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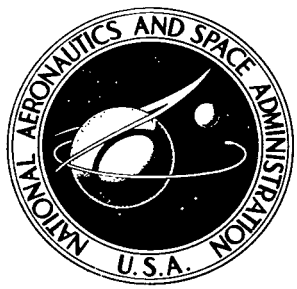

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COMPILATION OF XENON FLASH TUBE DATA FOR PILOT WARNING INDICATOR SYSTEMS

by Robert Gagnon and Anthony R. Lewis

Electronics Research Center
Cambridge, Mass. 02139

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16. Abstract

To provide design data for Pilot Warning Indicator (PWI) systems, we measured the characteristics of six types of xenon strobe lamps (14 units) built to operate as aircraft beacons and one type of xenon strobe lamp (2 units) which was not designed for that purpose. Flash lamp output was measured with a radiometer (EG&G Model 580-23A), factory-calibrated against a secondary standard. Four filters (central wavelengths 0.825, 0.876, 0.927, and 0.974 μm) were used to obtain more detailed spectral characteristics. Properties determined for each lamp were: pulse shape, pulse width, pulse rise time, lamp steradiancy, peak irradiance, peak radiant intensity, peak optical power, average optical power, optical energy output, and conversion efficiency.

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SUMMARY

To provide design data for Pilot Warning Indicator (PWI) systems, we measured the characteristics of six types of xenon strobe lamps (14 units) built to operate as aircraft beacons and one type of xenon strobe lamp (2 units) which was not designed for that purpose. Flash lamp output was measured with a radiometer (EG&G model 580-23A), factory-calibrated against a secondary standard. Four filters (central wavelengths 0.825, 0.876, 0.927, and 0.974 μm) were used to obtain more detailed spectral characteristics. Properties determined for each lamp were: pulse shape, pulse width, pulse rise time, lamp steradiancy, peak irradiance, peak radiant intensity, peak optical power, average optical power, optical energy output, and conversion efficiency.

INTRODUCTION

A Pilot Warning Indicator (PWI) system, using xenon flash tubes as radiation sources, is presently being developed by NASA. To facilitate the design of detectors for the system, we have measured the characteristics of commercially available xenon flash tubes, primarily those currently in use as aircraft beacons. Of particular interest was the measurement of radiated power to set acceptance thresholds and the determination of pulse-width and pulse rise-time for pulse-discrimination circuits which improve the signal-to-noise ratio.

The information presented here is for specific flash tubes; manufacturers may change specifications from time to time and variation in production runs is to be expected. Our data are intended as an aid to designers and should, in no way, be regarded as rating one tube against another.

EXPERIMENTS

A diagram of the experimental setup is shown in Figure 1. The optical bench ensured the stability and constant separation distance of the radiometer and xenon lamp system. The radiometer (EG&G model 580-23A, S/N385) was factory-calibrated against a secondary standard, Figure 2. The oscilloscope (Tektronix 502A,

