The Concentrated-Arc Lamp in a Light Beam Communication System

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An experimental light beam telegraph circuit which utilizes a concentrated-arc lamp has been in cperation for more than three years over lower New York, N. Y. The 3/4-mile circuit has demonstrated that in fog-free localities dependable high quality communication is possible over light beam systems.

COMMUNICATION possibilities of parts of the electromagnetic spectrum higher in frequency than the shortest radio waves were investigated early in 1939 by The Western Union Telegraph Company. A study of atmospheric transmission characteristics, as well as the energy sources and detectors then available, pointed to the wave length band between 0.3 and 1.5 microns, or millionths of a meter, as the most promising. This band covers the visible spectrum together with the adjacent ultraviolet region down to the transmission limit of ordinary glass and the infrared region out to the long wave threshold of photoelectric detectors.

Signaling by means of a beam of radiation requires modulation of the beam amplitude, frequency, or phase. Tests on the infrared, visible, and ultraviolet light sources available, showed none to be ideally suited for light beam communication purposes. Those which could be modulated at audio frequencies were of low intensity, while stable high-intensity sources, such as tungsten filament lamps, could not be modulated except by valves or shutters outside of the lamps. The ideal source seemed to be one of high intensity, stable position and characteristics, and one capable of being modulated directly without the use of light valves. From the standpoint of economy of energy, and the desirable secrecy characteristics of narrow-beam transmission, a small-size transmitting source was also required. The search for a light source having these specifications led to the discovery of the concentrated-arc lamp.

This lamp employs two fixed, permanent electrodes which are mounted in a glass bulb filled with an inert gas, usually argon. Figure 1 shows that the cathode or negative electrode consists of a tantalum tube packed with zirconium oxide. The positive electrode or anode is a molybdenum plate with a hole in the center which provides a window for the emergence of the light that radiates from the cathode. During manufacture, the exposed oxide surface at the end of the cathode is reduced to metallic zirconium. When the lamp is operating, this extremely thin layer of zirconium metal is melted and maintained as an incandescent pool by the intense argon ion bombardment of the arc. The majority of the visible radiation of the lamp is emitted from this incandescent surface. This radiation has a continuous spectral distribution of the black- or gray-body type which reaches its maximum value near one micron and extends from at least 0.3 to 5 microns, which are the limits of the spectral band transmitted by the glass of the bulb.

Extending for a few thousandths of an inch from the cathode surface is a region filled with excited and ionized zirconium vapor and argon gas. The radiation from this, the cathode glow space, has three components; a continuum extending from the short ultraviolet to about 0.5 micron; the normal, singly, and doubly-ionized zirconium line spectra; and the normal and singly-ionized argon line spectra. Most of the zirconium lines occur in the ultraviolet part of the spectrum while the strongest argon lines are concentrated in the infrared, peaking around 0.8 micron.

When the current through the lamp is modulated at audio frequencies, a substantial part of the radiation also is modulated. A comparison shows that, as the modulating frequency is increased, the amplitude of the continuum, which originates from the cathode surface, decreases rapidly. The line radiation from the cathode glow space, however, decreases but little with increase in modulating frequency.

The greatest amount or quantity of modulated radiation is found in the spectral region between 0.7 and 1.0 micron. This is the portion of the spectrum which is adjacent to the visible on the long wave or infrared side. A second and much smaller peak of modulated radiation occurs in the ultraviolet region centering around 0.35 micron.

The long wave region offers several advantages as the spectral band in which to operate a light beam communication system. Caesium-silver-oxide types of photoelectric cells, which have the high sensitivity and good audio-frequency response required of the detector or receiver of modulated radiation in the system, reach

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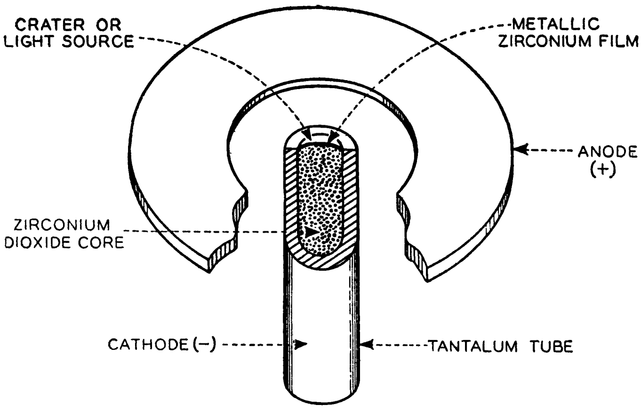


