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PROGRAM SPECIFICATION PLAN FOR THE DETERMINATION OF ATMOSPHERIC EFFECTS ON LASER SPACE COMMUNICATIONS

Volume II

9 November 1965

NORTH AMERICAN AVIATION, INC.
SPACE and INFORMATION SYSTEMS DIVISION

FOREWORD

This document is the concluding report of Task IV, Program Specification, of the Laser Space Communications Systems (LACE) Study. It was prepared by the Space and Information Systems Division of North American Aviation, Inc. This report is submitted in accordance with requirements of Contract NASw-977, Supplemental Agreement, dated 15 February 1965.

TECHNICAL REPORT INDEX/ABSTRACT

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PROGRAM SPECIFICATION PLAN FOR THE DETERMINATION OF ATMOSPHERIC EFFECTS ON LASER SPACE COMMUNICATIONS - VOL. II

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*LASER SPACE COMMUNICATIONS, *OPTICAL PROPAGATION, *ATMOSPHERIC EFFECTS, *PROGRAM SPECIFICATION, *MEASUREMENT PROGRAM RECOMMENDATIONS, *EXPERIMENTAL DESIGN, *SCHEDULING, *RESOURCES SUPPORT REQUIREMENTS, *SITE ANALYSIS, *MANAGEMENT APPROACH CONSIDERATIONS, *ESTIMATED COSTS.

ABSTRACT

This document, published in a text-briefing chart format, comprises the conclusion of Task IV, Program Specification, of the Laser Space Communications Systems (LACE) Study. As such, it is a continuation and expansion of earlier published work under this same contract.

The areas of study covered in this report include an analysis, comparison and recommendation of measurement program implementation and approaches; the specification of a complete test program including objectives, experimental design, scheduling, resources, requirements, and procedures for implementation; and management approach considerations.

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INTRODUCTION

INTRODUCTION

The overall objective of the Laser Space Communications System (LACE) Study is to provide a plan for the implementation of a comprehensive experimental program to determine atmospheric effects on laser propagation, with particular emphasis on effects related to optical space-ground communication. The conduct of such a field test program has the potential of providing a large number of secondary benefits such as field operational experience with electro-optical systems and procedures, and validation of theoretical techniques for predicting system performance.

The present study effort is a continuation and expansion of earlier work under this contract and has been divided into four published task reports: Task I, Problem Definition; Task II, Experiment Specification; Task III, System Implementation Study; and Task IV, Program Specification.

The Task I, II, and III reports have already been published. This report is concerned with the conclusion of earlier effort initiated under Task IV. The areas of investigation included in this report were established with the following objectives: 1) analysis, comparison and recommendation of measurement program implementation approaches; 2) the specification of a complete test program including objectives, experimental design, scheduling, resource requirements, and procedures for implementation; and 3) management approach considerations.

In developing this plan it has been necessary to consider experiment grouping, availability of resources, sites, links, vehicles, and overall plan for data acquisition and handling to allow the most straightforward and organized means of correlation of the test results. In addition, there has been a real necessity for delineation of what is important in the experimental program and the factors that tie into it. Consideration has been given to how the program is to be phased so that results are maximized for a particular cost. In the case of a program as diverse as the LACE experimental program should be, it has also been essential to give some serious consideration to, and provide recommendations for, a management approach which would allow NASA, with a reasonable expenditure of their in-house resources, to effectively control and direct the total program so that the desired results would be forthcoming.

The result of this analysis is the discussion and specification of three program approaches, namely - a minimum experimental program; a pilot test program; and an extended sub-program experimentation. Based upon this program approach analysis, recommendations for immediate program implementation are presented.

INTRODUCTION

- LACE TEST PROGRAM OBJECTIVES

  PRIMARY

  Obtain Sufficient Experimental Data to Permit the Inclusion of Atmospheric Effects in Future Laser System Design

  SECONDARY BENEFITS

  Provide Field Test Experience With Practical Electro-Optical Systems and Operational Procedures

  Provide Validation of Theoretical Model Useful for System Performance Prediction

- TASK IV OBJECTIVES AND SCOPE

  PROVIDE EXPERIMENTAL PROGRAM PLAN INCLUDING:

  Experiment Grouping and Approaches

  Site and Vehicle Considerations

  Operational Techniques and Data Handling

  Schedule Factors

  Resource Requirements and Availability

  PROVIDE RECOMMENDATIONS FOR EXPERIMENTAL APPROACH, PROGRAM PHASING, AND MANAGEMENT APPROACH

PROGRAM SPECIFICATION SUMMARY

NASA OPTICAL SPACE COMMUNICATION PROGRAM - BACKGROUND AND RELATED WORK

In order to effectively utilize the optical portion of the spectrum for future space communication systems, NASA has been engaged in a series of studies, both in-house and contracted, to define and solve, if possible, the problem areas which currently limit the implementation of such systems.

Studies of deep space optical communications systems and preferred system concepts have been performed by Hughes Aircraft for the Manned Spacecraft Center (MSC); by General Electric for NASA Headquarters; and by Westinghouse, again for MSC. These studies have provided results that indicate the feasibility of such systems and delineated problem areas which require technique study and development.

Among these problem areas is that of precision laser beam pointing in which contracted studies for system concepts and technique concepts have been conducted by Kollsman Instrument and General Telephone. The development of a precision beam pointing system has been contracted by Marshall Space Flight Center to the Perkin-Elmer Company.

Another key problem area utilization of deep space optical communications is that of the acquisition and tracking of signals with very great angular precision and narrow fields of view. A study of this problem has been conducted by the Northrop Corporation for MSC. Connected with the problems of acquisition, and beam pointing from space, is the study which has been conducted by Perkin-Elmer under sponsorship of MSFC of the Optical Technology Satellite. In this study those experiments necessary for performance in space to evaluate the effects of space and launch environment upon large optics, and the capability of acquisition and beam pointing from a space platform were studied. The two study contracts for the Optical Technology Apollo Extension System awarded to Perkin-Elmer/Convair and Grumman/Chrysler will further this type of effort in the definition of the system characteristics and experiment characteristics of an orbiting optical laboratory.

NASA OPTICAL SPACE COMMUNICATION PROGRAM - BACKGROUND AND RELATED WORK

SERIES OF RELATED STUDIES TO DEFINE PROBLEMS AND PROVIDE SOLUTIONS IN BOTH SYSTEMS AND TECHNIQUES AREAS

- System Analysis - Hughes, General Electric, Westinghouse
- Precision Beam Pointing - Kollsman, Perkin-Elmer, General Telephone
- Deep Space Acquisition and Tracking - Northrop
- Optical Tech Satellite - Perkin-Elmer/Convair and Grumman/Chrysler

NASA OPTICAL SPACE COMMUNICATION PROGRAM - BACKGROUND AND RELATED WORK (Cont.)

A particular technique or concept which has also been under study and development towards the optical space communication mission is the MIROS concept for which techniques are currently under development by the Philco Corporation, Westinghouse and North American Aviation, Space & Information Systems Division.

The range of components and techniques under NASA sponsorship include such items as heterodyne receivers, under development by Sylvania, gallium-arsenide arrays in which RCA has been contracted and laser material development at Linde.

The effects of the atmosphere on optical propagation as it applies to space communication has been under some experimental study by International Telephone and Telegraph Company; and the present LACE contract for a planning study of an experimental program to determine such effects.

In addition, the NASA has contracted for satellite tests with an active source in the Gemini program (IBM and RCA) and with corner reflectors on the Explorers 22 and 27 (contracted from the Ames Research Center to Electro-Optical Systems).

These programs should yield available techniques, operational experience, and an understanding of the atmosphere effects at a suitable time for utilization of all the information on a program for the design of operational space communication hardware.

NASA OPTICAL SPACE COMMUNICATION PROGRAM - BACKGROUND AND RELATED WORK (CONT.)

- MIROS - PHILCO, WESTINGHOUSE, NORTH AMERICAN
- COMPONENTS & TECHNIQUES - SYLVANIA, RCA, LINDE
- ATMOSPHERIC EFFECTS - ITT, NORTH AMERICAN (LACE)
- SATELLITE TESTS - IBM/RCA, EOS

EXPERIMENTAL PROGRAM APPROACH CONSIDERATIONS - FACTORS BEARING ON THE PROBLEM

The approach to a program of field experimentation to determine atmospheric effects on laser propagation has included consideration of a wide range of factors. Among them has been the practical consideration of the availability of qualified experimentalists, the unknown field-capability and limitations of existing hardware, and cost and scheduling implications. The analysis performed under Task IV has led to some generalized program conclusions that form the basis of the development of an experimental program approach.

In developing the experimental program one must provide a reasonable balance between the theoretical and experimental approach to the problem. It is extremely important that the theory developed to date to predict system performance in a turbulent atmosphere be validated. The theoretical results can be utilized as a guide in designing the experiments, interpreting the results, and preparing models for system performance prediction. However, in order to have a firm basis for making statistical inferences about atmospheric conditions and system performance, it is also necessary that a wide range of data be collected through repeated testing over a diversity of experimental conditions. This implies a number of geographic locations to provide climatic and orographic variability. From this approach it will be possible to specify best and worst case conditions as well as providing data from which correlations between synoptic meteorology and system performance may be established.

The LACE analysis to date has yielded considerable ambiguity and uncertainty in the performance characteristics of experimental equipment and the contributing effects of operational procedures and techniques. If these characteristics and effects are not known and controlled, or accurately accounted for, the experimental results may be invalid because of excessive confounding and bias. Thus it appears evident that considerable small scale testing of different experimental configurations should be performed to accurately determine capability (and minimize experimental error) before making major field test commitments.

