SCR 295

STUDY OF CELESTIAL/INERTIAL TEST FACILITY

FINAL REPORT

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October 31, 1966

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CORPORATE SYSTEMS CENTER
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I. INTRODUCTION

This report covers a study performed for the National Aeronatics and Space Administration/Electronics Research Center (NASA/ERC) under the provisions of Contract NAS 12-106. The objective of the study was to identify equipment necessary to provide a ground based testing capability for the evaluation and qualification of current and future optical sensors employed as elements of celestial navigation and guidance systems. An equally important objective was the determination of technical requirements uniquely associated with the equipment and activity as they would influence laboratory building design. Later the scope of the study was extended to include the analysis of "the technical requirements of the inertial test facility that must be integrated with the celestial test facility to achieve an efficiently operating research complex in the Space Guidance Laboratory of ERC."

At the time the study was initiated ERC representatives provided the following guide lines, which were based upon the ERC test philosophy:

1. Maximum flexibility of the facility and equipment is desired.
2. The test facility should not be oriented toward any one specific observable or configuration.
3. It will be sufficient to check one test parameter at a time; the ability to check several parameters simultaneously is not necessary.
4. Automated testing is not desired.
5. The program should be oriented toward simulators rather than sensors.
6. The test requirements of horizon scanners as a category of sensors should be ignored in the study.

Adherence to these guide lines, particularly the first, has had the effect of removing from consideration highly refined and sophisticated simulators which are distinguished by a matching of their spectral distribution characteristics as close as possible to a specific observable. Therefore, such specialized simulators have low utility and minimal, if any, flexibility.

Ideally, the orderly and logical progression of the study program would have provided for the determination of necessary building design features and modifications only after the completion of the equipment identification phase of the program. However, the building planning and construction schedules required that this type of information be made available to ERC earlier than would otherwise have been possible. Therefore, the building information transmitted to ERC represented general requirements based on the experience of UACSC in the operation of similar test facilities rather than requirements imposed by specific equipment. However, later examination has disclosed no discrepancies.

Because of the nature of the program objectives this report does not provide a sophisticated scientific analysis of optical theory pertaining to sensor testing and evaluation. Instead the intent has been to provide the necessary practical information required for the establishment of a test facility. The prior experience of UACSC in establishing and operating similar facilities is reflected in much of the information that is presented.

The report as a totality does not reflect the many iterations in thought and principle which entered into the work. Particularly, the solidification of ideas by NASA/ERC, as new perspective was provided by UACSC, brought forth a proper and natural technical focusing which, except by a chronological diary, can not be reported in a report such as this.

II. ANALYSIS

A. Identification and Definition of Observables

It was originally intended to identify the observables to be considered in the study in accordance with the requirements of the various defined and appropriate NASA missions. However, at a meeting held on March 8, 1966, ERC directed that only the Jupiter Fly-by mission be considered as the basis for identification of the observables. An analysis of this mission, which was already being performed by UACSC under the provisions of Contract NAS 12-40, indicated that useful observables would be the Sun, the Earth, the Moon, Jupiter, Venus, Mars, and stars of +3 visual magnitude and brighter. Following are summaries of the pertinent characteristics of each of the observables:

1. The Sun

The Sun is made up of three concentric gaseous spheres which from the innermost to the outermost, are known as the photosphere, the chromosphere and the corona.[1-4] The photosphere is the sharply defined apparent surface seen by ordinary observation, and the diameter[1] (referred to as the diameter of the Sun) is 1.4×10^6 KM. Most of the light and heat are radiated from the photosphere. The light is a continuum interrupted by thousands of weak Fraunhofer absorption lines. The brightness of the disc decreases smoothly (Figure 1) from the center to edge. The continuum between 0.29μ and 2.5μ accounts for 95 percent of the total radiation. The visual magnitude of the photosphere is -26.78.

The chromosphere is a nearly transparent gaseous layer between the photosphere and corona extending to a height of 10^4 KM. The spectrum is made up of a bare trace of continuum with many bright emission lines and strong Fraunhofer absorption lines. The predominant radiation is the crimson of neutral H.

The corona is the faint (white) halo surrounding the chromosphere (observed visually only during total eclipse). The main features are the halo that surrounds the Sun to a mean distance of roughly the radius and the long streamers which sometimes extend several solar diameters into space. A small fraction of the light at lower levels is concentrated in the bright emission lines of Fe, Ni, Ca and other atoms. The bulk of the light is that scattered from the photosphere. The surface brightness is about 10^{-6} that of the protosphere. The total light emission approximates that of a full Moon, about -12.5 visual magnitude.

There are several complex transient phenomena such as sunspots and flares[5-7] about which very little is know. The bulk of radiation is apparently confined to the radio frequencies and periods of maximum activity are predictable.

[1-4] Superscripts indicate references listed on page 56

Following is a list of figures and tables concerning the solar observables.

2. The Planets

The emission in the visible spectrum for the planets considered, is not a noteworthy observable because of relatively low surface temperatures.[2, 4, 8] The primary light observed is reflected sunlight. Venus and Jupiter are relatively constant reflectors over the visible and near IR spectrum, while the reflectivity of the Moon and Mars increases considerably as the IR is approached. The planetary observables are summarized in Figures 3 and 4 and Tables II through IV.

3. The Stars

A star may be characterized by its position, its magnitude (luminosity) and its spectral class (color temperature).

Table V shows how the 100 brightest stars ranging from -1.44 to 2.58 magnitude are distributed over the spectral classes.

Figure 5 shows the relation between color temperature T_c, effective temperature T_e, and the spectral classes for the main sequence of stars. It is based on C. W. Allen's data[2].

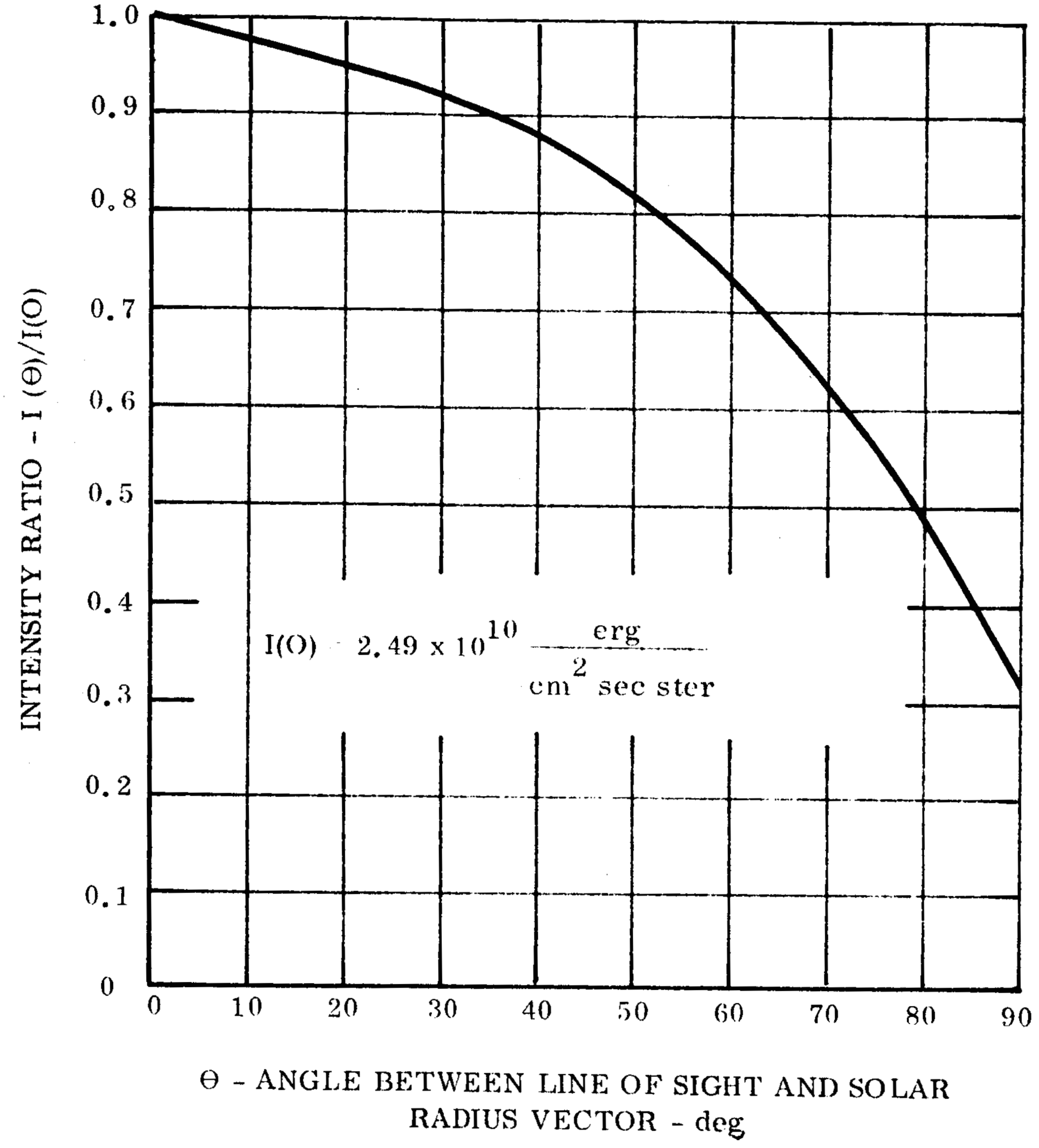

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Figure 1 Solar Limb Darkening

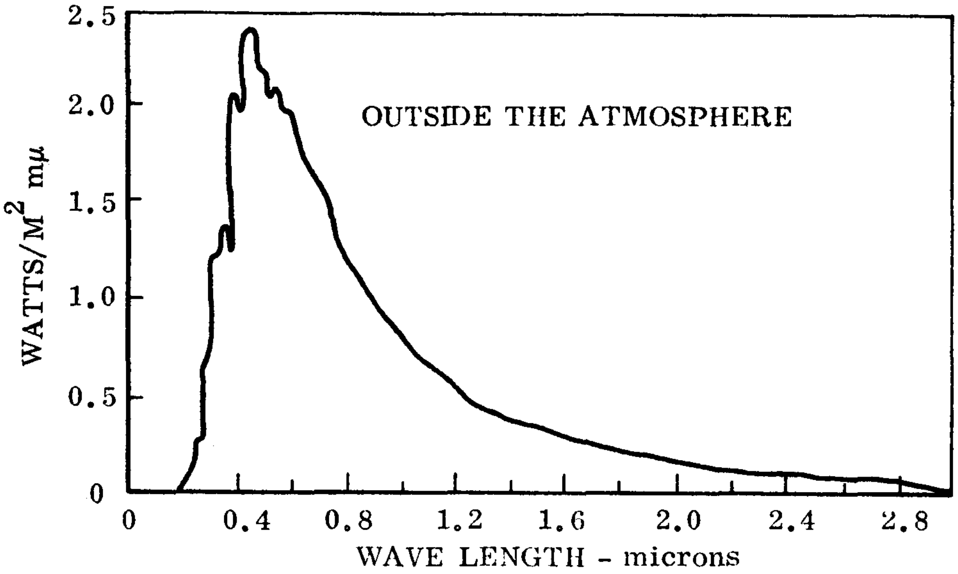

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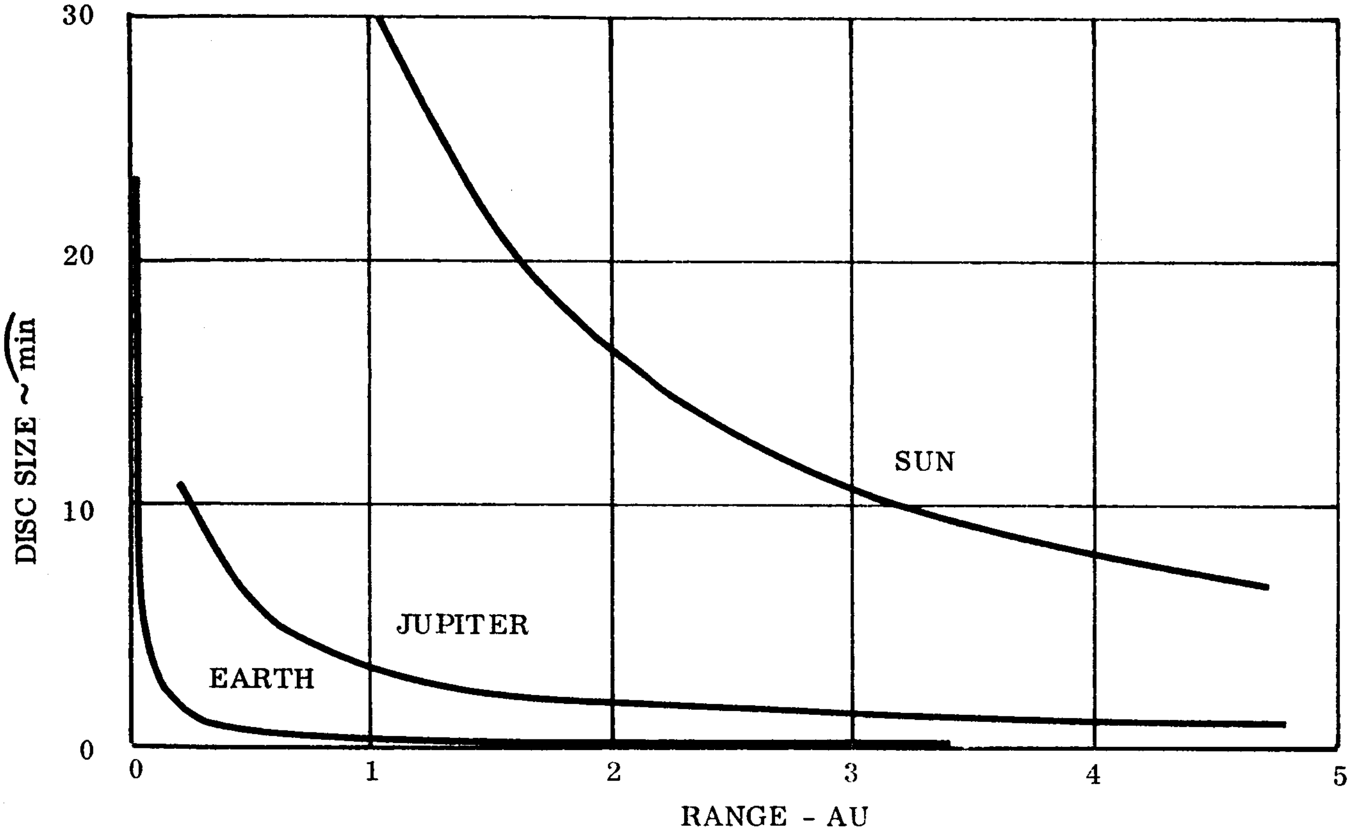
Figure 2 Solar Irradiance at Earth Oribt (1AU)



