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James L. Harris

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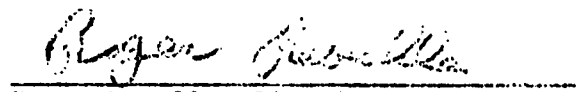
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# A FEASIBILITY STUDY OF PHOTOELECTRIC ANTICOLLISION SYSTEMS

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## 1.0 Introduction

The problem of air collisions is one which is currently receiving a tremendous amount of attention. A recent electronics periodical<sup>1</sup> lists twenty-four industrial organizations with an interest in anticollision programs. The article also states that in the last two years more than two hundred proposals for collision prevention systems were submitted to the FAA. The effort covers all regions of the electromagnetic spectrum from radar to ultraviolet.

The Visibility Laboratory has for a number of years carried on a program of investigation of the possible application of visible spectrum photoelectric systems to problems of search and detection. On the basis of this experience, this laboratory was requested by the Navy to carry out a short term study of the feasibility of anticollision instrumentation utilizing photoelectric apparatus operating in the visible spectrum. This report contains the results of this brief study program.

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1. Electronic Design, June 8, 1960

## 2.0 Selected Approach

The advantages and fundamental limitations of visible spectrum photoelectric search apparatus are exceedingly familiar to this laboratory. After due consideration of the brevity of this study program and the extent of national effort on the anti-collision problem, it was decided that the best interests of the funding agency would not be served by attempting to describe a preferred system. Instead, the study program considered a variety of classes of systems of varying complexity and cost, outlining, in so far as time and funding permitted, the fundamental performance limitations of each.

This report is, therefore, not a proposal for an anticollision system, but rather a document which hopes to relate this laboratory's experience in photoelectric detection apparatus to the anti-collision problem. It is hoped that this document will serve as a valuable aid in the evaluation of proposals for visible spectrum anticollision instrumentation.

## 3.0 Possible Classes of Systems

There are certain broad classifications covering the majority of anticollision systems. One classification is that which distinguishes collision avoidance systems (CAS) from pilot warning instruments (PWI). CAS equipment not only detects the presence of other aircraft, but in addition, obtains information about course, position, and speed in order to evaluate the collision threat and

perhaps indicate a course of action. The PWI system, on the other hand, indicates only that a detection has been made and notes the angular position of the detection. There is, of course, the possibility of any number of systems in between these extremes performing some portion of the CAS function as outlined above.

A second classification of value is the distinction between cooperative and non-cooperative systems. A cooperative system is one in which both aircraft must have some degree of instrumentation. A non-cooperative system is one in which the equipment is self-contained in a single aircraft, allowing this aircraft to practice collision avoidance against other aircraft who may or may not have collision avoidance equipment.

The following specific types of visible spectrum systems will be considered:

A. Non-Cooperative Systems

1. Passive Contrast Detection. This system assumes detection of other aircraft by means of reflected solar energy. Information output consists of elevation angle and azimuth angle only.

2. Pulsed Light Systems. This system involves the detection of other aircraft by means of the reflected return from a transmitted light pulse. Information output consists of elevation angle, azimuth angle, and range.

## B. Cooperative Systems

1. Modulated Light Systems. This system assumes that the aircraft to be detected will carry a modulated light source. The modulation may be a simple sinusoidal modulation. The information obtained on detection would then consist of elevation angle and azimuth angle. The modulation may be of a more complex form in which case the information obtained might consist of elevation angle, azimuth angle, aircraft altitude, aircraft speed and aircraft course.

2. Transponder System. This system requires that each aircraft carry a pulsed light source, a detection unit, and a transponder unit. The information output of such a system might include elevation angle, azimuth angle, aircraft altitude, aircraft speed, aircraft course and aircraft range.

### 4.0 Detection Geometry

The most meaningful method of specifying detection range requirements is in terms of warning time before collision. For an aircraft of specified speed this warning time translates into a collision range. The volume in space which an anticollision detector must search is defined by the locus of points of all aircraft which can reach the point of collision at the same time that the search aircraft reaches this point. If a specification is made as to the maximum horizontal and vertical speeds of aircraft to be encountered, then the search volume becomes a portion of a cylinder centered at the point of collision.

Figure 1 shows two typical search volumes. The first is for the case where aircraft are to be encountered having speeds no greater than the search aircraft. As might be expected under these conditions, there is no necessity for a search to the rear since no aircraft can overtake the search aircraft. The second case shown is when aircraft may be encountered having twice the speed of the search aircraft. A search to the rear is now required, however, the detection range to the rear is only one-third that required in the forward direction because of the 3 to 1 ratio of closing velocities in the two directions.

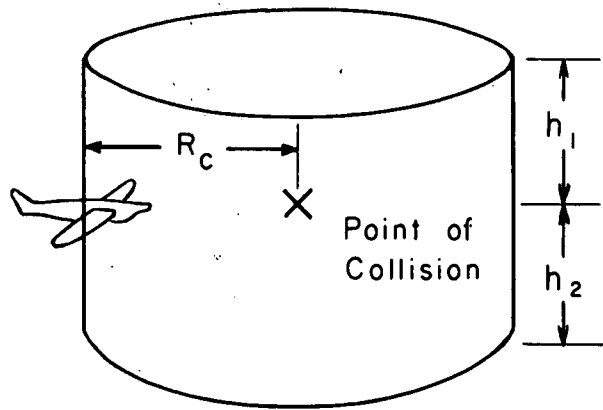
The importance of a proper specification of search volume will be more apparent after study of the sections which follow. Specification of equal detection range in all azimuths will result in a general decrease in attainable performance capability for any of the systems to be considered.

The general description of the required search volume may be derived as follows:

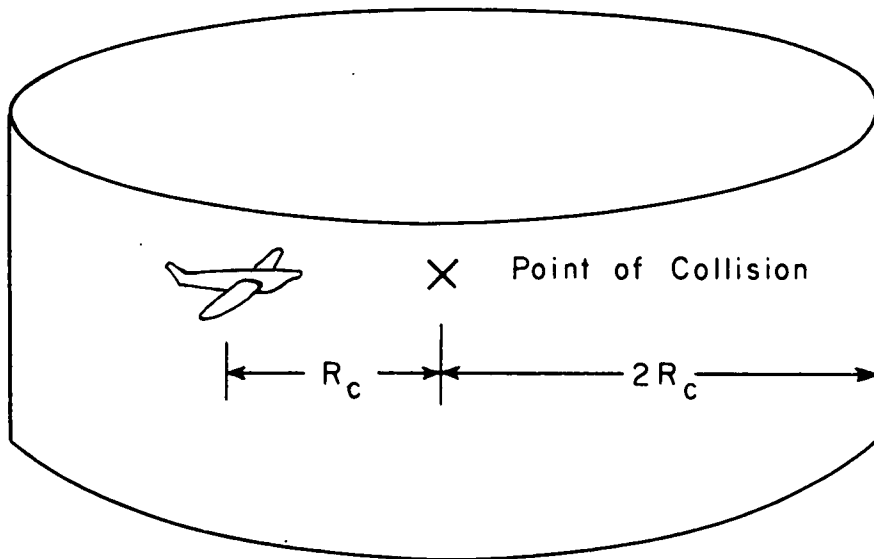
Let  $\theta$  be an angle measured in azimuth from the projected flight path of the search aircraft and let  $\phi$  be an elevation angle measured from a horizontal plane at the search aircraft. The required detection range as a function of  $\theta$  and  $\phi$  will now be derived.