In examining the program approach, careful consideration has been given to the necessity of space tests versus non-space tests so that the data required for space system design can be obtained most efficiently and economically. In this regard, it has become apparent that the definition of what utilization should be made of space tests to complete the knowledge of the atmospheric effects can only reasonably be made following some period of less expensive non-space experiments.

EXPERIMENTAL PROGRAM APPROACH CONSIDERATIONS - FACTORS BEARING ON THE PROBLEM

FACTORS BEARING ON PROBLEM

- THEORETICAL MODEL VALIDATIONS
- STATISTICAL BASE FOR PERFORMANCE PREDICTION REQUIRES EXTENSIVE EXPERIMENTATION
- METEOROLOGICAL SPREAD IMPLIES VARIETY OF SITES AND SEASONS
- EQUIPMENT, TECHNIQUE, PROCEDURE UNCERTAINTIES
- COST-EFFECTIVE CONSIDERATION OF SPACE VS NON-SPACE TESTS

LACE PROGRAM SCOPE TRADE-OFF CONSIDERATIONS

Detailed consideration of the overall LACE program objectives and the many factors bearing on the program implementation has led to the development of three program approaches. These approaches range from a very minimum experiment to an extensive integrated experimental program. It can be seen that the three approaches proposed vary mainly according to the range between the number of experiments and experimental variables, equipment configuration analyzed, test cycles (replication), and test sites and links.

It became evident in the consideration of the program scope, that regardless of the extent of the program selected, the minimum experimental program should be conducted. Further, it was felt that implementation of the extended subprogram phase should include the conduct of a "warmup" pilot program.

LACE PROGRAM SCOPE TRADE-OFF CONSIDERATIONS

MINIMUM EXPERIMENTAL PROGRAM

- Provide Preliminary Data to Verify Theory Only
- Single Site and Link
- Limited Experiments; Minimum Test Duration and Variables

PILOT EXPERIMENTAL PROGRAM

- Includes Minimum Experimental Program Objectives
- Comprehensive Range of Experiments and Experimental Variables
- Equipment Configuration Checkout and Comparative Analysis
- Several Test Cycles (Replications)
- Multiple Paths and Links (Horizontal, Mountain Terminus, Airborne/Balloon)
- Provides Background for Expanded Testing (i.e., Multiple Sites, Satellites)

EXTENDED SUBPROGRAM EXPERIMENTATION

- Minimum and Pilot Experimental Programs Necessary Prerequisites
- Multiple Site, Link, Environment, and Experimental Variable
- Provides Large Sample Empirical Data
- Extensive System Operational Experience

ANTICIPATED PROBLEM AREAS

In undertaking the implementation of the LACE field test program, certain problem areas are anticipated. These problems exist both in technical areas and management areas. Emphasis must be placed in these areas to insure and maintain an effective program.

As indicated under Experimental Approach Considerations, there is a real problem in undertaking a field test program with laser equipment which is essentially available in a laboratory type of design at this stage of the development. The reliability of such equipment in a field environment is apt to present a real problem in maintaining a test schedule in the field without excessive downtime for maintenance, rework and reconfiguration of the components. There is, in addition, a requirement for extremely accurate tracking for certain types of measurement (see the Task II report) which will strain current technology and which must be carefully considered in the design of the equipment for performing the measurements. In view of the requirement for repeated measurements over a period of weeks or perhaps months, a repeatability of performance is necessary in the equipment so that the statistical data analysis can be performed without introduction of unwanted bias from measurement instrument error.

In the management area the problem of utilization of the small specialized test teams with a wide geographic spread presents a communication and control problem among experimenters. This problem must be handled effectively for the program success and should be achieved without over-restrictive control of the experimenters. However, it must be assured that a consistency of experimental design, experimental configuration, data acquisition, and analysis does exist among them in order that the data be meaningful in satisfying the program objectives. In addition to this there is the necessity for establishing means for close coordination and data consistency among other non-NASA programs which are being currently conducted on a rather extended geographic scale by the Defense Department, Bureau of Standards and other organizations.

ANTICIPATED PROBLEM AREAS

TECHNICAL

- Field Reliability of Lab-Type Electro-Optical Equipment
- Tracking Error Degradation of Measurements
- Repeatability of Measurement Equipment to Permit Statistical Data Analysis

MANAGEMENT

- Effective Utilization of Small, Specialized Test Teams With Wide Geographic Dispersion
- Achieving Balance Between Restrictive Over-Control and Chaotic Under-Control of Experimenters
- Meshing With Existing D.O.D., N.B.S. and Non-Government Optical Propagation Programs

PROGRAM APPROACH CONCLUSIONS

In order to assure the most effective and economic utilization of resources, it is concluded that the experimental approach should consist of an initial phase of small scale pilot experiments to validate theoretical results, evaluate the concepts, components and techniques, operational procedures and data analysis routines that will be used in more extended testing. This initial experimental program should have a flexibility of design such that improvement and modification of the basic equipment configuration and experimental technique is possible during the test period.

Planning for an extended subprogram experimentation phase should be initiated at a point in the pilot test phase that will allow timely consideration of long leadtime items such as equipment design and development, facilities, and resources availability, etc.

For extended testing, in particular, the greatest efficiency in implementation can be obtained by utilization of experimenters who have been engaged in similar activities both within industry and within government organizations. Such teams of experiments are usually small and already widely spaced geographically from one end of the country to the other. It would therefore be wise to so structure the extended LACE implementation program that portions of the test program can be conducted by established teams of experimenters without frequent or lengthy relocation problems. This will provide the experience of the experimenter, the economy of conducting reasonably local tests, and the geographic diversity simultaneously. As noted under anticipated problems, this approach to the total program, while it is efficient, requires an extraordinary effort in the area of program management in order that there be a consistency among the techniques of the various experimenters and a reasonable integration of their efforts into a total experimental program.

PROGRAM APPROACH CONCLUSIONS

PROGRAM SHOULD BEGIN WITH SMALL SCALE PILOT EXPERIMENTS TO

- Validate Theoretical Results
- Evaluate Test Concepts, Techniques, and Components
- Derive Preliminary Experimental Data on Atmospheric Effects
- Check Out Operational Procedures and Data Analysis Approaches Prior to Firming Design for Extensive Testing

EXTENDED EXPERIMENTAL SUBPROGRAM SHOULD

- Be Initiated in Sufficient Time to Account for Long Leadtime Items (Planning Factors, Equipment Development, Facilities, Support Items, Etc.)
- Permit On-Going Program Evaluation and Satisfaction of Future Planning Milestones
- Include Geographic Diversity and Utilization of Existing Small Teams of Experimenters

PROGRAM SEQUENCE RECOMMENDATIONS

The first phase of the test program to determine atmospheric effects on optical propagation was the LACE Planning Study (NASw-977) currently nearing completion. This study has provided the definition of the problem (Task I); requirements and specification of necessary experiments (Task II); system implementation considerations (Task III); and a total program plan or specification (Task IV).

As a result of the analysis of the program approach and conclusions, it is recommended that a small scale pilot test program follow this planning study. As indicated previously this phase of the program would be used to design, build and field test specified test equipment configurations, provide preliminary atmospheric effects data; and develop detailed plans, procedures and data methods for extended experimental subprograms involving different links including non-spacecraft vehicles, a number of time periods, and locations.

In conjunction with the parallel extended subprogram tests a continuing data analysis, test evaluation and possible redirection of test activities should be carried out. As sufficient results of these tests are available, space vehicle test requirements should be established and methods for their accomplishment determined.

Design analysis of atmospheric effects on optical systems should then be conducted resulting in a handbook of guidelines for the inclusion of these effects in system design.

As prototype operational systems are developed, the degradation of their performance due to the atmosphere should be evaluated in field tests.

PROGRAM SEQUENCE RECOMMENDATIONS

- LACE PLANNING STUDY
- PILOT TEST PROGRAM
  - Design, Fab., Field Test, Analyze Results
- PARALLEL EXTENDED EXPERIMENTAL SUB-PROGRAMS (NON-SPACECRAFT)
  - Maximize Common Equipment Design, Consistent Test Procedures, Data Format and Reduction Techniques
  - Variety of Locations and Experiment Groups
- CONTINUING DATA ANALYSIS, TEST EVALUATION AND DIRECTION
- CONTINUING PLANNING OF ANY NECESSARY SPACE TESTS BASED UPON FIELD TEST RESULTS
- PREPARATION OF DESIGN GUIDELINES FOR ATMOSPHERIC EFFECTS ON ELECTRO-OPTICAL SYSTEMS
- EVALUATION OF OPERATIONAL SYSTEM PERFORMANCE DEGRADATION DUE TO ATMOSPHERE

