NATIONAL BUREAU OF STANDARDS REPORT

6410

Development, Testing, and Evaluation of Visual Landing Aids
Consolidated Progress Report for the Period January 1 to March 31, 1959

By
Photometry and Colorimetry Section
Optics and Metrology Division

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

THE NATIONAL BUREAU OF STANDARDS

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NATIONAL BUREAU OF STANDARDS REPORT

NBS PROJECT

0201-20-2301
0201-20-2327

May 1959

NBS REPORT

6410

Development, Testing, and Evaluation of
Visual Landing Aids

Consolidated Progress Report
to
Ship Installations Division
and
Aerology Division
Bureau of Aeronautics
Department of the Navy
Washington 25, D. C.

For the Period
January 1 to March 31, 1959

U. S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

Development, Testing, and Evaluation of Visual Landing Aids January 1 to March 31, 1959

I. REPORTS ISSUED

Report No.	Title
5902	An Approach-Beacon System
6337	Output Characteristics of Three 200-Watt Series-Series Transformers With Multiple Lamps as Load
6352	Development, Testing, and Evaluation of Visual Landing Aids, Consolidated Progress Report for the Period October 1 to December 31, 1958
21P-4/59	Photometric and Chromaticity Tests of an Angle-of-Approach Light Type AA-1, Class H
21P-6/59	Qualification Tests of a Fluorescent, Buoy-Mounted Seadrome Channel-Marker Light
21P-10/59	Intensity Distribution Measurements of a Condenser-Discharge Buoy Light
Specification (Draft)	Light, Marker, Sealane, Medium Intensity
Specification (Draft)	Light, Marker, Runway Circling
Specification (Draft)	Relay Assembly
Letter Report	Intensity Adjustment of Lightweight Optical Landing System
Letter Report	Intensity Control for Optical Landing System
Letter Report	Review of Standard Drawings for Seadrome Lighting
Letter Report	Guide for Compilation of Airfield Lighting Data

II. VISIBILITY METERS AND THEIR APPLICATION

Visibility Meter for Shipboard Use. A method for making this measurement has been designed which will yield a resultant measurement in terms of the log of the ratio of the back-scatter to the local source. It seems possible to eliminate most of the error due to the ambient light when measurements are made in daylight. The proposed instrument design should minimize the need for periodic recalibration of the photosensitive device. It seems possible to design the electronic circuitry in such a way that it will afford a stable calibration utilizing relatively simple circuitry with no critical elements therein.

The electronic system proposed for the visibility meter is shown in figure 1. In this scheme an optical-beam switch 1 revolving at relatively low speed will alternately permit the detector 4 to sample the back-scatter from the telescope interposed with pulses directly from the local flux source A which has been attenuated to approximately the same level. The optical-beam switch 1 will consist of a flat disk which has two diametrically opposite mirrors separated by two similar apertures. On the same shaft with the optical-beam switch 1 is a pair of flash-synchronizing cams 3. These are located at 90° with respect to one another, so that one cam triggers the source when the aperture is in the beam and the other cam triggers the source when the local flux source is presented to the detector 4. These two flash cams 3 will alternately trigger the one-shot multivibrators 6 and 7. These one-shot multivibrators will serve to control the time duration that the gates 8 and 9 are opened for reception of the useful light pulse from the photomultiplier 4. The period that the gates 8 and 9 are thus open may be made only slightly longer than the duration of the flash. This will permit the integrators 11 and 12 to summate the results of the pulses from the flux source A in the summator 11, and the resultant of the back-scatter pulses B in the summator 12. The average value of these two integrations will be fed back to control the dynode source for the detector 4 so that it will always operate at its optimum sensitivity level, wherein neither end of the scale will reach saturation, and wherein aging effects of the detector and the light source will automatically be compensated for. An additional feedback from the detector 4 to the "or" gate 19 may also be desirable for controlling the initial sensitivity level of the detector automatically in terms of the ambient light. In this case the output of the detector 4 would be compared with the reference source 20 to establish an approximate sensitivity level in terms of the ambient light available. It is not yet clear whether this second feedback will be necessary. This can best be determined experimentally. It will be noted that "or" gate 10 provides triggering of the flash source coincident with both the positioning of the aperture and the mirror of the beam switch 1.