The cylinder has a radius

$$r = v_{2H} T_c \quad (1)$$



Case 1. ( $V_{1H} = V_{2H}$ )



Case 2 ( $V_{1H} = \frac{1}{2} V_{2H}$ )

$R_c$  = Range to point of collision

$h_1$  = Height of upper cylinder

$h_2$  = Height of lower cylinder

Figure 1. Geometry of the required search volumes.



where  $v_{2H}$  is the horizontal speed of the aircraft to be detected and  $T_c$  is the required warning time before collision. But

$$T_c = \frac{R_c}{v_{1H}} \quad (2)$$

where  $R_c$  is the range to collision and  $v_{1H}$  is the horizontal speed of the search aircraft. Therefore

$$r = \left( \frac{v_{2H}}{v_{1H}} \right) R_c \equiv \rho_H R_c \quad (3)$$

where  $\rho_H$  is the ratio of the velocities as defined in equation (3). The upper cylinder height  $h_1$  is

$$h_1 = v_{2D} T_c \quad (4)$$

where  $v_{2D}$  is the descent speed of the aircraft to be detected. Once again substituting for  $T_c$  from equation (2)

$$h_1 = \left( \frac{v_{2D}}{v_{1H}} \right) R_c \equiv \rho_D R_c \quad (5)$$

and in a similar manner

$$h_2 = \left( \frac{v_{2A}}{v_{1H}} \right) R_c \equiv \rho_A R_c \quad (6)$$

where  $v_{2A}$  is the ascent speed of the aircraft to be detected.

The detection range to the periphery of the cylinder is defined by the equations

$$R_D = \frac{R_c \rho_V}{\sin \phi}, \quad \phi > \tan^{-1} \frac{\rho_V}{\cos \theta \pm \sqrt{\cos^2 \theta + (1 - \rho_F)^2}} \quad (7)$$

$$R_D = \frac{R_c \left[ \cos \theta \pm \sqrt{\rho_F^2 - \sin^2 \theta} \right]}{\cos \phi}, \quad \phi < \tan^{-1} \frac{\rho_V}{\cos \theta \pm \sqrt{\cos^2 \theta - (1 - \rho_F)^2}} \quad (8)$$

Where  $\rho_A = \rho_D \approx \rho_V$ .

Equation (7) defines the roof and floor of the cylinder while equation (8) defines the cylinder wall. Numerically, the proper choice of equations is the one which yields the smallest value of  $R_D$ .

## 5.0 Non-Cooperative Systems

This section contains derivations of equations and numerical examples of performance capability for passive contrast detection and pulsed light systems.

### 5.1 Passive Contrast Detection

This system may be visualized as a scanner which detects aircraft by virtue of their natural contrast with respect to the background.

### 5.1.1 Derivation of Equations

Consider a small sector of the field of view defined by the elevation and azimuth angles  $\Delta\phi$ ,  $\Delta\theta$ . The change in output current from a scanning system due to the presence of a target is

$$\Delta i = \frac{C_R A_T B A_L S}{R_D^2} \quad (9)$$

where  $C_R$  is the apparent contrast of the target,  $A_T$  is the target area,  $B$  is the background luminance,  $A_L$  is the area of the entrance pupil of the optical system,  $S$  is the sensitivity of the photocell, and  $R_D$  is the detection range as defined by the cylindrical volume described in the preceding section.

The rms shot noise associated with this signal is

$$i_n = \left[ 2 \epsilon B \Delta\phi \cos \phi \Delta\theta A_L S \Delta f \right]^{\frac{1}{2}} \quad (10)$$

where  $\epsilon$  is the electronic charge,  $\Delta\phi \cos \phi \Delta\theta$  is the incremental solid angle, and  $\Delta f$  is the electrical bandpass. The signal-to-noise ratio is

$$\frac{s}{n} = \frac{C_R A_T}{R_D^2} \left[ \frac{B A_L S}{2 \epsilon \Delta\phi \cos \phi \Delta\theta \Delta f} \right]^{\frac{1}{2}} \quad (11)$$

The bandpass,  $\Delta f$ , is inversely proportional to time spent in analyzing this incremental solid angle or

$$\frac{s}{n} = \frac{C_R A_T}{R_D^2} \left[ \frac{B A_L S T}{2 \epsilon \Delta \phi \cos \phi \Delta \theta} \right]^{\frac{1}{2}} \quad (12)$$

In order that the systems operate with high efficiency, the dwell time,  $T$ , should be adjusted so that the signal-to-noise ratio is constant over the entire search volume, therefore,

$$T = \frac{2 \epsilon R_D^4 \left(\frac{s}{n}\right)^2 \Delta \phi \cos \phi \Delta \theta}{C_R^2 A_T^2 B A_L S} \quad (13)$$

The total time available for a search of the field is

$$T_T = \sum T = \frac{2 \epsilon \left(\frac{s}{n}\right)^2}{A_L S} \int_0^{2\pi} \int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} \frac{R_D^4 \cos \phi \, d\phi \, d\theta}{C_R^2 A_T^2 B} \quad (14)$$

For the simplifying assumptions that the inherent contrast,  $C_0$ , the target area, and the background luminance are constants\* then

$$T_T = \frac{8 \epsilon \left(\frac{s}{n}\right)^2}{A_L S C_0^2 A_T^2 B} \int_0^{\pi} \int_0^{\frac{\pi}{2}} \frac{R_D^4 \cos \phi \, d\phi \, d\theta}{T_A^2} \quad (15)$$

where  $T_A$  is the contrast transmittance of the atmosphere.

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\* In practice, these parameters are not constants, but vary with elevation and azimuth. At a later point in this report it will become clear that primary concern is with the order of magnitude of system requirements and within this context the assumptions are justified.