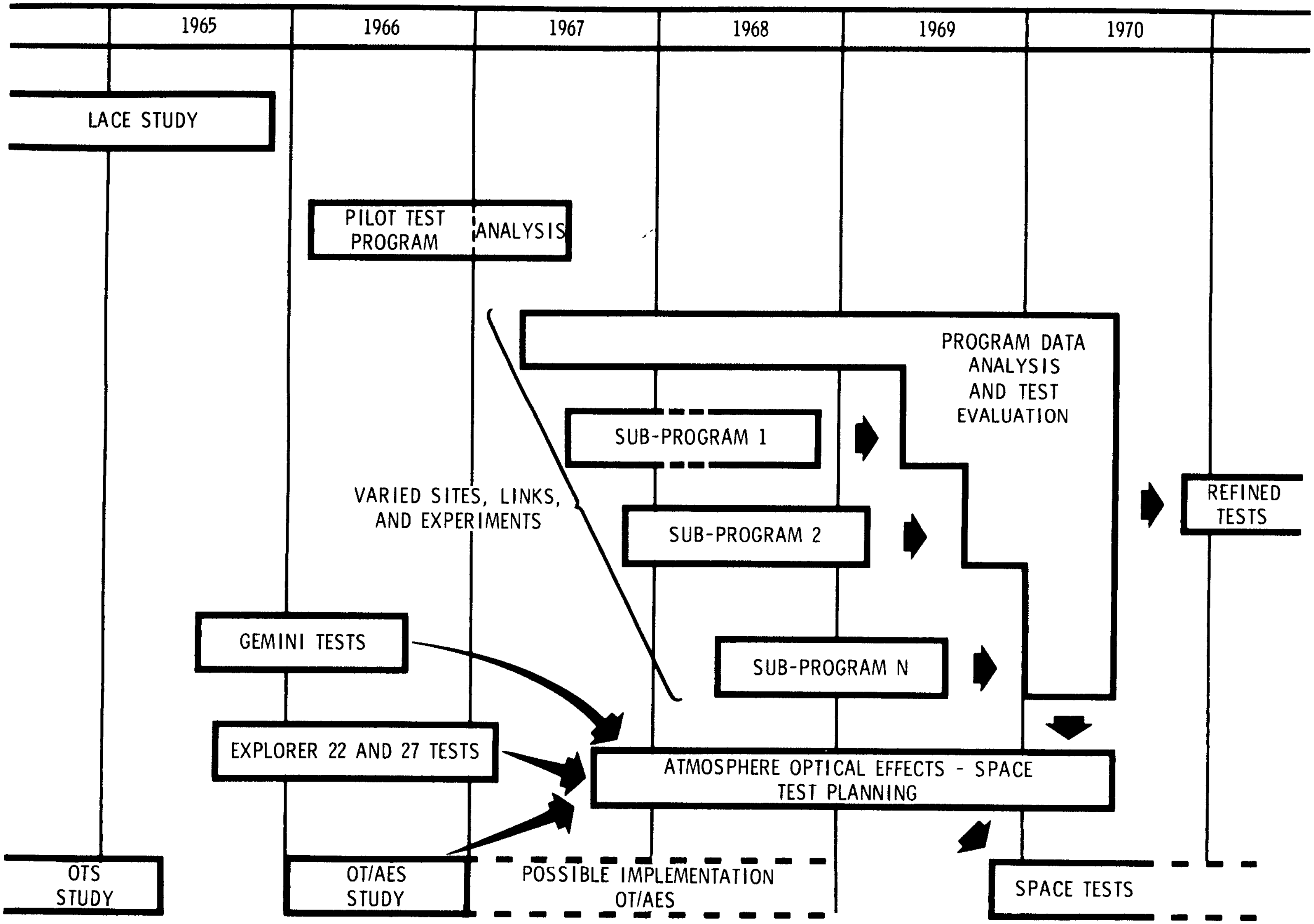
REPRESENTATIVE TOTAL PROGRAM SCHEDULE

The previous charts have presented objectives, rationale, and other considerations concluding, and recommendations for the program sequencing. This chart illustrates the recommended time phasing of a total LACE program. The exploratory nature of the recommended pilot test phase should provide preliminary validation of theoretical consideration; some statistical data on atmospheric effects; and a solid foundation for the later conduct of experiments and design of operational systems. For example, it is strongly felt that the sufficient early ground to ground link experimentation must be performed before it is practical to specify firm configurations for other links and platforms.

Although it would be possible to divide the pilot test effort and conduct the field experimentation at several locations, it is felt that the initial portion (at least) should be implemented at a single site (preferably at a flat dry lake bed region). For planning purposes, however, it has been assumed that the extended experimental subprograms will be conducted at 4 to 6 sites and/or links.

As indicated, the pilot test phase could be accomplished in approximately 18 months. Depending on the nature of the results of the pilot phase, the subprograms would extend over a 2 to 3 year period, with the built-in program review points, along the way, as a result of the on-going data analysis and test evaluation. Also, it would be the intent of the overall program planning task to make maximum use of other related tests and studies (e.g. Gemini, Explorer, OT/AES, etc.) as inputs to the atmospheric effects experimentation and for the follow-on LACE space test planning.

REPRESENTATIVE TOTAL PROGRAM SCHEDULE



LACE IMPLEMENTATION COSTS - PILOT PROGRAM SUMMARY

The costs presented in this analysis are gross estimates for planning purposes only. This chart is a composite of all estimated costs anticipated for the pilot measurement program including the minimum program. It does not include the costs for the extended sub-programs or any ground to space link testing.

A reasonably detailed breakdown of these estimates is given in the last section of this report.

LACE IMPLEMENTATION COSTS - PILOT PROGRAM SUMMARY

	CALENDAR YEARS				
	1ST	2ND	3RD	4TH	TOTAL
PERSONNEL	$290K	$130K			$420K
EQUIPMENT & SUPPORT	175	25			200
OTHER COSTS	60	60			120
	$525K	$215K			$740K

PROGRAM DEVELOPMENT ANALYSIS

STATUS OF THEORETICAL RESULTS

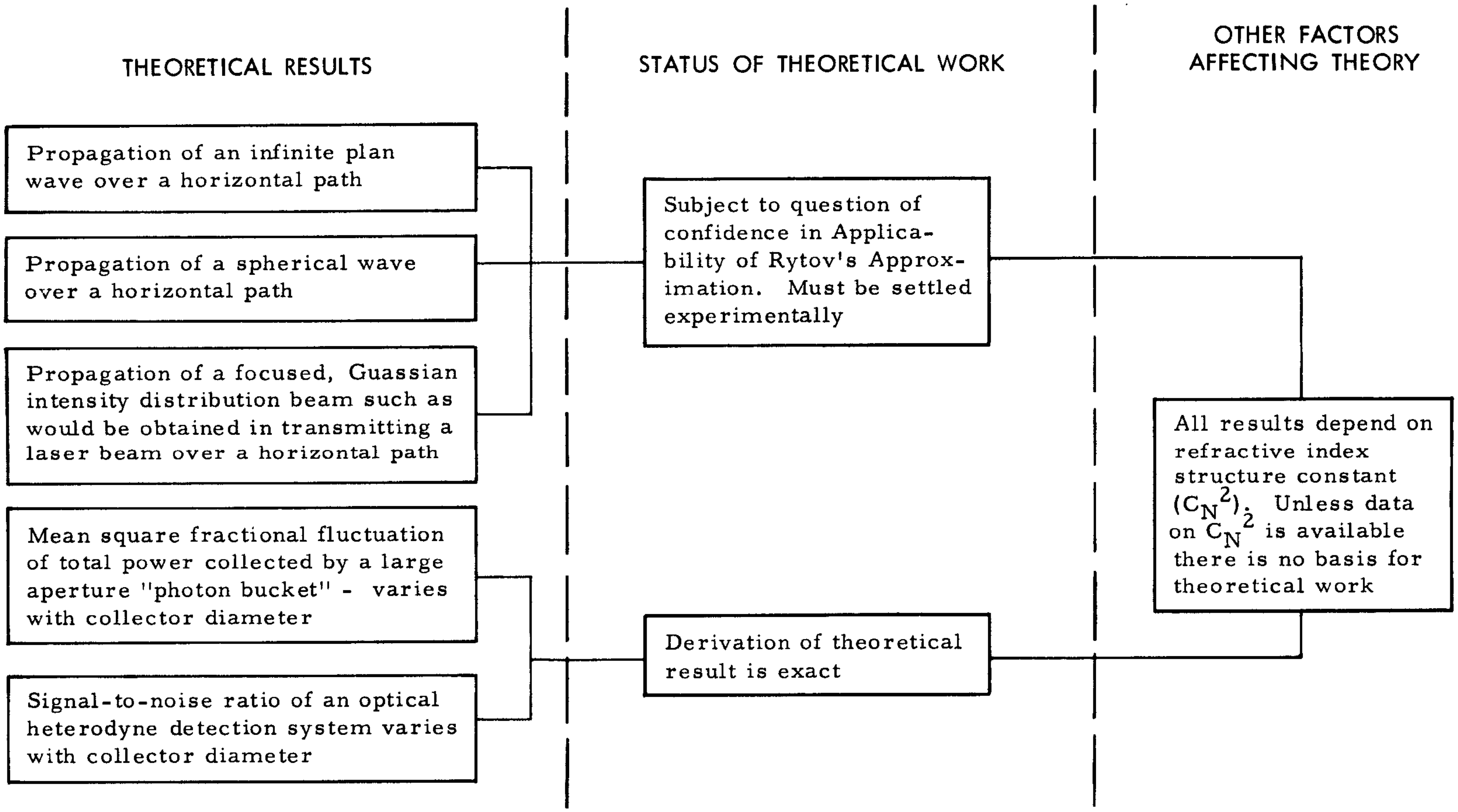
We have found that by the application of Rytov's Approximation, we are able to obtain the statistics of optical propagation from the statistics of turbulence of the propagation media. Based on extensive measurements of turbulence statistics, there is little doubt that the Kolmogoroff Similarity Theory is able to provide a satisfactory description of turbulence statistics up to but not including a constant of proportionality. With the Kolmogoroff theory, we have obtained explicit results for propagation statistics for all cases of interest. From the propagation statistics we have been able to develop exact predictions of optical systems performance in a sufficient number of cases to lead us to the conclusion that all cases will yield to a fairly straightforward approach.

