experiment Engineering Branch) to discuss the investigations which will require LAPR-II data. The scientists will be asked to describe experimental designs and objectives. The experiment descriptions will include study site locations, target spectral reflectivities, desired spectral band combinations, data acquisition dates and times, Skyvan flight altitudes and headings, and anticipated atmospheric conditions. This information will be evaluated by the LAPR-II engineer and translated to specifications for the arrangement of spectral filters on filter wheels, minimum spectral radiances for signal saturation, and electronic gains.

Task 2: Determination of Optical Characteristics and Angular Field-of-View

The objectives of the second task will be: (1) to quantitatively characterize the spectral transmittance of the filters and of the optical system and (2) to determine the angular field-of-view of each detector and the total angular field-of-view across an array.

Before installation into the LAPR-II filter wheels, each interference filter will be examined using a spectrophotometer. The examination will result in the determination of the following transmittance parameters to within plus-or-minus 0.5 nm: (1) the centroid wavelength (λ_0), (2) the bandwidth at full-width-half maximum (FWHM) transmittance, (3) the spectral band shape and transmittance, and (4) the filter blocking characteristics from 200 to 1500 nm.

After LAPR-II has been completely assembled, these same transmittance characteristics will be examined for the complete optical system. Radiation from a calibrated quartz-halogen lamp will be passed through a spectrometer, collimated, and coupled into the LAPR-II optical systems. The radiometer will be mounted on a nodal slide such that the axis of rotation passes through the second nodal point of the lens being studied. The nodal slide will be sequentially stepped to each array element (detector) and the spectrometer scanned. Analyses of the resultant data will yield: (1) the system spectral band centroid (λ_0) for each element; (2) the system channel spectral band shape and response for each element; (3) the system channel spectral blocking (leakage) characteristics for each element; (4) the angular instantaneous field-of-view for each element as a function of field angle; (5) the total effective array field-of-view; (6) the lens spectral on-axis transmittance; and (7) the lens vignetting characteristics as a function of field angle and field stop.

Task 3: Determination of Spatial Resolving Power

The spatial resolving power of the sensor will be characterized by determining the cross-track (along the linear arrays) Modulation Transfer Function (MTF). To determine the MTF, an integrating sphere will diffusely illuminate a square wave grating. The grating will be mounted on a translator driven by a stepping motor with 2000 discrete shaft positions per revolution. Since each revolution will advance the lead screw of the translator 0.0635 cm, each step will be equivalent to a 3.17×10^{-5} cm displacement of the grating in the object plane and will be translated to the image plane as a 3.175×10^{-6} cm displacement. The light will be filtered and then imaged by the lens upon the array. The lens, a Computar* 2.8/50 mm enlarging lens optimized at F/5.6 at a 10:1 demagnification was supplied with MTF curves. The stepping motor will be incremented by a computer and the output of the array will be sampled at some preselected rate. Each array will be mounted on a micropositioner with six degrees of freedom. Critical alignment of the array will be made by maximizing the contrast as displayed on an oscilloscope. This maximization will be essentially a minimization of the focussing error.

The modulation will be determined by,

$$M(\nu) = \frac{I_{max} - I_{min}}{I_{max} + I_{min}}$$

where ν is the spatial frequency, and I_{max} and I_{min} are maximum and minimum irradiances from the illuminated grating. After inserting the lens' correction, the normalized transfer function will be plotted as a function of frequency.

Task 4: Calibration and Determination of Radiometric Characteristics

The overall objective of this task will be to quantitatively describe LAPR-II's response to the radiance impinging upon the sensor's apertures. To accomplish this, each array/filter wheel/lens assembly will view through a portal into a six-foot integrating sphere which provides a nearly uniform radiance target over the total spectral response range of LAPR-II. The sphere is maintained and calibrated by the Sensor Evaluation Branch (Code 972) which will provide all calibration constants relating to the sphere. The sphere is calibrated relative to the National Bureau of Standards spectral radiance and spectral irradiance scales. For the initial calibration of LAPR-II, each array/lens assembly will view the sphere through two of the six spectral filters on the associated filter wheel, and the response of each detector at three different levels of irradiance will be recorded as serial PCM on magnetic tape. At each irradiance level, the detector integration time will be

*Trade names are given for description purposes only and do not imply an endorsement by NASA.

varied over three reasonable values and thus, responses will be recorded for different integration times. In addition, responses will be recorded for two different electronic gain settings. This procedure will take four variables per array into account: two spectral bands, three irradiance levels, three detector integration times, and two electronic gain settings. Since data will be recorded for all possible factor combinations, a total of 36 data sets (2X3X3X2 = 36) will be acquired for the initial calibration of each array in LAPR-II.