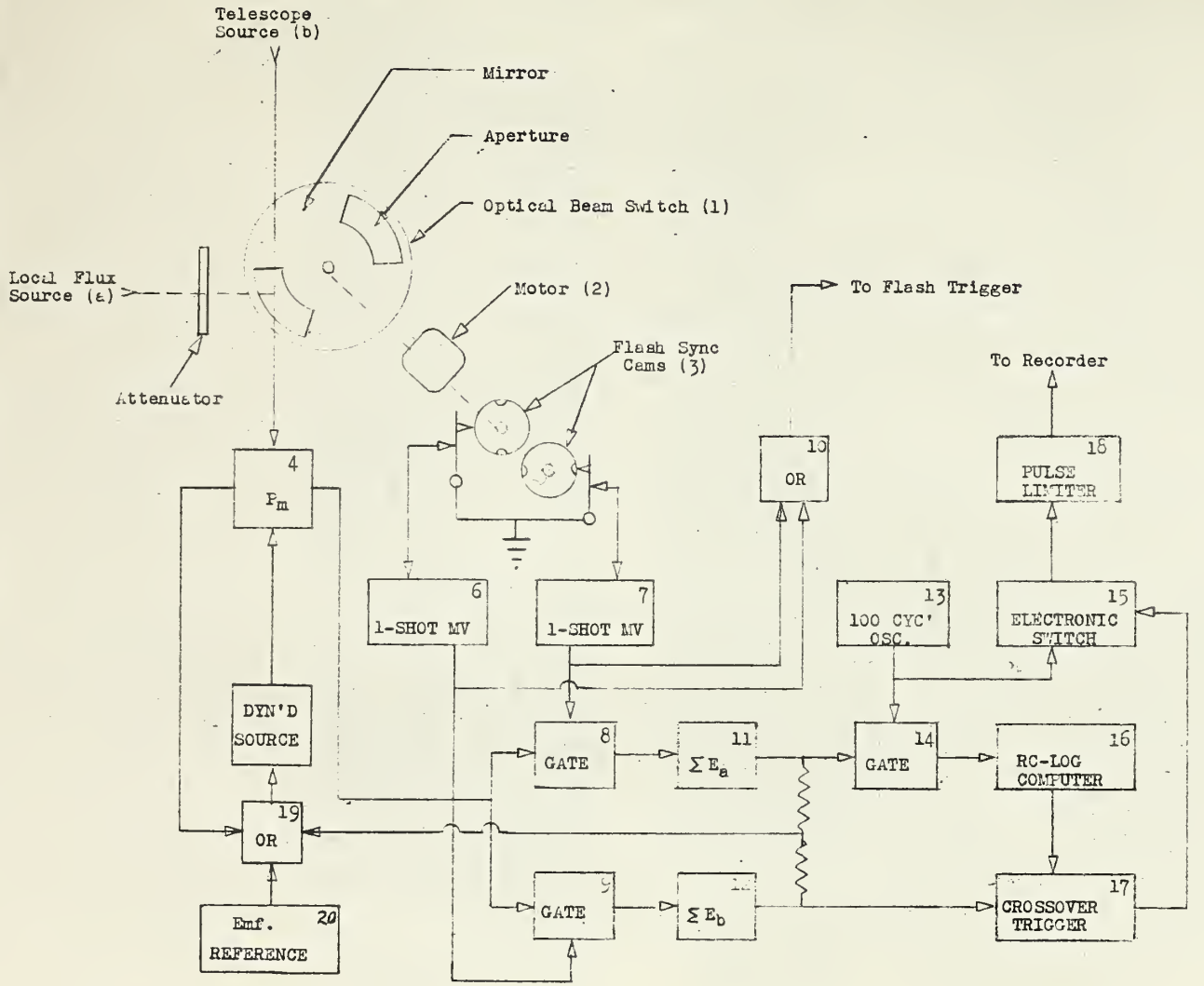


FIGURE 1

ORIGINAL DATE OF DRAWING March 10, 1959			
REVISIONS			
NO	E C N	CHANGE	DATE
1			
2			
3			
4			

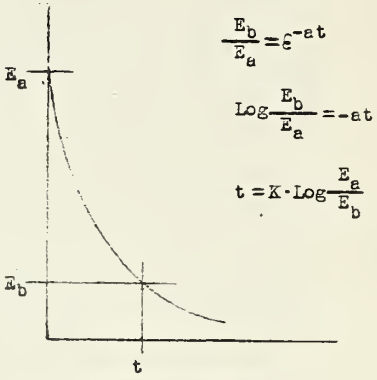
Function of Computer Block 16.

$$E_b = E_a \epsilon^{-at}$$

$$\frac{E_b}{E_a} = \epsilon^{-at}$$

$$\text{Log}\frac{E_b}{E_a} = -at$$

$$t = K \cdot \text{Log}\frac{E_a}{E_b}$$



PIECE NO	NOMENCLATURE	NO REQ'D

NATIONAL BUREAU OF STANDARDS
WASHINGTON 25 D. C.

VISIBILITY METER back-scatter type

FOR

MODEL	TYPE	SCALE
DIMENSIONS IN INCHES (Unless otherwise specified)	DRAFTSMAN	CHECKER
TOLERANCES (Unless otherwise specified)	PROJECT ENGR L. E. Auder	PROJECT ENGR
DECIMALS ± .005 FRACTIONS ± .015 ANGLES ± ½°	SUBMITTED BY	CHIEF SEC
DO NOT SCALE THIS PRINT	EXAMINED BY	CHIEF ENGINEER
DIV. SEC. 1 7 THIS PRINT ISSUED	APPROVED BY	CHIEF DIV
	Project #2301	

In order to establish a measurement in terms of the ratio of the two integrated signals established in 11 and 12 it is first necessary to assume that E_a shall always be the larger signal. This can readily be established by the appropriate selection of the optical attenuator in the path from the source A. The ratio computer determines the logarithm of the ratio of the integrated signals from 11 and 12. This is accomplished as follows. The gate 14 is open most of the time permitting the integrated signal from 11 to maintain a charge on a condenser in the RC-log computer 16 which is equal to the signal E_a. Whenever a new cycle of the oscillator 13 begins, the gate 14 is closed permitting the condenser in 16 to start falling according to the exponential curve depicted in the diagram. Simultaneously with the closing of the gate 14 and the beginning of the exponential fall of the voltage E_a the electronic switch 15 is turned on. The switch 15 stays on for the time t depicted in the exponential diagram. When the E_a voltage charge in the