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ORBITAL IMAGERY FOR PLANETARY EXPLORATION

CONDENSED SUMMARY

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ORBITAL IMAGERY FOR PLANETARY EXPLORATION

CONDENSED SUMMARY

Compiled by

Astro Sciences Center

of

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CONDENSED SUMMARY REPORT

1. INTRODUCTION

This report is a condensed summary of work reported in detail by Volumes I through V of "Orbital Imagery for Planetary Exploration." The purpose of the study was to estimate the requirements imposed upon spacecraft subsystems by the use of imaging sensor systems on unmanned planetary orbiting spacecraft. This study plays a key role in the identification of advanced technology development needs. By comparing the estimated support requirements provided by this study to the projected capabilities of spacecraft subsystems, some of the needs for advanced technology development of subsystems may be determined. Since this study deals only with imaging experiments which might be performed on unmanned planetary orbital missions, a comprehensive determination of advanced technology requirements must await completion of additional studies dealing with alternative mission modes. Nonetheless, since orbital imagery is expected to play an important part in planetary exploration, this study represents an essential contribution to the intelligent planning of advanced technology development.

The study focuses upon orbital imaging experiments because such experiments are expected to impose severe requirements upon spacecraft subsystems in future unmanned planetary exploration. The term imaging, as used in this study, means the collection of two-dimensional information from a planetary scene in an essentially simultaneous manner, either by direct two-dimensional recording or by rapid scanning. The planetary targets considered by the study are Mercury, Venus, the Moon, Mars, and Jupiter, while the time frame of interest covers launch opportunities from 1975-1995. The study subtasks were (1) exploration objectives, (2) measurement definition, (3) orbit selection, (4) imager scaling laws, and (5) experiment support requirements.

The exploration objectives task provided an explicit statement of those objectives of unmanned planetary orbital exploration which might be accomplished by remote sensing experiments. By considering the scientific goals of space exploration, the current knowledge of planetary phenomena, and conceptual measurement techniques, additional analysis identified those measureable planetary phenomena which can be investigated usefully by imagery from orbital altitudes.

The measurement definition task interpreted the exploration objectives into measurement specifications from the viewpoint of the scientist who must interpret the data. A set of nominal values (pertaining to ground resolution, imaged area, solar illumination constraints, etc.) was defined for each measurement, together with a range of values over which the measurement was deemed useful to the scientist. The measurement specifications were used in the orbit selection procedure and in the final estimation of experiment support requirements.

The orbit selection task defined operational orbits for the required experiments. Experiments with similar operational requirements were grouped into families, and orbits were selected for these families. The resultant orbital parameters were also used in the estimation of subsystem support requirements for each of the experiments.

The imager scaling laws defined the quantitative relationships between the imager characteristics and its ability to meet the required measurement specifications from a specific orbit. For each imager type, a collection of scaling laws which relate the experiment support requirements to the measurement specifications, to the sensor system characteristics, and to the orbit variables were derived.

The experiment support requirements task combined the results of previous tasks. Both measurement specifications and orbit parameters were used with the scaling laws to estimate typical support requirements demanded by each imaging experiment.

This condensed summary report discusses, in each of the task areas, the method of analysis and the results of the analysis. A more detailed summary report is provided by Volume I-Technical Summary. The exploration objectives task is documented in Volume II-Definitions of Scientific Objectives which describes in some detail those planetary phenomena for which remote sensing appears useful. The results of the orbit selection task are tabulated in Volume III-Orbit Selection and Definition. Volume IV-Imaging Sensor System Scaling Laws provides a detailed derivation of scaling laws for ultraviolet line scanners, television camera systems, photographic film camera systems, infrared line scanners, passive microwave imagers, and side-looking radar systems. A classified appendix (confidential) to Volume IV presents scaling laws for infrared television camera systems. Volume V-Support Requirements for Planetary Orbital Imaging presents an extensive tabulation of typical experiment support requirements for orbital imaging experiments at Mars, Venus, Mercury, and Jupiter.

2. EXPLORATION OBJECTIVES

Both scientific and engineering objectives of planetary exploration were identified by a systematic analysis of the goals of space exploration. The scientific goal deals with understanding the origin and evolution of the solar system, while the engineering goal was defined as achieving the scientific goal in an efficient manner. These goals were expanded in steps of increasing detail resulting in the identification of subgoals, exploration objectives, and observable planetary properties, or "observables." The analysis of the scientific goal, down through the exploration objectives level, is portrayed in Figure 1. Down to this level of detail, it was not necessary to take account of detailed differences between the