If M photocells are used for performing this search task then the total time can be reduced by a factor of M by splitting the field up into M sectors. Then

$$T_T = \frac{8\epsilon \left(\frac{s}{h}\right)^2}{A_L M S C_0^2 A_T^2 B} \int_0^\pi \int_0^{\frac{\pi}{2}} \frac{R_D^4 \cos \phi \, d\phi \, d\theta}{T_A^2} \quad (16)$$

The magnitude of the detection task is defined by the product of the required entrance pupil area and the number of photocells. This product is

$$A_L M = \frac{8\epsilon \left(\frac{s}{h}\right)^2}{T_T S C_0^2 A_T^2 B} \int_0^\pi \int_0^{\frac{\pi}{2}} \frac{R_D^4 \cos \phi \, d\phi \, d\theta}{T_A^2} \quad (17)$$

### 5.1.2 Discrimination Requirements

An effective anticollision detector must have a low false alarm rate. An equipment with a high rate of false alarms would be very disconcerting to the pilot and will ultimately result in loss of faith and/or switching the equipment to the "off" position. This requirement dictates that a passive contrast detector must have the ability to do an effective job of discriminating against objects, other than aircraft, in the field of view.

While a great deal of work has been done on "spatial filtering", by far the majority of effort has been devoted to the detection of "point sources" in the presence of objects of extended

angular subtense. For the short range anticollision detector the aircraft to be detected may have angular subtense comparable to clouds or ground structures. This type of spatial filtering is not, therefore, an effective tool for this problem.

Another possible discrimination cue is the fact that two aircraft traveling at constant velocity are on a collision course if the angular position of the line of sight does not change. It is possible that a discrimination mechanization based on this fact might be designed. There would be a major difficulty with this technique for use with a passive (no range information) system. Distant objects will have a very low rate of change of the line of sight. For example, at night, based on this criterion, the aircraft would find itself on "collision course" with every star in the sky. An additional factor is that it is not readily apparent that such a mechanization would have the desired simplicity.

Another, and more plausible, criterion for discrimination is that of color recognition. This is initially attractive because it is compatible with anticollision painting programs now in existence. The fluorescent paints now available are particularly beneficial for the mechanization of such a discrimination method. With proper optical filtering, inherent contrasts in the red portion of the spectrum might typically be in the range from 2 to 20 for a fluorescent orange aircraft viewed against a blue sky. The contrast is determined by sun position as well as overcast and undercast conditions. For atmospheric conditions where selective (small

particle) scattering prevails, there would be some gain in contrast transmittance by operating at the red end of the spectrum and for the same reason a blue sky would appear "darker". A multiplier phototube having an S-17 photocathode (i.e., RCA 7029) should have good sensitivity against a fluorescent orange target.

There are a variety of ways in which a color discrimination system could be mechanized. One method is to use separate red and blue channels. Detection would occur if the red channel output indicated the presence of an object rendering greater red flux than the background. Discrimination could be obtained by taking a ratio between the difference and sum of the red and blue channels. It should be pointed out that the color discrimination process will inherently be more "noisy" than the detection channel. There will, therefore, be a time lag between detection and color discrimination.

### 5.1.3 Numerical Example

Figure 2 is a plot of equation (17) employing the following assumptions:

Inherent Contrast,  $C_o = 2$

Velocity of Searching Aircraft,  $v_{1H} = 300$  knots

Velocity of Aircraft to be Detected,  $v_{2H} = 600$  knots

Maximum Ascent or Descent Velocity,  $v_v = 80$  knots

Background Luminance,  $B = 1000$  foot-lamberts

Total Search Time  $T_T = 2$  seconds

$A_L M$  - Product of Optical Entrance Pupil Area and No. of Photocells  
(square feet)

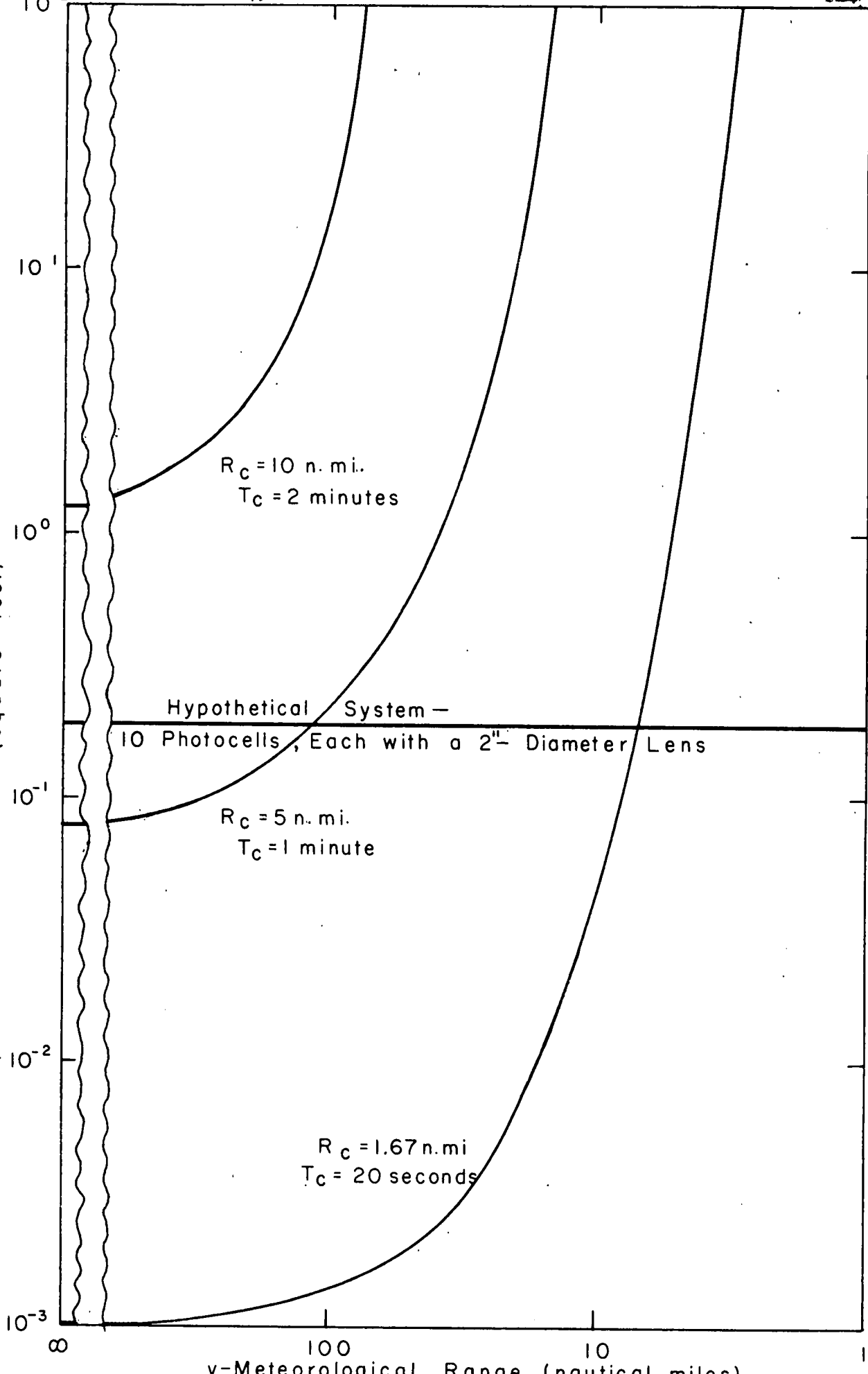


Figure 2. Limiting performance capability of passive contrast detectors.