VENUS, MARS AND THE MOON ARE BELOW THE EARTH CURVE, (TABLE III)

66-2988

Figure 3 Apparent Disc Size of the Sun and Planets

TABLE I

PHYSICAL CONSTANTS OF THE SUN

Solar Diameter 1.4×10^6 KM

Mean Distance from Earth 1.5×10^8 KM (1 AU)

Total Energy Output 3.86×10^{33} erg/sec

Energy Flux at Surface 6.34×10^{10} erg/cm^2 sec

Effective Surface Temperature 5780° K

Stellar Magnitude (photovisual) -26.78

Absolute Magnitude (photovisual) +4.84

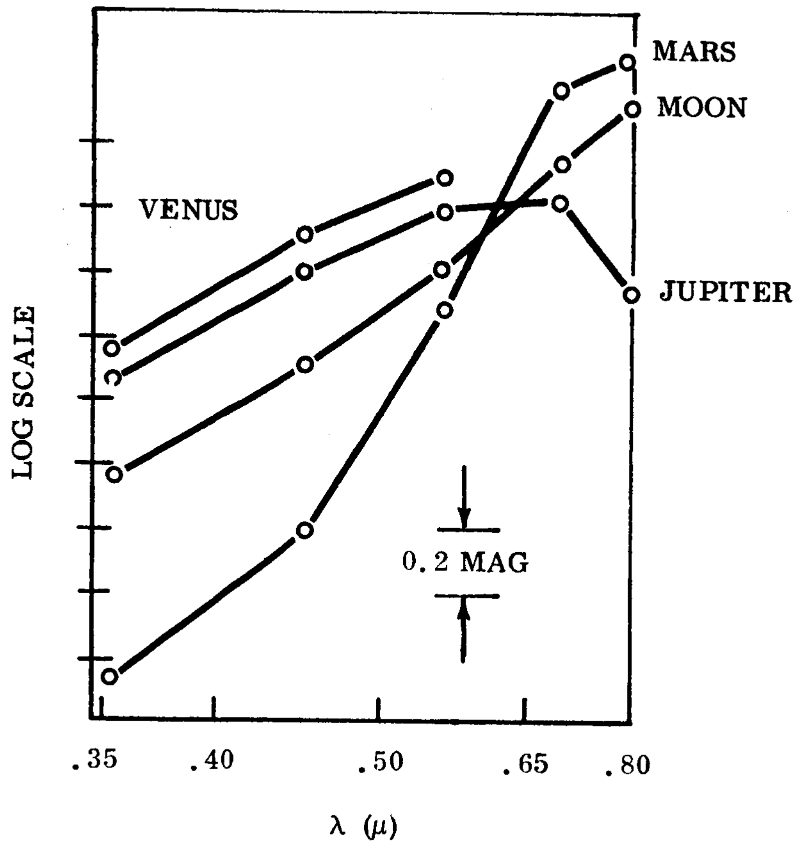


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Figure 4 Wavelength Dependence of Reflectivity of the Planets

TABLE II

APPARENT DISC SIZE OF SUN AND PLANETS

Moon		Mars		Venus	
Range	Disc Size	Range	Disc Size	Range	Disc Size
.93 AU	5.11 arc sec	1.61 AU	5.82 arc sec	.75 AU	22.2 arc sec
1.8 AU	2.58 arc sec	1.87 AU	5.01 arc sec	1.33 AU	12.5 arc sec
2.53 AU	1.89 arc sec	2.17 AU	4.33 arc sec	2.6 AU	6.45 arc sec
3.23 AU	1.48 arc sec	3.13 AU	3.00 arc sec	3.3 AU	5.06 arc sec
3.89 AU	1.23 arc sec	3.43 AU	2.74 arc sec	3.85 AU	4.33 arc sec
4.44 AU	1.08 arc sec	3.69 AU	2.54 arc sec		
5.04 AU	.95 arc sec				

Sun		Jupiter		Earth	
Range	Disc Size	Range	Disc Size	Range	Disc Size
.98 AU	32.8 arc min	5.5 AU	.58 arc min	.053 AU	5.6 arc min
1.1 AU	29.2 arc min	4.85 AU	.65 arc min	.24 AU	1.2 arc min
1.26 AU	25.3 arc min	4.41 AU	.76 arc min	.35 AU	.83 arc min
1.9 AU	17.7 arc min	3.45 AU	.98 arc min	.93 AU	.31 arc min
2.74 AU	11.6 arc min	2.46 AU	1.32 arc min	2.55 AU	.12 arc min
3.33 AU	9.7 arc min	1.92 AU	1.74 arc min	3.90 AU	.075arc min
3.95 AU	8.3 arc min	1.22 AU	2.65 arc min		
		.95 AU	3.35 arc min		

TABLE III

ALBEDOS OF THE PLANETS

	p (U)	p(B)	p(v)	p(R)	p(I)	q_v	A(V)
Venus	.353	.492	.586	---	---	1.296	.76
Earth	---	---	.367	---	---	1.095	.36
Mars	.052	.080	.154	.286	.310	1.04	.16
Jupiter	.270	.370	.445	.466	.347	1.65	.73
Moon	.066	.088	.115	.16	.17	.585	.0

TABLE IV

PHYSICAL CONSTANTS OF THE PLANETS

	Diameter	Solar Flux Rec.	T(BL. BDY.)
Venus	6100	245 W/ft^2	249° K
Earth	6378	130 W/ft^2	250° K
Mars	3380	56 W/ft^2	226° K
Jupiter	71,350	5 W/ft^2	130° K
Moon	1738	130 W/ft^2	284° K

TABLE V

DISTRIBUTION OF 100 BRIGHTEST STARS ACCORDING TO SPECTRAL CLASS

Class	Number of Stars in Class	Cumulative Number
O	4	4
B	30	34
A	19	53
F	14	67
G	3	70
K	21	91
M	8	99

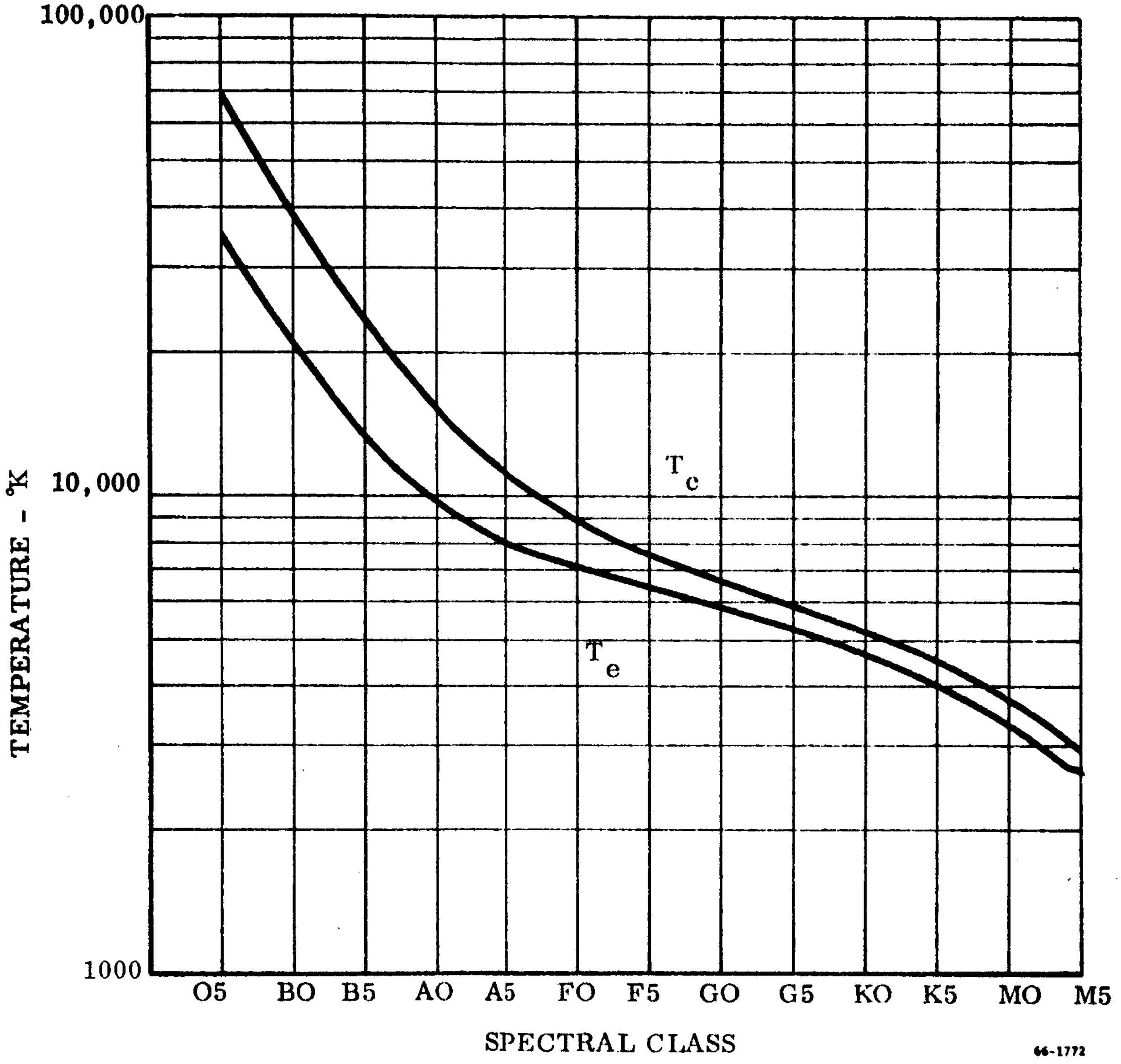


Figure 5 Color Temperature (T_c) and Effective Temperature (T_e) vs Spectral Class for Stars of the Main Sequence

The 100 brightest stars are distributed over all spectral classes and their color temperature ranges from 3000°K to 70,000°K.

From the photovisual mangitudes the photopic illuminance in lumens/cm^2 may be derived. However, detectors have response curves that differ from the photopic luminous efficiency curve. Consequently, it is possible to formulate magnitudes m_D in terms of specific detectors for the stars with known spectral distributions.

Table VI gives approximate photovisual magnitudes m_V and magnitudes, m_D, in terms of a phototube with an S-4 sensitivity curve and a typical silicon photodiode, for a number of stars.

The effective power I_{eff} received by a detector in an optical system due to a star with magnitude m_D is:

$$I_{eff} = A_{eff} \times T \times E_{eff} \text{ (watts)}$$

where

A_{eff} = the effective aperture (cm^2)

T = the transmission coefficient for the system

E_{eff} = the incident effective power. (watts/cm^2)

The incident effective power is given by the expression:

$$E_{eff} = 2.512^{-m_D} \times C \times 2.08 \times 10^{-10} \text{ (watts/cm}^2\text{)}$$

where

C = mechanical equivalent of light (watts/lumen).

Table VII gives the effective incident power E_{ff} due to the stars Mirach and Castor for a phototube with an S-4 sensitivity curve and for a typical silicon photodiode, respectively.

The sky background ranges in brightness from 1 ft-lambert or less to 1000 ft-lambert or more, depending on altitude, zenith angle, and angle to the sun and in color temperature from 6000°K to 50,000°K or more.[10] The outer-space background however, is about 3×10^{-5} lambert.[11]

TABLE VI

PHOTOVISUAL AND "DETECTOR" MAGNITUDES FOR A NUMBER OF STARS

Star	m_V	m_D	
		S-4	Silicon
Ankaa	2.37	3.5	1.6
Mirach	2.07	2.9	0.8
Achernar	0.49	1.3	0.3
Mira	2.0	4.2	-0.8
Canopus	-0.7	-0.3	-0.9
Suhail	2.23	3.6	0.7
Alioth	1.78	1.8	1.8
Mizar	2.12	2.2	2.0

TABLE VII

EFFECTIVE INCIDENT POWER E_{eff} FOR A PHOTOTUBE WITH AN S-4 SENSITIVITY CURVE AND FOR A TYPICAL SILICON DIODE

Star	E_{eff} (Watt/cm^2)	
	S-4	Silicon
Mirach	1.49×10^{-11}	10.2×10^{-11}
Castor	14×10^{-11}	21.8×10^{-11}

B. Review of Advanced Technology

Section V, which indentifies current equipment, does not review the most advanced technology presently in use, i.e., techniques and instrumentation available for the generation, calibration, and measurement of observables associated with celestial navigation and guidance. Instead, it has to do with unsophisticated items of equipment by means of which only one characteristic of an observable can be tested. However, for more sophisticated testing and more elaborate devices, the instrumentation can become equally elaborate.