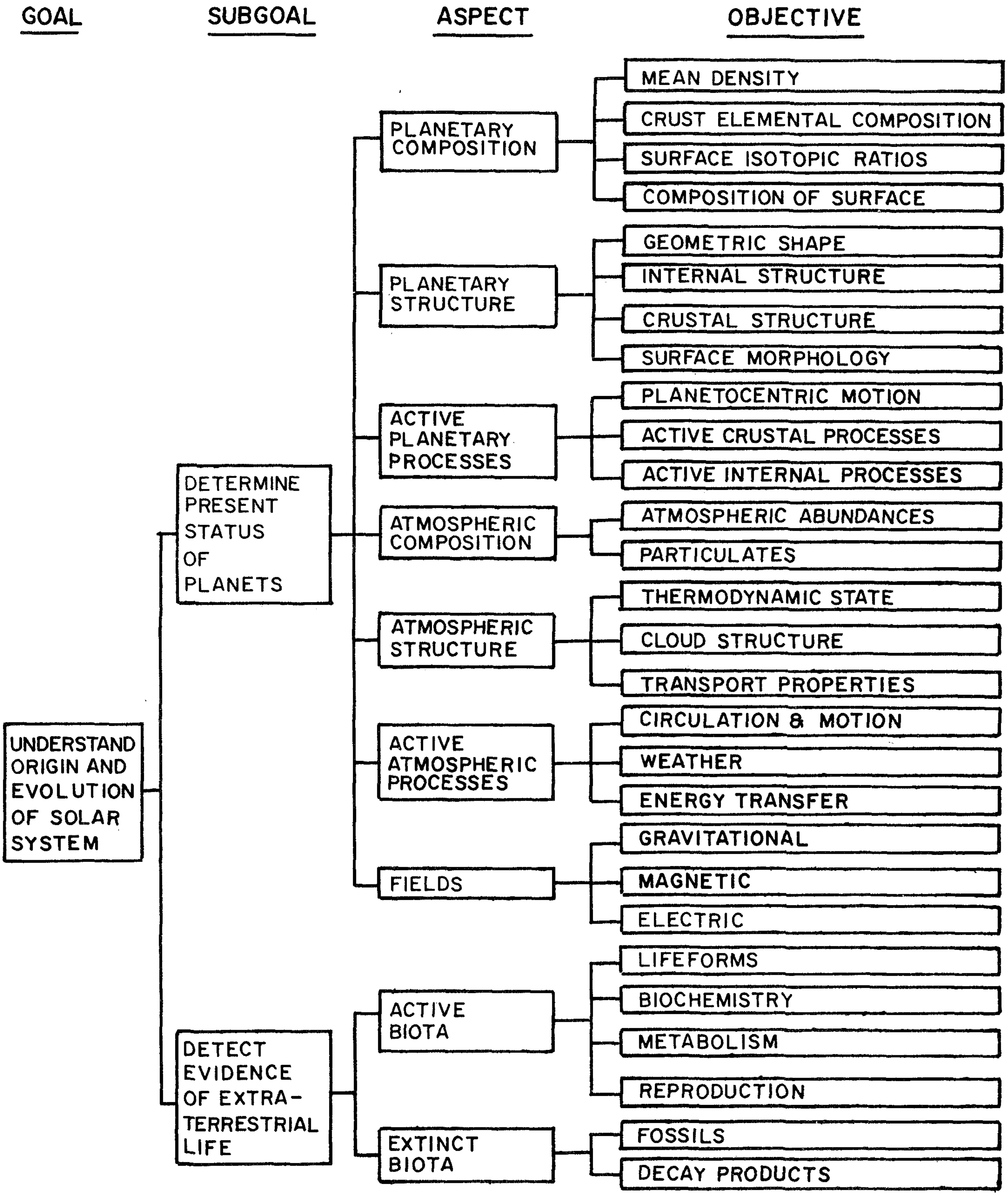

FIGURE I. ANALYSIS OF SCIENTIFIC GOAL.

planets, the location of the experimental platform, or the class of measurement (i.e., direct or remote sensing). Once the observables were defined in terms of physical phenomena and conceptual measurement techniques, the potential utility of remote sensing was assessed. If remote sensing was deemed useful, the observable was analyzed in greater detail to determine whether or not imagery obtained from an orbiting spacecraft might contribute materially to achievement of the exploration objective. This judgement was based on the characteristics of the observable (planetary distribution, characteristic size, temporal variation, etc.) at each of the target planets without regard to instrument availability or current technological capability. The observables defined in support of engineering exploration objectives were not analyzed in sufficient detail to define measurement specifications, but were correlated with the scientific observables.

Analysis of the scientific goal, as shown in Figure 1, led to the definition of nearly thirty exploration objectives dealing with understanding a planetary body (composition, structure, and active processes), the surrounding atmosphere (composition, structure, and active processes), fields, and both active and extinct biology. Nearly one hundred different observables were defined in support of these exploration objectives, but remote sensing was judged useful for only about half of these with emphasis upon those objectives dealing with planetary composition, planetary structure, atmospheric structure, and active atmospheric processes. Orbital imagery is expected to be useful in the study of more than half of the observables for which remote sensing is appropriate. In particular, orbital imagery can play a major role in the study of planetary structure and active atmospheric processes. Orbital imagery is not expected to contribute materially to an understanding of either planetary or atmospheric composition. The complete results of the exploration objectives task are given in Volume II-Definitions of Scientific Objectives.

3. MEASUREMENT DEFINITION

From the standpoint of the sensor system designer, the planet-dependent observable descriptions do not adequately describe the nature and quality of the desired imagery. The observable descriptions define what should be measured, but do not define how the measurement should be performed in terms of the operational conditions and measurement accuracy necessary for proper image interpretation. Therefore, the observable descriptions were recast in a form meaningful to both the scientist and the sensor system engineer. The resulting measurement definitions provided nominal specifications for orbital imaging measurements, and are summarized in Table 1.

The nominal specifications themselves do not indicate the amount of flexibility (or image degradation) the scientist is willing to accept. In order that overly-stringent support requirements not result from the measurement specifications, measurement worth curves were provided. The letter-digit combinations listed in Table 1 (e.g. A7) refer to these worth curves. The worth curves are included in Volume I and indicate, for each specification, how the nominal value may vary without degrading the scientific value of the experiment. The experiment support requirements estimated in this study are based upon the worth curve data rather than the nominal specifications given in the Table. It must be emphasized that the measurement definitions do not, in any way, reflect the current technological capabilities of imaging sensor systems. The measurements defined here indicate the imaging experiments the scientist would truly like to perform, rather than what he thinks he could perform.

The specifications shown in Table 1 imply an exploration heirarchy involving first, second, and even third generation missions aimed at acquiring data of increasing detail.