In the Navy's letter of instruction to this laboratory it was specified that the atmospheric clarity should be 0.6 per sea mile or better. This corresponds to a meteorological range of 7.7 nautical miles. It may be noted that for this value of meteorological range, a 10-photocell system employing 2-inch diameter optics will provide satisfactory coverage for the case of a collision range of 1.67 nautical miles. Because of the 2 to 1 ratio of aircraft velocities this corresponds to a 5 nautical mile detection range in the forward direction, which is the value specified to this laboratory by the Navy. It should also be noted from Figure 2 that the same system provides considerably longer range capability as the meteorological range increases. At altitudes above 10,000 feet meteorological ranges in excess of 100 nautical miles would be common. It should be noted that  $A_L M$  is inversely proportional to the background luminance, B, which on a dark night may be smaller by a factor of as much as  $10^8$ . The system, therefore, has no nighttime capability.

## 5.2 Pulsed Light System

This system is the optical equivalent of radar. A light pulse is transmitted, reflected from the target, and detected by a receiver located at the same point as the transmitter.

### 5.2.1 Derivation of Equations

Let  $I$  be the peak intensity of the source,  $T_A$  be the atmospheric transmittance, and  $E$  be the peak illuminance at the target aircraft. Then

$$E = \frac{I T_A}{R_D^2} \quad (18)$$

If the target aircraft is assumed to have an average reflectance,  $r$  (foot-lamberts/foot-candle), then the luminance of the target aircraft due to the incident pulse will be

$$B_T = \frac{I T_A}{R_D^2} r \quad (19)$$

where  $r$  is specified for the direction from which the pulse was received. The flux which will be returned to the search aircraft is

$$F = \frac{I T_A^2 r A_T A_L}{R_D^4} \quad (20)$$

To make optimum use of the transmitted power, the intensity,  $I$ , should be made to vary as a function of  $\theta$  and  $\phi$  in such a way that  $F$  becomes independent of  $\theta$  and  $\phi$ , or

$$I(\theta, \phi) = \frac{F R_D^4}{T_A^2 r A_T A_L} \quad (21)$$

The total flux transmitted would be

$$P = 4 \int_0^{\pi} \int_0^{\frac{\pi}{2}} I(\theta, \phi) \cos \phi \, d\phi \, d\theta \quad (22)$$

or

$$P = \frac{4F}{r A_T A_L} \int_0^{\pi} \int_0^{\frac{\pi}{2}} \frac{R_D^4 \cos \phi \, d\phi \, d\theta}{T_A^2} \quad (23)$$

The received signal has a peak value of

$$i_S = F S \quad (24)$$

and the flux from the background will be

$$F_B = 4 A_L \int_0^{\pi} \int_0^{\frac{\pi}{2}} B \cos \phi \, d\phi \, d\theta \quad (25)$$

The shot noise resulting from this background flux is

$$i_n = \sqrt{2 \epsilon F_B \Delta f} \quad (26)$$

The signal-to-noise ratio is, therefore,

$$\frac{s}{n} = \frac{P r A_T A_L^{\frac{1}{2}} S^{\frac{1}{2}}}{\left[ 4 \int_0^{\pi} \int_0^{\frac{\pi}{2}} R \cos \phi \, d\phi \, d\theta \right] \sqrt{2 \epsilon^{\frac{1}{2}} \Delta f^{\frac{1}{2}}} \left[ 4 \int_0^{\pi} \int_0^{\frac{\pi}{2}} B \cos \phi \, d\phi \, d\theta \right]^{\frac{1}{2}}} \quad (27)$$

If the detector consists of M photocells each with an entrance pupil area  $A_L$  then

$$A_{LM} = \frac{2 \epsilon \left(\frac{s}{n}\right)^2 \left[ \int_0^\pi \int_0^{\frac{\pi}{2}} B \cos \phi \, d\phi \, d\theta \right] \left[ \int_0^\pi \int_0^{\frac{\pi}{2}} \frac{R_D^4 \cos \phi \, d\phi \, d\theta}{T_A^2} \right]^2}{P^2 \tau r^2 A_T^2 S} \quad (28)$$