In general, the two main parameters to simulate in tests of a passive sensor are the radiation emitted and the relative motion between the source and the sensor. Frequently the latter is omitted because of the difficulty associated with the dynamic measurements of very small angles. Radiation sources are difficult to simulate when the sources are large such as a nearby planet . This difficulty arises because of the high complexity of such a model and the extreme amount of data needed to construct one. The model landscape needed for testing landmark sensors under various illuminations is perhaps the best example of this problem. Also, because the characteristics of such detailed sources are time variant, the model will only statistically represent the real item and lead to very difficult comparisons between theory and experiment.

Shown below is a list of several simulators which are required for testing elements of sophisticated systems. In most cases, system type tests are projected because it is this area which will require the largest amount of development or modification. The area of data acquisition and data display has not been included in the present study, but forms a vital ingredient in the total facility requirements. This is particularly true in dynamic tests of the instruments.

Description	Functional Purpose	Operational Purpose	Availability
Multiple Star Source	Provide 2 or 3 stars which can move relative to each other and simulate star pairs or triplets	Permit evaluation of Stellar devices in the presence of multiple stars	Several types have been built
Celestial Navigation Calibrators	Provide for initilization, lock on, and following of stars	Provide for check out of Stellar devices	Several systems in existence
Spin Table	Simulate spin stabilized missile	Check out Stellar devices used in spin stabilized systems	One system in existence

Description	Functional Purpose	Operational Purpose	Availability
Horizon Simulator	Provide a model of earth atmosphere. Model dependent on sensor. Presently three models desired: 1. 4 - 40 (Infrared) 2. 14 - 16 (CO_2 band) 3. Ultraviolet	In the complete simulation, permits checkout of horizon sensor subsystem. Also, allows for error analysis of sensors and sensivity to horizon shape change	Only limited simulators available. CO_2 and ultra-violet need further development
Planet Simulators	Provide various types of planet configurations for testing planet sensors which operate on geometric configuration	For navigation updating and for close orbit orientation	Several types of simulators have been built. Development will be dependent on planet sensor mechanization
Star Field Simulator	For testing of star field readers	Determine capability of instrument to recognize stellar patterns	Limited availability. Must be designed to meet general laboratory operational environment

C. Forecast of New Technology

During the next decade considerable changes will be wrought in the field of interplanetary travel. For the systems to be used in the 1980's, development of instruments will commence in the near future. Presently, the navigational aids for the interplanetary travel are a simple extension of the astronomical tools developed over the centuries. Digression from this past way are beginning to appear in the form of horizon sensors operating on the ultraviolet band around the earth. The additional navigational aids which can be expected to be under development in the near future are the following:

Phenomena Utilized	Device	Development Required
Radio Stars	Radio star detector & discriminator	High gain antenna to permit reduction of size
Methane Gas Mantle	Detector for radiation balance	Atmospheric structure surrounding planet
Mossbauer Detector	Velocity meter and interstellar distance measurement	System development for utilization of the information
Nuclear Radiation	Scintillation counters	Method of using radiation variations and concentration as a navigational aid
Reflected light beams	Laser projector and receiver	Accurate positioning and stabilization

These navigational aids will lead to new test equipment requirements. Because of the projection into the future, some of this test equipment may never be required if in the instrument development a useable device fails to materialize. However, the following items reflect the anticipated needs by NASA/ERC in the next decade. Cost of the items cannot be projected accurately, and for this reason is omitted.

Description	Equipment Description	Comment
Radio Star Simulator	Several sources of radio star frequency which are adaptable in gain and inertial interference	
Gaseous Atmosphere Simulator	Not desirable because of lack of deflection of structure of gaseous mantle	

Mossbauer Simulator	Mossbauer device with movable platen to permit evaluation of device	Similar devices for locking of space vehicle have been under development
Radiation Sources which adequately simulate nuclear radiation	Depending upon radiation source, the particular device and simulator can be constructed. It is expected that this would be a complement to present day horizon sensors	Development of thin film components is leading this effort
Laser Sources	Injection lasers with movable reflectors	

III. IDENTIFICATION OF CHARACTERISTICS

A. Simulation Parameters and Tolerances

This section specifies the parameters associated with simulation of the observables and the tolerances which are desirable. Simulation of the complete range of parameters would be desirable for simulator versatility, but certain practical aspects such as cost, time, component state of the art, etc., require the restriction of certain ranges with a corresponding loss in versatility. The first such problem, space limitations, has already been encountered. Thus, the decision to consider three separate simulators rather than a package combining all three observables (the Sun, planets, and stars) has already been made.

1. Parameters and Tolerances of Real Observables

The observable, in all cases, is simply the flux emanating from or reflected by the object of interest. The parameters involved in observation are intensity, wavelength interval, disc size, phase, range, relative motion, and background. Disc size, phase, and range obviously are not considered in the case of stellar observables, nor is phase considered in relation to the Sun. The tolerances on these parameters are directly related to the tolerances associated with the flux densities. In the following sections the accuracy of their densities will be estimated and their tolerances defined (within practical bounds).

a. The Sun

The solar spectrum (Figure 2 and Table VIII) and its integral (Table IX) are the most well defined observables, the data being good to better than 5 percent. Since most of the energy is between 0.2μ and 2.5μ, the ideal simulator should duplicate the spectral shape between these limits. (See Section III.A.2.)

The solar disc size (Figure 3) is known to at least 1 percent in the visible spectral region and likewise should be accurately simulated.

b. The Planets

The majority of the radiation observed from the planets is reflected sunlight. An indication of the reflectivity of the planets (at full phase, $\psi = 0$) is given in Table X and Figure 6. There is much confusion and disagreement among investigators concerning reflectivities; therefore, a conservative estimate of 50 percent accuracy has been established.

TABLE VIII (REF. 7)

SPECTRAL IRRADIANCE NORMAL TO THE SUN'S RAYS OUTSIDE THE ATMOSPHERE

Δλ mμ	Q_{λ} Δλ watts m-2	Δλ mμ	Q_{λ} Δλ watts m-2	Δλ mμ	Q_{λ} Δλ watts m-2
0 - 100	<.01	380 - 385	6.00	525 - 550	49.15
100 - 220	.27	385 - 390	5.63		
220 - 225	.14	390 - 390	5.73	550 - 555	9.74
		395 - 400	7.00	555 - 560	9.58
0 - 225	.41			560 - 565	9.52
225 - 230	.26	375 - 400	30.54	565 - 570	9.50
230 - 235	.27			570 - 575	9.57
235 - 240	.28	400 - 405	8.71		
240 - 245	.29	405 - 410	9.48	550 - 575	47.91
245 - 250	.30	410 - 415	9.60		
		415 - 420	9.67	575 - 580	9.57
225 - 250	1.40	420 - 425	9.47	580 - 585	9.52
				585 - 590	9.52
250 - 255	.38	400 - 425	46.93	590 - 595	9.48
255 - 260	.53			595 - 600	9.35
260 - 265	.95	425 - 430	8.80	575 - 600	47.44
265 - 270	1.20	430 - 435	8.70		
270 - 275	1.14	435 - 440	9.40	600 - 610	18.02
		440 - 445	10.40	610 - 620	17.64
250 - 275	4.20	445 - 450	10.70	620 - 630	17.32
				630 - 640	16.90
275 - 280	1.09	425 - 450	48.00	640 - 650	16.61
280 - 285	1.56				
285 - 290	2.42	450 - 455	10.89	600 - 650	86.49
290 - 295	3.08	455 - 460	10.89		
295 - 300	3.02	460 - 465	10.75	650 - 660	16.38
		465 - 470	10.89	660 - 670	16.25
275 - 300	11.17	470 - 475	10.70	670 - 680	15.81
				680 - 690	15.39
200 - 305	3.00	450 - 475	54.12	690 - 700	14.95
305 - 310	3.50				
310 - 315	3.90	475 - 480	10.80	650 - 700	78.78
315 - 320	4.05	480 - 485	10.47		
320 - 325	4.65	485 - 490	10.00	700 - 710	15.04
		490 - 495	10.20	710 - 720	14.41
300 - 325	19.10	495 - 500	10.30	720 - 730	14.20
				730 - 740	13.90

TABLE VIII (Continued)

$\Delta\lambda$ mμ	Q_λ $\Delta\lambda$ watts m-2	$\Delta\lambda$ mμ	Q_λ $\Delta\lambda$ watts m-2	$\Delta\lambda$ mμ	Q_λ $\Delta\lambda$ watts m-2
325 - 330	5.50	475 - 500	51.77	740 - 750	13.47
330 - 385	5.60				
335 - 340	5.60	500 - 505	9.08	700 - 750	71.02
340 - 345	5.80	505 - 510	9.80		
345 - 350	5.82	510 - 515	9.63	750 - 760	13.59
		515 - 520	9.60	760 - 770	12.98
325 - 350	28.32	520 - 525	9.65	770 - 780	12.53
350 - 355	5.90			780 - 790	12.38
355 - 360	5.85	500 - 525	48.50	790 - 800	12.08
360 - 365	6.15				
365 - 370	6.35	525 - 530	9.75	750 - 800	63.56
370 - 375	6.62	530 - 535	9.85		
		535 - 540	9.90	800 - 810	11.90
350 - 375	30.87	540 - 545	9.90	810 - 820	11.58
		545 - 550	9.75	820 - 830	11.45
375 - 380	6.18			830 - 840	11.01
				840 - 850	10.71
800 - 850	56.65	1500 - 2000	80.90		
850 - 860	10.51	2000 - 2100	9.31		
860 - 870	10.21	2100 - 2200	7.95		
870 - 880	10.08	2200 - 2300	6.82		
880 - 890	9.93	2300 - 2400	5.89		
890 - 900	9.63	2400 - 2500	5.10		
850 - 900	50.36	2000 - 2500	35.07		
900 - 910	9.27	2500 - 2600	4.46		
910 - 920	9.14	2600 - 2700	3.90		
920 - 930	8.99	2700 - 2800	3.42		
930 - 940	8.77	2800 - 2900	3.01		
940 - 950	8.55	2900 - 3000	2.68		
		2500 - 3000	17.45		
900 - 960	44.72				
		3000 - 3100	2.41		
950 - 960	8.25	3100 - 3200	2.06		
960 - 970	8.15	3200 - 3300	1.91		
970 - 980	8.09	3300 - 3400	1.71		
980 - 990	7.68	3400 - 3500	1.53		
990 - 1000	7.54				
		3000 - 3500	9.62		

TABLE VIII (Continued)

$\Delta\lambda$ mμ	$Q_\lambda \Delta\lambda$ watts m-2
950 - 1000	39.71
1000 - 1010	7.30
1010 - 1020	7.15
1020 - 1030	7.02
1030 - 1040	6.87
1040 - 1050	6.73
1000 - 1050	35.07
1050 - 1060	6.60
1060 - 1070	6.46
1070 - 1080	6.33
1080 - 1090	6.19
1090 - 1100	6.05
1050 - 1100	31.63
1100 - 1200	52.92
1200 - 1300	42.29
1300 - 1400	34.08
1400 - 1500	27.68
1100 - 1500	156.95
1500 - 1600	22.65
1600 - 1700	18.70
1700 - 1800	15.55
1800 - 1900	13.02
1900 - 2000	10.98
3500 - 3600	1.38
3600 - 3700	1.24
3700 - 3800	1.12
3800 - 3900	1.02
3900 - 4000	0.92
3500 - 4000	5.68
4000 - 4100	.885
4100 - 4200	.806
4200 - 4300	.736
4300 - 4400	.677
4400 - 4500	.617
4000 - 4500	3.721
4500 - 4600	.557
4600 - 4700	.448
4700 - 4800	.438
4800 - 4900	.428
4900 - 5000	.408
4500 - 5000	2.279
5000 - 6000	2.79
6000 - 7000	1.47
7000 - ∞	2.65

TABLE IX (REF. 7)

SPECTRAL IRRADIANCE NORMAL TO THE SUN'S RAYS OUTSIDE THE ATMOSPHERE (INTEGRAL OF)

λ_1 mμ	$\sum_0^{\lambda_1} Q_\lambda \Delta\lambda$ watts m-2	λ_1 mμ	$\sum_0^{\lambda_1} Q_\lambda \Delta\lambda$ watts m-2	λ_1 mμ	$\sum_0^{\lambda_1} Q_\lambda \Delta\lambda$ watts m-2
100	.001	435	190.4	710	700.1
320	0.3	440	199.8	720	714.6
225	0.3	440	199.8	730	728.8
		450	220.9	740	742.7
230	0.7			750	756.1
235	0.9				
240	1.2	455	231.8	760	769.7
245	1.5			770	782.7
250	1.8	460	242.7	780	795.2
		465	253.5	790	807.6
255	2.2	470	264.4	800	819.7
260	2.7	475	275.1		
265	3.7	480	285.9	810	831.6
270	4.9	485	296.3	820	843.2
275	6.0	490	306.3	830	854.6
		495	316.5	840	865.6
280	7.1	500	326.8	850	876.3
285	8.7	505	336.6		
290	11.1	510	345.4	860	886.8
295	14.2	515	356.1	870	897.1
300	17.2	520	365.7	880	907.1
		525	375.3	890	917.1
305	20.2			900	926.7
310	23.7				
315	27.6	530	385.1		
320	31.6	535	394.9	910	936.0
325	36.3	540	404.8	920	945.1
		545	414.7	930	954.1
330	41 8	550	424.5	940	962.9
335	47.4			950	971.4
340	53.0	555	434.2		
345	58.8	560	443.8	960	979.7
350	64.6	565	453.3	970	987.8
		570	462.8	980	995.9
		575	472.4	990	1003.6