TABLE I. SUMMARY OF MEASUREMENT SPECIFICATIONS

OBSERVABLE	PLANET	GROUND RESOLUTION	IMAGE SIZE	POSITIONAL ACCURACY	PLANETARY COVERAGE	PLANETARY DISTRIBUTION	ACQUISITION TIME		REPETITION RATE		SENSOR REFERENCES	SENSOR TYPE	SPECTRAL REGION	BANDWIDTH	OVERLAP	SUN ELEVATION	SUPPORT MEASUREMENTS	COMMENTS
							IMAGE	COVERAGE	IMAGE	COVERAGE								
1)*Surface Elevations	Moon	5 km A7	500 km B5	10 km C7	100% D1	-	-	-	-	-	a,d,f,i	a Visible	5750Å F3	1000Å G3	20% H1	20° I1	S/C Altitude, Local Time	Vertical resolution for all bodies is 1 km (J1) except Jupiter which is 4 km (J2).
	Mercury	5 km A7	800 km B6	10 km C7	100% D1	-	-	-	-	-	b,d,g,i	b	5750Å F3	1000Å G3	20% H2	20° I1	S/C Altitude, Local Time	
	Mars	5 km A7	1000 km B6	10 km C7	100% D1	-	-	-	-	-	c,e,g,i	c	6250Å F4	1000Å G3	20% H2	20° I1	S/C Altitude, Local Time	
	Venus	5 km A7	2000 km B8	10 km C7	100% D1	-	-	-	-	-	g,i	d Visible Stereo	5750Å F3	1000Å G3	60% H3	80° I4	S/C Altitude	
	Jupiter	50 km A8	20000 km B11	50 km C9	100% D1	-	-	-	-	-	h,j	e	6250A F4	1000A G3	60% H3	80° I4	S/C Altitude	
												f Radar	50 cm F18	-	20% H1	-	S/C Altitude	
												g	50 cm F18	-	20% H2	-	S/C Altitude	
												h	1 m F21	-	20% H2	-	S/C Altitude	
												i Radar Stereo	50 cm F18	-	60% H3	-	S/C Altitude	
												j	1 m F21	-	60% H3	-	S/C Altitude	
2) Layering	Moon	10 cm A1	1 km B2	10 m C2	<1%	Determined by prior mapping	-	-	-	-	a,d,f	a Visible	5750Å F3	1000Å G2	20% H1	45° I2	-	
	Mercury	10 cm A1	1 km B2	10 m C2	<1%	Determined by prior mapping	-	-	-	-	b,e,g	b	5750Å F3	1000Å G2	20% H2	45° I2	-	
	Mars	10 cm A1	1 km B2	10 m C2	<1%	Determined by prior mapping	-	-	-	-	c,e,g	c	6250A F4	1000A G2	20% H2	45° I2	-	
	Venus	10 cm A1	1 km B2	10 m C2	<1%	Determined by prior mapping	-	-	-	-	e,g	d Radar	10 cm F17	-	20% H1	-	-	
	Jupiter	1 m A3	1 km B2	10 m C2	<1%	Determined by prior mapping	-	-	-	-	h	e	10 cm F17	-	20% H2	-	-	
												f Multifreq.Radar	50 cm F18	3 bands G16	20% H1	-	-	
												g	50 cm F18	3 bands G16	20% H2	-	-	
												h	60 cm F18	3 bands G16	20% H2	-	-	
Contacts	Mercury	1 km A6	800 km B6	10 km C6	100% D1	-	-	-	-	-	b,d,g,j,l,o	a Ultraviolet	2250Å F1	500Å G1	20% H1	90° I5	-	
3) (Regional)	Mars	1 km A6	1000 km B6	10 km C6	100% D1	-	-	-	-	-	e,h,j,l,p	b	2250Å F1	500Å G1	20% H2	90° I5	-	
	Venus	1 km A6	2000 km B8	10 km C6	100% D1	-	-	-	-	-	l	c Visible	5750Å F3	1000Å G2	20% H1	20° I1	-	
	Jupiter	5 km A7	10000 km B10	50 km C9	5% D3	Global	-	-	-	-	m	d	5750Å F3	1000Å G2	20% H2	20° I1	-	
												e	6250Å F4	1000Å G2	20% H2	20° I1	-	
4) (Local)	Moon	100 m A5	100 km B4	1 km C4	100% D1	-	-	-	-	-	a,c,f,i,k,n	f Infrared	1.75μ F7	0.1μ G2	20% H1	20° I1	-	
	Mercury	100 m A5	100 km B4	1 km C4	10% D2	See regional maps	-	-	-	-	b,d,g,j,l,o	g	1.5μ F6	0.1μ G2	20% H2	20° I1	-	
	Mars	100 m A5	100 km B4	1 km C4	10% D2	See regional maps	-	-	-	-	e,h,j,l,p	h	1.75μ F7	0.1μ G2	20% H2	20° I1	-	
	Venus	100 m A5	100 km B4	1 km C4	10% D2	See regional maps	-	-	-	-	l	i Infrared	120μ F12	20μ G9	20% H1	90° I5	-	
												j	120μ F12	20μ G9	20% H2	90° I5	-	
5) (Betailed)	Moon	1 m A3	1 km B2	10 m C2	<1%	See local maps	-	-	-	-	a,c,f,i,k,n	k Radar	10 cm F17	-	20% H1	-	-	
	Mercury	1 m A3	1 km B2	10 m C2	<1%	See local maps	-	-	-	-	b,d,g,j,l,o	l	10 cm F17	-	20% H2	-	-	
	Mars	1 m A3	1 km B2	10 m C2	<1%	See local maps	-	-	-	-	e,h,j,l,p	m	60 cm F18	-	20% H2	-	-	
	Venus	1 m A3	1 km B2	10 m C2	<1%	See local maps	-	-	-	-	l	n Multiband	.15-2μ F1,3,7	6 bands G19	20% H1	45° I2	-	
												o	.15-2μ F1,3,6	6 bands G19	20% H2	45° I2	-	
												p	.5-2.5μ F4,7	6 bands G19	20% H2	45° I2	-	
Structure of Features	Mercury	1 km A6	800 km B6	10 km C6	100% D1	-	-	-	-	-	b,d,g,j,l	a Visible	5750Å F3	1000Å G2	20% H1	20° I1	S/C Altitude, Local Time	Vertical resolution same as horizontal
	Mars	1 km A6	1000 km B6	10 km C6	100% D1	-	-	-	-	-	c,e,h,j,l	b	5750Å F3	1000Å G2	20% H2	20° I1	S/C Altitude, Local Time	
6) (Regional)	Venus	1 km A6	2000 km B8	10 km C6	100% D1	-	-	-	-	-	j,l	c	6250Å F4	1000Å G2	20% H2	20° I1	S/C Altitude, Local Time	
	Jupiter	10 km A7	20000 km B11	200 km C10	5% D3	Global	-	-	-	-	k,m	d Visible Stereo	5750Å F3	1000Å G2	60% H3	80° I4	S/C Altitude	
												e	6250Å F4	1000A G2	60% H3	80° I4	S/C Altitude	
7) (Local)	Moon	100 m A5	100 km B4	1 km C4	100% D1	-	-	-	-	-	a,d,f,i,l	f Visible Color	5750Å F3	3 bands G4,17	20% H1	60° I3	S/C Altitude	
	Mercury	100 m A5	100 km B4	1 km C4	10% D2	See regional maps	-	-	-	-	b,d,g,j,l	g	5750Å F3	3 bands G4,17	20% H2	60° I3	S/C Altitude	
	Mars	100 m A5	100 km B4	1 km C4	10% D2	See regional maps	-	-	-	-	c,e,h,j,l	h	6250Å F4	3 bands G4,17	20% H2	60° I3	S/C Altitude	
	Venus	100 m A5	100 km B4	1 km C4	10% D2	See regional maps	-	-	-	-	j,l	i Radar	50 cm F18	-	20% H1	-	S/C Altitude	
												j	50 cm F18	-	20% H2	-	S/C Altitude	
8) (Detailed)	Moon	1 m A3	1 km B2	10 m C2	<1%	See local maps	-	-	-	-	a,d,f,i,l	k	1 m F21	-	20% H2	-	S/C Altitude	
	Mercury	1 m A3	1 km B2	10 m C2	<1%	See local maps	-	-	-	-	b,d,g,j,l	l Radar Stereo	50 cm F18	-	60% H3	-	S/C Altitude	