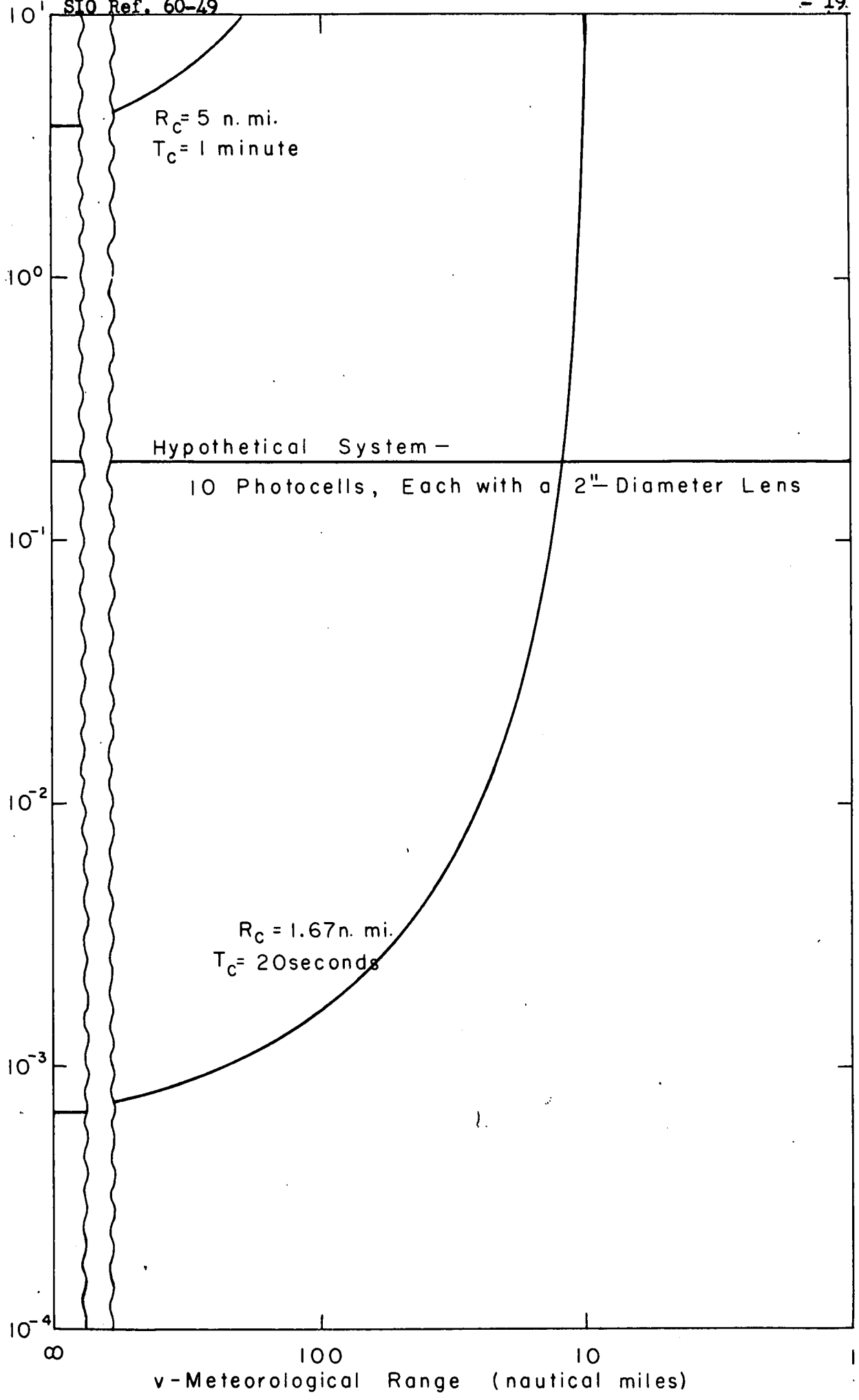
### 5.2.2 Discrimination Requirements

Since a pulsed light system gives range information, the discrimination against objects is an easy task. If the aircraft to be detected can be made to carry retroreflectors, then the return from these targets can be made to be large compared to the return from other possible objects such as clouds, etc. Thus, it would appear that a pulsed light system could have good capability as far as discrimination against false targets.

### 5.2.3 Numerical Example

Figure 3 shows a sample calculation based on equation (28). The calculation was based on a peak luminous flux of  $7 \times 10^8$  lumens and a pulse duration of one microsecond. The pulsed lamp parameters were chosen from pulsed sources known to exist at the present time. The value of background luminance was chosen to be  $10^{-5}$  foot-lamberts which corresponds to a very dark night. Ten square feet of retroreflective material was used, having a specific brightness of  $10^4$  foot-lamberts per foot-candle. A comparison of

$A_L M$  - Product of Optical Entrance Pupil Area and No. of Photocells  
(square feet)



figures 2 and 3 indicates that the pulsed light system is more sensitive to both meteorological range and detection range. This is to be expected because the light pulse must travel both to and from the target. Equation (28) reflects this double transit in that  $A_L^M$  is proportional to range to the eighth power and atmospheric transmittance to the fourth power. Figure 3 shows that the hypothetical receiver of 10 photocells with 2-inch diameter lenses does not satisfy the Navy specifications for detection range and atmospheric clarity, even on the darkest night, and with the optimistic estimate that the target aircraft carries 10 square feet of retroreflective material. Since  $A_L^M$  is directly proportional to the background luminance, the system obviously has no daytime capability. Neither increase in  $A_L^M$  or pulse power can accommodate the eight orders of magnitude improvement needed for daytime operation.

## 6.0 Cooperative Systems

This section contains derivation of equations and numerical examples of performance capability for modulated light systems and transponder systems.

### 6.1 Modulated Light Systems

This system would consist of a photoelectric equipment whose function is to detect a modulated light source carried by all other aircraft.

### 6.1.1 Derivation of Equations

The light source carried aboard the aircraft to be detected is assumed to emit a light pulse whose peak intensity is  $I$ . The peak illuminance at the entrance pupil of the detector is, therefore,

$$E = \frac{I T_A}{R_D^2} \quad (29)$$

where  $T_A$  is the atmospheric contrast transmittance and  $R_D$  is the detection range. For the system to operate with highest efficiency the intensity of the pulse source should vary with azimuth and elevation in such a way that  $E$  is constant from all aircraft which are on a collision course at the range described by the detection cylinder. Therefore,

$$I(\theta, \phi) = \frac{E R_D^2}{T_A} \quad (30)$$

The total flux content of the pulse is, therefore,

$$P = 4 \int_0^\pi \int_0^{\frac{\pi}{2}} I(\theta, \phi) \cos \phi \, d\phi \, d\theta \quad (31)$$

or

$$P = 4 E \int_0^\pi \int_0^{\frac{\pi}{2}} \frac{R_D^2}{T_A} \cos \phi \, d\phi \, d\theta \quad (32)$$

The peak received signal is

$$i_S = E A_L S \quad (33)$$

where again  $A_L$  is the entrance pupil area of the receiver optical system and  $S$  is the sensitivity of the photocell. Substituting from equation (32)

$$i_S = \frac{P A_L S}{4 \int_0^\pi \int_0^{\pi/2} \frac{R_D^2}{T_A} \cos \phi \, d\phi \, d\theta} \quad (34)$$

The photon shot noise due to the received background flux is

$$i_n = \sqrt{8 \epsilon \Delta f \int_0^\pi \int_0^{\pi/2} B A_L S \cos \phi \, d\phi \, d\theta} \quad (35)$$

The signal-to-noise ratio would, therefore, be

$$\frac{s}{n} = \frac{P A_L^{\frac{1}{2}} S^{\frac{1}{2}}}{8 \sqrt{2} \epsilon^{\frac{1}{2}} \Delta f^{\frac{1}{2}} \int_0^\pi \int_0^{\pi/2} \frac{R_D^2}{T_A} \cos \phi \, d\phi \, d\theta \left[ \int_0^\pi \int_0^{\pi/2} B \cos \phi \, d\phi \, d\theta \right]^{\frac{1}{2}}} \quad (36)$$

Assuming the receiver consists of  $M$  photocells each with an entrance pupil area  $A_L$ , then

$$A_{LM} = \frac{128 \epsilon \left(\frac{s}{h}\right)^2 \Delta f \left[ \int_0^\pi \int_0^{\pi/2} \frac{R_D^2}{T_A} \cos \phi \, d\phi \, d\theta \right]^2 \int_0^\pi \int_0^{\pi/2} B \cos \phi \, d\phi \, d\theta}{P^2 S} \quad (37)$$



The bandpass,  $\Delta f$ , is inversely proportional to the pulse length,  $\tau$ , therefore,

$$A_{LM} = \frac{128 \epsilon \left(\frac{s}{n}\right)^2 \left[ \int_0^\pi \int_0^{\frac{\pi}{2}} \frac{R_D^2}{T_A} \cos \phi \, d\phi \, d\theta \right]^2 \int_0^\pi \int_0^{\frac{\pi}{2}} B \cos \phi \, d\phi \, d\theta}{P^2 \tau S} \quad (38)$$

It should be noted that the product  $P\tau$  is the total flux emitted in the light pulse. Since the denominator contains the term  $P^2\tau$ , it is indicated that, for a fixed average power,  $A_{LM}$  is minimized by using a pulse of short duration and high intensity. Both the pulsed case and continuous case will be treated in the numerical example. Equation (38) is valid for the continuous source case by letting  $\tau$  take on the value of the information period (i.e., time between independent observations) and  $P$  becomes the steady state of luminous flux output of the source.