condenser in 16 falls to the voltage E_b, the crossover trigger 17 turns off the electronic switch 15. This operation results in the electronic switch 15 being turned on for a time t during the total period of the oscillator 13. The pulse limiter 18 serves merely to provide controlled amplitude of the square pulse signal from the electronic switch 15, so that the recorder will see only a duty-cycle-effected modulation of the electronic switch 15 by the computation. Since this logarithmic computation is accomplished approximately 100 times per second (at the frequency of oscillator 13) the recorder attached to 18 will integrate the duty cycle of the constant amplitude output so as to record an average voltage which is proportional to the time t. It is apparent from the arithmetic on the block diagram that this duty-cycle integration will result in a signal which is proportional to the logarithm of the ratio of the two integrated signals stored in 11 and 12. It should be noted that the modulated pulse output from the pulse limiter 18 will consist of unipolarity pulses whose amplitude is constant and which reverts to zero whenever the electronic switch 15 is in "off" state.

In order to minimize the flutter in the recording to an acceptable level and yet show a relatively rapid change in visibility, the summating period for the integrators 11 and 12 should be approximately 30 seconds. In order to provide a relatively smooth integration for the signals in 11 and 12, the flasher should have a repetition rate of approximately 1 or 2 flashes per second. This flash rate will be determined by the speed of the motor 2 which signals the trigger for the flashes via the flash-synchronizer cams 3. The speed of the motor 2 could be made variable if necessary to avoid possible synchronization with other flashing devices which might be in operation in the area.

Transmissometers.