	Mars	1 m A3	1 km B2	10 m C2	<1%	See local maps	-	-	-	-	c,e,h,j,l	m	1 m F21	-	60% H3	-	S/C Altitude	
	Venus	1 m A3	1 km B2	10 m C2	<1%	See local maps	-	-	-	-	j,l							
Surface Topography	Mercury	1 km A6	800 km B6	1 km C12	100% D1	-	-	-	-	-	b,d,g,i							Vertical resolution: (Regional) - 1 km (J1) for all except Jupiter at 4 km (J2) (Local) - 50 m (J3) (Detailed) - 10 m (J4)
	Mars	1 km A6	1000 km B6	1 km C12	100% D1	-	-	-	-	-	c,e,g,i							
9)* (Regional)	Venus	1 km A6	2000 km B8	1 km C12	100% D1	-	-	-	-	-	g,i	a Visible	5750Å F3	1000Å G3	20% H1	20° I1	S/C Altitude, Local Time	
	Jupiter	10 km A7	20000 km B11	200 km C10	5% D3	Global	-	-	-	-	h,j	b	5750Å F3	1000Å G3	20% H2	20° I1	S/C Altitude, Local Time	
												c	6250Å F4	1000Å G3	20% H2	20° I1	S/C Altitude, Local Time	
10)* (Local)	Moon	100 m A5	100 km B4	100 m C3	100% D1	-	-	-	-	-	a,d,f,i	d Visible Stereo	5750Å F4	1000Å G3	60% H3	80° I4	S/C Altitude	
	Mercury	100 m A5	100 km B4	100 m C3	10% D2	See regional maps	-	-	-	-	b,d,g,i	e	6250A F4	1000A G3	60% H3	80° I4	S/C Altitude	
	Mars	100 m A5	100 km B4	100 m C3	10% D2	See regional maps	-	-	-	-	c,e,g,i	f Radar	50 cm F18	-	20% H1	-	S/C Altitude	
	Venus	100 m A5	100 km B4	100 m C3	10% D2	See regional maps	-	-	-	-	g,i	g	50 cm F18	-	20% H2	-	S/C Altitude	
												h	1 m F21	-	20% H2	-	S/C Altitude	
11)* (Detailed)	Moon	1 m A3	1 km B2	1 m C1	<1%	See local maps	-	-	-	-	a,d,f,i	i Radar Stereo	50 cm F18	-	60% H3	-	S/C Altitude	
	Mercury	1 m A3	1 km B2	1 m C1	<1%	See local maps	-	-	-	-	b,d,g,i	j	1 m F21	-	60% H3	-	S/C Altitude	
	Mars	1 m A3	1 km B2	1 m C1	<1%	See local maps	-	-	-	-	c,e,g,i							
	Venus	1 m A3	1 km B2	1 m C1	<1%	See local maps	-	-	-	-	g,i							
Surface Appearance	Mercury	1 km A6	800 km B6	10 km C6	100% D1	-	-	-	-	-	b,e,h							
	Mars	1 km A6	1000 km B6	10 km C6	100% D1	-	-	-	-	-	c,f,h							
12) (Regional)	Venus	1 km A6	2000 km B8	10 km C6	100% D1	-	-	-	-	-	h	a Visible	5750Å F3	1000Å G2	20% H1	20° I1	-	
	Jupiter	10 km A7	20000 km B11	200 km C10	5% D3	Global	-	-	-	-	i	b	5750Å F3	1000Å G2	20% H2	20° I1	-	
												c	6250Å F4	1000Å G2	20% H2	20° I1	-	
13) (Local)	Moon	100 m A5	100 km B4	1 km C4	100% D1	-	-	-	-	-	a,d,g	d Visible Color	5750Å F3	3 bands G4,17	20% H1	60° I3	-	
	Mercury	100 m A5	100 km B4	1 km C4	10% D2	See regional maps	-	-	-	-	b,e,h	e	5750Å F3	3 bands G4,17	20% H2	60° I3	-	
	Mars	100 m A5	100 km B4	1 km C4	10% D2	See regional maps	-	-	-	-	c,f,h	f	6250Å F4	3 bands G4,17	20% H2	60° I3	-	
	Venus	100 m A5	100 km B4	1 km C4	10% D2	See regional maps	-	-	-	-	h	g Radar	50 cm F18	-	20% H1	-	-	
												h	50 cm F18	-	20% H2	-	-	
14) (Detailed)	Moon	1 m A3	1 km B2	10 m C2	<1%	See local maps	-	-	-	-	a,d,g	i	1 m F21	-	20% H2	-	-	
	Mercury	1 m A3	1 km B2	10 m C2	<1%	See local maps	-	-	-	-	b,e,h							
	Mars	1 m A3	1 km B2	10 m C2	<1%	See local maps	-	-	-	-	c,f,h							
	Venus	1 m A3	1 km B2	10 m C2	<1%	See local maps	-	-	-	-	h							
15)Variable (Reg)	Mars	1 km A6	1000 km B6	10 km C6	10% D2	Mare and poles	5 min E6	100 hrs E11	1 day E13	.25 yr E16	a,b							
16)Surface (Local)	Mars	100 m A5	100 km B4	1 km C4	1% D4	Mare and poles	5 min E6	100 hrs E11	1 day E13	.25 yr E16	a,b	a Visible	6250Å F4	1000Å G2	20% H2	20° I1	-	
17)Appearance (Det)	Mars	1 m A3	1 km B2	10 m C2	<1%	Mare and poles	5 min E6	100 hrs E11	1 day E13	.25 yr E16	a,b	b Visible Color	6250Å F4	3 bands G4,17	20% H2	60° I3	-	
Surface Winds	Mercury	10 km A7	800 km B6	10 km C7	100% D1	-	10 sec E3	-	1 hr E9	.50 yr E17	a							
18)* (Regional)	Mars	10 km A7	1000 km B6	10 km C7	100% D1	-	10 sec E3	-	1 hr E9	.25 yr E16	b							
												a Visible	5750Å F3	1000Å G2	20% H2	45° I2	S/C Altitude, Local Time	
19)* (Local)	Mercury	100 m A5	100 km B4	1 km C4	1% D4	See regional maps	0.1 sec E2	-	1 min E8	-	a	b	6250A F4	1000Å G2	20% H2	45° I2	S/C Altitude, Local Time	
	Mars	100 m A5	100 km B4	1 km C4	1% D4	See regional maps	0.1 sec E2	-	1 min E8	-	b							
20)Topographic Changes	Moon	1 m A3	1 km B2	1 m C1	<1%	Determined by prior mapping	1 hr E7	-	-	300 hrs E12	a,d,f,i	a Visible	5750Å F3	1000Å G3	20% H1	20° I1	S/C Altitude, Local Time	Vertical Resolution All 10 m (J4)
	Mercury	1 m A3	1 km B2	1 m C1	<1%	Determined by prior mapping	1 hr E7	-	-	300 hrs E12	b,d,g,i	b	5750Å F3	1000Å G3	20% H2	20° I1	S/C Altitude, Local Time	
	Mars	1 m A3	1 km B2	1 m C1	<1%	Determined by prior mapping	1 hr E7	-	-	300 hrs E12	c,e,g,i	c	6250Å F4	1000Å G3	20% H2	20° I1	S/C Altitude, Local Time	
	Venus	1 m A3	1 km B2	1 m C1	<1%	Determined by prior mapping	1 hr E7	-	-	300 hrs E12	g,i	d Visible Stereo	5750Å F3	1000Å G3	60% H3	80° I4	S/C Altitude, Local Time	
	Jupiter	10 m A4	10 km B3	100 m C3	<1%	Determined by prior mapping	1 hr E7	-	-	300 hrs E12	h,j	e	6250Å F4	1000Å G3	60% H3	80° I4	S/C Altitude, Local Time	
												f Radar	50 cm F18	-	20% H1	-	S/C Altitude	
												g	50 cm F18	-	20% H2	-	S/C Altitude	
												h	1 m F21	-	20% H2	-	S/C Altitude	
												i Radar Stereo	50 cm F18	-	60% H3	-	S/C Altitude	
												j	1 m F21	-	60% H3	-	S/C Altitude	