TABLE IX (Continued)

λ_1 mμ	$\sum_0^{\lambda_1} Q_\lambda \Delta\lambda$ watts m-2	λ_1 mμ	$\sum_0^{\lambda_1} Q_\lambda \Delta\lambda$ watts m-2	λ_1 mμ	$\sum_0^{\lambda_1} Q_\lambda \Delta\lambda$ watts m-2
355	70.5			1000	1011.1
360	76.4	580	482.0		
365	82.5	585	491.5	1010	1018.4
370	88.9	590	501.0	1020	1025.6
375	95.5	595	510.5	1030	1032.6
		600	519.8	1040	1039.5
380	101.7			1050	1046.2
385	107.7	610	537.9		
390	113.3	620	555.5	1060	1052.8
395	119.0	630	572.8	1070	1059.3
400	126.0	640	589.7	1080	1065.6
		650	606.3	1090	1071.8
405	134.7			1100	1077.8
410	144.2	660	622.7		
415	153.8	670	639.0	1200	1130.7
420	163.5	680	654.8	1300	1173.0
425	172.9	690	670.2	1400	1207.1
		700	685.1	1500	1234.8
430	181.7				
1600	1257.4				
1700	1276.1				
1800	1291.7				
1900	1304.7				
2000	1315.7				
2100	1325.0				
2200	1332.9				
2300	1339.8				
2400	1345.6				
2500	1350.7				
2600	1355.2				
2700	1359.1				
2800	1362.6				
2900	1365.5				
3000	1368.2				

TABLE IX (Continued)

λ_1 mμ	$\sum_{0}^{\lambda_1} Q_\lambda \Delta\lambda$ watts m-2
3100	1370.6
3200	1372.7
3300	1374.6
3400	1376.3
3500	1377.8
3600	1379.2
3700	1380.4
3800	1381.6
3900	1382.6
4000	1383.5
4100	1384.4
4200	1385.2
4300	1385.9
4400	1386.6
4500	1387.2
4600	1387.8
4700	1388.2
4800	1388.7
4900	1389.1
5000	1389.5
6000	1392.3
7000	1393.8
∞	1396.4

TABLE X

ALBEDOS OF THE PLANETS	λ = .358	.448	.554	.690	.820 μ
VENUS	.458	.640	.761	---	---
EARTH	---	---	.360	---	---
MARS	.054	.083	.160	.297	.322
JUPITER	.446	.610	.735	.770	.573
MOON	.0396	.0515	.067	.094	.099

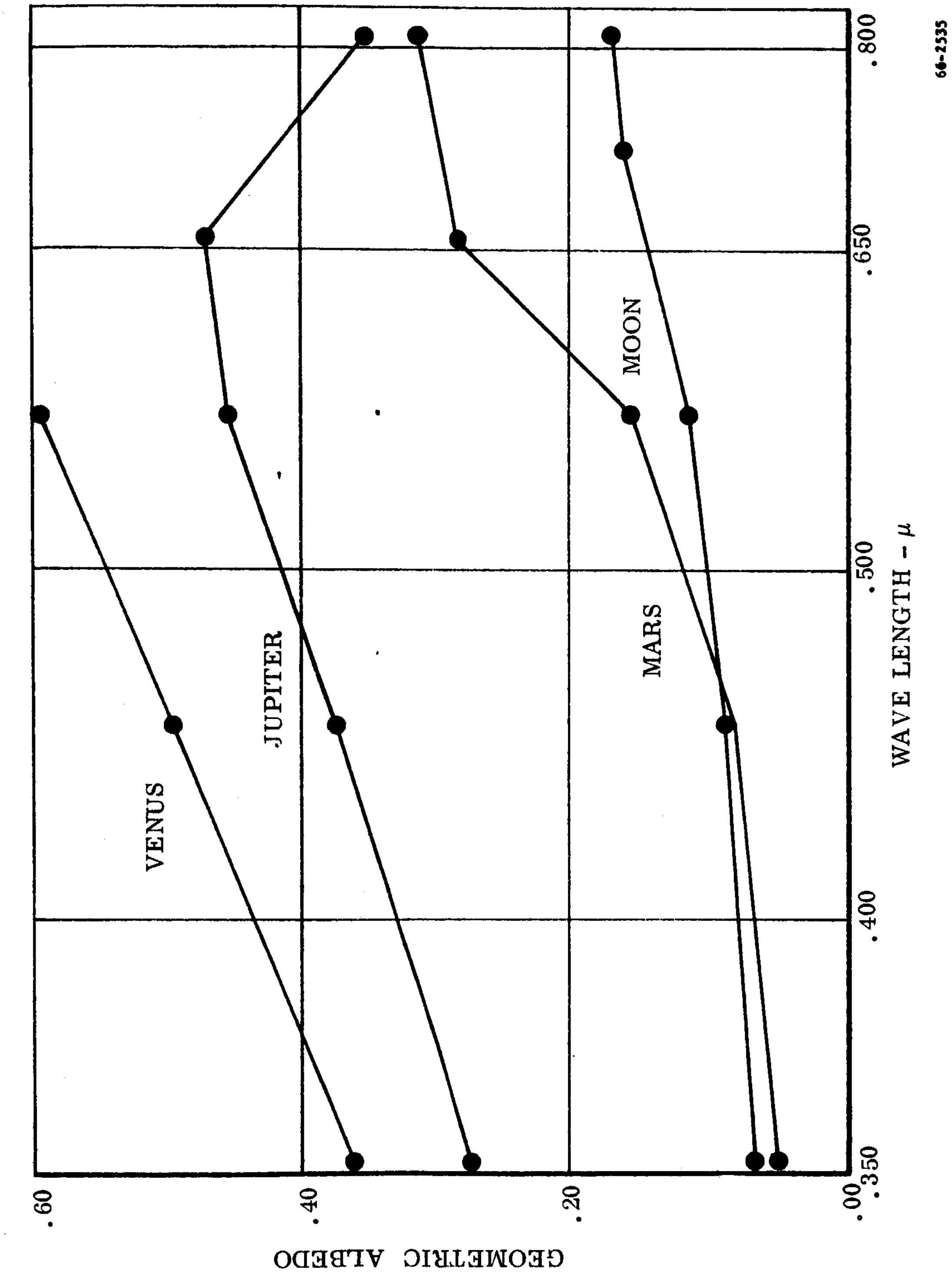


Figure 6 Wavelength Dependence of Reflectivity

c. The Stars

Stellar signatures are most difficult to define, measure, and simulate. Figure 5 presents the relation between spectral class, color temperature, and effective temperature for the main sequence of stars. The stated flux corresponding to given magnitudes and classes may vary by a factor of two.

2. Practical Aspects of Simulation

The foregoing material presents the parameters and tolerances associated with real observables. To simulate these in their entirety is not practical or desired by ERC as agreed in the initial contract discussion of March 8, 1966. This section will present a discussion of practical bounds to simulation consistent with ERC mission aims of 1.) development of optical sensors to aid inertial navigation systems and 2.) the desire to be highly flexible with long range utility. In addition, a third constraint is implicit, namely, to avoid concentration on specialized simulators useable only with as yet undefined sensors.

a. Basic Principles of Simulation and Test

The testing of an electro-optical navigation sensor involves the simulation of the object to be viewed and its surroundings and the angular position and rate of the object within the field.

The object to be viewed, or observable, so far as the viewing sensor is concerned, has a spectral irradiance which exists only in the spectrum of response of the sensor and its optical system. The combination of these produces an electrical signal which can be represented by:

$$I_S = \int_{\lambda_1}^{\lambda_2} H_\lambda K T_\lambda R_\lambda \, d\lambda$$

where

I_S = signal current

H_λ = spectral irradiance of the observable

T_λ = spectral transmittance of the optical system

K = collecting power or gain of the optical system

R_λ = spectral response of the detector

Similarly the background current is given by

$$I_B = \int_{\lambda_1}^{\lambda_2} B_\lambda K T_\lambda R_\lambda \, d\lambda$$

where

B_λ = spectral irradiance of background.

A practical and highly flexible technique of measuring dynamic sensor performance is to separately measure each parameter K, T_λ, and R_λ of the sensor to establish spectral performance. This can be done by using a spectrophotometer to measure optical system performance and a calibrated spectrometer to measure detector performance.

Having done this, the object and background can be represented by convenient sources H_0 and H_B having sufficient emission in the spectral region of detector sensitivity to produce the desired values of I_S and I_B.

The advantages of this approach are to simplify simulator design and increase simulator flexibility. This in turn eases the problem of measuring dynamic sensor performance under the required angular position and rate relations between sensor and simulator.

In most cases development requirements for angular and rate performance are satisfied by testing under one, or at most, two degrees of freedom. Since relative motion is involved, either the simulator, the optical path or the sensor can undergo the angular position and rate excursion. In general, the simulator will be larger than the sensor and for that reason is preferentially fixed. Where practical, deflection of the optical path by a precision optical wedge is desirable because of the mechanical advantage generally gained, a factor permitting attainment of greatest accuracy for least effort. Positioning and excursion of the sensor by a precision single or dual axis rate table is a practical and perhaps more generally applicable technique.

An advantage of the dual axis rate table is that it generally places minimum demand on the aperture and field of view requirements of the simulator. Indeed, as sensor sophistication increases, the requirements for aperture and field of view imposed on the simulator can rapidly exceed practical limits.

It is considered that a principle objective of this contract effort is to avoid the establishment of parameters and tolerances which in combination serve to form an implicit specification for a simulator of high complexity, high unit cost, and limited mobility on the premise that within other NASA complexes such devices will exist and be available to ERC. The following discussions then will stipulate the philosophy of simulation that will apply to each observable.

b. Stellar Simulation

Stellar simulators will be required to do two things; simulate a single star and simulate a star field. In either case, the stars can be considered as point sources. Thus, the ideal simulator would consist of a series of black body sources, capable of operating at the appropriate temperatures, behind a pinhole screen. These sources would extend over a broad wavelength interval. Realistically, the operating regions of black body sources are limited, as are those of the photodetectors. The practical broad band interval of simulation will be 0.2μ to 1.5μ. The UV limit is imposed by necessity of a vacuum chamber (atmosphere absorbs UV) to extend to lower wavelengths; the IR limit is set because of the operating regions of most current photodetectors (Table XI) and the unlikelihood of designing a cryogenic sensor to extend to the far IR.

Due to the lack of knowledge about stellar signatures in general, the tolerance associated with flux from a given star will be arbitrarily set at 10 percent.

It is not necessary to obtain sources with enough fidelity over the 0.2μ to 1.5μ region to fall within this criteria because the appropriate H_0 and H_B can be selected rather easily without spectral matching. It is desirable to simulate with several sources each of which is satisfactory within a given spectral region, e.g., 0.2μ to 0.4μ (UV), 0.4μ to 0.75μ (visible), 0.75μ to 1.5μ (IR).

The background to be simulated in the case of a single star may be diffuse and allow for brightness variations between 10^{-5} and 10^{3} ft-lambert, while presenting a 2-3 deg field to the sensor. This field of view requirement is due to the 10 arc sec accuracy indicated by the Jupiter Fly-by analyses assuming that the accuracy is 1/1000 of the field yields a 2.78 deg field. While not truly simulating the field of stellar or sky background, this technique provides adequate simulation to those sensors that operate on the principle that the target star is the brightest point source in the field.

Field simulators are by nature complex devices that should be designed with specific mission requirements in mind. Due to the complexities and lack of mission requirements, any further discussion of field simulation would be pointless at the present time. It is possible to use a given number of individual star simulators to simulate a given field; however, the difficulty in arranging the individual simulators and simulating an appropriate background leaves doubt as to the desirability of this method.

TABLE XI

PHOTO-DETECTOR CHARACTERISTICS

DESIGNATION	WAVE LENGTH OF PEAK RESPONSE	10% RESPONSE PTS.	TYPICAL SENSITIVITY
S-1	0.8μ	0.5 - 1.07μ	20 μa/1m
S-3	0.42μ	0.35 - 0.85μ	10 μa/1m
S-4	0.40μ	0.3 - 0.6μ	40 μa/1m
S-5	0.34μ	0.2 - 0.6μ	40 μa/1m
S-8	0.365μ	0.3 - 0.65μ	2 μa/1m
S-9	0.48μ	0.31 - 0.62μ	30 μa/1m
S-10	0.45μ	0.32 - 0.69μ	40 μa/1m
S-11	0.44μ	0.32 - 0.62μ	70 μa/1m
S-13	0.44μ	0.27 - 0.62μ	60 μa/1m
S-17	0.5μ	0.3 - 0.62μ	40 μa/1m
S-19	0.33μ	0.18 - 0.6μ	40 μa/1m
S-20	0.42μ	0.3 - 0.75μ	150 μa/1m
S-21	0.44μ	0.23 - 0.62μ	30 μa/1m
CdS Photoconductor	0.58μ	0.33 - 0.74μ	$6.8 \frac{ma/1m}{(ft^2)}$ at $1 \frac{1m}{ft^2}$
CdSe Photoconductor	0.74μ	0.62 - 0.86μ	$0.2 \frac{ma/1m}{(ft^2)}$ at $2 \frac{1m}{ft^2}$
Si Photovoltaic diode	0.92μ	0.35 - 1.14μ	$0.5 \frac{\mu a/1m}{(ft^2)}$ at $500 \frac{1m}{ft^2}$
Ge Photovoltaic diode	1.55μ	0.4 - 1.8μ	$0.5 \frac{\mu a/1m}{(ft^2)}$ at $10 \frac{1m}{ft^2}$
GaAs Photovoltaic diode	0.85μ	0.42 - 0.92μ	627 ma/watt
Se Photovoltaic diode	0.57μ	0.26 - 0.69μ	$1.0 \frac{\mu a/1m}{(ft^2)}$ at $930 \frac{1m}{ft^2}$
Si Phototransistor	0.8μ	0.5 - 1.07μ	$2.5 \frac{\mu a/1m}{(ft^2)}$ at $100 \frac{1m}{ft^2}$
Ge Phototransistor	1.55μ	0.38 - 1.7μ	$50 \frac{\mu a/1m}{(ft^2)}$ at $75 \frac{1m}{ft^2}$

c. Solar Simulation

Practical bounds on solar simulation are quite readily established. As mentioned in Section II. A, most of the radiant energy emitted by the sun falls between 0.2μ and 2.5μ. For the same reasons as mentioned in the case of stellar simulators, the 0.2μ to 1.5μ wavelength interval is established. The tolerance associated with the flux in any interval, however, should be 5 percent. The UV, visible and IR intervals discussed in the case of the stars also pertains to the Sun.

d. Planetary Simulation

Because the radiant flux observed from the planets is essentially reflected sunlight, one approach to planetary simulation will be in the utilization of the solar simulator(s) in conjunction with filters whose transmittance matches the reflectance of the various planets. The recommended approach is the use of a tungsten source with the appropriate energy characteristics as discussed in Section III. A. 2. a. The total tolerance on flux (including the effects of filters, the phase variation and disc size) should be less than the 50 percent referred to in Section III. A. 1. b.