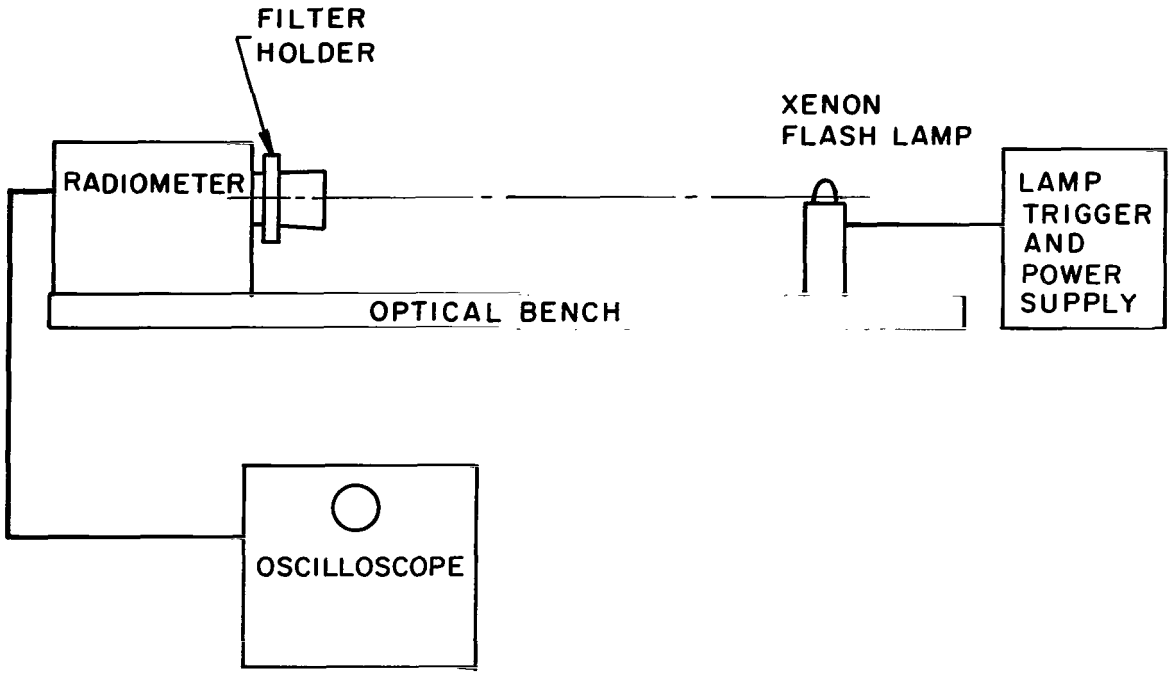

Figure 1.- Experimental Set Up

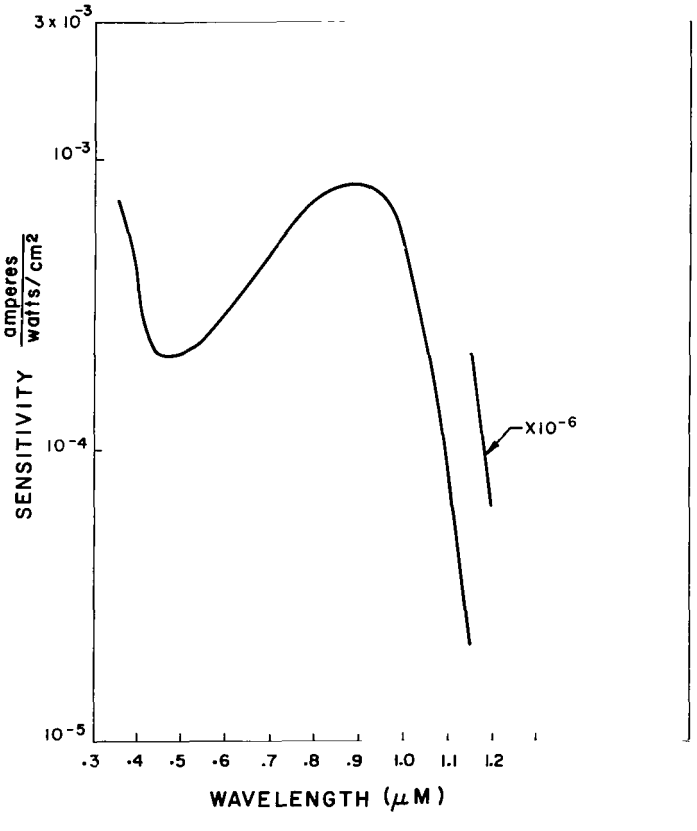

Figure 2.- Sensitivity of Radiometer (EG&G Model 580-23A S/N 385) Calibration Performed by EG&G

Dual-beam S/N 025935) was calibrated at NASA, ERC, just prior to the tests. Pulses were recorded with an oscilloscope camera for analysis. Filters could be inserted in the receptor cone of the radiometer to observe the output in a specific passband. Four filters were used with central wavelengths of 0.825, 0.876, 0.927, and 0.974 μm; the filter transmission characteristics are shown in Figure 3.

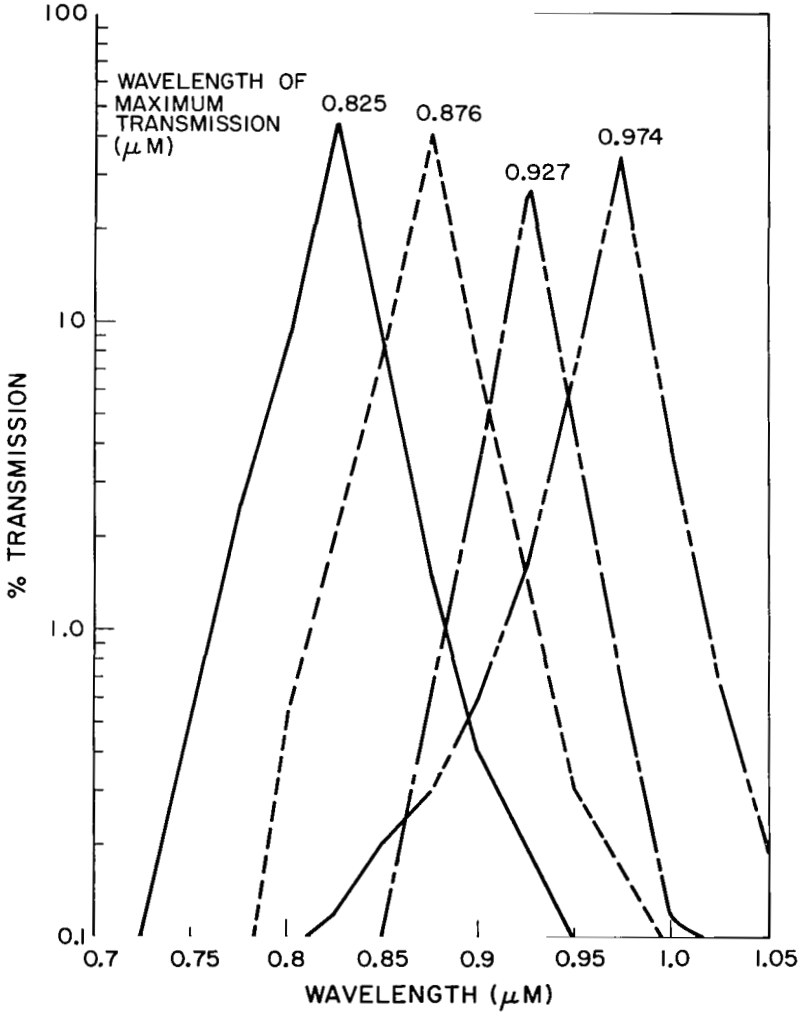

Figure 3.- Optical Filter Transmission Characteristics (Filters from Optical Technology, Inc.)