*Measurements made on this observable may be applicable to engineering objectives.

Note: Values given in this table are nominal values. Lettered references (e.g.A7) refer to worth curves given in Volume I.

TABLE I. SUMMARY OF MEASUREMENT SPECIFICATIONS (Continued)

OBSERVABLE	PLANET	GROUND RESOLUTION	IMAGE SIZE	POSITIONAL ACCURACY	PLANETARY COVERAGE	PLANETARY DISTRIBUTION	ACQUISITION TIME		REPETITION RATE		SENSOR REFERENCE	SENSOR TYPE	SPECTRAL REGIONS	BANDWIDTH	OVERLAP	SUN ELEVATION	SUPPORT MEASUREMENTS	COMMENTS
							IMAGE	COVERAGE	IMAGE	COVERAGE								
Surface Thermal Anomalies **21) (Regional)**	Moon Mercury Mars Venus Jupiter	1 km A6 1 km A6 1 km A6 1 km A6 10 km A7	500 km B5 800 km B6 1000 km B6 2000 km B8 10000 km B10	10 km C6 10 km C6 10 km C6 10 km C6 100 km C9	100% D1 100% D1 100% D1 100% D1 100% D1	- - - - -	1 hr E7 1 hr E7 1 hr E7 1 hr E7 1 hr E7	- - - - -	10 hr E10 10 hr E10 10 hr E10 10 hr E10 10 hr E10	- - - - -	a,c,f b,d,g b,d,g d,h e	a IR b c Microwave d	50μ F12 50μ F12 50 cm F18 50 cm F18	10μ G9 10μ G9 10 cm G14 10 cm G14	20% H1 20% H2 20% H1 20% H2	- - - -	- - - -	**Desired Temperature Resolution:** **Moon 1°K** **Mercury 5°K** **Mars 2°K** **Venus 5°K** **Jupiter 2°K**
22) (Local)	Moon Mercury Mars Venus	100 m A5 100 m A5 100 m A5 100 m A5	100 km B4 100 km B4 100 km B4 100 km B4	1 km C4 1 km C4 1 km C4 1 km C4	5% D3 5% D3 5% D3 5% D3	See regional maps See regional maps See regional maps See regional maps	1 hr E7 1 hr E7 1 hr E7 1 hr E7	- - - -	10 hr E10 10 hr E10 10 hr E10 10 hr E10	- - - -	a,c,f b,d,g b,d,g d,h	e f Multiband g h	60 cm F20 3μ-100 cm F12,18 3μ-100 cm F12,18 3μ-100 cm F19	10 cm G13 4 bands G18 4 bands G18 3 bands G16	20% H2 20% H1 20% H2 20% H2	- - - -	- - - -	
23) (Detailed)	Moon Mercury Mars Venus	1 m A3 1 m A3 1 m A3 1 m A3	1 km B2 1 km B2 1 km B2 1 km B2	10 m C2 10 m C2 10 m C2 10 m C2	1% D4 <1% <1% <1%	See local maps See local maps See local maps See local maps	1 hr E7 1 hr E7 1 hr E7 1 hr E7	- - - -	10 hr E10 10 hr E10 10 hr E10 10 hr E10	- - - -	a,c,f b,d,g b,d,g d,h							
Atmos. Thermal Anomalies **24)* (Regional)**	Mars Venus Jupiter	10 km A7 10 km A7 10 km A7	1200 km B8 2000 km B9 20000 km B11	50 km C8 50 km C8 200 km C10	100% D1 100% D1 100% D1	Polar regions - Cloud belts, red spot	1 hr E7 1 hr E7 1 hr E7	- - -	 - -	.50 yr E17 .50 yr E17 .50 yr E17	a,b,d a,c,e a,c,e	a IR b Microwave c	20μ F11 5 mm F13 5 cm F15	6μ G7 10 mm G10 10 mm G10	20% H2 20% H2 20% H2	- - -	- - -	**Desired Temperature Resolution:** **Same as above**
25)* (Detailed)	Mars Venus Jupiter	1 km A6 1 km A6 1 km A6	100 km B4 200 km B4 2000 km B9	10 km C6 10 km C6 20 km C8	10% D2 10% D2 20% D2	See regional maps See regional maps See regional maps	1 hr E7 1 hr E7 1 hr E7	- - -	1 day E13 1 day E13 1 day E13	- - -	a,b,d a,c,e a,c,e	d Multiband e	3μ-10 mm F11,13 3μ-10 cm F11,15	4 bands G18 4 bands G18	20% H2 20% H2	- -	- -	
26) Global Cloud Coverage	Mars Venus Jupiter	10 km A7 10 km A7 10 km A7	1200 km B8 2000 km B9 20000 km B11	50 km C8 50 km C8 200 km C10	100% D1 100% D1 100% D1	Polar regions - -	15 min E6 15 min E6 2 min E8	1 day E13 100 hr E11 1 day E13	- - -	.05 yr E14 .10 yr E15 .10 yr E15	a,b,c,d,e a,b,c,d,e a,b,c,d,e	a UV b Visible (BW & color) c IR d IR e Multiband	3000A F2 5750A F3 1.5μ F6 24μ F11 .2-30μ F2,3,6,11	1000A G1 1000A G2 1μ G6 8μ G8 6 bands G19	20% H2 20% H2 20% H2 20% H2 20% H2	Day I6 Day I6 - - Day I8	- - - - -	
Convective Cells and Turbulence **27)* (Regional)**	Mars Venus Jupiter	10 km A7 10 km A7 10 km A7	1000 km B6 1000 km B6 10000 km B10	50 km C8 50 km C8 100 km C9	100% D1 100% D1 100% D1	Equatorial and polar areas Solar and anti-solar points Cloud belts, red spot	1 hr E7 1 hr E7 1 hr E7	- - -	- - -	.25 yr E16 .50 yr E17 .50 yr E17	a,b,c,d a,b,c,d,e,f a,b,c,d,e,f	a UV b Visible c IR	2500A F1 6250A F3 10μ F11	1000A G5 1000A G2 8μ G7	20% H2 20% H2 20% H2	Day I6 Day I6 -	- - -	
28)* (Detailed)	Mars Venus Jupiter	1 km A6 1 km A6 1 km A6	100 km B4 100 km B4 1000 km B8	5 km C5 5 km C5 10 km C6	20% D2 20% D2 20% D2	See regional maps See regional maps See regional maps	1 hr E7 1 hr E7 1 hr E7	- - -	1 day E13 100 hr E11 1 day E13	- - -	a,b,c,d a,b,c,d,e,f a,b,c,d,e,f	d e Microwave f	24μ F11 2 cm F16 6 cm F16	8μ G8 2 cm G11 6 cm G11	20% H2 20% H2 20% H2	- - -	- - -	
29)*Cloud Formation	Mars Venus Jupiter	1 km A6 1 km A6 10 km A7	1000 km B6 1000 km B6 10000 km B10	10 km C6 10 km C6 100 km C9	20% D2 20% D2 20% D2	Equatorial and polar areas Subsolar and polar areas Belts, red spot, tropics	1 min E5 1 min E5 10 sec E3	- - -	10 min E6 10 min E6 2 min E8	.25 yr E16 .25 yr E16 -	a,b,c,d,f a,b,c,d,f a,b,c,e,f	a UV b Visible (BW & color) c IR d e f Multiband	3000A F2 5750A F3 1.5μ F6 24μ F11 20μ F11 .2-30μ F2,3,6,11	1000A G1 1000A G2 1μ G6 10μ G8 10μ G8 6 bands G19	20% H2 20% H2 20% H2 20% H2 20% H2 20% H2	Day I6 Day I6 Day I6 - - Day I8	- - - - - -	