Components. Twenty type WL-759 tubes of recent production have been received from the manufacturer and are being tested. Tests to date indicate that the tubes will be satisfactory in all respects.

Information received from the Instrument Division of the Weather Bureau indicated that manufacture of type 6B4 tubes used as V109 of the transmissometer receiver power supply had been discontinued except for special orders and that the cost of these tubes would be increased considerably. Therefore a search was made for a replacement tube which would perform as well as the type 6B4 and which could be used with a minimum of modification of the receiver power supply. A triode-connected type 6K6 tube was the only satisfactory replacement found. Tests were made using a tube of this type and a wide range of load conditions on the signal line. With all load conditions the performance of the instrument when the type 6K6 tube was used was equal to or very slightly better than the performance when a type 6B4 tube was used. Modification of the receiver power supply is very simple, namely: a) Connect terminal 4 of socket X109 to terminal 3 of socket X109. b) Connect terminal 8 of socket X109 to terminal 7 of transformer T103. With these modifications, type 6K6 and type 6B4 tubes can be used interchangeably.

Field technicians have often expressed a need for a longer time constant in the metering section of the receiver power supply. The length of the time constant has been restricted in the past by the lack of a suitable high capacitance capacitor for use as C107. This restriction has been removed with the development of the tantalum capacitors. Tests have been made using for C107 100-microfarad, 30-volt, tantalum capacitors manufactured by the Fansteel Metallurgical Corporation. The time constant of the receiver metering section is lengthened so it is very nearly equal to the time constant of the indicator. With this modification of the receiver, trigger tubes which had previously been considered as not usable because of unstable pulse rates could be used satisfactorily. The capacitor is sufficiently small so it may be connected directly across the terminals of the present C107.

Slant Visibility Meter. The compressor has been repaired and the instrument restored to service.

Measurements of Illumination and Sky Brightness. A report has been drafted giving the results of measurements of the effect of runway- and approach-light systems on background luminance and horizontal illumination. A few more measurements are required to complete the analysis. This report should be completed next quarter.

Indicator Bridge Modification. Work on the modification of the transmissometer bridge has been resumed. In this modification the voltage-regulating tube, V203, is replaced with a triode. Studies have been made over a period of months comparing the stability of the modified bridge with that of the present bridge. These data indicate that the modified bridge is more stable than the present bridge. A report covering this work has been drafted.

Errors in Transmissometer Measurements Resulting from Scattered Light from the Light Source. A receiver having an adjustable field stop has been installed in place of the regular receiver, adjusted, and placed in operation. There has been only one occasion with weather suitable for test since the receiver was installed.

III. DEVELOPMENT OF AIRFIELD LIGHTING AND MARKING COMPONENTS

Approach Beacon. NBS Report 5902, An Approach- Beacon System, has been completed and issued. This report summarizes the work of the National Bureau of Standards in the development of the system and gives the results of field and service tests. Instructions for the installation and operation of the approach beacons are included as appendices.

Runway Distance Markers. Two internally illuminated runway distance markers have been received at the Field Laboratory from NAS Cecil Field. Installation of these markers is planned for the first part of next quarter. Tests in poor visibility conditions should be completed by September 30.

Runway Turnoff Indicators. Recently unsolicited favorable comments have been received from private pilots in regard to the information provided by closely spaced runway lights marking runway turn-offs. These comments state that putting the lights along the taxiway is preferred to putting the lights along the runway on each side of the taxiway entrance. The generally unfavorable reports from airline pilots (reported in the Progress Report for July 1 to September 30, 1958) are believed to be due to lack of familiarity of the pilots with the system and its purpose.

Taxiway Lighting (TED NBS SI-5007). A study is being made of requirements of taxiway lighting so that a draft of a standard for the installation of taxi lights and taxi guidance signs can be prepared.

Circling-Guidance Lights. A draft specification has been prepared for circling-guidance lights. This specification is based upon the experimental lights of this type obtained by the National Bureau of Standards. The requirements for these lights are outlined in NBS Report 4741. Photometric characteristics of these lights are given in NBS Test Report 21P-22/58. The intensity requirements of the specification are based upon the use of a 500-watt, 20-ampere lamp with a C-13 filament mounted with the plane of the filament parallel to the axis of the runway.