In a cooperative system additional information such as course, altitude, speed, etc., may be transmitted between aircraft. It should be noted, however, that a system designed for detection transmits essentially one bit of information per information period. The required bandwidth of the receiver is directly proportional to the number of bits of information transferred. To transmit and receive a message consisting of  $n$  bits of information, while maintaining the desired signal-to-noise ratio, requires that  $A_{LM}$  be increased by a factor of  $n$  or that the transmitted power be increased by a

factor of  $n^{\frac{1}{2}}$ . By utilizing separate detection and "additional information" channels a system could be designed which would give unaltered detection performance with the additional information supplied at a closing range reduced by a factor of  $n^{\frac{1}{4}}$ . For example, a 16-bit message could be received by the system at a closing range equal to  $\frac{1}{2}$  the detection range.

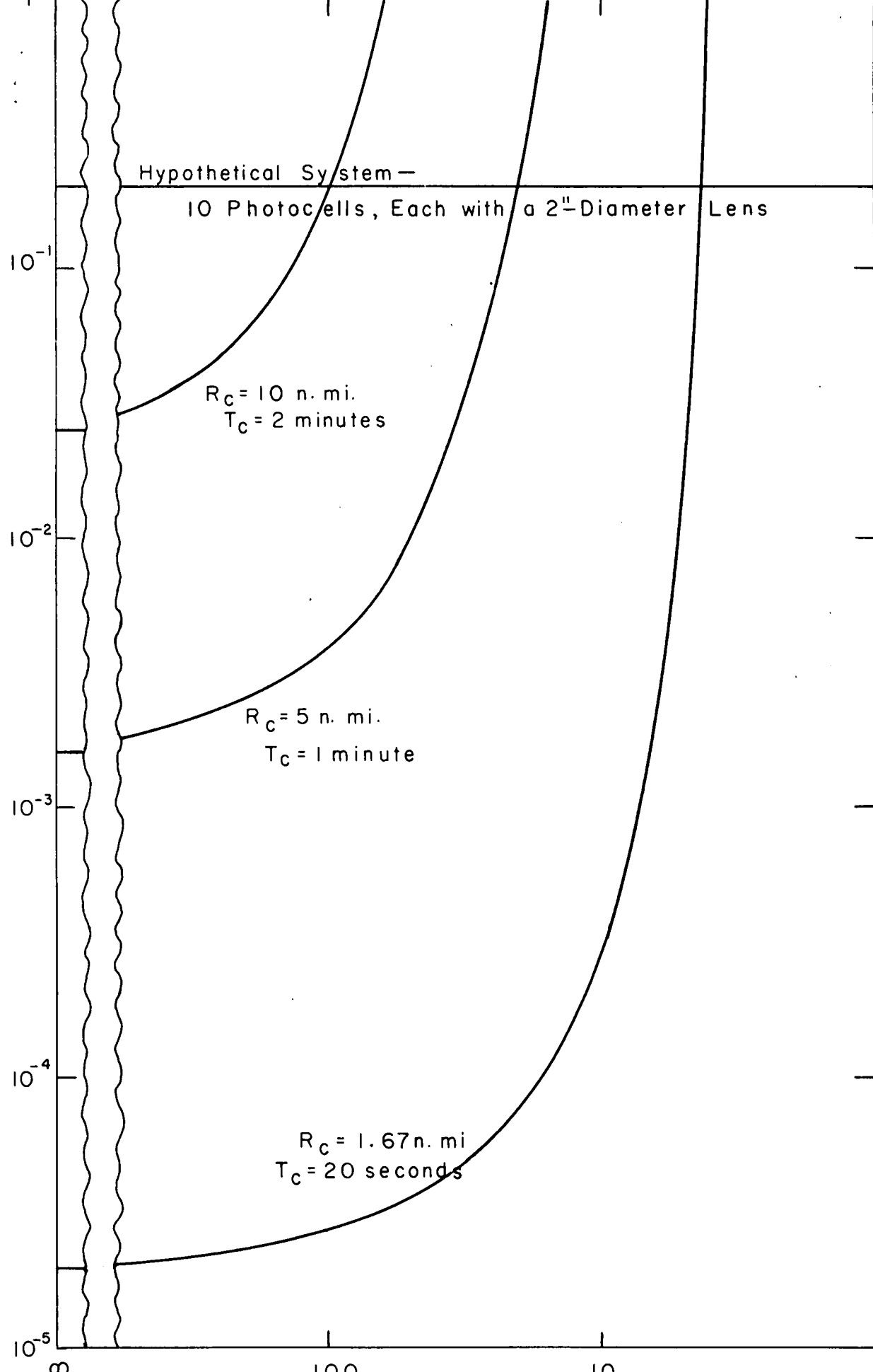
### 6.1.2 Discrimination Requirements

Modulation of the light source serves as a valuable aid to the task of discriminating against false targets. This is particularly true of a short duration light pulse (for example, 1 microsecond) in that very few natural sources can be expected to have temporal fluctuations of this nature. While a short duration pulse is superior, even the presently used anticollision flashing lamps offer some possibility for selective filtering to eliminate false targets.

### 6.1.3 Numerical Example

Figure 4 shows the results of a sample calculation based on equation (38). The curve is for a continuous source (or low frequency modulation) of approximately 20 watts power operating on a very dark night (background luminance of  $10^{-5}$  foot-lamberts). This same curve also depicts the performance capability for a pulsed light source emitting a one microsecond pulse having an average power of 20 watts, but for a background luminance of 10 foot-lamberts. Since for both systems  $A_{LM}$  is directly proportional to the background luminance, this represents dramatic demonstration of the tremendous performance gain achievable with short duration pulse systems.

$A_L M$  - Product of Optical Entrance Pupil Area and No. of Photocells  
(square feet)



v - Meteorological Range (nautical miles)

## 6.2 Transponder System

The equations of section 6.1 apply equally well to a transponder system. If each aircraft has a pulsed lamp and the detector specified in section 6.1, then the addition of appropriate electronics to the system allows transponder operation. When a pulse is received by the detector the lamp is immediately flashed. The aircraft which originated the light pulse, therefore, receives a return light pulse delayed from the original pulse by the time required for double transit of the range between the two aircraft. Therefore, range information may be obtained.

As indicated in section 6.1 additional information may be transmitted at reduced range or at the expense of an increase in detector size ( $A_L M$ ) or average pulse power.