As examples of our results we may quote theoretical results for $C_l\ (\rho)$, the covariance of the log-amplitude of the signal detected at two points a distance ρ apart located in the plane at the end of the propagation path; and for $D\ (\rho)$, the wave structure function, a measure of the mean square phase and log-amplitude difference between two points a distance ρ apart. These results are expressed in terms of Z, the path length; k, the wave number $(2\pi/\lambda)$; $C_N{}^2$, the turbulent refractive index structure constant of proportionality associated with the Kolmogoroff theory; and type of source (i. e. infinite plane wave, point source, and focused guassian intensity beam). These results are dependent on the validity of the applicability of Rytov's approximation, and upon the structure constant, $C_N{}^2$. (In the results presented for a horizontal path, $C_N{}^2$ is constant and can be extracted as a factor. For non-horizontal paths, $C_N{}^2$ appears in one of the integrals leading to the final result, and must be integrated over.)

Additionally, exact expressions are available for obtaining total power fluctuations collected by a large aperture "photon bucket"; and for determining the signal-to-noise ratio of an optical heterodyne detection system. These expressions also depend upon $C_N{}^2$.

At the present time we have, admittedly, crude estimates for typical values of $C_N{}^2$ at various altitudes. We have little idea of the magnitude of the error in these values, and no data on how $C_N{}^2$ varies with synoptic weather conditions, georaphic location or local terrain features.

STATUS OF THEORETICAL RESULTS



THEORETICAL RESULTS

Propagation of an infinite plan wave over a horizontal path

Propagation of a spherical wave over a horizontal path

Propagation of a focused, Guassian intensity distribution beam such as would be obtained in transmitting a laser beam over a horizontal path

Mean square fractional fluctuation of total power collected by a large aperture "photon bucket" - varies with collector diameter

Signal-to-noise ratio of an optical heterodyne detection system varies with collector diameter

STATUS OF THEORETICAL WORK

Subject to question of confidence in Applicability of Rytov's Approximation. Must be settled experimentally

Derivation of theoretical result is exact

OTHER FACTORS AFFECTING THEORY

All results depend on refractive index structure constant (C_N^2). Unless data on C_N^2 is available there is no basis for theoretical work

MINIMUM EXPERIMENTAL PROGRAM

An experimental oriented program would try to test most types of optical systems under a wide variety of environments so as to be able to predict performance, with an accompanying set of measurements intended to verify theoretical results. Such a program would be quite extensive and to the extent that extrapolation from measurements already made can be trusted, it would provide a high degree of confidence in its predictions. In contradistinction, a heavily theoretical program would rely on theory to predict what any system will do. Experiments would be carried out only to the extent necessary to test the theory and to provide the basic input parameters for the calculations. A large part of the necessary theoretical work for making these predictions has already been accomplished or is currently in progress. The purpose of the minimum program is to place emphasis upon the theoretical approach.

The scope of this program is limited, therefore, to verification of the accuracy of calculations of phase and log amplitude, consideration of only a few experimental variables and replications, and a single experimental configuration.

The following charts give, in further detail, the basis and design of the minimum experimental program.

MINIMUM EXPERIMENTAL PROGRAM

PURPOSE

- PERFORM EXPERIMENTS ONLY TO EXTENT NECESSARY TO TEST THEORY
- PROVIDE PRELIMINARY BASIC PARAMETERS FOR BASIC SYSTEM PERFORMANCE CALCULATIONS

SCOPE

- LIMITED VERIFICATION OF ACCURACY OF CALCULATIONS OF PHASE AND LOG-AMPLITUDE
- MINIMUM NUMBER OF EXPERIMENTAL VARIABLES
- TEST PERIOD OF SHORT DURATION — FEW REPLICATIONS
- SINGLE EXPERIMENTAL CONFIGURATION — NO COMPARATIVE ANALYSIS

MINIMUM PROGRAM EXPERIMENTAL VARIABLES

A good test runs through as many independent variables as possible. For instance, dependence on path length, wavelength, and refractive index structure constant should all be considered. A good experimental set up will allow each of these to be varied over a large range if possible.

A good test of the theory should be designed so as not to violate any of the configuration assumptions inherent in the calculation being tested. This may mean, for instance, that the propagation path must be "sufficiently close" to uniform so that the turbulence statistics do not vary over the path if uniform turbulence statistics were assumed in the computation. Likewise, the wave being propagated must start in a condition "sufficiently close" to that assumed in the analysis, i.e., plane wave, point source, or collimated beam. Careful attention must be paid to the precise meaning of "sufficiently close." Unless this consideration is heeded, there is no assurance that the experiment will give results related to the theory.

While it is more or less true that an experiment (or a set of experiments) cannot prove a theory, but can disprove it, this is not entirely the case here since we are testing not so much a theory as the accuracy of an approximation. Accuracy is something that an experiment can verify, but accuracy may be satisfactory for one type of computation and not for another. In particular, calculations pertaining to both phase and log-amplitude should be tested. Separate experiments sensitive to either wave front or intensity fluctuations should be implemented.

MINIMUM PROGRAM EXPERIMENTAL VARIABLES

- PROPAGATION PATH
- PROPAGATION WAVE CONSIDERATIONS
- RECEIVER MEASUREMENTS

PROPAGATION SOURCE CONSIDERATIONS - MINIMUM AND PILOT PROGRAM

One must be certain that the experiment set-up uses an optical source which launches an unperturbed wavefront which closely resembles that assumed in the theoretical computations.

We have three options for the experimental setup. The optical source can be designed to simulate the infinite plane wave, the point source, or the focused Gaussian intensity beam. Of the three, the point source appears least likely to be suitable for our purposes. The spread of the beam into several steradians will so severely attenuate the beam at a range of even a mile that no useful measurements could be made. As an alternative, we might consider a small but finite size source. If the receiver equipment were not so large that it could resolve the extent of the source, off hand one might be tempted to rely on physical intuition and assert that this is a good simulation of the point source. However, the inhomogeneities in the atmosphere which are near the source will be able to "resolve" the finite size.

From the point of view of the best known solution to the propagation problem, the infinite plane wave source is the one that should be simulated. Obviously, the source for an infinite plane wave, requiring an infinite diameter collimator lens, calls for an infinite budget and is not a reasonable choice. A reasonable simulation with a finite diameter collimator is possible. The experimental setup has the principal advantage that the appropriate theory is familiar to most workers, and the principal disadvantage that it relies on physical "arguments" to prove the equivalence of the theory and experiment, which again may offer a loophole in interpreting the results if they prove to be negative.

Perhaps the simplest of the three source configurations to simulate is the Gaussian-intensity-distribution source, corresponding to a laser beam. The source considerations are so straight-forward that they need no discussion here.

PROPAGATION SOURCE CONSIDERATIONS — MINIMUM AND PILOT PROGRAM

CANDIDATES	QUALIFICATIONS	CONCLUSION
Point Source	Spread of Beam Into Several Steradians Will Severely Attenuate the Beam at a Range of Even One Mile	Not Recommended
Infinite Plane Wave	Should Be Simulated for Best Known Solution to Propagation Problem, But Would Require Infinite Diameter Collimator Lens - or Infinite Budget	Not Recommended
Collimated Beam	Reasonable Simulation of Plane Wave Source With a Finite Diameter Collimator Is Possible. Physical Assumptions Necessary	Not Recommended
Guassian-Intensity-Distribution	Simplest and Most Accurate Source to Simulate	Recommended

SITE SELECTION ANALYSIS - MINIMUM AND PILOT PROGRAM

The site selected for the propagation experiments should provide a long path - several miles, with the ground features so uniform that we can be reasonably certain that the turbulence statistics do not change along the path. This means that the ground must be sufficiently level so that the propagation path height above the ground is constant. The ground roughness must be constant over the path length. Obstructions to wind flow should be absent or uniformly distributed along the path. (The former is preferable.)

A path over water would meet all these requirements. However, because the end points of the path should not be different from the rest of the path, they should not be on the shore. Both stations should be on the water. This would entail use of boats with associated optical stability problems. An alternative type of site, which would avoid station stability problems, would make use of a dry lake bed of the type which abounds in the southwestern United States. Long, completely uniform paths are easily located. Aside from the logistic problems of setting up and maintaining a field lab in the desert environment associated with a dry lake bed, this appears to be an optimum site location. Even the logistics need not be too formidable a problem if the site is chosen in relation to an existing government facility, many of which enclose, or border, a dry lake bed (e.g. NOTS, China Lake, Edwards A. F. B., White Sands, etc.).

Further detailed discussions pertinent to site selection are contained in the Task III report.

SITE SELECTION ANALYSIS - MINIMUM AND PILOT PROGRAM

- Long Horizontal Path — Several Miles
- Uniform, Level Ground Features
    - ✓ Roughness Constant Over Path Length
    - ✓ Path Height Above Ground Constant
    - ✓ Turbulence Statistics Similar Along Path
- Obstructions to Wind Flow Absent or Uniformly Distributed Along Path
- Alternate Paths Over Water

  Dry Lake Bed

Recommended Site - Dry Lake Bed

EXPERIMENTAL VARIABLES AND MEASUREMENTS - MINIMUM PROGRAM

Because of the ease and accuracy with which the laser beam source can be produced as compared to the infinite plane wave, it is recommended that all measurements be based on a laser beam source. By use of suitable optics, the beam diameter at the source can be made to take any value. Likewise, the beam can be produced in a collimated form or else focused in the receiver plane. This will permit the following experimental variables: 1) wavelength (e. g., .6333μ, 1.15μ, and 3.39μ); 2) path length; 3) source diameter; and 4) focused or unfocused.