Series Relay Assembly. A specification has been drafted for a relay assembly with a series coil. The relay is to be operated from a series circuit lighting a fueling lane to control the taxiway light at the entrance to the fueling lane.

Flush-Type Lights. Feasibility-model lights manufactured by the Outlook Engineering Corporation of the type described in NBS Test Report 21P-8/58 have been received. These lights are of three types, projecting 0.0, 0.5, and 1.0 inch above the runway surface. Intensity distribution measurements are being made of these lights. After these measurements are completed, the lights will be installed at an airfield for service testing.

Maintenance Manual. A form to be used in the compilation of technical data relating to items of airfield lighting has been prepared. The form is in two parts. Part I provides a guide for obtaining data useful in planning, stocking, requisitioning, and other administrative functions. Part II provides a guide for the operational and maintenance organizations.

Transformer Characteristics. NBS Report 6337 giving the results of measurements of the electrical characteristics of 200-watt series-series isolating transformers with 115-volt multiple lamps as loads has been completed and issued.

Lamps for Aviation Ground Lighting Service. Drafts of MS drawings giving the characteristics of the 20-ampere, 500-watt, T-24 bulb lamp designed for use in the medium intensity seadrome light and the 20-ampere, 500-watt, PAR-56 approach light lamp have been prepared. A new drawing is required for the T-24 lamp, but the PAR-56 lamp can be added to Drawing MS24348.

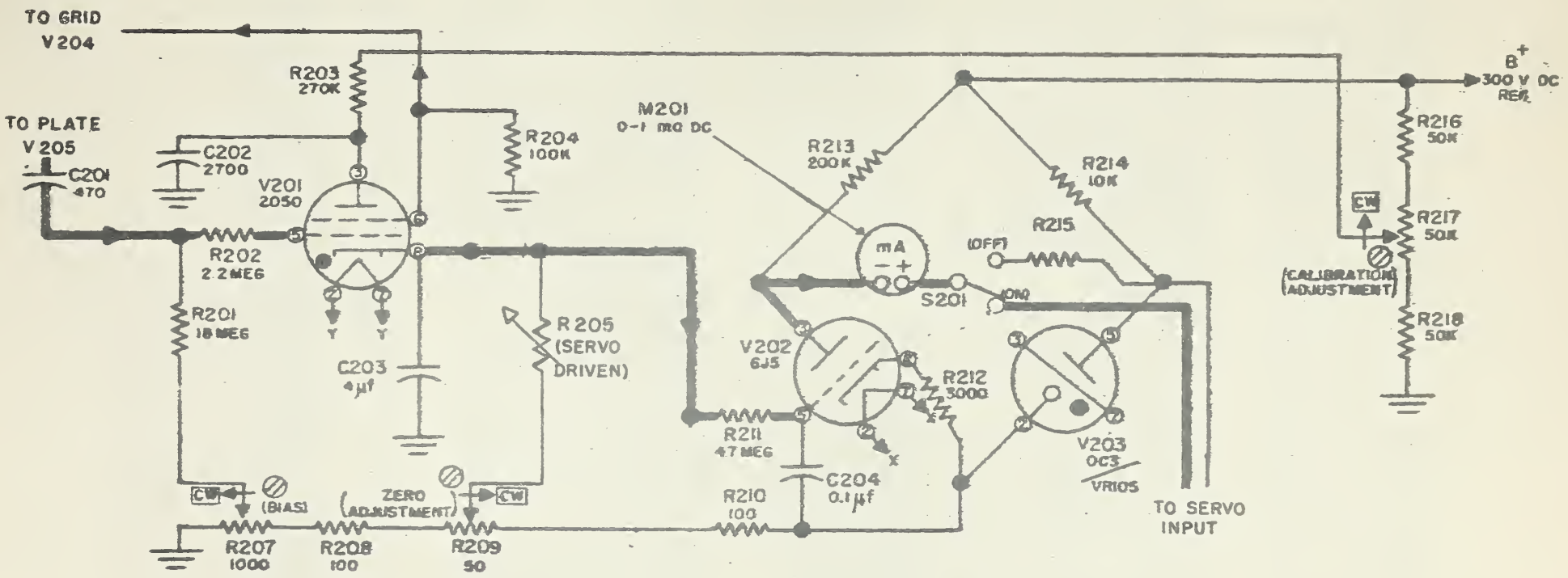
Automatic Intensity Control (TED NBS SI-5004). A design has been developed to overcome the difficulties resulting from the small differences in the transmissometer readings corresponding to intensity steps 3, 4, and 5 which were discussed in the Progress Report for last quarter. The principle of this design is illustrated in figure 2. A modified transmissometer indicator will be connected to the signal line of the station transmissometer. The output of this indicator will control a servo system which will maintain the output at a fixed level by varying the resistance of R205. The resistance setting of R205 is thus inversely proportional to the transmission. Therefore the optimum brightness setting for a given resistance setting can be determined from the data given in the Progress Report for last quarter, and a brightness control switch can be so connected to the servo that it will be properly positioned when R205 is adjusted so that the system is in balance. Since the indicator will be operating at about half of its full scale level, the effect of shifts in the indicator zero will be insignificant. R205 can be either a continuously variable or a step resistor as desired.