Figure 1. Internal construction of the concentrated-arc lamp

their maximum sensitivity in this region. A second advantage lies in the fact that this portion of the spectrum is not visible. Thus, the visible part of the radiation of the lamp may be removed by an infrared-transmitting colored-glass filter to make the signaling beam invisible with but little loss. A third factor which makes the infrared more desirable than the ultraviolet or visible regions lies in the spectral-transmission characteristics of the atmosphere which shows less attenuation under conditions of haze as the wave length of the radiation employed is increased.

At present, concentrated-arc lamps are made in sizes ranging from 2 to 100 watts (Figure 2). A 2-watt lamp has a source spot which is only 0.003 inch in diameter and has a maximum brightness of 62,000 candles per square inch. As the lamp wattage increases, the size of the luminous crater of the lamp grows larger but the brightness is less. Thus, the choice of which size lamp to use for a particular light beam communication system will depend upon the characteristic most desired.

Theoretically, the intensity of the beam of radiant energy will depend upon the brightness of the source and the diameter of the projecting lens while the width or spread of the beam will depend upon the diameter of the source and the focal length of the lens. A 2-watt lamp being the brightest should project the most intense beam and the one capable of being received over the longest distance. If perfect optics could be secured, this would be the case in practice, but the extremely small source diameter of the 2-watt lamp puts the accuracy of the projecting lens or mirror to a severe test. Thus, unless a very accurate lens is used some of the larger wattage and less brilliant lamps may give the stronger beam. The small source diameter of the 2-watt lamp does result in extremely narrow beams. For example, a 2-watt lamp, if sharply focused with a perfect lens which has a focal length of one foot, should project a beam which, at a distance of one mile, would be only 16 inches in diameter. Actual lenses are good enough to produce beams which approach this value. The beam width in this case is less than one minute of arc. Aiming such a beam requires an accurate sighting device, micrometer adjustments on the pointing mechanism, and very rugged and stable mounts.

If a 100-watt lamp were to be focused sharply with the same 1-foot-focal length projecting lens, the beam would be 312 inches or 26 feet in diameter at a distance of one mile. This beam has a spread of 17 minutes of arc, which is also a very narrow angle, so sturdy mounts and accurate micrometer controls still are required. The sharpest and most intense beam is produced when the lens is adjusted to focus the image of the source spot at the distant receiver which is, in most cases, a focus for infinity. Broader beams can be produced by placing the source inside the principal focal point of the lens, but in such cases, the brightness of the beam will decrease in almost exact proportion to the increased cross-sectional area of the beam.

Concentrated-arc lamps are thus most suitable for narrow-beam systems. The 2-watt lamps are best for use on long distance light beam circuits between fixed points where sturdy mounts and accurate lenses can be provided. Larger lamps are more suitable for use in portable equipment or other types of service where greater beam spreads are required. All sizes of lamps can be employed in very short throw wide beam systems.

The modulation characteristics of the small-wattage lamps are superior to those of the large. Modulation ratio is defined as the ratio between the per cent candle power change and per cent current change.

The per cent modulation ratio decreases with the increase in modulating frequency, the wave length of the spectral region employed and the lamp wattage. A 2-watt lamp, for example, will give percentage modulation ratios of 76 at 200 cycles, 63 at 1,000 cycles and 49 at 5,000 cycles if measured with an antimony type of photoelectric tube, which responds chiefly to the blue and ultraviolet radiation. A photoelectric cell of the caesium-silver-oxide type, which utilizes the longer wave radiation, will show percentage modulation ratios of 35 at 200 cycles, 25 at 1,000 cycles and 17 at 5,000 cycles. The shorter wave length radiation can be more completely modulated, but the amount or quantity of