Disc size and range are important in the case of solar and planetary simulators. The observed effect of varying either one is a corresponding variance in the observed flux. The flux observed at some range (R) from the observable is given by $F = K/R^2$, where K is a constant. The disc size at the same range is given by $\Theta = D/R$ where D is the diameter of the observable. Because the flux varies as Θ^2 and the disc size varies as 1/R, allowing variable flux allows simulation of both range and disc size.

B. Relative Motion

The relative motions associated with the various phases of the Jupiter Fly-by mission (Section II. A.) are as shown below:

Limit Cycle	6.85 deg/min (2mrad/sec)
100 n mi Earth orbit	4 deg/min
2 days after injection into midcourse trajectory	9×10^{-4} deg/min
190 days after injection into midcourse trajectory	13.2×10^{-5} deg/min
437 days after injection (entry into Jupiter sphere of influence)	21.6×10^{-6} deg/min

In addition to these rates, consideration must be given to the simulation of Earth's rate, 0.25 deg/min, characteristic of synchronous orbits, and to reaction rates resulting from disturbing influences within the vehicle, such as, personnel or equipment movement and torques generated by rotating equipment. For the purposes of this investigation an arbitrary upper limit of 240 deg/min has been assigned to the reaction rates.

Rates from 240 deg/min down to the rate of the Earth can easily be obtained from conventional rate tables. Slower midcourse rates associated with the Jupiter Fly-by mission probably could be generated from sophisticated, gas bearing tables. However, the necessity of providing these extremely low rates merits further consideration. For example, if an optical path of 30 feet between sensor and source is assumed, with sensor optics having a focal length of 12 inches, an overall optical system resolution of approximately 200 lines/mm would be required to distinguish the angular distance travelled in 1 min at a rate of 9×10^{-4} deg/min. The implication is that under some conditions the minimum rate or relative motion requirement will be determined by the resolution capability of the sensor optics rather than by associated tracking system characteristics or mission profile.

As optical resolution improves, the desirability of simulating very low rates will increase. This will be particularly true in the case of optical tracking system tests where dead band characteristics will be an important consideration. Therefore, it is recommended that a gas bearing rate table be utilized to provide relative motion between simulator and sensor since such tables are capable of much smoother and more uniform motion at low rates than are conventional mechanical bearing tables. Also, a two-axis table would be preferable to a single-axis device since the necessity for time-consuming reorientation of the sensor on the table would be minimized.

C. Accuracy of Instrumentation

In Section III.A.1, the tolerances associated with simulated flux were given as

Solar flux	5 percent
Stellar flux	10 percent
Planetary flux	50 percent

The following must be considered in any discussion of instrument accuracy:

1. Accuracy of spectral simulation
2. Stability and uniformity spatially (over FOV and distance) and temporally
3. Accuracy of position and rate
4. Accuracy of calibration and alignment equipment

Since items 1-3 have been discussed (at least in the original material) to some degree, this paragraph should properly deal only with item 4 and its relation to items 1-3.

Absolute simulation and hence absolute measurements should be avoided. If the observable simulator generates enough flux in roughly the right passband to produce the desired response functional test of the sensor can be performed.

Absolute characteristics of sensor components can be determined separately. A discussion of the instruments required for this purpose was NOT to be included here by direction since optical measurements were to be made by another activity.

If Section C is required, all instrumentation accuracy requirements should be developed with equal emphasis and a complete rewrite is recommended.

For some types of celestial sensor tests the accuracy of determination of the line of sight between the sensor and the simulated observable must also be considered. Referring again to the analysis of the Jupiter Fly-by mission, it has been determined that, for a maximum permissable final inclination error of the vehicle of 0.2 deg, a total system error of 0.5 deg could be tolerated. Compilation of an error of the navigational optics could be as great as ±10 arc sec. Since available read out devices, such as the "Inductosyn," are capable of accuracies better than one arc sec, this measurement requirement imposes no apparent difficulty.

Details regarding this and other references to the Jupiter Fly-by mission analysis will be contained in a final report which is being prepared in accordance with the provisions of Contract NAS 12-40.

There appears to be no unusual accuracy requirements imposed upon other instrumentation equipment associated with the celestial sensor test operation. The accuracies provided by available standard equipment should be satisfactory.

IV. INTEGRATION OF SIMULATION FACILITIES

A. Objectives

Extension of the scope of the study to include the high rise building makes it necessary to define the techniques and equipment requirements necessary to coordinate and correlate the operation of equipment in the high rise building with that in the low rise building. The scheduled flow of work normally will be the development and initial test of stellar, planetary, solar or other optical sensors in the low rise building, then transfer to the high rise building for mating with inertial system components where an overall system check will be performed using the optical navigation information provided by the optical sensor as a means of updating or checking the inertial system performance.

B. Techniques

Irradiance standards should be available for the generation of both broadband and spectral optical flux densities over the near UV, visible and IR ranges. Broadband flux density requirements in each range are as follows: In the UV 2000 to 4000 A range a maximum flux density on the order of 1.3×10^{-2} watts/cm^2. In the near infrared 7500 to 15,000 A 4.9×10^{-2} watts/cm^2 maximum irradiance should be available as calibration references for broadband secondary standards, such as photometers. Initially, the spectral distribution of energy across these three bands can conform to that of a tungsten source. However, future requirements may dictate certain departures from this, particularly in narrow regions. Determination of exact requirements in these regions must await the definition of the spectral response of the specific sensor involved.

Secondary standards, both broadband and narrowband, should be available as a means of transferring calibration references from the irradiance standards to the simulators being used with the sensor. In the UV, visible and even in the very near IR several commerical photometers are available which can satisfy these requirements. For the full IR range, infrared radiometers should be provided. The purpose of these secondary standards is to permit the calibration of the observable simulators used in both the low rise and high rise buildings for a given sensor in order that the response of the sensor will be the same in both instances.

In addition to secondary standards, metrological tooling such as an autocollimating theodolite and auxiliary optical components will be required to initially align both simulator and sensor. Ultimate precision in the order of arc seconds will be required of these instruments, and initial procurement should be directed towards this precision.

Specialized equipment to monitor variations in the radiant flux, angular alignment, and other critical parameters will be required during critical testing phases. In general, however, these can be adapted by using equipment described above. They fall in the category of equipment designed or modified for use with a special sensor.

In addition to the above, recalibration procedures should be established to assure that simulators and secondary standards to not drift beyond the tolerance necessary to maintain accurate outputs. This is particularly important when tungsten are used. With such sources recalibration should be carried out at intervals of 2 hours or less during operation.

C. General Procedures

The general procedure to be followed in the testing of an optical sensor is: First, calibrate the secondary standard against the primary standard. Second, set up the observable simulator with the secondary standard. Third, align the simulator and sensor and proceed with calibration tests in the low rise building. Fourth, monitor and/or recalibrate the simulator as required during these tests. Fifth, calibrate the observable simulator in the high rise building. Sixth, transfer the optical sensor from the low rise building to the system package and install in the high rise building. Seventh, align simulator and sensor in the system test fixture. Eighth, monitor and/or recalibrate simulator at specified intervals, during system tests.

V. IDENTIFICATION OF CURRENT EQUIPMENT

The basic equipment items required in the testing and evaluation of Celestial Sensors are shown in Table XII. With the exception of items 3 and 4, stellar and planetary simulators, all of the items are currently available and require no modification for the intended application.

TABLE XII

BASIC EQUIPMENT REQUIREMENTS

ITEM NO.	DESCRIPTION	SPECIFICATIONS	EST. PRICE	DELIVERY	REMARKS
1	Table, 2 Axis, Rate	1. Axes Vertical and Horizontal 2. Axes Capable of Simultaneous or Independent Drive 3. Digital Position Readout Every 1° Accurate to ± 2 sec 4. Rate Drive: From 7 sec/sec to 10°/sec 5. Rate Set Accuracy: 1% 6. Load: Vol. Capacity: 150 - 1 Ft.^{3} 7. Random Planar Wobble: ± 0.1 sec	150 K	3 Months	
2	Simulator, Solar	1. Wavelength Interval: 0.2 - 1.5 μ 2. Flux Tolerance 5% 3. Disc Size Tolerance 1% (Visible Region) 4. Intensity: 140 MW/CM^2 (Incident) 5. Beam Diameter Nominal 12 in. Diameter Each Work Surface 6. Power Requirements: 440V, 3 Phase, AC	20K	30 Days	
3	Simulator, Stellar	1. Collimation Accuracy (Source Subtence): 5 sec 2. Magnitude Range: -1 to +3 Visual 3. Simulator Aperture: > 3 in. Dia. < 6 in. Dia. 4. Ghosts $\leq$ 4 Mag. Dimmer Than Dimmest Star 5. Background: 10^{-2} to 10^3 foot Lamberts 6. Field: 2-3° (Max)			Development Required (Optical)
4	Simulator, Planetary	1. Collimation Accuracy (Source Subtence): 30 min. 2. Magnitude: -5 to +3 with Phase Sim. 3. Field: 2 to 3° Max. 4. Aperture: > 3 in. Dia. < 6 in. Dia. 5. Ghosts $\leq$ 4 Mag. Dimmer Than Dimmest Planet 6. Background: 10^{-2} to 10^3 ft. Lamberts			Development Required (Optical)

TABLE XII (Continued)

ITEM NO.	DESCRIPTION	SPECIFICATIONS	EST. PRICE	DELIVERY	REMARKS
5	Photometer	1. Ranges: 0.2 - 0.4 μ 0.4 - 0.75 μ 0.75 - 1.5 μ 2. Meter: Linear Response, Density and Photometric Scales 4. Sensitivity: 0.0001 Microlunens Per Division in Most Sensitive Range	1.2 K	30 Days	Ranges May Be Obtained With Multiple Units, Or Interchangeable Multiplier Tubes
6	Radiometer	1. Wavelength Interval: 0.2 - 1.5 μ 2. Calibration Accuracy: ± 8% 350 to 1200 mμ ± 15 % 200 to 350 mμ	13 K	60 Days	
7	Blackbody, Standard	1. Emissivity: 0.99 ± 1% 2. Aperture: 0.5 in. Dia. 3. Intensity: 5 Watts/CM^2/Steradian 4. Temp. Range: 200°C to 1000°C 5. Spect. Ranges: 0.2 - 0.4 μ 0.4 - 0.75 μ 0.75 - 1.5 μ 6. Aperture Plate Capability to .008 in. Dia. in 8 Separate Plates (Equal Radiation Qtys.)	2 K	30 Days	
8	Table, Single Axis Rate	1. Speed Range: 0 to ± 600 °/sec. 2. Speed Accuracy: ± 0.1% of Indic. Speed or ± 0.0001 °/sec whichever is greater 3. Wow and Flutter: 0.1% of Indic. Speed or .0001°/sec whichever is Greater 4. Acceleration: 100 Deg/Sec^2 up to 500 Deg/Sec 5. Static Torque: 5 FtLb Min. 6. Acceleration Due to Table Vibration: ± 0.01 "g" 7. Power Reqmts: 117 V AC 60 ~ 8. Table Capacity: 300 Lbs.	12 K		
9	Test Equipment General Lab. Use		100 K		Misc: Oscilloscopes, Meters, Power Supplies, Theodolites, Autocollimators, Mirrors and Optical Equip.

VI. EQUIPMENT REQUIRING DEVELOPMENT OR MODIFICATION

Each of the stellar and planetary simulators will consist of an assembly of a light source and controls, holders for filters, masks and apertures, and a collimator. Simulators of this type have been made to order by several manufacturers, but always to somewhat different (not necessarily more difficult) specifications than are required here. Thus, the degree of design and modification which is required is minimal.

Performance specifications for these simulators would refer to the parameters I_S and I_B as discussed in Section III. A. 2. As is indicated by the stated relationships between I_S, I_B and the parameters of the sensor under test, numerical specification of I_S and I_B would require definition of the particular sensor.