Whatever quantities are measured at the receiver end of the link should be such as to provide a test of the theoretical predictions discussed earlier. Ideally, measurements should consider both phase and intensity effects. If a plane wave or spherical wave transmitter were used, then perhaps the two simplest measurements would be of $C_1(\rho)$ by a direct photodetector measurement processed by an analog computer, and a photographic procedure of recording the spread of the source as imaged by a camera. From the spread, the wave structure function can be computed and compared with $D(\rho)$.

With the preferred source, which is the variable diameter laser beam projector, both phase and intensity type effects can be measured with a small aperture photodetector, thus avoiding the need for photographic techniques. Measurements would be made of $C_1(0)$ by processing the intensity fluctuations observed with a small collection aperture detector, and of the beam spread at the receiver, made by traversing the detector through the laser beam. $C_1(0)$ is obviously related to intensity fluctuation effects, while the beam spread is directly related to the transmitter antenna gain which is determined by the phase distortion effect.

In summary, the minimum program measurements should be made with a variable diameter, changeable wavelength laser source, operating over a variable path length at a dry lake site, using a point collector to measure the log intensity variance and the beam spread. These measurements will provide a fairly comprehensive basis for establishing the non-validity, validity, or limits of validity of the Rytov Approximation, and permit extrapolation of optical propagation effects to situations not measured.

EXPERIMENTAL VARIABLES AND MEASUREMENTS - MINIMUM PROGRAM

EXPERIMENTAL VARIABLES

- Source
  - Laser
  - Wavelength (e.g., 0.6333μ, 1.15μ, and 3.39μ)
  - Variable Diameter
  - Focused or Unfocused
- Path Length
  - Up to Approximately 10 Miles

MEASUREMENTS

- Receiver
  - Log Intensity Variance
  - Beam Spread
- Path
  - Temperature Profile and Power Spectrum
  - Wind Velocity
  - General Synoptic Meteorological

MINIMUM MICROMETEOROLOGY FOR EXTRAPOLATION OF RESULTS TO PROPAGATION OVER UNMEASURED PATHS

The key environmental number in using the theory to set the strength of atmospheric optical effects is the refractive index structure constant, C_N. If we know the distribution of C_N over any path, we can compute the atmospheric optical effects for propagation over that path. C_N is not easily measured directly. However, we know that local refractive index variations in the atmosphere are directly related to minute local temperature variations, the correlation of which is governed by the same two-thirds power law as for refractive index correlation, and by the temperature structure constant C_T^2. It can be shown that

$$C_N \simeq 10^{-6} \, (\rho/\rho_o) \, C_T$$

where (ρ/ρ_o) is the ratio of atmospheric density at the altitude at which C_N is measured, to atmospheric density at sea level.

The temperature structure constant, C_T, can be measured directly with a high speed, high sensitivity thermometer. The power spectrum of the temperature fluctuations observed can be used to compute C_T^2 (with the wind velocity or rate of motion of the thermometer used to convert temporal to spatial frequency.)

A two phase micrometeorological program is therefore desirable. In the first phase, a high speed thermometer would be used in conjunction with the optical propagation experiments to confirm the possibility of measuring C_T^2 and relating this to C_N^2 and to the strength of the optical fluctuation effects. In the second phase (as a follow-on to the minimum program), the value of C_T would be measured at various altitudes, times of day and year, and at several geographic environments to develop relationships with gross meteorological conditions.

The measurement of C_T at high altitudes is the major problem and is currently under attack. The most promising approach appears to be the possibility of radiosonde balloon (or parachute) probing of the minute temperature variations with a high speed thermometer. The scope and details of such a measurement program could be established from the results of initial, limited measurements taken during the minimum or pilot program.

MINIMUM MICROMETEOROLOGY FOR EXTRAPOLATION OF RESULTS TO PROPAGATION OVER UNMEASURED PATHS

- DETERMINE DISTRIBUTION OF REFRACTIVE INDEX STRUCTURE CONSTANT, C_N^2, OVER PATH
    - ✓ DEVELOP HIGH SPEED TEMPERATURE (10^{-2} SEC) MEASUREMENT SET-UP
    - ✓ PERFORM MEASUREMENT OF TEMPERATURE AND WIND ALONG PATH TO ESTABLISH C_T, THE TEMPERATURE STRUCTURE CONSTANT, AND THEREBY DETERMINE C_N ($C_N \approx C_T$)
- DEVELOP A PLAN FOR AN ON-GOING MEASUREMENT PROGRAM OF C_T
    - ✓ AT VARIOUS ALTITUDES, TIMES OF DAY AND YEAR, AND GEOGRAPHIC LOCATIONS
    - ✓ AND POSSIBLE CORRELATION TO GROSS METEOROLOGICAL CONDITIONS

PILOT TEST PROGRAM OBJECTIVES AND SCOPE

A great deal of the background presented with the minimum program discussion is also applicable to the development of the design of the pilot test program. However, as indicated under the program trade-off consideration, the pilot program would provide more breadth and depth in the total understanding of the propagation problem.

The pilot program would be divided into a number of tasks and tests that would yield atmospheric effects data and a solid basis for more extensive experimentation.

PILOT TEST PROGRAM OBJECTIVES AND SCOPE

OBJECTIVES

- Development and Test of Basic Measurement Techniques
- Acquisition of Preliminary Atmospheric Data
- Provide Background and Basis for Extended Experimental Sub-Program Phase

TASKS

- ✓ Equipment Evaluation — Performance and Test Suitability
- ✓ Site Survey and Site Activiation
- ✓ Detailed Test Procedures
- ✓ Data Collection and Analysis Plan
- ✓ Preparation for Sub-Program Implementation (Including Detailed Test Design and Analysis Plan)

TESTS

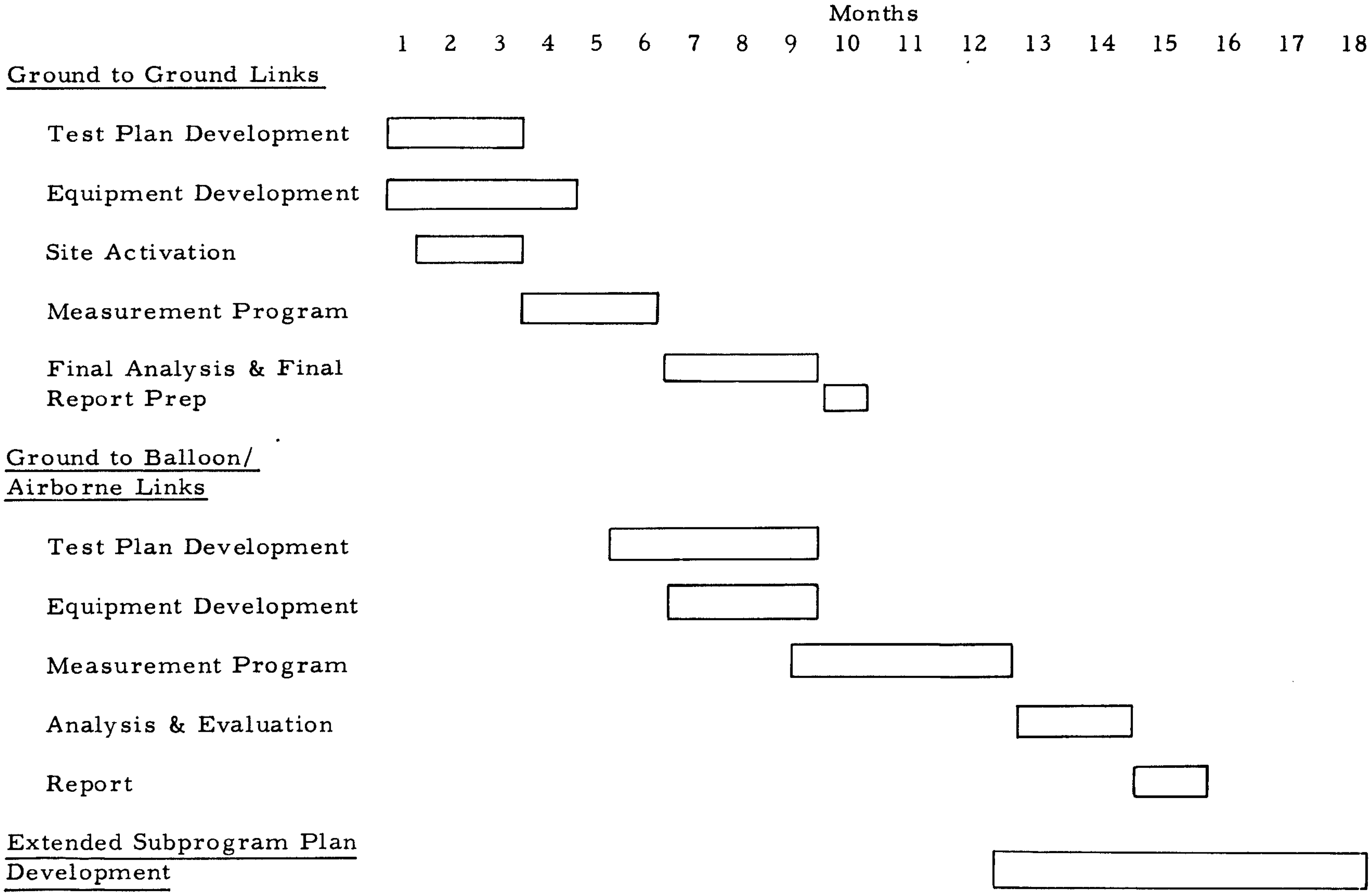
- ✓ Equipment and Concept Checkout
- ✓ Limited Atmospheric Effects Data Acquisition
- ✓ Operational Procedure Testing
- ✓ Develop Preliminary System Performance Factors

TOTAL PILOT TEST PROGRAM SUMMARY (TYPICAL SCHEDULE)

The total pilot test program has been divided into tasks and tests related to ground to ground links, ground to balloon/aircraft links; and the development of an extended sub-program experimental plan. The ground to ground link pilot test phase will be the basis for defining the nature and scope of the follow-on tests. That is, it will be difficult to establish the extent and depth of the other portions of the total LACE program until this portion of pilot test phase has been conducted. Therefore, it is necessary that a range of measurement concepts and techniques be evaluated. In the subsequent discussion, emphasis is placed on the ground-to-ground link.