Measurement

Pulse form.- The pulse shapes of the total unfiltered radiated power are shown in Figures 4 through 10. The computed rise-times and pulse widths are given in Table I. Rise-time is taken as the time interval between the 10 percent and 90 percent amplitude points on the leading edge of the pulse. The pulse width, τ, is defined as:

$$\tau = \frac{\left| \int_{\tau_0}^{\tau_1} V(t)\,dt \right|^2}{\int_{\tau_0}^{\tau_1} |V(t)|^2\,dt} \qquad (1)$$

where $V(t)$ is the voltage developed across the sampling resistor at the radiometer output and $\tau_1 - \tau_0$ is the total width of the pulse given by the baseline.

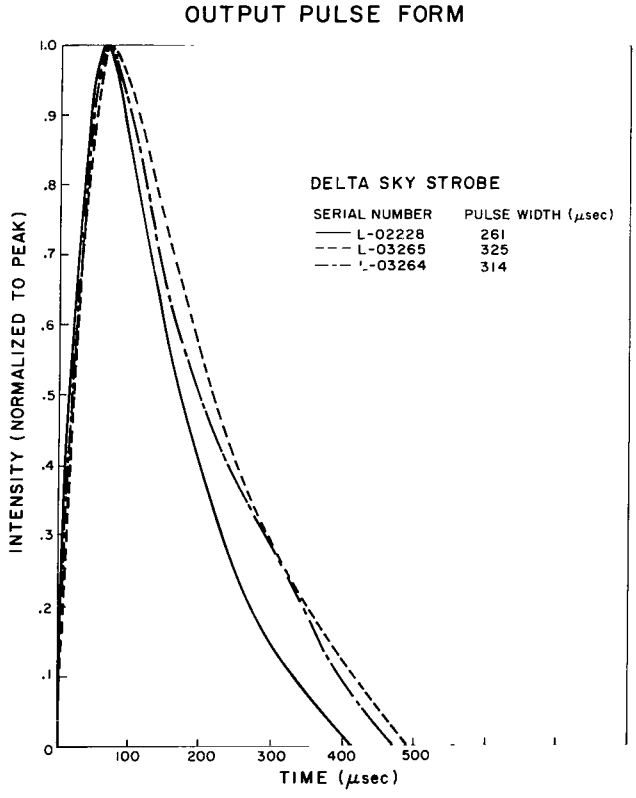

Figure 4.- Output Pulse Form

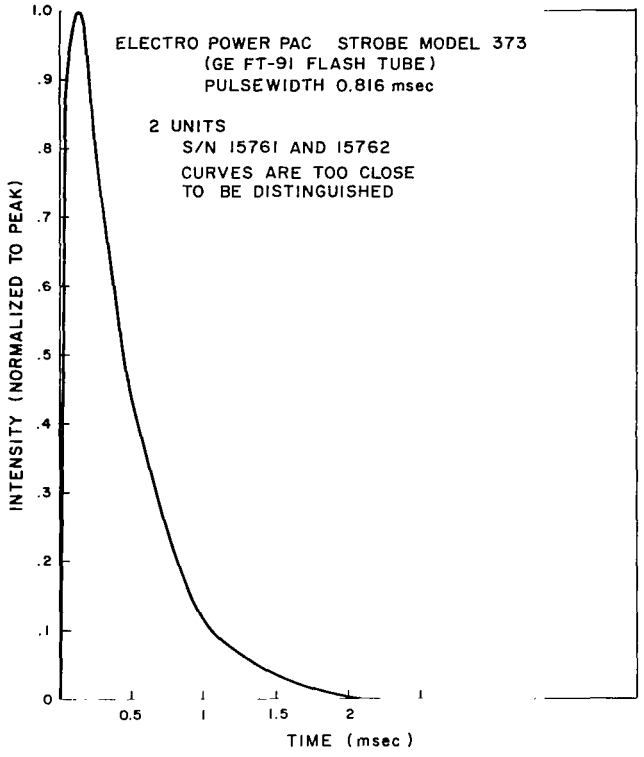

Figure 5.- Output Pulse Form

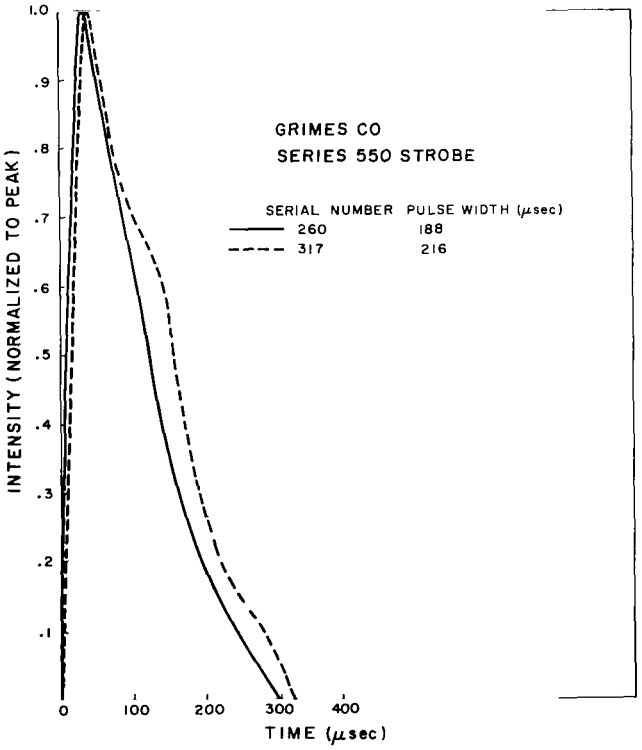

Figure 6.- Output Pulse Form

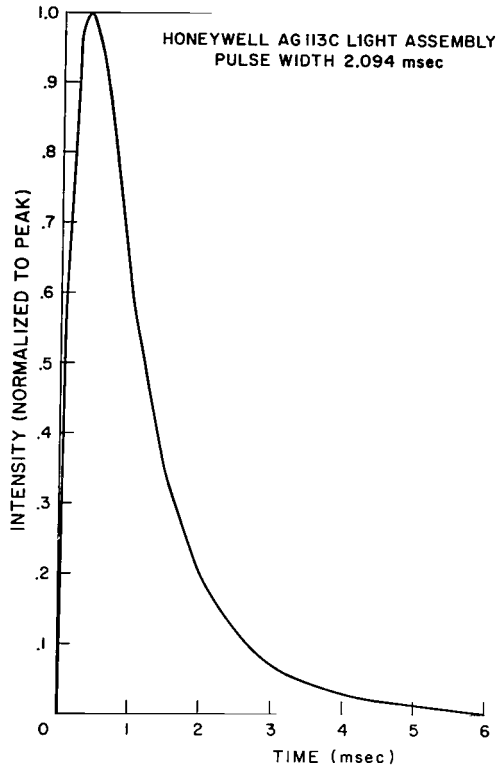

Figure 7.- Output Pulse Form

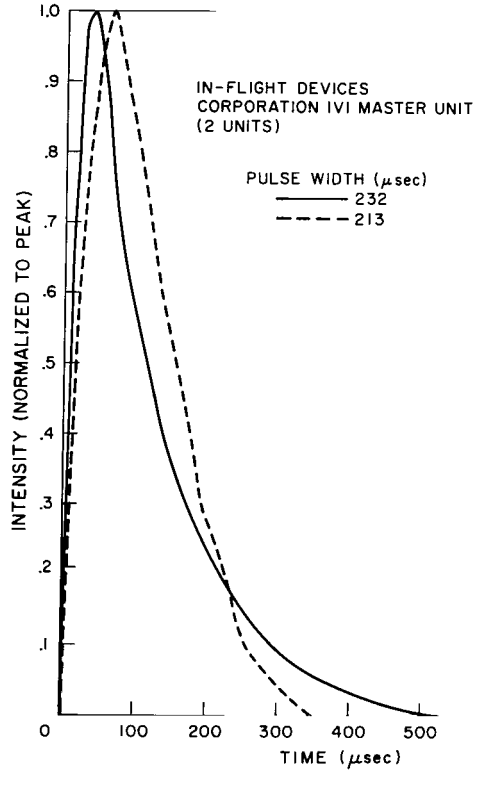

Figure 8.- Output Pulse Form

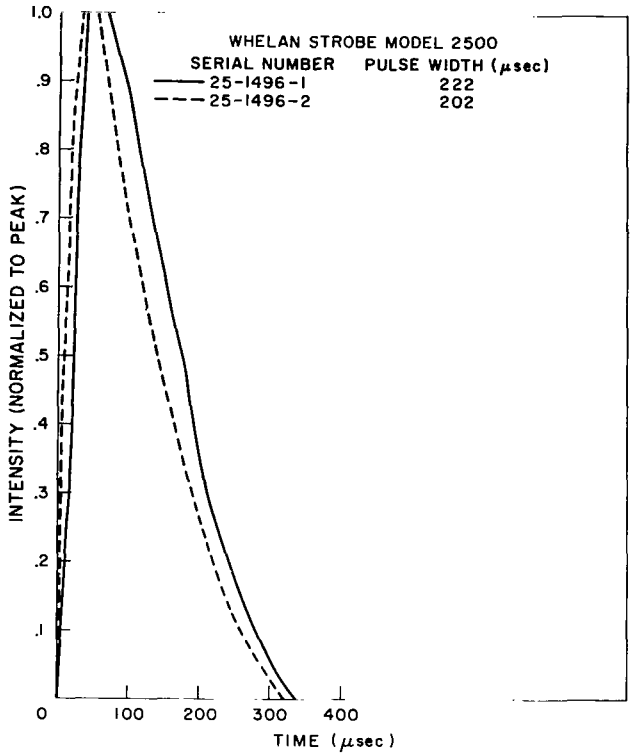

Figure 9.- Output Pulse Form

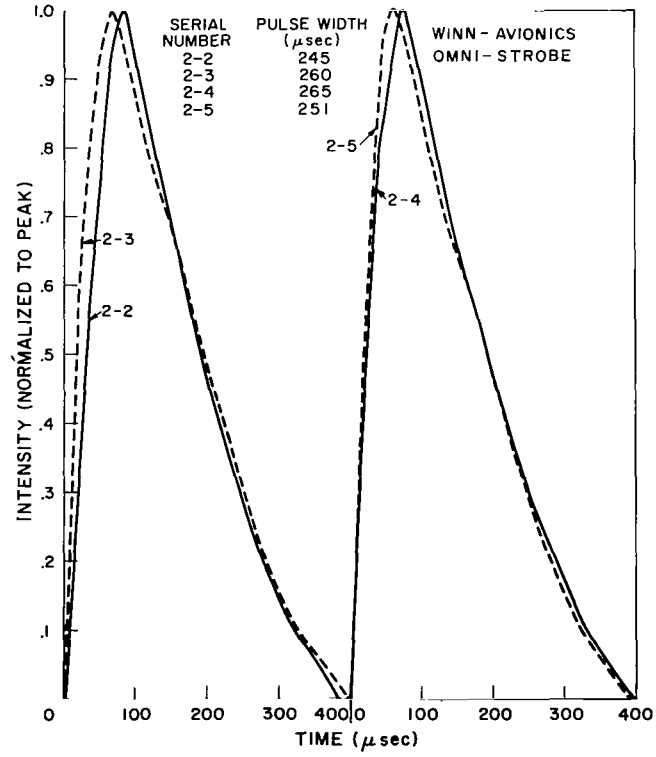

Figure 10.- Output Pulse Form

Table I.- Pulse Form Characteristics of Some Xenon Flash Tubes

Manufacturer	Model	Serial Number	Telec (Joules)	Rise Time (μsec)	Pulse Width (μsec)	Notes
Delta	Skystrobe	L-02228	17.8	44	261	160μF Capacitor
		L-03264	18.4	43	314	
		L-03265	18.4	52	325	
Electro Power Pac	373	15761	5.47	40	816	with GE FT-91 Flash Tube
		15761	17.3	40	816	
		15762	5.47	40	816	
Grimes Co.	Series 550	260	20.7	22	188	
		317	20.7	31	216	
Honeywell	Wingtip AG113C Light Assembly	7792	14.1	360	2094	
In-Flight Devices	IVI Master Unit		10.95	21	232	
		16JE 6-3	10.95	45	213	