## 7.0 System Summary

Figure 5 indicates the requirements imposed on the various systems for a collision range of 1.67 nautical miles as a function of the time of day and for selected values of atmospheric clarity. Figures 6 and 7 are similar plots for values of collision range of 5 and 10 nautical miles. It is clearly indicated that none of the systems using active sources is effective for daytime use. Passive contrast detection appears to be the only plausible visible spectrum system for daytime use. Figure 5 also clearly indicates that nighttime operation requires the use of an active light source of some type.

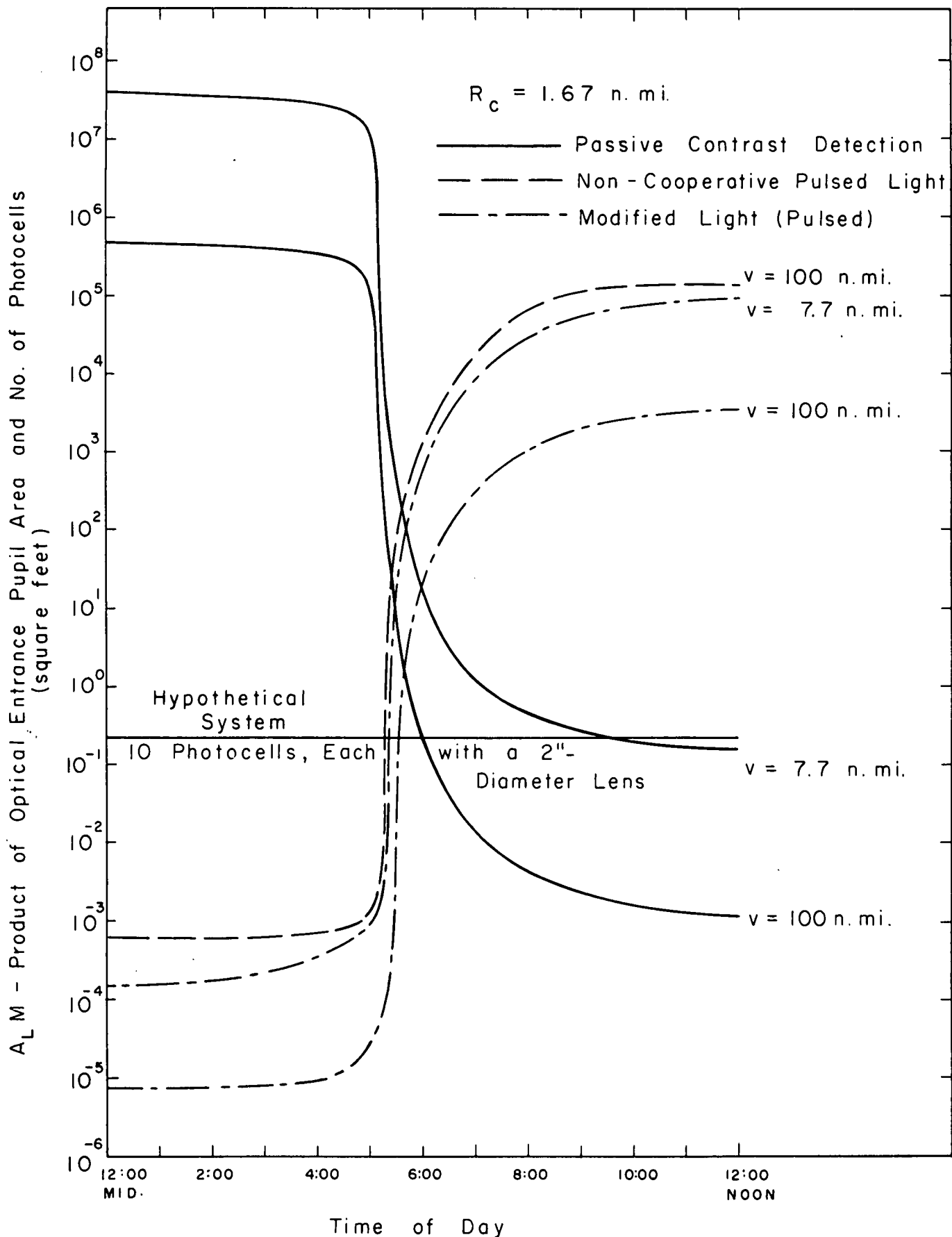


Figure 5. Characteristics of the various types of systems as a function of the time of day.