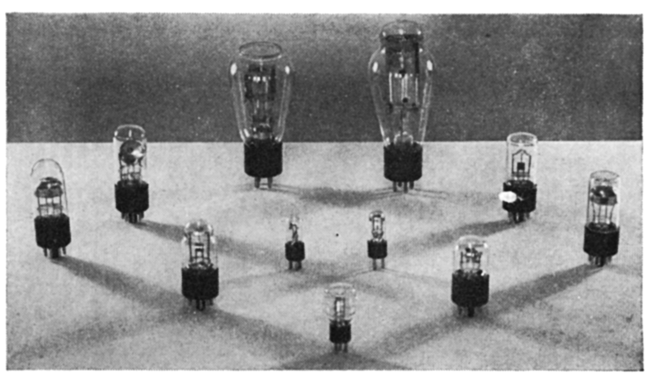


Figure 2. Various types and sizes of concentrated-arc lamps

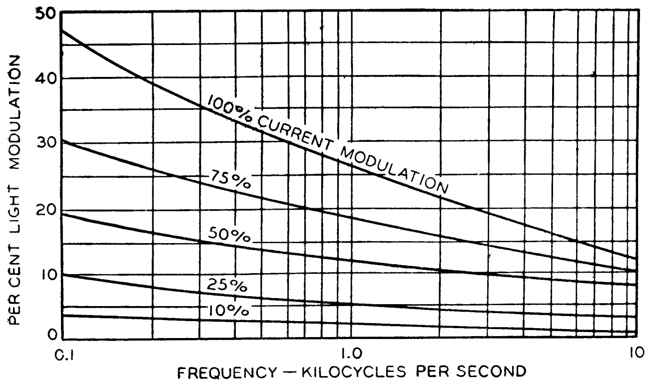


Figure 3. Frequency characteristic of 2-watt concentrated-arc lamp taken with a caesium photoelectric tube

modulated radiation, which is the important factor for light beam communication systems, is much greater in the longer, near-infrared region. A 100-watt lamp shows less than one half of the percentage light modulation of a 2-watt lamp. Because of its much greater output, however, the total modulated radiation of the 100-watt lamp is many times that of the 2-watt lamp.

As compared with a 100-watt argon-filled lamp, a krypton-filled 100-watt lamp shows a gain in modulation ratio of 56 per cent from the antimony or blue-sensitive photoelectric cell and a gain of 21 per cent from the red-sensitive caesium photoelectric cell.

The complete modulation characteristic of a 2-watt argon-filled concentrated-arc lamp when measured with a caesium photoelectric cell is shown in Figure 3. Larger wattage lamps have the same type of characteristic curves. At 100 per cent current modulation, this 2-watt lamp has a drop in output of 11.5 decibels between 100 cycles and 10 kc. The uniformity of the spacing of the curves for the various percentage of current modulation indicate a fairly linear relationship between modulated light output and modulating current.

The dynamic relationship between the lamp current and the lamp light is not absolutely linear. While the light output follows the current accurately on the peaks of the modulation cycle, it does not do so as the current and the light approach zero on the opposite half of the cycle. The resulting distortion of the modulated light wave is found from analysis to consist largely of the second harmonic of the modulating frequency. For this reason, the per cent of second harmonic frequency in the modulated light wave is used as a measure of the distortion of the lamps.

Per cent distortion tends to rise with an increase in the per cent of current modulation, the lamp wattage and the modulating frequency.

Impedance and phase characteristics of the 2-watt concentrated-arc lamp cause it to act as an inductive load. As the frequency increases, the impedance at first decreases, reaching a minimum of 150 ohms at 1,200 cycles, and then rises to 270 ohms at 10 kc. Its average value over the audio frequency range is about 200 ohms. The resistive component of this impedance has a negative value at low frequencies. This is a normal characteristic for arc lamps and is the reason why a ballast resistance always must be connected in series with the lamps to insure stability. At frequencies of 2,600 cycles and above, the resistance is positive. Current lags the voltage by an amount which decreases as the frequency increases, and the light lags the current, the phase angle increasing with the modulating frequency.

A summary of the impedance and phase characteristics of all the different sizes of concentrated-arc lamps shows the impedance of the lamps and the frequency, at which the resistive component of the impedance becomes positive, decrease as the lamp wattage increases. The phase angle decreases with the increase in lamp wattage.

These impedance characteristics must be considered in the design of modulators for the lamps. For example, the 2-watt lamp has a negative resistance at frequencies less than 2,600 cycles. If this lamp is connected into a circuit whose natural resonance is less than 2,600 cycles and if the positive resistance of the circuit is less than the negative resistance of the lamp, the circuit will oscillate. Thus, resistance must be added to some circuits to secure stability.