30)*Precipitation Rate	Mars Venus Jupiter	10 km A7 10 km A7 10 km A7	1000 km B6 1000 km B6 10000 km B10	50 km C8 50 km C8 100 km C9	100% D1 100% D1 100% D1	Wave of darkening and poles Equator, poles and mountains -	1 min E5 1 min E5 1 min E5	- - -	10 min E6 10 min E6 10 min E6	.25 yr E16 .25 yr E16 .25 yr E16	a b b	a Radar b	2.5 cm F14 5 cm F15	3 bands G17 3 bands G17	20% H2 20% H2	- -	- -	
Thunderstorms **31) (Regional)**	Mars Venus Jupiter	10 km A7 10 km A7 10 km A7	1000 km B6 1000 km B6 10000 km B10	50 km C8 50 km C8 100 km C9	100% D1 100% D1 100% D1	Equatorial and temperate zones - -	10 μsec E1 10 μsec E1 10 μsec E1	 - -	1 min E8 1 min E8 1 min E8	.10 yr E15 .10 yr E15 .10 yr E15	a a b	a Passive RF b	50 m F22 5 m F21	1 m G15 1 m G15	20% H2 20% H2	- -	- -	
32) (Detailed)	Mars Venus Jupiter	1 km A6 1 km A6 1 km A6	100 km B4 100 km B4 500 km B5	5 km C5 5 km C5 5 km C5	20% D2 20% D2 20% D2	See regional maps See regional maps See regional maps	10 μsec E1 10 μsec E1 10 μsec E1	- - -	1 min E8 1 min E8 1 min E8	.10 yr E15 .10 yr E15 .10 yr E15	a a b							
Cyclone Formations **33) (Regional)**	Mars Venus Jupiter	10 km A7 10 km A7 10 km A7	1000 km B6 1000 km B6 10000 km B10	50 km C8 50 km C8 100 km C9	100% D1 100% D1 100% D1	- Subsolar point Cloud belts, red spot	10 min E6 10 min E6 1 min E5	- - -	- - -	.25 yr E16 .25 yr E16 .25 yr E16	a,b,c,d a,b,c,d a,b,c,d	a Visible b IR c	5750A F3 1.5μ F6 24μ F11	1000A G2 1μ G6 10μ G8	20% H2 20% H2 20% H2	Day I6 Day I6 -	- - -	
34) (Detailed)	Mars Venus Jupiter	1 km A6 1 km A6 1 km A6	100 km B4 100 km B4 1000 km B6	10 km C6 10 km C6 10 km C6	20% D2 20% D2 20% D2	See regional maps See regional maps See regional maps	10 min E6 10 min E6 1 min E5	- - -	1 hr E9 1 hr E9 10 min E6	.25 yr E16 .25 yr E16 .25 yr E16	a,b,c,d a,b,c,d a,b,c,d	d Multiband	.2-30μ F3,6,11	6 bands G19	20% H2	Day I8	-	
35) Suface to Atmosphere Transfer	Moon Mercury Mars Venus Jupiter	1 km A6 1 km A6 1 km A6 10 km A7 10 km A7	500 km B5 500 km B5 200 km B4 1000 km B6 1000 km B6	10 km C6 10 km C6 10 km C6 50 km C8 100 km C9	100% D1 100% D1 100% D1 100% D1 100% D1	- - - - Red spot and tropical regions	1 min E5 1 min E5 1 min E5 1 min E5 1 min E5	1 day E13 1 day E13 1 day E13 100 hr E11 1 day E13	- - - - -	.10 yr E15 .10 yr E15 .05 yr E14 .10 yr E15 .10 yr E15	a,c b,d b,d,e e,f e,f	a Visible b c Vis. Color d e IR f Microwave	5750A F3 5750A F3 5750A F3 5750A F3 24μ F11 30 cm F17	1000A G2 1000A G2 3 bands G4,17 3 bands G4,17 8μ G8 10 cm G12	20% H1 20% H2 20% H1 20% H2 20% H2 20% H2	45° I2 45° I2 60° I3 60° I3 - -	- - - - - -	
36) Radio Bursts	Jupiter	100 km A8	50000 km B12	500 km C11	100% D1	Subsatellite pts. of satellites	1 msec E2	-	1 min E8	-	a	a Passive RF	50 m F22	3 bands G17	20% H2	-	Local Time	
37) Auroras	Mars Venus Jupiter	10 km A7 10 km A7 10 km A7	1000 km B6 1000 km B6 10000 km B10	50 km C8 50 km C8 100 km C9	100% D1 100% D1 100% D1	Polar regions Polar regions Polar regions	1 min E5 1 min E5 1 min E5	- - -	1 hr E9 20 hr E10 1 hr E9	.25 yr E16 .25 yr E16 .25 yr E16	a,b a,b a,b	a Visible b Vis. Color	5750A F3 5750A F3	1000A G2 3 bands G17	20% H2 20% H2	Night I7 Night I7	- -	
38) Animal Life	Mars Venus	20 cm A2 20 cm A2	400 m B1 400 m B1	100 m C3 100 m C3	- D5 - D5	Wave of darkening and poles Mountains and poles	1 sec E4 1 sec E4	- -	10 sec E5 10 sec E5	- -	a,b,c,d e,f	a Visible b Vis. Stereo c Vis. Color d Multiband e Radar f Radar Stereo	6250A F4 6250A F4 6250A F4 2.5μ F8 5 cm F15 5 cm F15	1000A G2 1000A G2 1000A G2 10 bands G20 - -	- 60% H3 - - - 60% H3	45° I2 80° I4 80° I3 45° I2 - -	- - - - - -	
39) Plant Life	Mars Venus	100 m A5 100 m A5	200 km B4 200 km B4	1 km C4 1 km C4	10% D2 10% D2	Wave of darkening and poles Mountains and poles	1 hr E7 1 hr E7	- -	- -	.25 yr E16 .25 yr E16	a,b,c d	a Visible b Vis. Color c Multiband d Radar	6250A F4 6250A F4 .5-5μ F8 5 cm F15	1000A G2 1000A G2 10 bands G20 -	- - - -	45° I2 60° I3 45° I2 -	- - - -	
40) Biochemical Systems	Mars Venus Jupiter	1 km A6 1 km A6 1 km A6	800 km B6 1000 km B6 2000 km B9	10 km C7 10 km C7 20 km C8	10% D2 10% D2 5% D3	Wave of darkening and poles Mountains and poles	1 hr E7 1 hr E7 1 hr E7	- - -	- - -	.25 yr E16 .25 yr E16 .25 yr E16	a b b	a Multiband b	.5-5μ F8 .5-5μ F8	10 bands G20 10 bands G20	20% H2 20% H2	45° I2 Day I6	- -	
41) Hydrocarbons	Moon Mercury Mars	1 km A6 1 km A6 1 km A6	500 km B5 800 km B6 800 km B6	10 km C7 10 km C7 10 km C7	10% D2 10% D2 10% D2	Global Global Global	- - -	- - -	- - -	- - -	a a b	a Multiband b	1-10μ F9 .5-10μ F10	10 bands G20 10 bands G20	- -	Day I6 Day I6	- -	

*Measurements made on this observable may be applicable to engineering objectives.