Whelan	2500	25-1496-1	28	26	222	
		25-1496-2	28	25	202	
Winn Avionics	Omnistrobe	2-2	10.6	54	245	
		2-3	10.6	39.5	260	
		2-4	10.6	47.5	265	
		2-5	10.6	37.5	251	

1. All units designed for aircraft except Electro-Power Pac.
2. Rise time taken between 10 percent and 90 percent amplitude points on leading edge of pulse
3. Pulse width defined in text Eq. (1).

The value of pulse-width, as defined in Eq. (1), is relatively insensitive to transient fluctuations near the peak whereas a definition of pulse width based upon the width at some fraction, say one-half of peak width is highly sensitive to just what value is selected for the maximum. Also, the pulse width as defined in Eq. (1) is approximately equal (for fast rise-times) to twice the RC time-constant of the lamp system.

The integrals were evaluated graphically using a compensating polar planimeter. With the observed xenon lamp pulse shapes this pulse-width generally corresponds to about the 20 percent amplitude level.

The following spectral characteristics were computed from the experimental data: peak irradiance, radiant intensity, peak optical lamp power, average optical lamp power, optical energy output, and conversion efficiency. These values are summarized in Table II.

Peak irradiance.- The peak energy flux at the detector, in the passband of the filter.

$$E_{\Delta\lambda} = \frac{V_P}{R_L S_{\Delta\lambda}} \tag{2}$$

where: $E_{\Delta\lambda}$ is the peak irradiance at the detector, watts/cm^2

V_P is the pulse maximum (from oscilloscope), volts

R_L is the load resistor at the radiometer output, ohms

$S_{\Delta\lambda}$ is the average detector sensitivity in the passband, amps/watt/cm^2 (fig. 2).