VII. IDENTIFICATION OF EXCEPTIONAL REQUIREMENTS

The recommended simulation technique has no requirement for extensions of technology in meeting equipment requirements. As noted in the preceding section, equipment which does not exist as a "shelf" item can be attained by either modification of existing equipment or by the assembly of several available items. However, as noted in Section II. C. new technological development can be expected to result in new, more sophisticated and as yet unsatisfied simulation requirements. These requirements are summarized in Section II. C.

VIII. ASSOCIATED FACILITY REQUIREMENTS

The requirements of two separate facilities were determined during the course of the study program. The first was the optical test facility to be housed in the low-rise building and the second involved the general arrangement and layout of the celestial test facility building called the high-rise building. At the onset of the contract, the building requirements for the high-rise building were in a state of flux and initially effort was concentrated on the low-rise building. Subsequently, it was established that the high-rise building also will house the inertial test facility. The inertial facility in the low-rise building was designated as a transitory facility accommodating the needs in the interim period created by the construction program phasing.

Since inertial systems being tested in the high-rise facility will frequently incorporate one or more optical subsystems, a provision for simulating observables is a necessary adjunct to this facility. The requirements for integration are covered in Section IV.

A. Low-Rise Building

Initial consideration of building features as originally planned elicited the following general recommendations, which were communicated to NASA/ERC during a meeting on March 24, 1966:

1) Over long optical paths such as can be accommodated by the optical tunnel, gradients of refractive index can be troublesome. It was recommended that steps be taken to minimize air currents and temperature and humidity gradients within the tunnel. Appropriate baffling and air-conditioning control and distribution would be helpful, but possibly even more feasible would be the use of a supplementary tube, of relatively small cross section, to contain the optical beam. It was also recommended that there be provision for access to the tunnel at several intermediate locations.

2) It was recommended that in rooms having a "dark room" capability the standard fluorescent illumination be supplemented or replaced with an incandescent system with controls to permit adjustment of light level. It was also pointed out that if space and utilization permitted, the use of intermediate light levels as a transition between dark rooms and normally illuminated areas reduced discomfort when moving from one type of area to another.

3) The use of light locks at dark room entrances was not recommended because of the waste space which they entail and because of their impedance to the movement of large equipment. Experience has shown that a more practical and positive solution is provided by door locks which can be locked from the inside and unlocked, by key, from the outside.

4) The need for power line isolation to prevent noise generated by one activity from appearing on power lines shared with other activities was pointed out. The location of isolating means must be determined on the basis of relative sizes and types of sharing activities. Similar attention to detail will be required for the ground system in the laboratory.

5) The need for mechanical isolation at noise generating sources was indicated. This is particularly important because of the proximity of both ends of the sensor test area to mechanical building facilities rooms containing pumps, compressors, air-conditioning equipment, etc.

Studies of building facility requirements continued and were extended to cover other areas of the building under the cognizance of the Guidance Laboratory in addition to the Celestial Sensor Test Facility. Figure 7, General Arrangement - NASA/ERC Building, and Figure 8, ERC Laboratory Pier and Pad Detail, show the results of these studies. The drawings were given to ERC representatives at a meeting on May 4, 1966 and are also included as part of this report. Phase I is the initial low-rise layout, Phase II considers the transfer of certain activities to the high-rise building.

Referring to Figure 7, the following details, considered by area involved, should be noted:

1. Inertial Sensor and System Laboratory Area

   a. Electrical Standards and Metrology Area - 309

      (1) Layout Status - No change, no pads are required; the interferometer will rest on an air bag.

      (2) Phase II Alterations - None

      (3) Rationale - Necessary to support test and assembly areas.

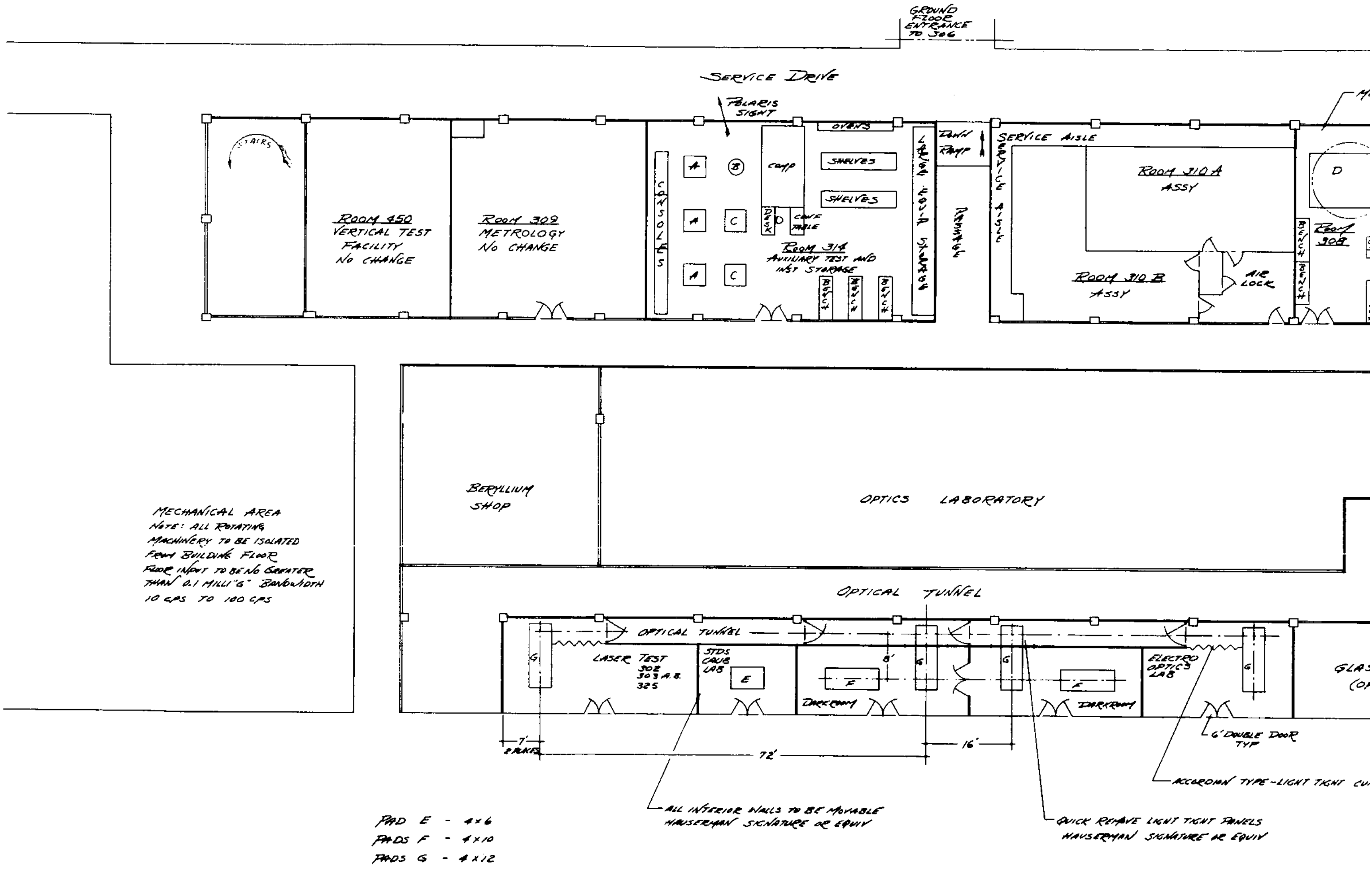
   b. Auxiliary Test Area - 314

      (1) Layout Status

      Polaris sight and monitoring capability included (pad B)

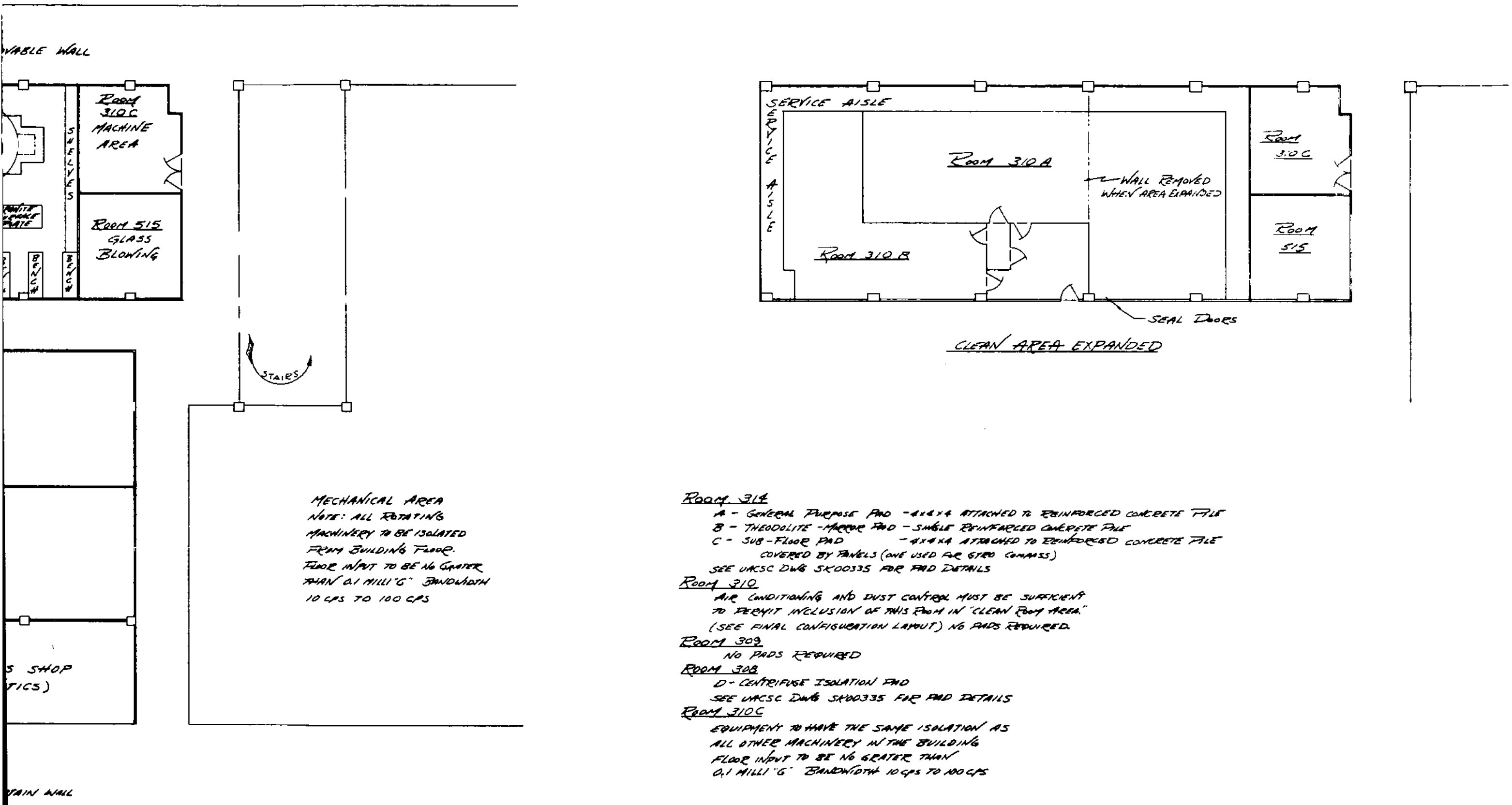
      Base for Gyro Compass included (pad C)

      Computer Buffer equipment included



MECHANICAL AREA
NOTE: ALL ROTATING MACHINERY TO BE ISOLATED FROM BUILDING FLOOR
FLOOR INPUT TO BE NO GREATER THAN 0.1 MILLI "G" BANDWIDTH 10 CPS TO 100 CPS

PAD E - 4×6
PADS F - 4×10
PADS G - 4×12



MECHANICAL AREA
NOTE: ALL ROTATING MACHINERY TO BE ISOLATED FROM BUILDING FLOOR. FLOOR INPUT TO BE NO GRATER THAN 0.1 MILLI "G" BANDWIDTH 10 CPS TO 100 CPS

ROOM 314
A - GENERAL PURPOSE PAD - 4x4x4 ATTACHED TO REINFORCED CONCRETE PILE
B - THEODOLITE - MIRROR PAD - SINGLE REINFORCED CONCRETE PILE
C - SUB-FLOOR PAD - 4x4x4 ATTACHED TO REINFORCED CONCRETE PILE COVERED BY PANELS (ONE USED FOR GYRO COMPASS)
SEE UACSC DWG SK00335 FOR PAD DETAILS

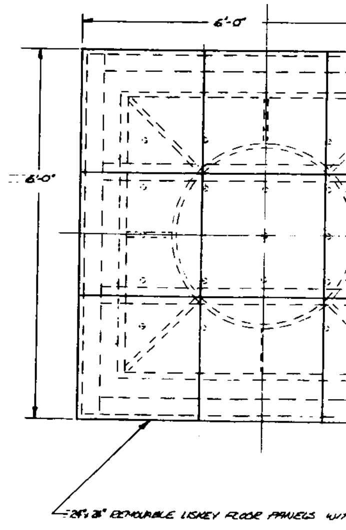
ROOM 310
AIR CONDITIONING AND DUST CONTROL MUST BE SUFFICIENT TO PERMIT INCLUSION OF THIS ROOM IN "CLEAN ROOM AREA." (SEE FINAL CONFIGURATION LAYOUT) NO PADS REQUIRED.