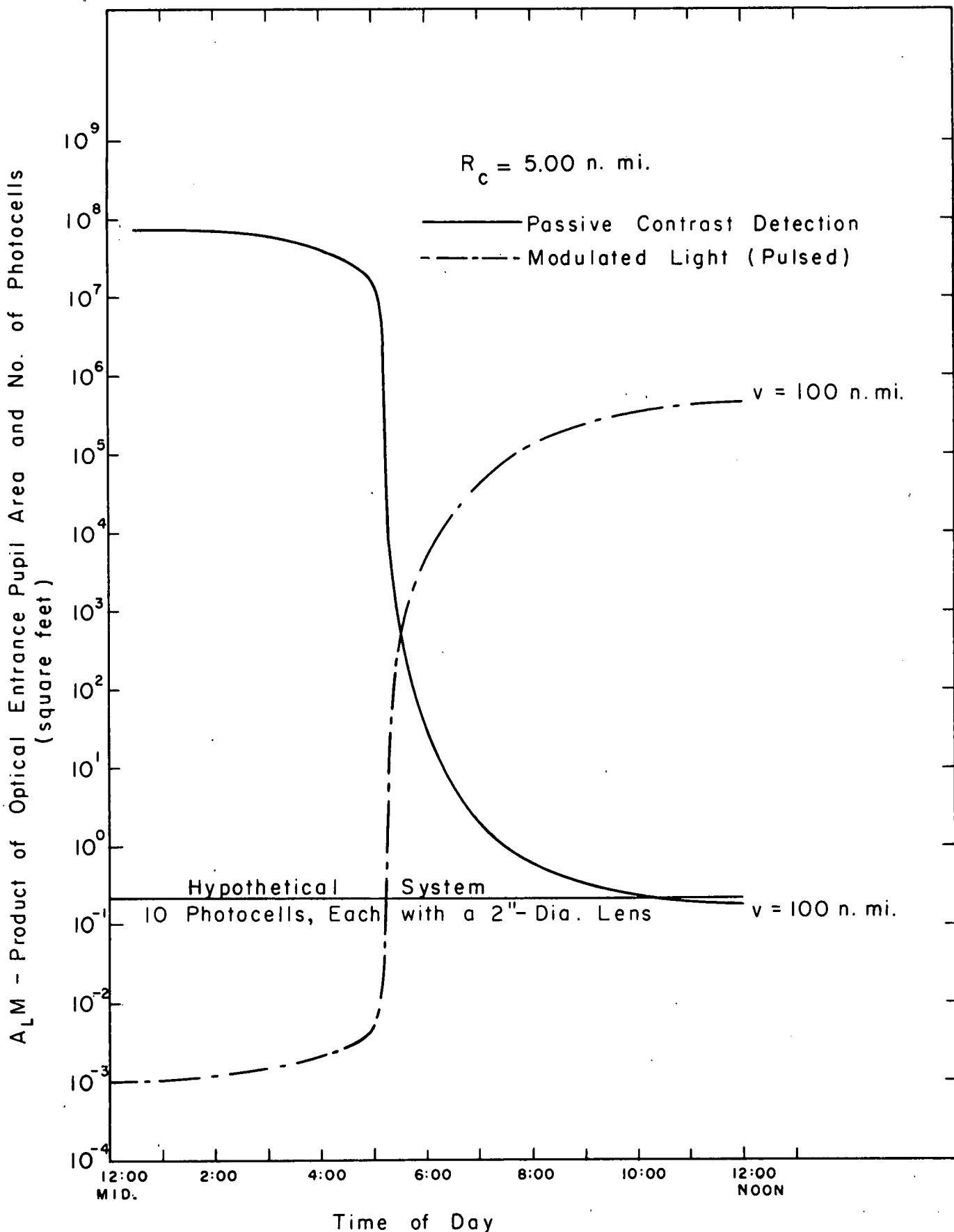


Figure 6. Characteristics of the various types of systems as a function of the time of day.

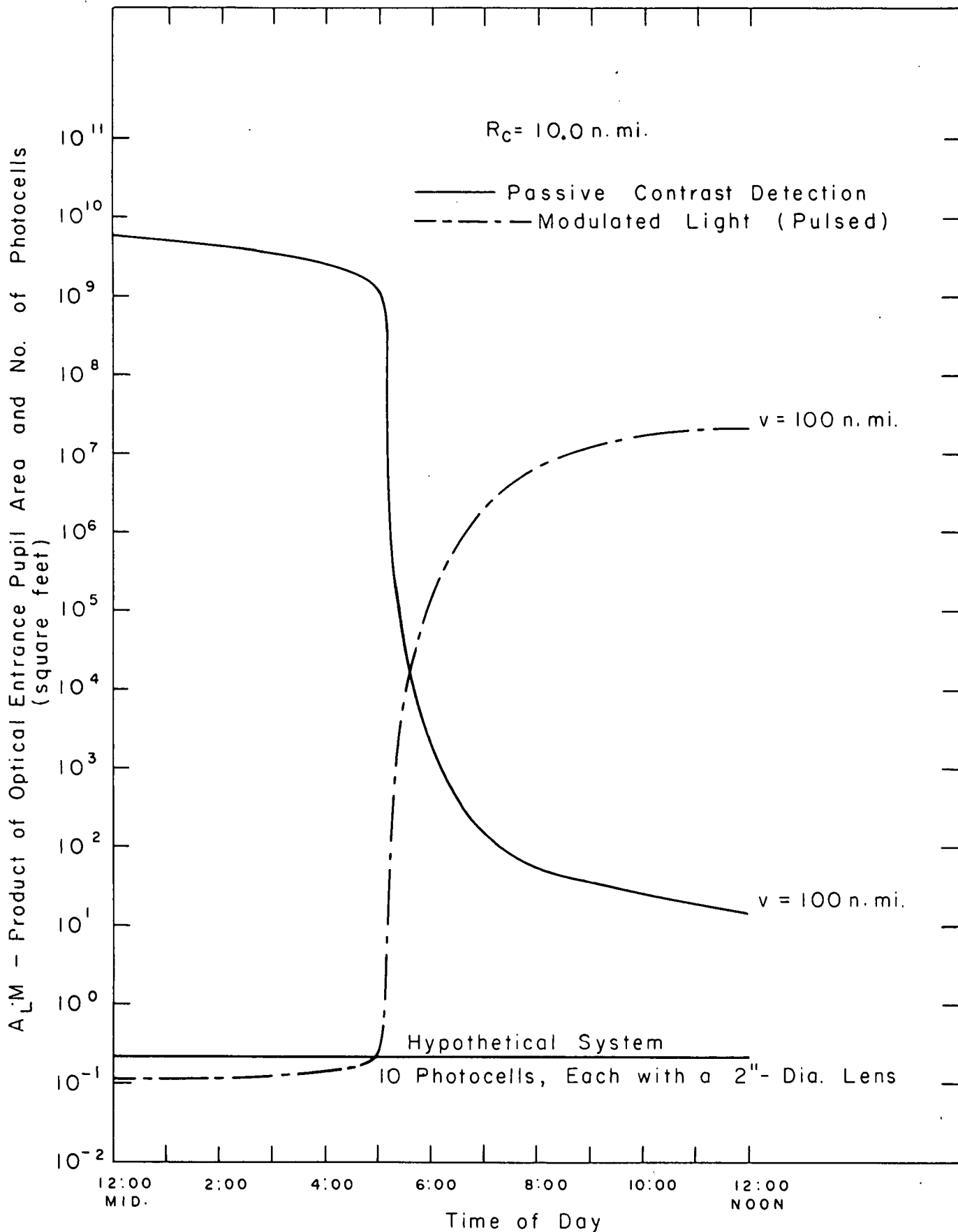


Figure 7. Characteristics of the various types of systems as a function of the time of day.

The horizontal line represents a system consisting of 10 photocells each with a 2-inch diameter lens. This is not meant to imply that a 10-photocell 2-inch system represents an upper limit or an optimum. Its purpose is simply to furnish a reference.

### 8.0 Conclusion and Recommendations

This study has furnished information as to the upper limits on performance capability of various visible spectrum anticollision systems. It is hoped that this information can be a valuable aid in evaluating proposals for anticollision equipments which specify operation in the visible spectrum.

It is believed, on the basis of the brief study indicated in this report, that a 24-hour a day pilot warning equipment could be designed and constructed. The system would use passive contrast detection with color discrimination during day light hours and a modulated light source on board each plane at night (this might possibly utilize present anticollision lamps). Information other than detection and angular location could be obtained only during night-time operation. The following specific recommendations are made on the basis of this study.

(a) Full evaluation of the desirability of visible spectrum anticollision equipment can be made only after comparison with the performance capability and cost of equipment designed for operation in other regions of the electromagnetic spectrum and with due consideration of the long range FAA planning.



(b) Specification of detection range should be in terms of collision warning time, rather than a fixed detection range for all azimuths and elevations. In the numerical examples given in this report this difference in specification can amount to a factor of 100 to 1 in the lens area or number of photocells required by the detector.

(c) The Navy specification of 0.6 per sea mile atmospheric transmission seems arbitrarily low in view of the indications that the majority of air collision have occurred in much clearer atmospheres. Further study of a realistic transmission figure should be made. All photoelectric systems will be very sensitive to this specification. An unnecessarily low specification of transmission may completely rule out systems capable of satisfactory operation under more reasonable transmission conditions.