That is, requirements for regional, local, and detailed scale imagery have been carefully defined. The worth curves in Volume I indicate that at Mars, Venus, and Mercury, the regional scale imagery requires minimum scene areas from about 600 x 600 km to 1500 x 1500 km with ground resolutions ranging from three to 20 km. Because of Jupiter's size, regional scale imagery at that planet demands minimum scene areas from 5000 x 5000 km to 15000 x 15000 km and acceptable ground resolutions of 20 to 100 km. Local scale imagery at Mars, Venus, and Mercury implies scene areas of about 100 x 100 km with a ground resolution of 200 meters for surface phenomena and three km for atmospheric phenomena. Since the nature of Jupiter's "surface" is unknown, no requirements have been defined for surface imagery except on a regional scale. Local scale atmospheric imagery at Jupiter should view areas of at least 600 to 1500 km on a side with a resolution of about three km. Detailed scale imagery has been defined for Mars, Mercury, and Venus and involves scene areas of about 500 x 500 meters and resolutions of five meters or less.

Some types of surface imaging experiments must supply vertical height information, if the scientific requirements are to be achieved. In general, regional scale experiments are directed towards detection of one to three km height differences, local scale 100 to 200 meters, and detailed scale 50 meters. Thermal mapping experiments require detection of five deg K temperature differences at Venus and Mercury, and two deg K at Mars and Jupiter. The fractional amount of the planet's area which must be imaged depends on the scale of exploration. That is, regional scale experiments generally require at least 70 percent coverage, local scale about ten percent, and detailed scale one percent or less. Finally, since most atmospheric phenomena are dynamic, nearly all of the regional scale atmospheric imaging experiments require rapid coverage of large areas, and many of the atmospheric experiments require repetitive imagery. This can be performed on a short period basis to detect temporal variations, or on a long period basis to detect seasonal variations.

Table 1 also shows that more imaging experiments (159) have been defined for Mars than for any other target planet, and that one-third (53) of the Mars experiments utilize the visible portion of the spectrum. This is largely because both the surface and the atmosphere can be observed visually. Mars appears to have the greatest biological potential, and more life detection imaging experiments are suggested for Mars than for any other planet. Orbital imagery at Mercury and Venus is less useful than at Mars, in the sense that there are fewer phenomena to observe or fewer ways to observe them. Venus has a thick cloud cover prohibiting visual observation of the surface from orbit, hence visual imagery at Venus does not play the same role as at Mars (only 8 of 77 imaging experiments at Venus are visual experiments). Most of the Venus imaging experiments deal with atmospheric phenomena, although about one-third are radar surface imaging experiments. At Mercury (79 experiments), the emphasis is placed upon visual observation of surface phenomena (33 experiments), since Mercury appears to have no appreciable atmosphere. Fewer experiments have been defined for Jupiter and the Moon (57 and 59, respectively). At Jupiter, the cloud cover is presumed to prevent visual imaging of the surface from orbit. No local or detailed scale surface radar imaging experiments are defined at Jupiter, since a surface may not even exist. At the Moon, no atmospheric imaging experiments are proposed, and sufficient regional scale surface imagery has already been obtained.

4. ORBIT SELECTION

Many of the 400 measurements defined in Table 1 require similar operational conditions, and it was unnecessary (and unrealistic) to select 400 different orbits, one for each experiment. Rather, the experiments were sorted into operationally compatible families for each planet, and orbits were selected for each family of experiments. This does not imply that all the experiments in a single family have similar subsystem support requirements, nor that they should be performed simultaneously on the same mission.

For those experiment families requiring large amounts of planetary coverage (seventy percent or more), orbit selection was based on achievement of contiguous coverage obtained through orbital drift. That is, the orbit trace apparently drifts across the planet surface in an orderly fashion, providing sequential coverage in longitude and time. The desired drift rate is closely related to the minimum acceptable scene area per image and the minimum acceptable image overlap. Thus the experiments in each family tend to have similar measurement specifications with regard to minimum scene area, minimum image overlap, and solar illumination constraints. In general, the orbits selected at each planet provide the maximum planetary coverage in minimum time using an orbit drift rate consistent with the minimum scene area and image overlap. Orbits were selected in the same manner for experiment families demanding much less coverage (ten, or even one percent). The desired distribution of such coverage is unknown, and has been assumed to be distributed randomly over the entire planetary surface.

The orbit selection process (and typical arrival conditions at each planet) is described fully in Volume I. Each selected orbit is defined in Volume III-Orbit Selection and Definition. Conclusions resulting from examination of the orbits selected for experiment families at Mars, Venus, Mercury, and Jupiter are summarized below. These conclusions are valid only for orbits providing contiguous coverage as defined above. Orbits were not selected for the Moon because during 1975-1995 it is likely that lunar orbital missions will involve manned operations or be in support of manned (orbital and surface) missions.

At Mars, the coverage required for regional scale imagery (70 percent) can be obtained from orbit in three to ten days, provided there are no solar illumination constraints or simply daylight illumination is required. A minimum of about 330 days is necessary to achieve 70 percent coverage at solar zenith angles less than 20 degrees, as is desired for visual stereo imagery. Image interval times (the time interval between opportunities for observing a specific location on the planet) are normally restricted to less than a couple of minutes or greater than a couple of hours. Seasonal repetitions are easily achieved.

At Venus, 120 Earth days are required to obtain 70 percent coverage under daytime conditions, or if there are no solar illumination constraints. Most of the imaging experiments at Venus require only daylight illumination or are independent of the solar illumination. Therefore, regional scale coverage can be repeated at most twice a planetary year. It is difficult to provide image interval times greater than a few minutes and less than 1.5 hours.

At Mercury, 70 percent coverage can be achieved in 30 to 40 Earth days, provided there are no solar illumination constraints or at worst daylight constraints. The coverage can be repeated every 30 to 40 days. However, only 64 percent of the surface is illuminated at solar zenith angles less than 40 degrees, and only 34 percent at zenith angles less than 20 degrees. Only about half the available area can be covered by an inertial orbit, and two Mercury years (about 180 Earth days) are required to obtain this coverage. Therefore, completely satisfactory visual color or stereo imagery at regional scale (70 percent coverage) cannot be obtained at Mercury.