ROOM 309
NO PADS REQUIRED

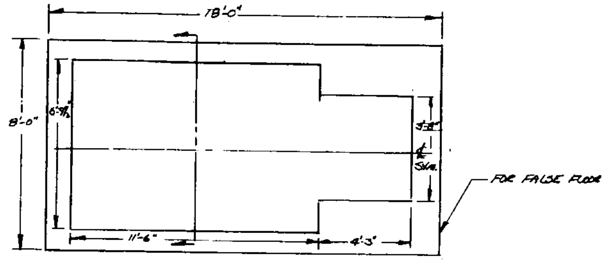
ROOM 308
D - CENTRIFUGE ISOLATION PAD
SEE UACSC DWG SK00335 FOR PAD DETAILS

ROOM 310C
EQUIPMENT TO HAVE THE SAME ISOLATION AS ALL OTHER MACHINERY IN THE BUILDING FLOOR INPUT TO BE NO GRATER THAN 0.1 MILLI "G" BANDWIDTH 10 CPS TO 100 CPS

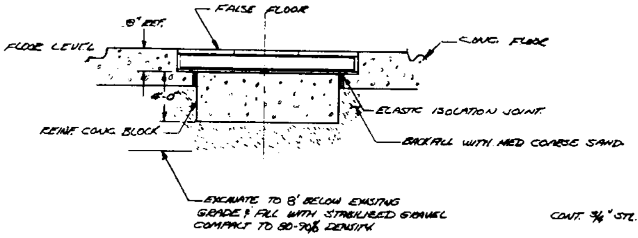
Figure 7 General Arrangement - NASA/ERC Building



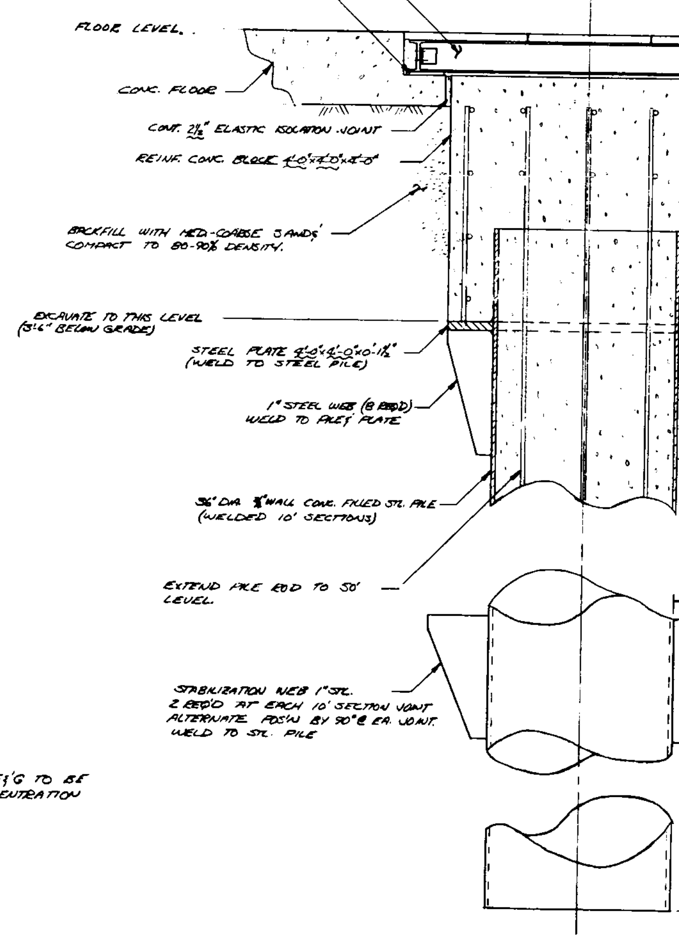
DET. 1 STABILIZED TEST PA



DET 3 CENTRIFUGE PAD (NO SCALE)



TYP SECTION THRU BLOCK



2. FLOOR LOADING IN OPTICS AREA FOR BLOCKS E, F & G TO BE 12000# OVER AN AREA OF 40 FT² ~ LOAD CONCENTRATION 1500#/FT² @ SUPPORT POINTS.

1. ALL CONCRETE 3000 PSI @ 28 DAYS.

NOTES:

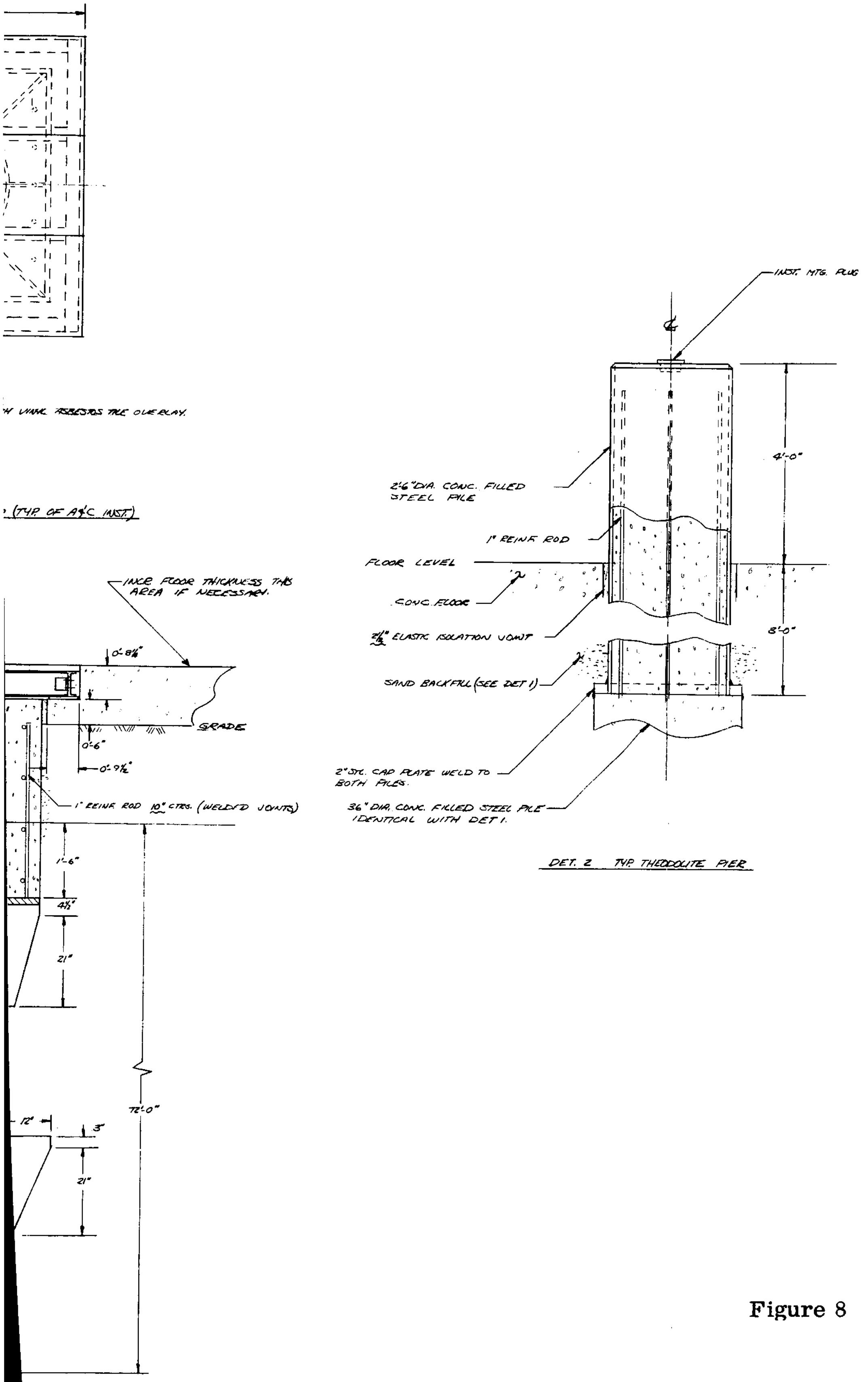


Figure 8 NASA/ERC Laboratory Pier - Pad Detail

46-2

Three general purpose bases included - 1 accelerometer,
2 gyro or system

Test stands moved from outer heavy traffic wall to interior

Base for alignment purpose set up or available to each test stand

(2) Phase II Alterations - This laboratory can be used as is or its functions transferred to the new area and this used as general laboratory or support areas. The latter is recommended because of its poor location with respect to the vibration environment.

(3) Rationale - All test operations should be concentrated in one area for ease of control of test procedures, data handling, equipment maintenance, personnel. This will be accomplished by centralizing test operations in the high-rise building. Pad isolation will be improved in the high-rise building.

c. Assembly Area - 310

(1) Layout Status

Machining area moved to provide more space in clean area

Function of rooms A and B interchanged

Air lock and shower moved

Air conditioning and filtration specified for adjacent room 308

(2) Phase II Alterations

Room 308 incorporated into clean room area

Service aisle extended to provide greater services

Air conditioning and filtration equipment need not be added as previously included

(3) Rationale

The low-rise building clean room size will be adequate to handle initial type of work (expected duration 1 to 1 1/2 years)

The additional area provided by room 308 to dust free complex should be sufficient to cover all maximum cleanliness type of sensor (conventional and exotic) system; assembly, disassembly, and repair functions

The clean areas function should not be distributed over many small areas but should be concentrated for the following reasons:

Ease of control procedures, personnel work habits as related to cleanliness

Minimization of personnel having to "suit up" for several different functions in different areas, as the same trained people would of necessity move between clean areas

Maintenance and cleaning facilitated

Duplication of expensive air conditioning and filtering equipment will not be necessary.

d. System Design 308

(1) Layout Status

Room divided to provide larger machining facility

Foundation for system (satellite table) centrifuge included, however covered by false floor until Phase II

System shaker (angular) foundation not required, it should, however, be isolated when installed

(2) Phase II Alterations

False floor provided for centrifuge foundation area removed

See Assembly area 310 further additional details

(3) Rationale

Limited environmental test facility should be expanded in new area to include:

Random vibration equipment

Linear vibration equipment

Special purpose shock testing

Temperature and altutude control

The above functions will generally be associated with sensitivity type tests and test equipment, i.e., test consoles, maintenance, and experienced personnel will be readily accessible.

Data reduction and computation facilities (precision test area) will be readily available.

2. Test Facility for Celestial Sensors

Figure 1 indicates the optical equipment pad positions with respect to the fixed walls around the laboratory work areas. All the other interior walls will be of a moveable type. The two pads shown penetrating the moveable type wall between a dark room area and the optical tunnel should be provided with quick removal paneling, light-insulated to isolate the work areas from one another.

The following features should be incorporated into all laboratory work areas:

1. Walls, ceilings, and doors should be light tight to provide an ambient level of less than 10^{-8} foot candles,
2. Vinyl coated (i.e., dust inhibiting) walls and ceilings,
3. Locks on all doors,
4. Individual shut-off capability on all air vents in the separate work areas,
5. Work area light tight air vents on the corridor walls,
6. Standard power (i.e., 115 V, 60 ~ 30 amp),
7. Isolated power sources and building isolated power and instrumentation grounds
8. Variable Intensity overhead lighting,
9. Compressed air and vacuum lines to pertinent areas

The Laser Test Laboratory and the Electro-Optics Laboratory may require special power sources, and should be provided with water outlets and sinks along with cold water drop and stable pad. The Optical Tunnel should have a flat black paint lining, and must have no air inlets or vents to eliminate turbulence effects.

In accordance with instructions received from ERC, all pads in this area are surface pads with isolation being achieved by the use of servo-level mounts providing maximum attenuation above two cps.

B. High-Rise Building

In accordance with the provisions of the extension in scope of the investigation, a study of the facility requirements of the planned high-rise building was made, and a conceptual configuration and general arrangement of the building was developed. Figure 9, Preliminary General Arrangement and Building Design Features - NASA/ ERC High-Rise Building, and Figure 10, Proposed Pier Design, were transmitted to ERC on July 1, 1966.

As shown on Figure 9 the space allocations are consistent with the objective of centralizing functions to achieve personnel control, functional control of the area, and minimization of distance between related areas.