IV. DEVELOPMENT OF SEADROME LIGHTING COMPONENTS

Channel Identification Lights. Detail shop drawings of the NBS design for a runway and channel identification light have been completed. Sets of these drawings were furnished to several prospective manufacturers of this light. Construction details and principles of operation were discussed with a number of these manufacturers and a light of the type now installed at NAS Norfolk was demonstrated to them.

Standard Drawings for Seadrome Lighting. As a part of project TED NBS SI-5003, the standard drawings for high-intensity seadrome lighting systems have been reviewed both by personnel of the Field Laboratory and by Washington personnel. A number of corrections, revisions, and additions were recommended by letter and in a conference with personnel of the Bureau of Aeronautics and of Yards and Docks.

Battery Operated Sealane Lights. A transistorized inverter was obtained from Lincoln Electronics for test as a possible replacement for the mechanical vibrator used in operating the 6-watt fluorescent lamp from a 12-volt storage battery. The unit was a compact device requiring neither an external ballast nor starter. It lighted the lamp, but the lamp current was only 30 milliamperes instead of the desired 110 milliamperes. It has been returned to the manufacturer for modification.



PARTIAL SCHEMATIC CIRCUIT DIAGRAM OF AUTOMATIC INTENSITY CONTROL SYSTEM

FIGURE 2

Modification of Type MB-1 Light (TED NBS SI-5006). The mold used in fabricating the silicone-rubber cable-connector assembly required in the modification of the type MB-1 light has been modified to relieve stress concentrations at the junction of the leads and the connector. (See Progress Report for July 1 to September 30, 1958.) Connectors cast in the new mold appear to be satisfactory. A report summarizing the work on this task is being prepared.

Medium-Intensity Sealane Lights. A draft specification has been prepared for a medium-intensity sealane marker light intended for buoy-mounted, cable-fed service. This specification is based on the experimental lights of the type obtained by the National Bureau of Standards on NAer Order 01801. These lights are described in NBS Test Report 21P-25/58. Cable-connector assemblies of the type described above are specified. A symmetric beam with an intensity of 4500 candles for all angles of elevation between 1.0 and 9.0 degrees is specified for the "white" units.

V. DEVELOPMENT OF CARRIER LIGHTING AND MARKING COMPONENTS

Lights for Carrier-Deck Personnel (TED NBS SI-5001). Further development of the polyethylene taxi-guidance wands has been delayed pending receipt of the results of service tests of the twenty wands delivered last quarter to the Visual Landing Aids Branch for service tests. Completion of a service test quantity of "eyeball" or goggle lights has been delayed pending receipt of information on the desired location and size of the battery for these lights.

Optical Landing Systems (TED NBS SI-5005). The draft of the specification for the fresnel-lens type optical landing system was reviewed in detail and a number of suggested revisions were discussed with Navy personnel at a conference. An intensity control system using transformers in place of magnetic amplifiers has been designed for this optical landing system and reported by letter. It is believed that this system will be simpler and less expensive than the present magnetic amplifier intensity control. A means of balancing the intensities of the datum and source lights of the lightweight optical landing system when the system is operated at low intensity settings has been designed and reported by letter.