Peak Radiant Intensity.- The peak power output of the lamp radiated into a unit solid angle in the filter passband.

$$I_{\Delta\lambda} = \frac{E_{\Delta\lambda} d^2}{T_{eff\Delta\lambda}} \tag{3}$$

where: $I_{\Delta\lambda}$ is the peak radiant intensity, watts/steradian

d is the lamp-to-detector distance in cm

$T_{eff\Delta\lambda}$ is the effective transmission of the optical filter in the passband as given in Eq. (4).

$$T_{eff\Delta\lambda} = \frac{\int_{\lambda_1}^{\lambda_2} T(\lambda)P(\lambda)d\lambda}{\int_{\lambda_1}^{\lambda_2} P(\lambda)d\lambda} \qquad (4)$$

where $T(\lambda)$ is the filter transmission as a function of wavelength, Figure 3

$P(\lambda)$ is the xenon lamp optical output power spectrum, Figure 11

λ_1, λ_2 are the 3 percent points of the product curve $T(\lambda)P(\lambda)$, Figure 11

The unfiltered radiated output power spectrum was measured for a typical lamp (GE FT-91 flash tube used with the Electro-Power Pac system); it was measured against a calibrated lamp through a Jarrell-Ash monochromator system. The lamp was operated at current densities comparable with those of aircraft strobe lights; intensities were taken at 10Å (1 μm) intervals. The values obtained for each wavelength interval was then multiplied by the filter transmission characteristic and the integrals in Eq. (4) evaluated graphically in the manner previously described.

Peak Optical Lamp Power.- The peak power output at the lamp in the filter passband.

$$P_{\Delta\lambda} = T_{\Delta\lambda}\ \Omega_L \qquad (5)$$

where $P_{\Delta\lambda}$ is the peak optical lamp power, watts

Ω_L is the solid angle into which the lamp radiates, steradians

The steradiancy of the lamps were calculated geometrically from the restricting mechanical apertures. All measurements and calculations were made for the radiometer and lamp in the same horizontal plane, with their axes oriented on the line connecting the center of the lamp with the center of the radiometer's detecting surface. No effort was made to locate a maximum energy point by rotating or tilting the xenon lamp.

Optical Energy Output.- The total energy radiated by the lamp in the filter passband is given by:

$$J_{op\Delta\lambda} = P_{\Delta\lambda} \int_{1\ cycle} U(t)\ dt \qquad (6)$$

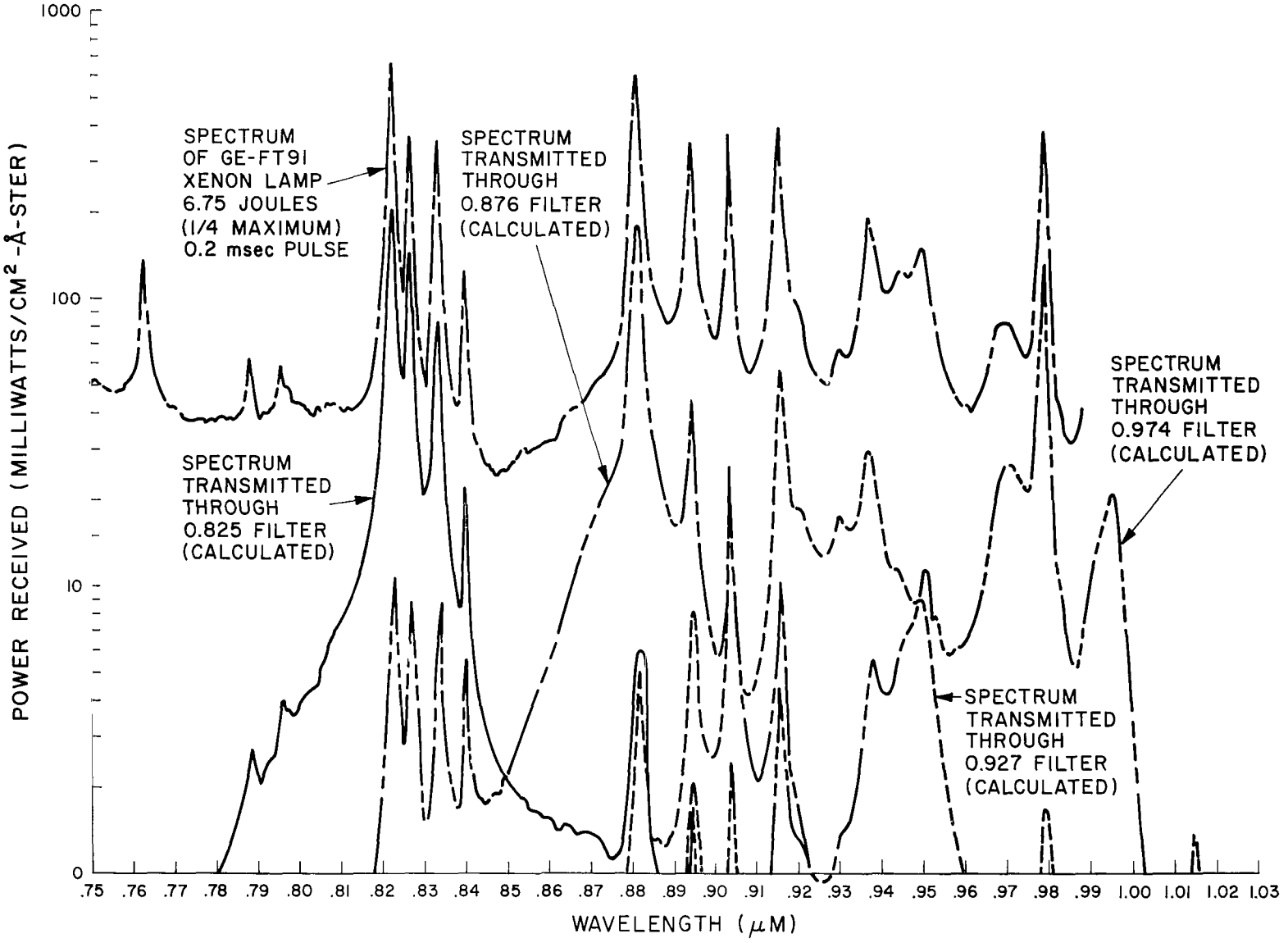

Figure 11.- Xenon Lamp Spectrum-Unfiltered and Transmitted Through Filters (Central Wavelengths 0.825, 0.876, 0.927 and 0.974 μMeters)

where $J_{op\Delta\lambda}$ is the optical energy output, joules

$U(t)$ is the observed pulse form normalized to unify at the peak

Average Optical Power.- Average optical power is shown as:

$$P_{ave\Delta\lambda} = \frac{J_{op\Delta\lambda}}{\tau} \tag{7}$$

Conversion Efficiency.- The efficiency with which the lamp system converts the stored electrical energy into radiated energy in the filter passband

$$\varepsilon_{\Delta\lambda} = 100 \frac{J_{op\Delta\lambda}}{J_{elec}} \tag{8}$$

where $\varepsilon_{\Delta\lambda}$ is the conversion efficiency, percent (%)

J_{elec} is the stored energy, joules

The stored electrical energy is given by

$$J_{elec} = \frac{1}{2} CV^2 \tag{9}$$

where C is the capacitance connected directly across the lamp, farads

V is the voltage across the capacitor terminals just prior to discharge, volts

TABLE II. SPECTRAL CHARACTERISTICS OF SOME XENON FLASH TUBES (Continued)

Manufacturer	Model	Serial Number	Notes	Peak Optical Power (watts) $P_{\Delta\lambda}$ 0.825	0.876	0.927	0.974	Average Optical Power (watts) $P_{ave\Delta\lambda}$ 0.825	0.876	0.927	0.974	Optical Energy (Joules) $J_{op\Delta\lambda}$ 0.825	0.876	0.927	0.974	Conversion Efficiency (%) $\epsilon_{\Delta\lambda}$ 0.825	0.876	0.927	0.974
Delta	Skystrobe	L-02228	1	1015	1208	1985	2193	664	770	1297	1433	0.17	0.21	0.34	0.37	0.96	1.2	1.9	2.1
		L-02228	2	921	1203	1843	1898	602	786	1205	1241	0.16	0.21	0.31	0.32	0.90	1.2	1.8	1.8
		L-03264		870	1201	1680	1700	564	778	1089	1102	0.18	0.24	0.34	0.35	0.96	1.33	1.86	1.88