Lamps of the 2-watt size can be modulated by connecting them directly into the plate circuit of the modulator vacuum tube, the modulating voltage being applied to the grid, as shown in Figure 4. The direct current required to maintain the arc is supplied by the normal plate current of the modulator vacuum tube.

Larger wattage lamps require a modulator circuit where an impedance matching transformer is used to couple the lamp to the modulator and the direct current for the arc is obtained from a separate supply source.

Since April 1943, an experimental light beam telegraph circuit using concentrated-arc lamps as the source of the modulated radiation, has been in operation over lower Manhattan. The circuit runs from the main

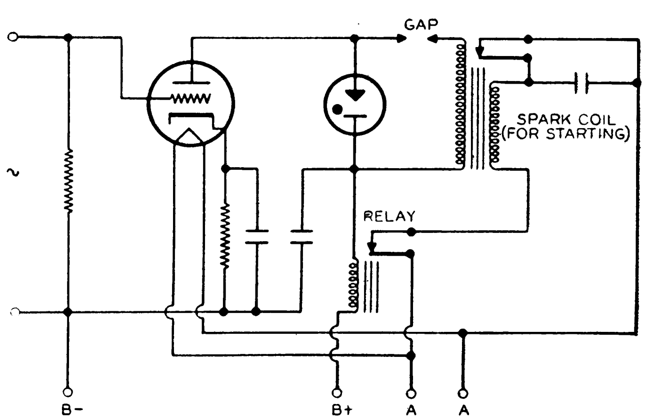
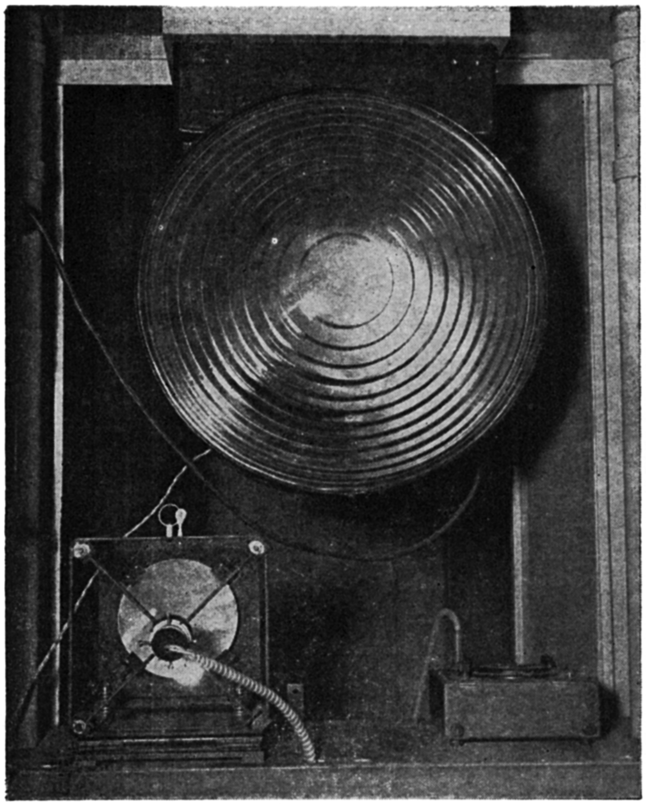