These data will permit the computation of several radiometric parameters for the assembled instrument with respect to each array/lens assembly given each factor combination. The radiometric response of the entire sensor with respect to each detector will be computed in terms of digital counts per unit value of radiance, and the linearity of the response will be checked. These values will lead to an absolute calibration of the sensor's response and the removal of vertical striping from the digital imagery. Since multiple scan lines will be recorded for each factor combination, the standard deviation (root-mean-square) of the sensor's response from each detector can be computed as a measure of system noise. The noise measurements will enable the computation of absolute radiometric accuracy, system signal-to-noise ratio, and noise equivalent radiance. Also, given a constant radiance across an array, the standard deviation of the calibrated response from all the detectors will serve as an indication of detector-to-detector radiometric precision.

In summary, for each detector of each array/lens assembly at each given combination of instrument factors (spectral band, integration time, electronic gain setting), the following characteristics will be quantified:

1. sensor response in terms of digital counts per unit value of incident radiance;
2. signal-to-noise ratio;
3. noise-equivalent-radiance in radiance units (power per unit area per unit solid angle); and
4. absolute radiometric accuracy of the calibration in terms of percent of the estimated radiance.

The calibration of LAPR-II will be checked while the sensor is installed in the aircraft. While the airplane idles on the ground, the sensor will view a light box with one level of calibrated irradiance. The response will be recorded for combinations of instrument factors (spectral filter, integration time, gain setting) relevant to the ensuing data acquisition mission. The level and variation of the response will be compared to results obtained in the laboratory as an evaluation of the calibration. The use of large, uniform canvas or wooden panels or the use of sandy beaches near Wallops Island will be considered in the future for inflight assessments of the sensor's radiometric response.

After the initial calibration of LAPR-II, the possible drift of sensor radiometric response characteristics due to changes in ambient temperature will be investigated. The instrument will be placed in a thermal vacuum chamber which is also maintained by the Sensor Evaluation Branch. Each array/lens assembly will view a 12-inch integrating hemisphere at three different irradiances. The sensor's response from each detector will be recorded for the same 36 factor combinations discussed previously, but an additional factor, temperature, will also be considered. Data will be recorded for three different temperatures by using the heating and cooling shrouds in the chamber. Thus, a total of 108 (3X36 = 108) data sets will be recorded in this test. Changes in sensor radiometric response parameters with temperature can then be quantitatively evaluated.

During the first year of operation, the acquisition of laboratory data for LAPR-II calibration will be repeated before and after each field campaign. That is, each time the instrument is placed in the aircraft, a calibration will be performed before the mounting and after the instrument is removed from the aircraft. Since the instrument will probably remain on the aircraft for the duration of several experiments, the sensor's response will be checked prior to each flight using the light box and possibly by overflying uniform panels or beaches. The temporal drifts in sensor radiometric response characteristics will be evaluated and the required frequency for repeating LAPR-II calibrations will be determined.

REVIEW AND REPORTING

The LAPR-II engineer (Mr. J. Smith, Experiment Engineering Branch) and the LAPR-II science coordinator (Mr. J. Irons, Earth Resources Branch) will report all progress on the fabrication, characterization, and calibration of LAPR-II. The science coordinator will report on a monthly basis to the MLA Science Team (headed by Dr. P. Cressy, Eastern Regional Remote Sensing Applications Center) and to the head of the Earth Resources Branch (Dr. R. Murphy). The engineer will report to the manager of the MLA development program (Dr. W. Barnes, Sensor Concepts and Development Branch) and to the head of the Experimental Engineering Branch (Mr. D. Smith). The LAPR-II engineer and science coordinator will submit a final written report on calibration and characterization for review and approval to the individuals mentioned above. The final report and progress reports will also be sent to Dr. Philip Slater of the University of Arizona for an outside review of the work.