		L-03265		790	1112	1515	1594	524	738	1006	1058	0.17	0.24	0.33	0.34	0.93	1.3	1.78	1.89
Electro Power Pac	373	15761	3,4,7	688	951	1407	1457	421	598	886	917	0.34	0.49	0.72	0.75	6.3	8.9	13.2	13.7
		15761	3,5,7	2447	3609	5391	5962	1540	2271	3392	3752	1.26	1.85	2.77	3.06	7.3	10.7	16.0	17.7
		15762	3,4,7	890	1254	1886	2012	560	789	1187	1266	0.46	0.64	0.97	1.03	8.4	11.8	17.7	18.9
		15762	3,4,6,7	109	152	223	238	68.8	95.7	141	150	0.056	0.078	0.115	0.122	1.0	1.4	2.1	2.2
		15762	3,5,6,7	376	524	767	729	237	330	483	459	0.19	0.27	0.39	0.37	1.1	1.6	2.3	2.2
Grimes Co.	Series 550	260		3584	4731	6849	7207	2362	3118	4514	4749	0.44	0.59	0.85	0.89	2.15	2.83	3.68	3.83
		317		3177	4355	6316	6983	2063	2827	4100	4533	0.44	0.61	0.88	0.98	2.15	2.95	4.28	4.73
Honeywell	Wingtip AG 113C Light Assembly	7792		21.0	30.4	46.8	51.9	13.4	19.3	29.7	33.0	0.028	0.040	0.062	0.069	0.2	0.29	0.44	0.49
In-Flight Devices	IVI Master Unit		2	1172	1597	2408	2419	683	932	1404	1410	0.16	0.22	0.33	0.33	1.45	1.97	2.98	2.99
				1175	1621	2370	2440	686	945	1382	1423	0.16	0.22	0.32	0.33	1.45	2.00	2.93	3.02
		16JE6-3		1247	1713	2574	2418	851	1170	1759	1651	0.18	0.25	0.37	0.35	1.66	2.28	3.42	3.21
Whelan	2500	25-1496-1		3516	4702	6429	6643	2542	3400	4648	4802	0.56	0.76	1.03	1.07	2.01	2.7	3.68	3.83
		25-1496-2		3191	4324	6211	6411	2205	2988	4292	4430	0.45	0.60	0.87	0.90	1.61	2.14	3.11	3.22
Winn Co.	Omnistrobe	2-2		1164	1640	2330	2440	779.3	1097	1560	1633	0.191	0.269	0.382	0.400	1.8	2.54	3.61	3.77
		2-3		943	1281	1780	1915	649.6	882	1225	1318	0.169	0.229	0.319	0.343	1.59	2.16	3.01	3.23
		2-4		876.4	1167	1587	1797	579.8	772.1	1050	1189	0.154	0.205	0.278	0.315	1.45	1.93	2.62	2.97
		2-5		859.1	1218	1644	1797	591.8	838.7	1133	1238	0.149	0.211	1.284	0.311	1.40	1.99	2.68	2.93