The total pilot test phase could be planned to extend over an 18-month period. This schedule would allow for an overlap in the ground to ground and ground to air link tests. Depending upon the extent of difficulty encountered and outcome of the early test periods, it is possible that the schedule could be stretched out or compressed. However, it is presently felt that this overall schedule is realistic for the pilot test objectives.

TOTAL PILOT TEST PROGRAM SUMMARY (TYPICAL SCHEDULE)

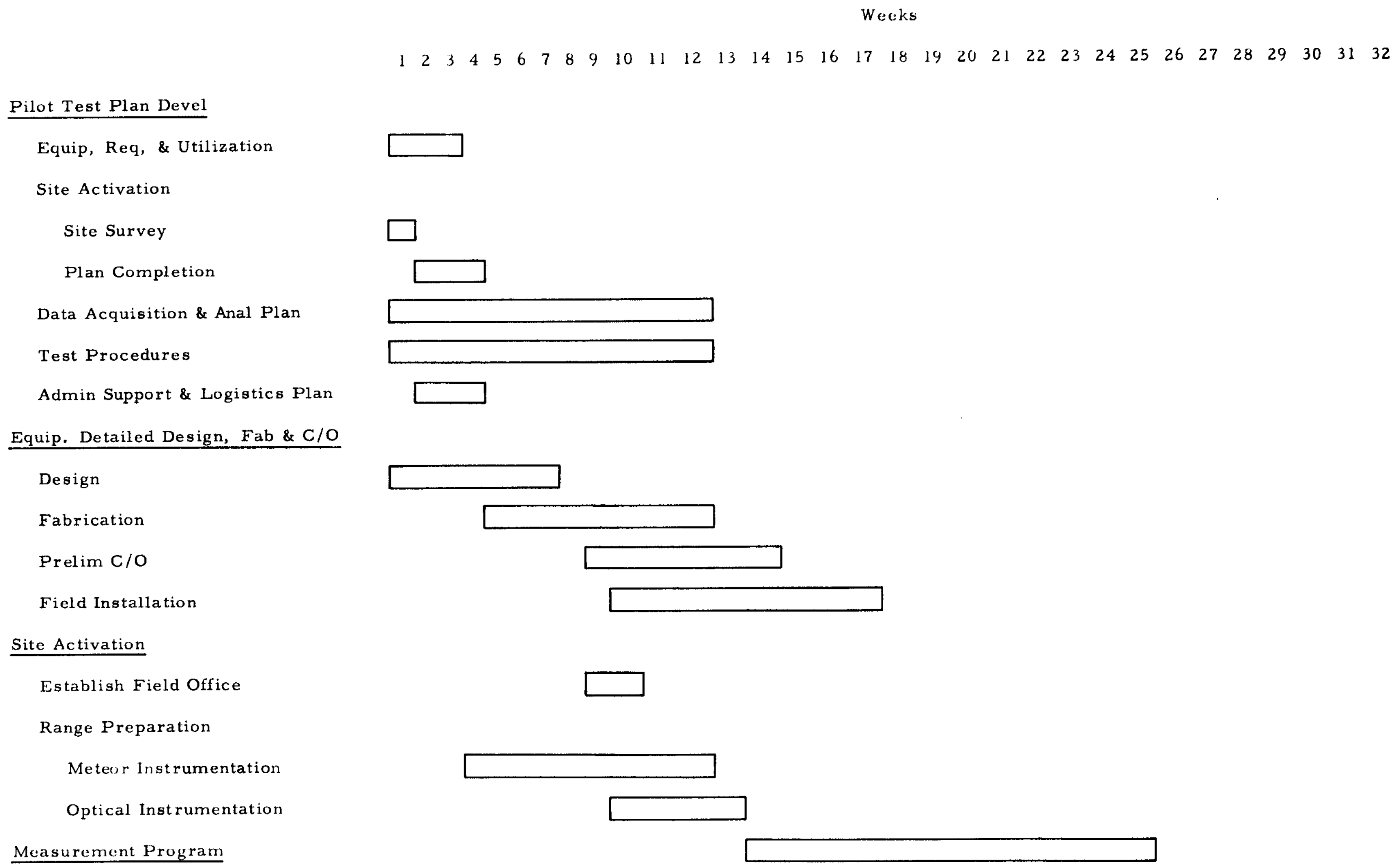


PILOT (GROUND TO GROUND LINK) TEST PROGRAM SUMMARY - TYPICAL

This chart presents a typical detailed breakdown of the tasks envisioned for the first phase of the pilot test program. Experience has shown that a thorough test plan development task is extremely important to the test conduct and quality of the results obtained. For this reason, adequate emphasis (12 weeks) has been placed upon this task, which will be conducted in conjunction with the equipment development task (up to 18 weeks), and the site activation task (10-12 weeks). The measurements program for this sub-phase, which is divided into three test and analysis cycles, will extend over a twelve-week period.

A portion of the effort expended for the test plan development site activation during this sub-phase will also be applicable to the ground to air link sub-phase.

PILOT (GROUND TO GROUND LINK) TEST PROGRAM SUMMARY - TYPICAL



PILOT (GROUND TO GROUND LINK) TEST - TYPICAL TEST PHASING

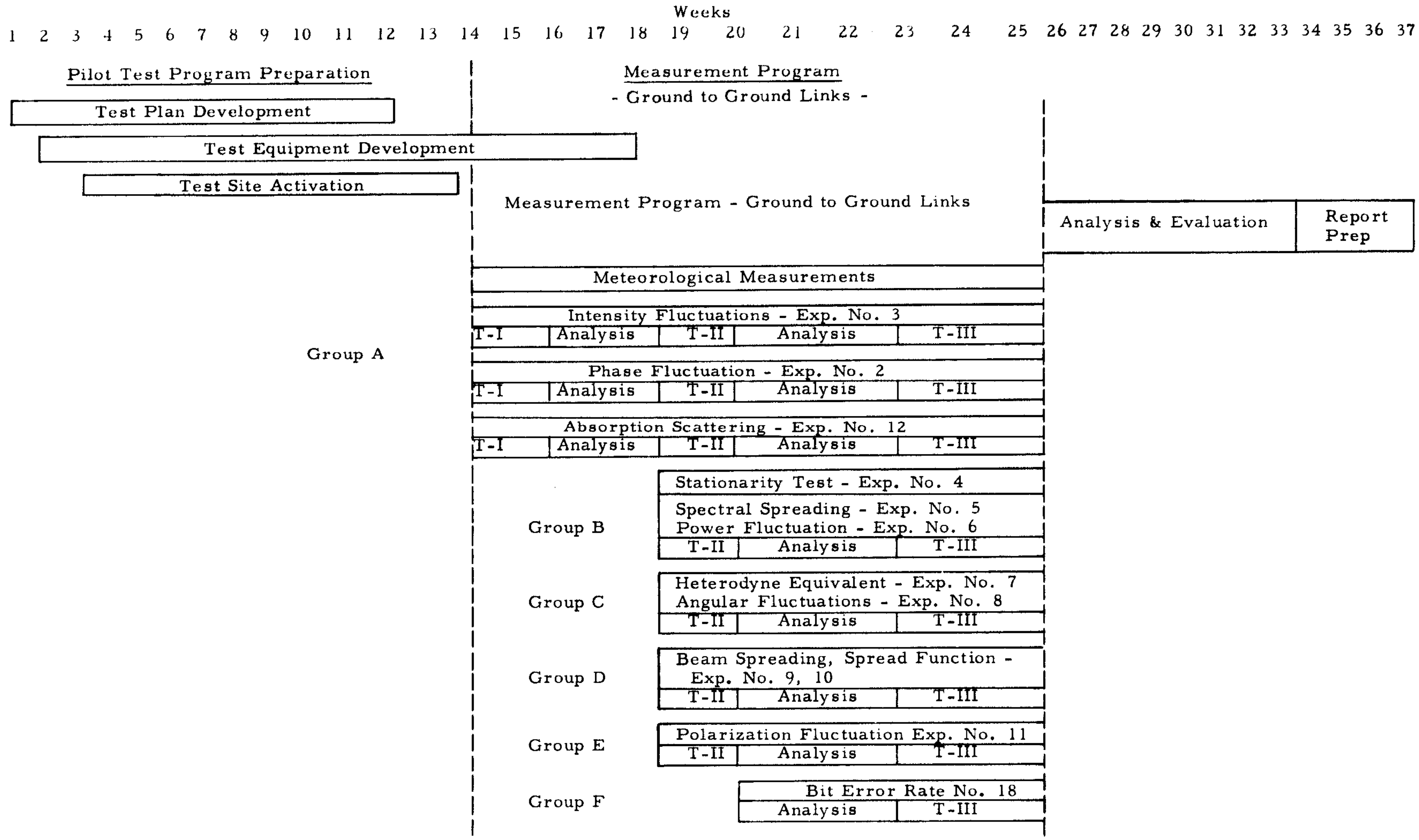
Typical sub-phasing of the entire ground to ground link portion of the pilot test program is illustrated in this chart. The three test periods (T-I, T-II, T-III) are projected as two weeks each in length. This period of time is flexible, depending upon setup time, difficulty encountered, etc. Each of the analysis periods will be utilized for evaluating the results of the preceding weeks, with emphasis upon experimental considerations that could have a bearing on the conduct of the next test period. It is expected, also, that these analysis periods will yield some preliminary atmospheric effects data that can be utilized in related and parallel laser propagation studies.