1. Inertial Test Area Features

a. Maximum Flexibility in Testing

All multipurpose stations

Electronic consoles can be introduced or removed without interrupting tests

Each test stand can be alignment cross-checked with at least two other stations

Direct view of each test station from primary reference

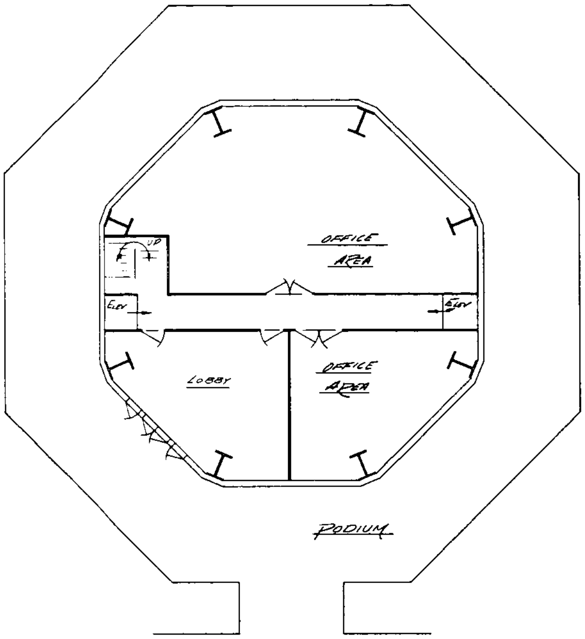
Several linear arrays of three stations each exist for multiple system or component tests

Individual arrays of three stands can be isolated to permit darkened testing of optical system adjuncts

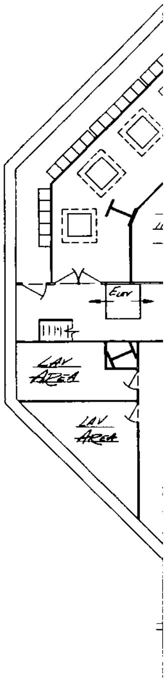
b. Space Utilization and Construction Features

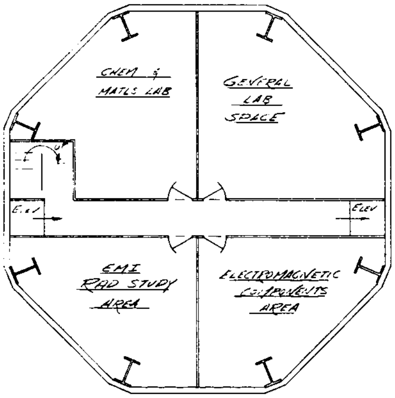
Working level beneath ground therefore no exterior wall heat load

Buffer air conditioning zone completely surrounding test area

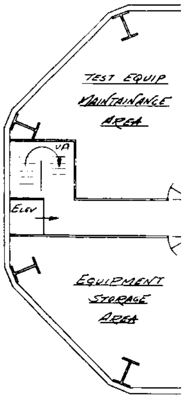


PLAN VIEW
FIRST FLOOR

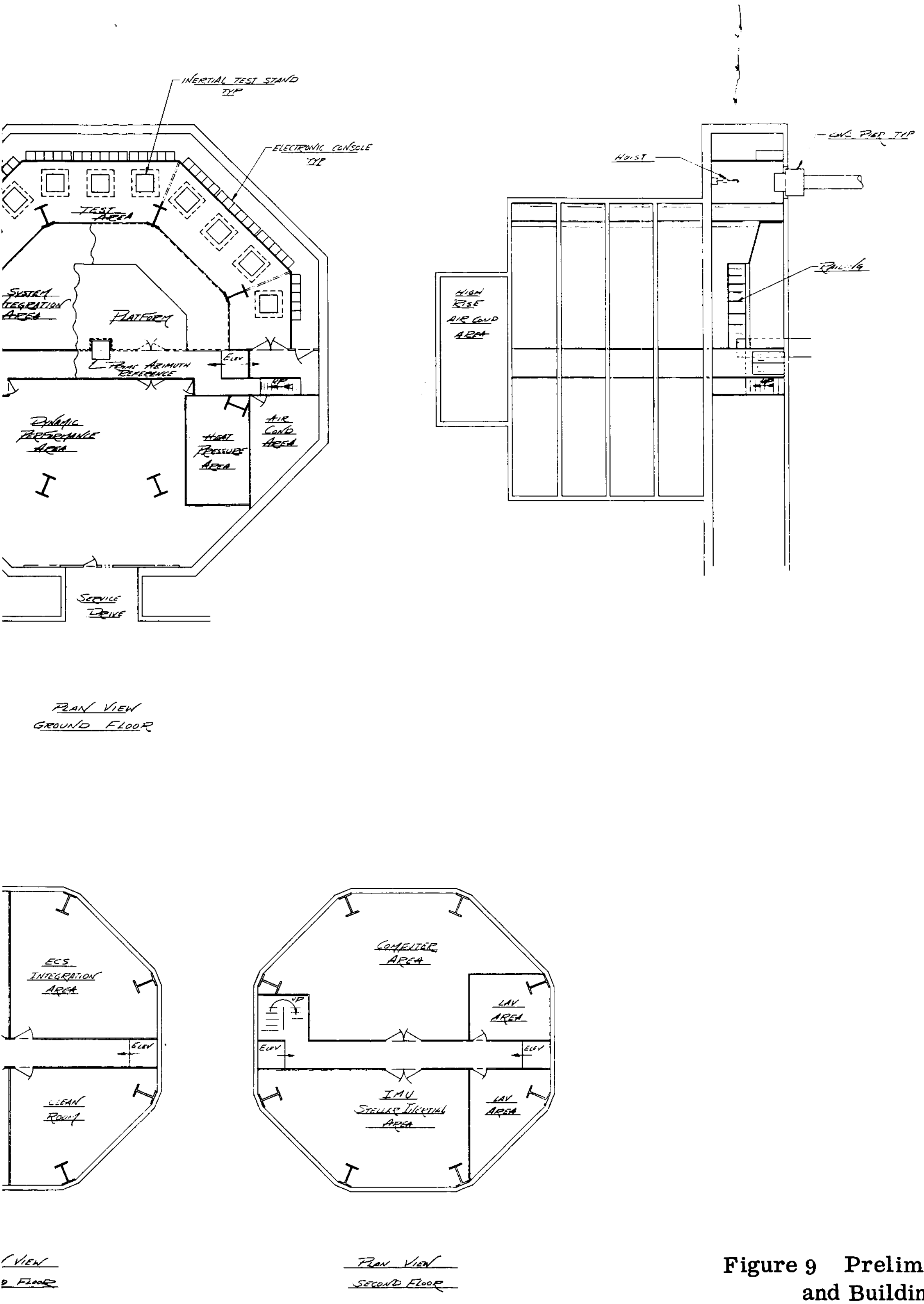




PLAN VIEW
FOURTH FLOOR



PLA
THIR

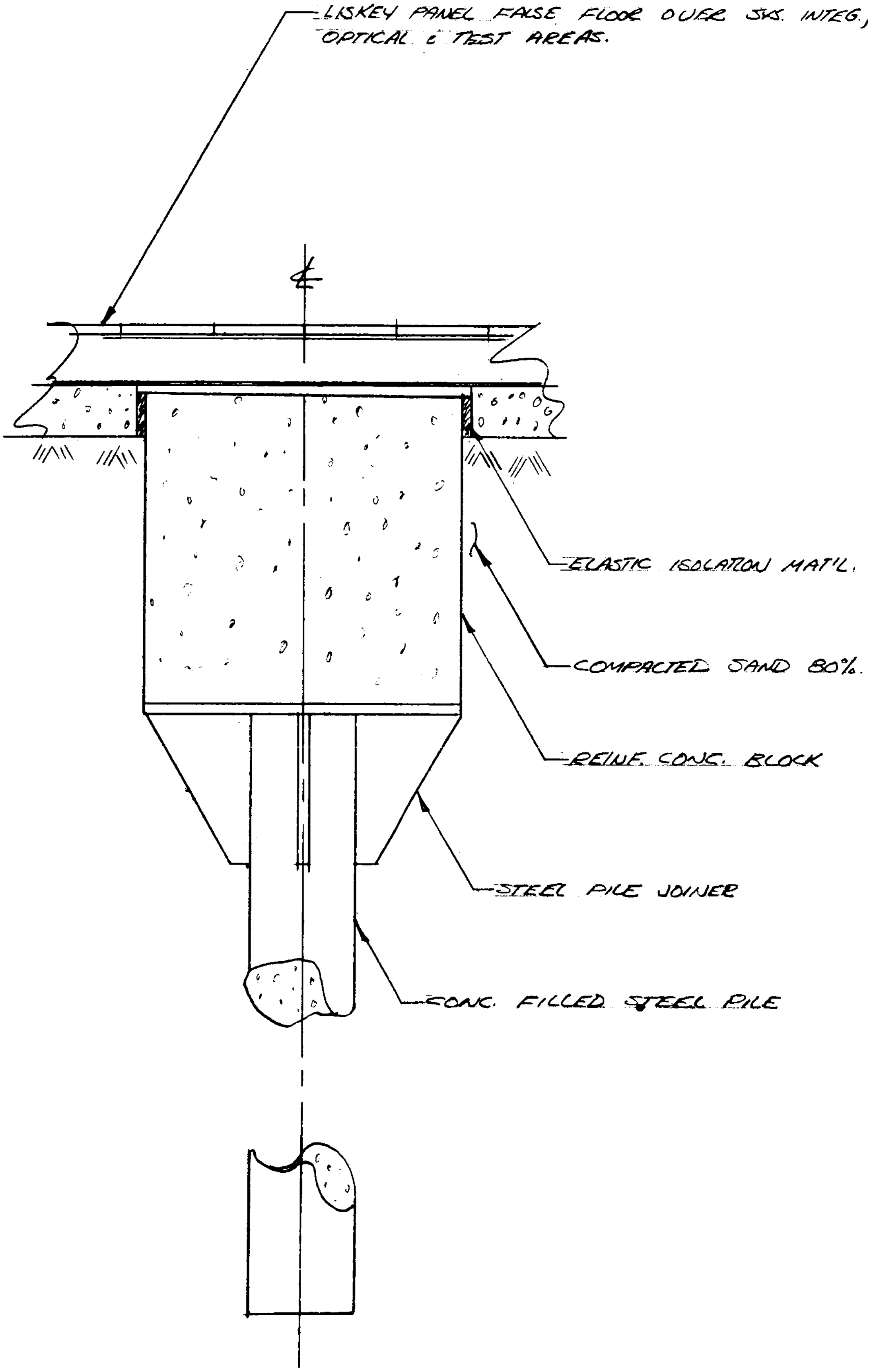


PLAN VIEW
GROUND FLOOR

VIEW
D FLOOR

PLAN VIEW
SECOND FLOOR

Figure 9 Preliminary General Arrangement and Building Design Features - NASA/ERA High-Rise Building


LISKEY PANEL FALSE FLOOR OVER SYS. INTEG., OPTICAL & TEST AREAS.
℄
ELASTIC ISOLATION MAT'L.
COMPACTED SAND 80%.
REINF. CONC. BLOCK
STEEL PILE JOINER
CONC. FILLED STEEL PILE

NOTE:

DESIGN OF PILE DEPENDENT UPON SUBGRADE CHARACTERISTICS DETERMINED BY ANALYSIS OF CORE SAMPLES & DRIVING OF TEST RODS TO BEDROCK.
FOLLOWING PARAMETERS WILL BE NECESSARY TO DESIGN TO SPECIFICATIONS.

1. PROFILE OF BEARING STRENGTH OF SOIL.
2. VIBRATION LEVELS & FREQUENCIES AT SITE.
3. WATER TABLE HEIGHT.
4 SHEAR PROFILE COEFFICIENT OF SOIL.
5. DENSITY PROFILE TO BEDROCK.
6. PROFILE OF SOIL MODULUS.

Figure 10 Proposed Pier Design - NASA/ERA Octagonal Building

Maximum space utilization of building inner area permitted by positioning of test area adjacent to the exterior wall

Viewing balcony permits view of both inertial test area and dynamic test area without interfering with working space allocation

A low ceiling (approx 8 ft) working space exists beneath the balcony area

Area is isolated from major traffic stream so that casual visitation will not occur

2. Building Space Allocation

The following functional areas are also provided in the high-rise building. A brief outline of the area function is also included.

a. IMU, Component, Computer Integration Maintenance Area

Final pretest integration and system calibration of IMU, computer, and components will take place in this area.

The area will also serve as a system maintenance area.

Inertial component pretest calibration and maintenance facilities will also be provided in this area.

b. IMU-Optical Integration and Maintenance Area

This area will provide prime optical sensor and system integration and calibration facilities.

Maintenance or individual recalibration of the optical sensors.

The area will contain all the specialized optical system equipment necessary to fulfill the functions required.

c. System Environmental Control Integration and Maintenance Area

Pretest, assembly and maintenance of environmental control systems.

Contamination of other system components by ECS will be minimized by having a specialized area for this function.

d. Computer Area

This area will house the hybrid facility computer and provide space for inflight computer checkout calibration and maintenance.

These functions are combined such that all specialized computer peripheral maintenance and checkout equipment is centralized.

e. System Clean Room

A clean room for specialized system disassembly or maintenance.

All major clean room work will be performed in the low-rise building clean area.

f. Office Area

General office area is provided.

g. Equipment Maintenance

This area will be specialized in the maintenance of the inertial test facility electronic and test futurization equipment.

A storage area is included adjacent to the maintenance area.

h. Materials and Chemical Laboratory

The materials and chemical laboratory will serve as development and service facilities to both component development and optical sensor development.

i. EMI and Magnetic Component Area

Specialized EMI testing shielding techniques and magnetic component (sensor motor, torquer, pick-offs, etc) development.

j. Dynamic Performance Reaction Evaluation Area

All specialized flight dynamic simulation equipment will be included in this area.

Equipment will be isolated from the remainder of the building by use of servo-level mounts.

k. Heat-Pressure-Radiation Reaction Evaluation Laboratory

All specialized unique ambient simulation equipment will be housed in this area.

The area will be mechanically and thermally isolated from the remainder of the building to prevent thermal or radiative disturbances.

3. Test Pads and Piers

Drawing SK00359 shows the general configuration of test pads and piers recommended for use in the high-rise building. However, detailed design would require test data which is not currently available. With the exception of the seismic measurements, all of the tests involve standardized soil mechanics determinations. The following data must be secured:

a. Determination of amplitude and frequency characteristics of ambient earth vibrations at the building site. Preferably a three-component seismometer should be used and measurements taken at the surface and at 5, 10, and 15 foot depths. If an existing caisson provides accessability, measurements should also be made on the bedrock. Test runs should be so scheduled as to provide information relative to diurnal and weekly (week-days vs week-end) variations in activity. The seismometers used should cover the micro-seismic range to 100 cps.

b. Determination of bedrock depth by ASTM standards.

c. Water table level, showing diurnal and seasonal variations.

d. Driving of test pile, noting type of pile and hammer and magnitude of hammer impulse. The number of hammer blows per foot of penetration should be logged for the entire length down to refusal depth. Static load test should be performed on the pile per ASTM-D1143-50-T.

e. Analysis of core samples of individual strata, from surface to refusal depth, by dry sample method, to yield the following:

Consolidation coefficient
Moisture content
Soil density
Shearing resistance before and after consolidation
Degree of surcharge load necessary to achieve 100 percent consolidation
Allowable soil pressures
Stress deformation

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