Notes
1. Special 160 μF Capacitor
2. Viewed at 90° with respect to preceeding measurement
3. With GE FT-91 Flash Tube
4. J_{elec} = 5.47 Joules
5. J_{elec} = 17.3 Joules
6. No Reflector
7. Not Designed for Aircraft

TABLE II. SPECTRAL CHARACTERISTICS OF SOME XENON FLASH TUBES

Manufacturer	Model	Serial Number	Notes	Lamp to Detector Separation (cm) d	Lamp Steradiancy (Steradians) Ω_L	Pulse Peak from Oscilloscope (mvolts) V_P				Peak Irradiance at Detector (mwatts/cm^2) $E_{\Delta\lambda}$				Peak Radiant Intensity (watts/ster) $I_{\Delta\lambda}$			
						0.825	0.876	0.927	0.974	0.825	0.876	0.927	0.974	0.825	0.876	0.927	0.974
Delta	Skystrobe	L-02228	1	126.8	9.55	1.04	0.86	0.64	0.64	2.67	2.05	1.58	2.02	106	127	208	230
		L-02228	2	127.0	9.55	0.94	0.85	0.59	0.55	2.41	2.03	1.46	1.74	96.5	126	193	199
		L-03264		139.1	9.55	0.74	0.71	0.45	0.41	1.90	1.69	1.11	1.30	91.2	126	176	178
		L-03265		138.4	9.55	0.68	0.66	0.41	0.39	1.74	1.58	1.01	1.23	83.0	117	159	167
Electro Power Pac	373	15761	3,4,7	114.9	2.24	3.55	3.5	2.35	2.2	9.1	8.4	5.8	7.0	298	424	628	650
		15761	3,5,7	114.9	2.24	13.0	13.3	9.0	9.0	33	32	22.	28	1093	1611	2406	2661
		15762	3,4,7	121.9	2.24	4.2	4.1	2.8	2.7	10.8	9.8	6.9	8.53	397	500	842	898
		15762	3,4,6,7	230.0	2.24	1.45	1.4	0.93	0.9	0.37	0.33	0.23	0.28	48.8	67.9	99.6	106
		15762	3,5,6,7	230.0	2.24	5.0	4.8	3.2	2.75	1.3	1.2	0.79	0.87	168	234	342	325
Grimes Co.	Series 550	260		134.6	8.88	3.5	3.2	2.1	2.0	8.97	7.64	5.19	6.32	403	533	771	811
		317		167.6	8.88	2.0	1.9	1.25	1.25	5.13	4.54	3.09	3.95	358	490	711	786
Honeywell	Wingtip AG 113C Light Assembly	7792		124.5	0.0267	8	8	5.6	5.6	20.5	19.1	13.8	17.7	788	1138	1752	1942
In-Flight Devices	IVI Master Unit			122.6	10.24	1.2	1.13	0.774	0.703	3.07	2.70	1.91	2.22	114	156	235	236
			2	122.6	10.24	1.2	1.15	0.76	0.71	3.08	2.74	1.88	2.24	115	158	232	238
		16JE6-3		138.4	10.24	1.0	0.95	0.65	0.55	2.56	2.27	1.60	1.74	122	167	251	236
Whelan	2500	25-1496-1		135.1	11.31	2.7	2.5	1.55	1.45	6.92	5.97	3.83	4.58	314	419	573	592
		25-1496-2		135.1	11.31	2.45	2.3	1.5	1.4	6.28	5.49	3.70	4.42	285	386	554	572
Winn Co.	Omnistrobe	2-2		91.4	10.43	2.1	2.05	1.32	1.25	5.38	4.89	3.26	3.95	111.6	157.2	223.4	233.9
		2-3		91.4	10.43	1.7	1.6	1.01	0.98	4.36	3.82	2.49	3.10	90.46	122.8	170.7	183.6
		2-4		91.4	10.43	1.58	1.46	0.90	0.92	4.05	3.48	2.22	2.91	84.0	111.9	152.1	172.3
		2-5		91.4	10.43	1.55	1.52	0.93	0.92	3.97	3.63	2.30	2.91	82.37	116.7	157.6	172.3

Notes
1. Special 160 μF Capacitor
2. Viewed at 90° with respect to preceeding measurement
3. With GE FT-91 Flash Tube
4. J_{elec} = 5.47 Joules
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