VI. PHOTOMETRIC AND ELECTRICAL TESTS OF AIRFIELD AND SEADROME LIGHTING EQUIPMENT (TED NBS SI-5003).

Connectors for Airfield-Lighting Cable. Tests of the maintenance of insulation resistance of cable connectors have continued. Seven splices prepared with A'G'A kits were kept in a water tank for four

months. Measurements of leakage current were made periodically. Two of these splices, four additional splices made with A'G'A kits, and three splices made with Scotchcast Splicing Kits were then buried in the field. Measurements of the leakage currents are being made periodically. A vulcanizer and splicing materials have been ordered from the Joy Manufacturing Company so that tests of vulcanized splices can be included in the program.

During the assembly of the A'G'A splices it was noted that two of the connectors received in the second lot could be separated by a force less than the specified 10 pounds. Tests made in the laboratory using connectors of both the first and second lots showed no substantial difference between the separating forces required for connectors of the second lot (which had zone-annealed pins and receptacles) and the first lot (which had uniformaly annealed pins and receptacles). The separating forces of connectors of both lots were close to the minimum specified. Unless the excess silicone jelly was removed from the mating surfaces of the connectors, the force required to separate the connectors was below the specified minimum.

The results reported above and the results of previous tests of connectors indicate that the specification of separating force should be separated into two parts: a) the force required to separate the conducting part of a connector, pin and receptacle only; and b) the force required to separate the mating rubber parts of the connector only.

Three-Color Angle-of-Approach Indicator. Tests of a three-color angle-of-approach light manufactured by the Crouse-Hinds Instrument Company have been completed and the results reported (NBS TEST 21P-4/59). The units tested met the significant requirements of specification MIL-L-19891(Aer) except for the chromaticity of the green plastic filter.

Preproduction FMF-6 Sealane Marker Light. A preproduction sample of a type FMF-6B sealane marker light manufactured by Mink-Dayton, Inc. was tested for conformance to the requirements of specification MIL-L-7835(Aer) and the results were reported (NBS Test 21P-6/59). The unit was acceptable except for a number of minor deficiencies which can be corrected during production.

Condenser-Discharge Buoy Light. Intensity distribution measurements have been made of a small battery-operated condenser-discharge buoy light submitted by P. R. Mallory and Co., Inc. and the results reported (NBS Test 21P-10/59). The light consumed about 3 watts and produced flashes having an effective intensity of 15 candles at a rate of 24 flashes per minute. The intensity was substantially independent of the angle of view.

VII. MISCELLANEOUS TECHNICAL AND CONSULTIVE SERVICES

The draft of specification MIL-R-26627, Regulator, Current, Airport Approach and Runway Lighting, was reviewed and a list of suggested revisions forwarded by letter.

The meeting of the Advisory Group to the U.S. Member of the ICAO Visual Aids Panel held March 17 at the FAA Technical Development Center, Indianapolis, was attended.

A brief summary giving the results of NBS studies of the mechanical effects of flush-type runway lights on aircraft landing gear was prepared for consideration by personnel concerned with the design of the lighting installations for NAS Lemore, California.

The text of the specification of Signal Light Colors has been read editorially. Clarification and amplification of certain sections of the work has been suggested. Progress is being made toward such revisions.

The U. S. National Committee on the Colors of Signal Lights met on January 7th. The reports of the subcommittees which are working on the details of the adoption of the standard by the several government and engineering agencies that sponsor specifications related to the standard indicated progress and the development of no new difficulties within this country. An ad hoc committee was appointed to study the possibility of clarifying the definition of "same chromaticity characteristics" in Part I of the Standard and also to draft definitions for the chromaticity of white signals using straight boundaries in place of the curved boundaries. The main committee will consider the relative merits of the two sets of boundaries at its next meeting which has been called for May 7th. Several minor amendments were adopted for Part II. Part III received a general approval but will be subject to more detailed consideration at the next meeting.