It should be noted that the early (T-I) emphasis in the program will be upon basic aspects of phase and amplitude fluctuations, followed by experiments in the more complex aspects of propagation effects. In fact, the T-I phase of the program can be considered to represent the minimum test program discussed earlier.

An experimental grouping (i.e., A, B, C, D, E, and F) has been established for reference purposes only, and is not meant to imply an implementation priority. Task III, System Implementation Study, presents a discussion of the relative merits, limitations and possible priority of implementation of the individual experiments. The test grouping presented here is only meant to illustrate a typical test phasing schedule, and is subject to final definition during the test plan preparation phase.

Meteorological measurements and absorption-scattering experimentation will extend throughout the entire pilot test phase.

PILOT (GROUND TO GROUND LINK) TEST - TYPICAL TEST PHASING



PILOT (GROUND TO GROUND LINK) TEST PROGRAM - SUMMARY OF OBJECTIVES AND SCOPE

The ground to ground link test program is summarized in this chart in terms of the test sub-phase and scope, experimental variables, secondary testing, test observation support, and objectives. Main emphasis in test sub-phase (T-I) is upon the validation and checkout of the basic phase and amplitude experimental set-up, and verification of Rytov's approximation, and represents the minimum experimental program. The controlled independent variables of T-I are planned as follows: Path Length - (horizontal) 3 miles, 10 miles; laser frequency - 6328 Å, 1.15 μ, and 3.39 μ (others may be substituted); Aperture Size - Receiver fixed, transmitter variable; Beam Diameter - continuously variable; diurnal varations. Other uncontrolled variables associated with meteorological conditions (e.g. C_N^2) will be measured and evaluated during the analysis period.

Test sub-phase (T-II) controlled variables are the same as (T-I), except that spatial correlation will be included. The receiver and path length variability will be as shown on the next chart, which gives a detailed breakdown of pilot test variables. The remaining experiments (#'s 4, 5, 6, 7, 8, 9, 10 & 11) will be added to evaluate their experimental interrelationships. Additionally, greater emphasis during (T-II) will be placed upon experimental equipment set-up analysis in order to determine the best configurations for later testing. The equipment evaluation will attempt to obtain optimum configurations for later testing. The equipment evaluation will attempt to obtain optimum configurations which minimize equipment error. The typical error sources to be evaluated are: modulators; beam splitters; S/N, gain; vibration; ambient environment; circuitry; averaging time; entrance aperture; phase lock loops; component integration effects; etc.

Test sub-phase (T-III) is similar to the previous sub-phases in most respects except that the path length should be changed from horizontal to near vertical, long range, surface to mountain top over several path lengths (e.g. 15 miles-4100 ft. elev.; 25 miles-7800 ft. elev.; 45 miles-10,000 ft. elev.). The communication bit error rate experiment (#18) will be performed during this test phase.

PILOT (GROUND TO GROUND LINK) TEST PROGRAM - SUMMARY OF OBJECTIVES AND SCOPE

Typical Test Week	1 2	3 4 5	6 7	8 9 10	11 12	13 14 15 16 17 18 19 20	21 22 23 24 25 26
Activity	Test Sub-Phase (T-I)		Test Sub-Phase (T-II)		Test Sub-Phase (T-III)		
Test Sub-Phase Scope	Parts of experimental configuration No. 2 and 3, no spatial correlation measurements	Analysis of test results	Spatial correlation measurements of exp. No. 2, 3, Testing Experimental Groups B. 4, 5, 6 C. 7 and 8 D. 9 and 10 E. 11	Analysis of test results	Same as Category II except use mountain top links. Add exp. No. 18	1. Test analysis and evaluation 2. Preparation for ground to air pilot tests 3. Initiate sub-program experimental planning	Report preparation
Experimental Variables (No. of Levels)	Path length (2) Frequency (3) Aperture size Receiver-fixed Trans-variable Beamwidth-variable		Same as I except add 3 spatial separations for experiments 1 and 2		Same as I and II except path length to several mountain tops included		
Secondary Testing	Experiment No. 12 config. (Absorption - scattering)		Same as I		Same as I and II		
Test Observation Support	1. Local meteorology 2. Remote indication along path		Same as I plus tethered meteorology balloon observation		Same as II		
Objectives	Evaluate Rytov's approximation and determine C_N^2		1. Inter-experiment correlation 2. Equip. and procedure analysis 3. Atmos data acq.		1. Long and near vertical link eval. 2. Final equip. config eval.		

PILOT TEST EXPERIMENTAL VARIABLE SUMMARY

This chart presents a summary of the independent variables and levels of variability suggested for each of the experimental configuration suggested for examination during the pilot test phase. These variables were selected primarily on the basis of consideration of the problem definition and error analysis of Task I and II.

PILOT TEST EXPERIMENTAL VARIABLE SUMMARY

Experiment	Receiver		Path Length (R)	Transmitter		
	Aperture	Spatial Separ. (ρ)		Aperture, Focal Length, & Beam Width	Wavelength	Other
1. Spatial & Temporal Correlation Function 2. Phase Structure Function 3. Amplitude Correlation Function	1. As small as possible (approx 1 mm) 2. May be increased as S/N decreases	1. Should range from 0 cm to 1 meter with emphasis on 0 to 20 cm 2. Range of ρ might be larger for long paths	1. Since $D_{\phi\phi} \sim R$, equal intervals are satisfactory 2. Since $C_{LL} \sim R^3$, intervals at large R should be smaller 3. Horizontal path 1, 2, 5, 10, 15 km 4. Long near vertical links 12, 15, 20, 30 km	Variable	6328Å 1.15 μ 3.39 μ or as established at a later date	—
4. Stationarity Test	1. Not an experimental variable 2. A function of Fresnel lens	1. Not applicable	1. Same path lengths as above	Same as above		—
5. Spectral Spreading	1. A range of variation would be desirable 2. 0.1 cm, 1 cm, 2 cm, 10 cm, 25 cm, 100 cm	1. Not applicable	1. Same path lengths as above	Same as above		—
6. Power Fluctuation	1. For short ranges should be larger than beam 2. Same sizes as No. 5	1. Not applicable	1. Same path lengths as above	Same as above		—
7. Heterodyne Equiv 8. Angular Fluctuation	1. Same as above	1. Not applicable	1. Same path lengths as above	Same as above		—
9 & 10. Spread Function & Beam Spreading	1. Same as above 2. Fresnel lens may be used at longer distances	1. Not applicable	1. Same as above	Same as above except beam width focused to minimum at receiver		—
11. Polarization	1. Same as No. 5	1. Not applicable	1. Same as above	Same as above		Linearly & circularly polarized

SUB-PROGRAM EXPERIMENTATION EXAMPLE

The sub-program experimentation program is an extension of the pilot program to an examination of a larger range of propagation parameters at a number of geographic locations, climatological regions, up and down links, and platforms. It would be premature at this time to plan a complete extended program much beyond what has been discussed earlier as being planned for the pilot program.

This chart is simply presented as an example of the approach that will be taken toward development of the extended program experimental design.

SUB-PROGRAM EXPERIMENTATION EXAMPLE

OBJECTIVE:	Near-Vertical Up and Downlink Laser Amplitude Characteristics
LOCATION:	White Sands Missile Range, New Mexico
VEHICLE(S):	Low Altitude Tethered Balloon and Variable Altitude Aircraft
CONTRACTOR:	To Be Established (e.g., Univ. of New Mexico) Balloon and Aircraft Ops. by AFCRL
PARAMETERS:	Laser Frequency and Beamwidth, Receiver Aperture, Dual Aperture Separation, Range, Zenith Angle
EXPECTED RESULTS:	Spectrum of Amplitude Fluctuation Probability Density of Amplitude Log-Amplitude Correlation Function
PROBLEM AREAS:	Balloon-Borne Laser Pointing Target Tracking Limited Altitude at Reasonable Cost Equipment Reliability

PROGRAM MANAGEMENT, SUPPORT, AND ESTIMATED COSTS

PROGRAM MANAGEMENT APPROACH

Because of the exploratory nature of the pilot program, close coordination is required by the participants during all phases of the program. While it may be possible to delegate some of the implementation support to other agencies, it is felt that a team approach is needed throughout the planning, development and field conduct to insure effective performance of all aspects.

The recommended program management approach for the extended experimental program was determined by consideration of a combination of factors. These included the present sources of experienced experimenters. The desirability of geographic dispersion of test sites, the present limitations of NASA center staff sizes in this field, and a requirement to minimize costs of obtaining the desired program results.