REFERENCES

Wharton, S. W., J. R. Irons, F. Huegel, 1981. LAPR: An Experimental Pushbroom Scanner. Photogrammetric Engineering and Remote Sensing, Vol. 47, No. 5. pp. 631-639.

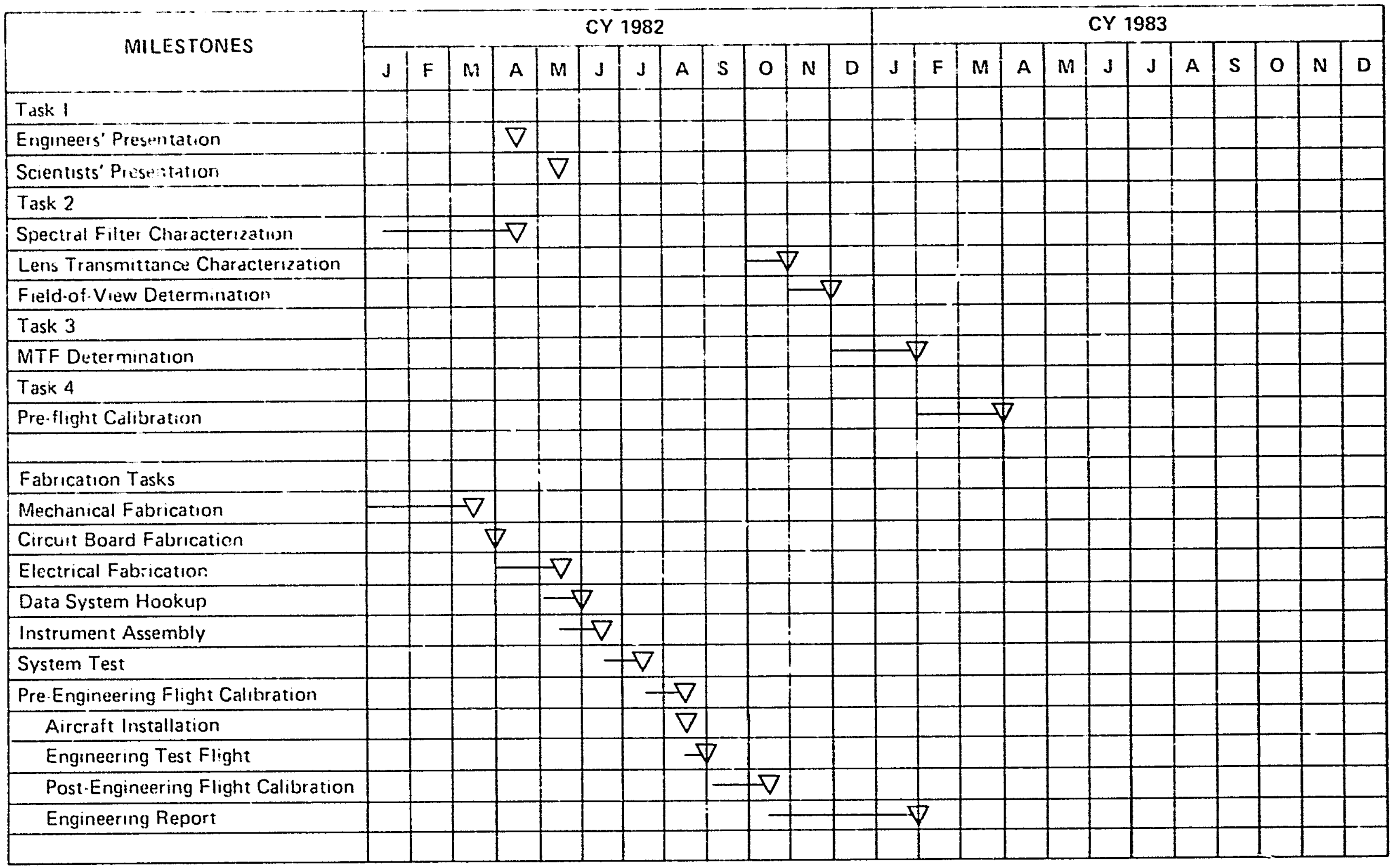

Figure 1. LAPR-II Calibration, Characterization, and Fabrication Schedule.