VIII. MISCELLANEOUS

Weather. There was very little weather suitable for low visibility testing at Arcata during this quarter. On February 15 winds with speeds exceeding 65 miles an hour occurred at the Field Laboratory, causing some damage to the equipment.

Fog Dispersal Testing. Cambridge Research Center has approved a contract to the Atmospheric Research Group and made arrangements with

Humboldt County to make installations and test fog dispersal equipment at the Arcata Airport during a period from June 15 to November 15. There may be an opportunity to correlate some of our observations of errors in transmissometer measurements resulting from scattered light with some of their observations of fog particle-size distribution.

Approach Lights. The FAA has let a contract for installing the configuration "A" center row approach-light system and removal of the slopeline approach lights at the Arcata Airport. The contract proposal called for the removal of our approach beacon installations and approach zone observation tower. This conflict has been resolved so that our installations will remain as they are.

U. S. DEPARTMENT OF COMMERCE
Lewis L. Strauss, *Secretary*

NATIONAL BUREAU OF STANDARDS
A. V. Astin, *Director*

THE NATIONAL BUREAU OF STANDARDS

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WASHINGTON, D. C.

Electricity and Electronics. Resistance and Reactance. Electron Devices. Electrical Instruments. Magnetic Measurements. Dielectrics. Engineering Electronics. Electronic Instrumentation. Electrochemistry.

Optics and Metrology. Photometry and Colorimetry. Optical Instruments. Photographic Technology. Length. Engineering Metrology.

Heat. Temperature Physics. Thermodynamics. Cryogenic Physics. Rheology. Engine Fuels. Free Radicals Research.

Atomic and Radiation Physics. Spectroscopy. Radiometry. Mass Spectrometry. Solid State Physics. Electron Physics. Atomic Physics. Neutron Physics. Radiation Theory. Radioactivity. X-rays. High Energy Radiation. Nucleonic Instrumentation. Radiological Equipment.

Chemistry. Organic Coatings. Surface Chemistry. Organic Chemistry. Analytical Chemistry. Inorganic Chemistry. Electrodeposition. Molecular Structure and Properties of Gases. Physical Chemistry. Thermochemistry. Spectrochemistry. Pure Substances.

Mechanics. Sound. Mechanical Instruments. Fluid Mechanics. Engineering Mechanics. Mass and Scale. Capacity, Density, and Fluid Meters. Combustion Controls.

Organic and Fibrous Materials. Rubber. Textiles. Paper. Leather. Testing and Specifications. Polymer Structure. Plastics. Dental Research.

Metallurgy. Thermal Metallurgy. Chemical Metallurgy. Mechanical Metallurgy. Corrosion. Metal Physics.

Mineral Products. Engineering Ceramics. Glass. Refractories, Enameled Metals. Concreting Materials. Constitution and Microstructure.

Building Technology. Structural Engineering. Fire Protection. Air Conditioning, Heating, and Refrigeration. Floor, Roof, and Wall Coverings. Codes and Safety Standards. Heat Transfer.

Applied Mathematics. Numerical Analysis. Computation. Statistical Engineering. Mathematical Physics.

Data Processing Systems. SEAC Engineering Group. Components and Techniques. Digital Circuitry. Digital Systems. Anolog Systems. Application Engineering.

• Office of Basic Instrumentation. • Office of Weights and Measures.

BOULDER, COLORADO

Cryogenic Engineering. Cryogenic Equipment. Cryogenic Processes. Properties of Materials. Gas Liquefaction.

Radio Propagation Physics. Upper Atmosphere Research. Ionospheric Research. Regular Propagation Services. Sun-Earth Relationships. VHF Research. Ionospheric Communication Systems.

Radio Propagation Engineering. Data Reduction Instrumentation. Modulation Systems. Navigation Systems. Radio Noise. Tropospheric Measurements. Tropospheric Analysis. Radio Systems Application Engineering. Radio-Meteorology.

Radio Standards. High Frequency Electrical Standards. Radio Broadcast Service. High Frequency Impedance Standards. Electronic Calibration Center. Microwave Physics. Microwave Circuit Standards.


NBS