Figure 4. Direct coupled modulator circuit for a 2-watt concentrated-arc lamp



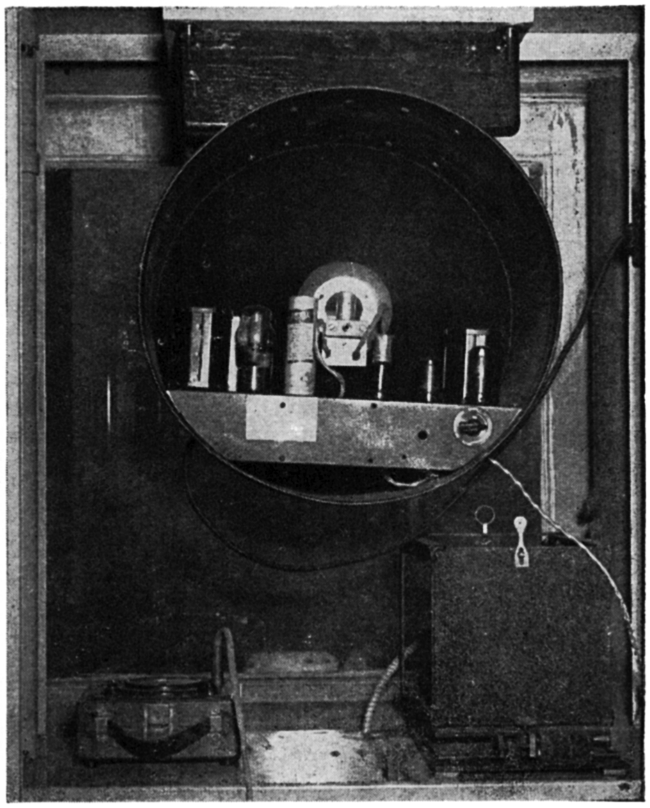


Figure 5. Front view (left) and rear view (right) of concentrated-arc transmitter (bottom) and receiver (top)

Western Union office to a branch office, an air-line distance of about three quarters of a mile. A teleprinter-telegraph circuit operating at 65 words per minute is carried by two light beam systems, one operating in each direction.

Figure 5 shows the light beam transmitting and receiving equipment at one end of this circuit. The transmitter, which is the smaller of the two units, consists of a 10-watt concentrated-arc lamp whose radiation is focused on the distant receiver by a parabolic mirror of good optical quality, which is six inches in diameter and has a 6-inch focal length. This combination produces a beam which is about ten feet in diameter at the distant receiver. Since the beam is so narrow it has not been thought necessary to filter out the visible radiation so as to use only the infrared portion to obtain an invisible and more secret beam. The receiver unit utilizes a molded Fresnel lens 18 inches in diameter to collect the radiant energy received from the distant transmitter and to concentrate it on a high-vacuum-type caesium-silver-oxide photoelectric cell. This equipment operates unattended. It is started and turned off from the circuit operating positions and requires only occasional attention. The 10-watt concentrated-arc lamp in this transmitter had operated over six months at the time of this writing.

To the camera and to the eye, the distant transmitting lens appears to be many times its true diameter because of its extreme brilliance. Movement but a few feet in any direction from the center of the incident beam causes the spot of light to disappear.

If the transmitter lens on this circuit were absolutely perfect and the atmosphere absolutely clear, there would be a signal loss over this 3/4-mile distance caused by the spreading of the beam, which would amount to 17 decibels. Calculations indicate that under ideal conditions, this system should operate up to about 30 miles. Under actual conditions, the additional loss due to lens imperfections and atmospheric conditions may be considerable. On a very clear night the received signal on this light beam circuit is 56 decibels above the noise level. In daylight, the noise increases so that the signal is 50 decibels above the noise. Sunshine, clouds, and light haze have little effect although heat waves or striae in the air may cause some fluctuation of the received signal. A light rain may cause the signal to drop 10 decibels and a very heavy rain 20 decibels. A moderate fog may reduce the received signal 30 decibels while a very heavy fog or snowstorm will interrupt the circuit.

During the $3^1/_2$ years that this circuit has been under test 9 hours a day 5 days per week, it has operated 96.7 per cent of the time. Of the 3.3 per cent lost time, 2.8 per cent was due to trouble in the equipment on the light beam section of the circuit. This figure is of the same order as might be expected with any experimental apparatus. The remainder of the lost time, or 0.5 per cent, was caused by interruptions to the light beam by fog, heavy snow storms, and smoke. Ordinary atmospheric haze caused no interruptions as the near-infrared radiation in the beam does pierce this type of diffusing medium better than visible light.

The attenuation or scattering of the beam depends upon the relative size of the suspended particles which make up the haze or fog and the wave length of the radiation employed. If the radiation has a wave length which is large in relation to the diameter of the particles, little scattering will occur. As the diameter of the particles approaches the magnitude of the wave length of the radiation, the attenuation rises rapidly. Fog particles may have diameters as much as 25 times as great as the wave length of the radiation employed in this equipment. As a result, the attenuation due to fog is very great and in very dense fogs it is impossible to produce a beam of radiant energy from a concentrated-arc lamp which will operate a light beam communication circuit for more than a few tenths of a mile.