To satisfy these constraints, it is felt that a prime contractor should be selected to work with NASA in providing overall program management. Included in this function would be the continuing data analysis and correlation, test coordination, evaluation and redirection, technical monitoring of subcontractors, and reporting on program results. A single point of communication and responsibility can thus be established which will maximize the quality of results obtained with given resources.

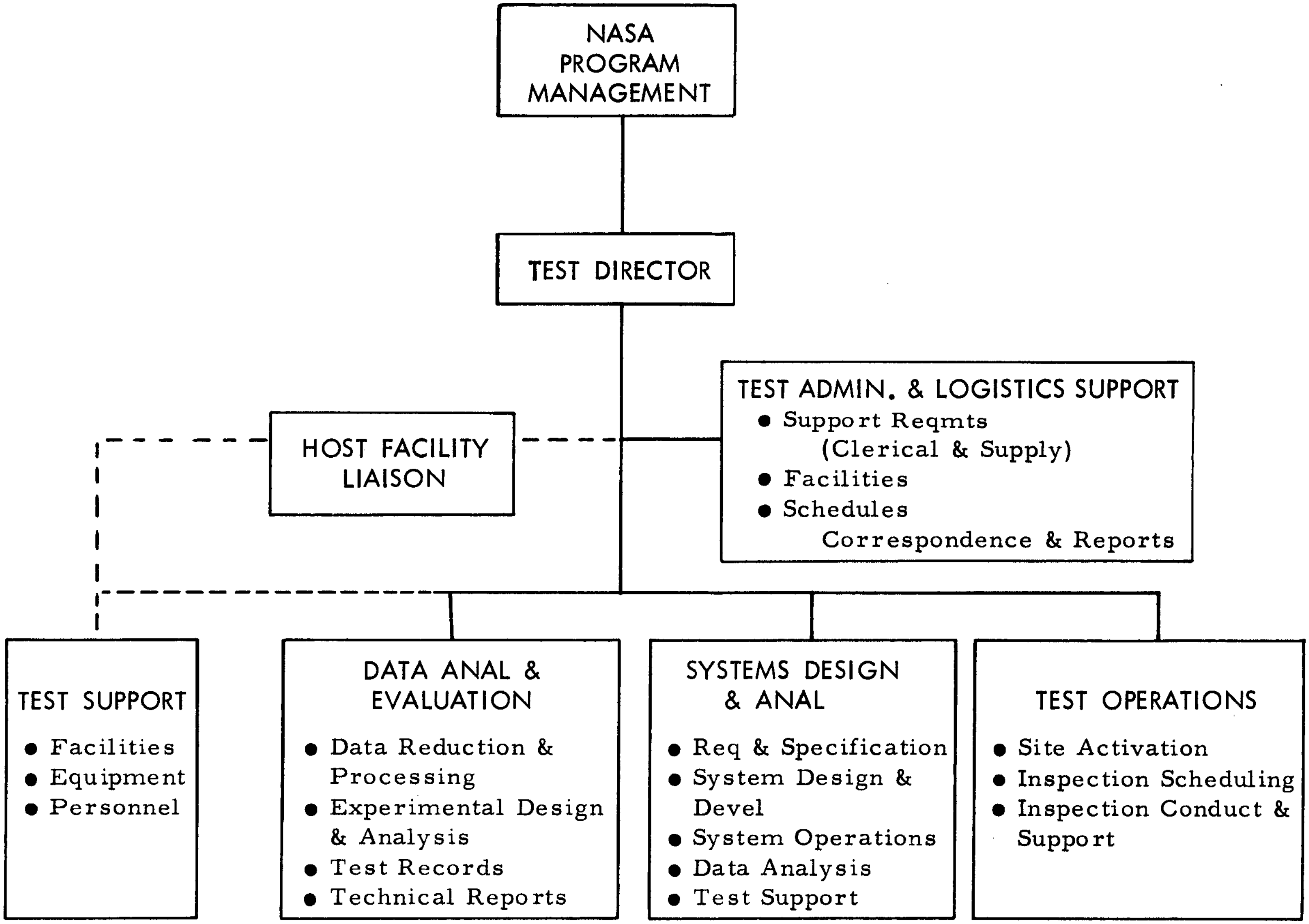
PROGRAM MANAGEMENT APPROACH

- INITIAL PILOT PROGRAM REQUIRES CLOSE COORDINATION AND CENTRALIZATION OF MANAGEMENT AND TECHNICAL EFFORT
- MAXIMUM EFFECTIVENESS (COST & TECHNICAL) OF EXTENDED EXPERIMENTATION INDICATES USE OF MULTIPLE PARALLEL TEST SUB-PROGRAMS WITH EXISTING EXPERIENCED TEAMS WITH MINIMUM RELOCATION
- DIRECT NASA MANAGEMENT AND INTEGRATION OF MANY SEPARATE SMALL TEST SUB-PROGRAMS WOULD REQUIRE COMMITMENT OF SIZEABLE TECHNICAL AND ADMINISTRATIVE STAFF
- SELECTION OF A PROGRAM MANAGEMENT AND INTEGRATION PRIME CONTRACTOR FOR EXTENDED EXPERIMENTAL PROGRAM IS THE MOST REASONABLE COURSE TO PROVIDE A SINGLE FOCAL POINT BETWEEN THE MULTIPLE NASA AND INDUSTRIAL ORGANIZATIONS PARTICIPATING IN THE PROGRAM

PILOT TEST FUNCTIONAL ORGANIZATION

This chart gives a typical functional organization chart for execution of the pilot test program. It is presented merely as an illustration of the functional relationship of the different test program tasks. A similar organization of tasks, but modified in scope, would be applicable to the minimum and extended experimental program. As indicated, the major tasks breakdown into test support, data analysis and evaluation, system design and analysis, and test operations. It is particularly important that the latter three functional groups be closely integrated to insure that the test objectives are satisfied.

PILOT TEST FUNCTIONAL ORGANIZATION



SUPPORTING INSTRUMENTATION, SERVICES, AND FACILITIES REQUIRED

This chart gives a representative list of the basic support that would be required during the initial field test phase of the pilot program. The same type of support would be required for each sub-program of the extended experimental program, except that additional consideration must be given to aircraft support, remote sites, etc. as the explicit requirement becomes evident.

The Task III report presents a comprehensive discussion of the various supporting instrumentation requirements.

SUPPORTING INSTRUMENTATION, SERVICES, AND FACILITIES REQUIRED

Item	Qty	Remarks
METEOROLOGICAL INSTRUMENTATION & SUPPORT		
Instrument Shelters (portable) Mercury Wet & Dry Bulb Thermometers Hygrothermograph, Microbarograph Portable Aerovane Wind-Speed and Direction Transmitter, Recorder, and Indicator	4 ea 4 ea 4 ea 4 ea	1. For use at laser path height at transmitter/receiver, and along path 2. Standard meteorological equipment satisfactory
Remote Temperature Sensors (for tower use)	24	Time constant 0.01 to 0.1 sec. Accuracy 0.01 °C
Semi-portable Meteorological Tower	4	1. 60-200 feet in height with capability of being set up in less than 4 hours 2. Six levels for recording and telemetering temperature, pressure, humidity, and wind (direction and velocity)
Recorders for Meteorological Tower and Tethered Balloon Data	to be specified	To be utilized in recording telemetered data
Rawinsonde Observations	to be specified	Every 12 hours during tests
Pibal Observations	to be specified	To be taken at field site and at terminal of long distance links for correlation with area Rawinsonde
Local Synoptic Observation	to be specified	WBAN form 10A and 10B for test period
Tethered Ballons	to be specified	1. Equipment will be same as that located on meteor towers 2. To be used to extend portable tower capability to altitudes of up to 10,000 feet 3. Altitude will be an experimental variable 4. Requirement for mountain links to be established
OTHER SERVICES & SUPPORT		
Film Processing	variable	Rapid, continuous processing of test segments
Vehicles (jeeps and 3/4 ton truck)	4-5	Equipped with two-way radio for test operations
Office and Instrumentation Facility	8-10 rooms	To be used by test personnel in planning, implementation, and analysis
Data Processing	to be specified	The final equipment design will determine explicit requirements

PILOT TEST PROGRAM ESTIMATED COST BREAKDOWN

The estimated pilot test program costs are given here in terms of personnel costs, equipment costs and other costs (data processing, host facility services). It is recognized that any change in the notes and assumptions shown, especially changes to the overall scope and means of implementation, will change the cost estimate considerably.

It is felt that the conduct of the minimum portion of the program only would represent a cost of 1/4 to 1/3 of the estimate for the first calendar year (i. e. $130, 000 to $175, 000).

PILOT TEST PROGRAM ESTIMATED COST BREAKDOWN

	Calendar Years		
	1st	2nd	Total
PERSONNEL COSTS			
Contractor[1]	$250K	$130K	$380K
Host Facility Support[2]	40K	5K	45K
			$425K
EQUIPMENT COSTS			
Optical Equipment Development, Instrumentation, and Support[3]	$ 75K	$ 25K	$100K
Meteorological Instrumentation & Support[3]	100K	- 0 -	100K
			$200K
OTHER COSTS			
Data Processing[3]	$ 50K	$ 50K	$100K
Facilities Services	10K	10K	20K
			$120K
TOTAL	$525K	$220K	$745K

Notes and Assumptions

1. Average 8-10 man level and per diem
2. Average 1-2 men for liaison and support
3. Assumes partial to total use of existing government and facilities