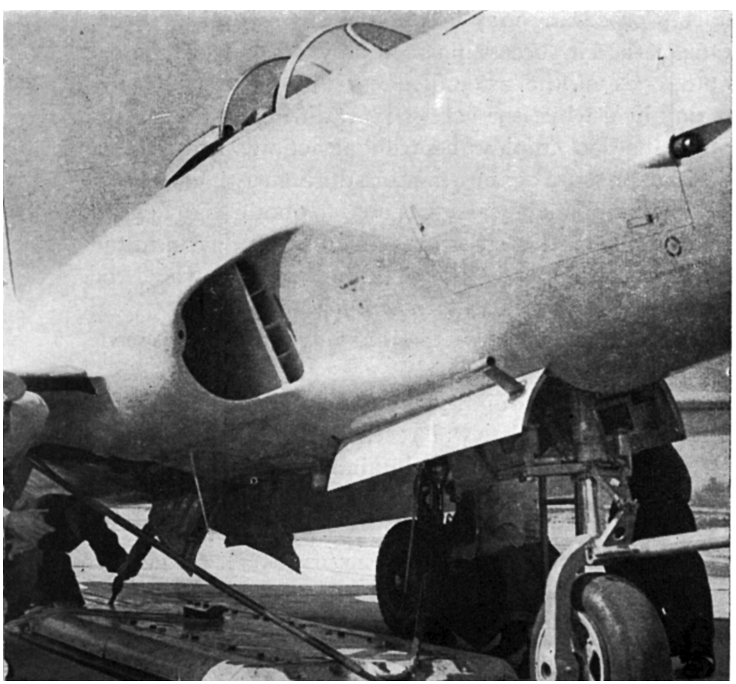
Concentrated-arc lamps thus are seen to have characteristics which fit them for use as sources of modulated radiation and particularly for narrow-beam communication circuits. Such circuits can be employed over short distances with good dependability. Long distance circuits, limited only by the optical range, should be possible in fog-free localities.

New Airplane Catapult

The "electropult," an unusual type of induction motor manufactured by the Westinghouse Electric Corporation, Pittsburgh, Pa., is designed for launching airplanes that require long take-off runs from small landing fields without the high inertia impact imparted by other catapults. The secondary winding of the motor is the track of the catapult, and its primary winding is the car to which the airplane is harnessed.

Two electropults are now in use by the Navy, one at Mustin Field, Philadelphia, Pa., and a larger one at the Naval Air Test Center, Patuxent River, Md. The track of the larger unit is 1,382 feet long, and is made up of 76 sections with 12-inch active core width, that are set flush with the surface of the runway. Resistance of the first 1,000 feet of track is decreased progressively in four steps. This graduation of resistance enables the tractive force to be held substantially constant as the speed is increased. The last 382 feet are used for stopping the car by dynamic braking and application of direct current.

Jet-propelled fighter airplane being prepared for launching by the Westinghouse "electropult," a linear induction motor



The car projects only $5^1/_2$ inches above the surface of the runway. On the under side of the car is the 3-phase primary winding in a flat core at a working air gap of 3/16 inch. The car wheels run on rails recessed in slots which straddle the stationary secondary winding, and a set of rails above the wheels prevents the car from being lifted. A space under the track houses the bus bars and collector rails that carry approximately 7,000 amperes during acceleration and 10,000 amperes during braking. The current collecting problem is extremely difficult because the car attains a speed of 225 miles per hour. The 12 collector shoes per phase are held against the collector rails by spring pressure. Provision is made for the pilot of the airplane to release the harness at the proper time.

One of the features of the launcher is a short-time power demand of approximately 12,000 kw. The power supply consists of a 2,200-horsepower aircraft engine coupled to a 750-kw d-c generator which supplies a d-c motor connected to a 24-ton flywheel and 3-phase alternator that supplies the catapult car. During the short time required to launch an airplane, the flywheel loses speed to furnish approximately 95 per cent of power needed. Slowing down of the flywheel and alternator reduces the frequency from 216 to about 192 cycles per second.

The electropult has launched jet-propelled airplane at 116 miles per hour in 4.1 seconds after a run of only 340 feet. Unassisted, the same airplane requires a take-off run of approximately 2,000 feet.