At Jupiter, the desired imaging experiments have no stringent solar illumination constraints. Complete, or nearly complete, planetary coverage can be obtained easily in about 20 to 40 Earth days. Virtually any image repetition rate can be provided by proper orbit selection.

5. IMAGER SCALING LAWS

The scaling laws resulting from this study are quantitative statements which relate an imaging system's capabilities to its characteristics. The scaling laws permit estimation of experiment support requirements, once the image specifications and orbit parameters have been defined. This functional relationship is portrayed in Figure 2.

Scaling laws were developed only for those types of imaging for which (1) a need exists (as expressed by the measurement definitions) and (2) adequate design experience was available. Unless the characteristics of a sensor system can be predicted over fairly wide ranges, scaling laws cannot be developed. Scaling laws were developed for visual, radar, infrared, ultraviolet, and passive microwave imagers.

The first step in obtaining scaling laws for a given type of imaging sensor was the collection and correlation of empirical data, in an attempt to relate the support requirements listed in Figure 2 to various characteristics of the sensor system. For example, the weight of a simple TV imaging system was found to be proportional to the diameter of the camera tube. Such empirical relations reflect the current state-of-art. Future capabilities must necessarily be speculative. In those few cases where sources of increased capability could be clearly foreseen, the presumed effect of state-of-art advances on the scaling laws were noted. If insufficient empirical data was available, or if no satisfactory empirical correlation between support requirements and the sensor characteristics was discovered, theoretical relations were developed.

The second step in obtaining scaling laws was to relate the important sensor system characteristics to measurement

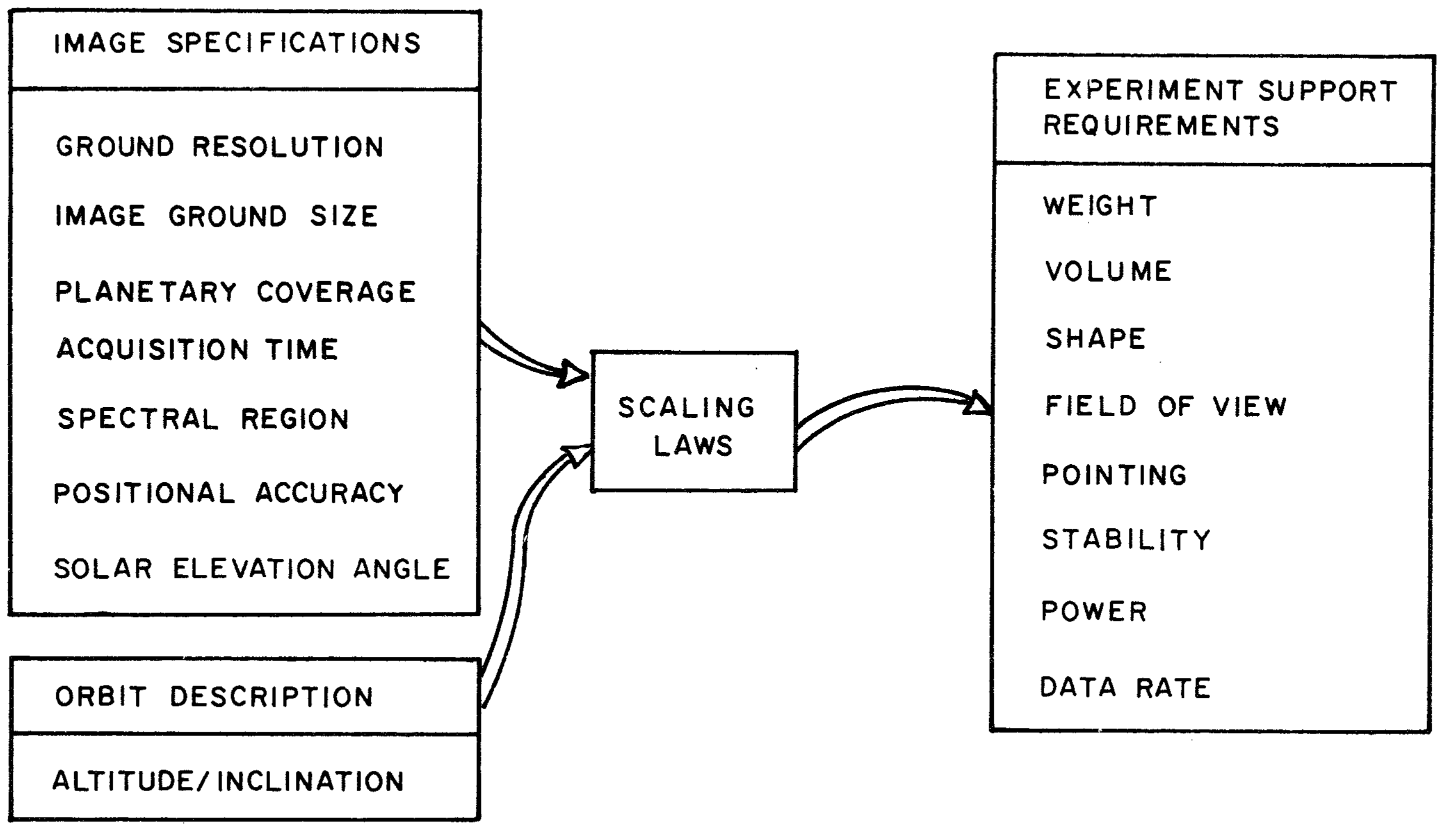

FIGURE 2. FUNCTION OF SCALING LAWS.

specifications and orbital parameters. Only in a few cases can the experiment support requirements be deduced directly from the measurement specifications and orbital parameters independently of the imaging system. That is, the first step in the analysis identified which sensor system characteristics determine the support requirements, the second step identified how those characteristics depend upon the measurement specifications and orbital parameters. For example, the weight of a simple TV imaging system depends upon the camera tube diameter, which in turn is related to the desired ground resolution, scene area, spacecraft altitude, and the TV line capability of the camera tube.

Finally, the scaling laws for each type of imaging system were organized in a manner which facilitates the estimation of support requirements, identifies the measurement specifications and orbital parameters which affect the support requirements, and delineates the sensor system variables which may be manipulated by the experiment designer. This systematic organization was expressed in a "logic diagram" for each imager type. Figure 3 shows, for example, a logic diagram for orbital TV imaging systems. Each box in the diagram represents a step in the system design, each balloon represents estimation of a support requirement. Figure 4 summarizes the scaling laws which are designed for use with the logic diagram. These figures are included here for illustrative purposes; a detailed explanation is given in Volume IV.

It should be emphasized that no artificial selection of sensor system variables was made in the analysis. For example, the exposure time selected for a TV system must be long enough to result in a satisfactory signal-to-noise ratio and must be short enough that motion of the system, or the imaged object, does not degrade the spatial resolution. These constraints are identified by the scaling laws and their method of employment, but no specific exposure time is implied by the scaling laws.

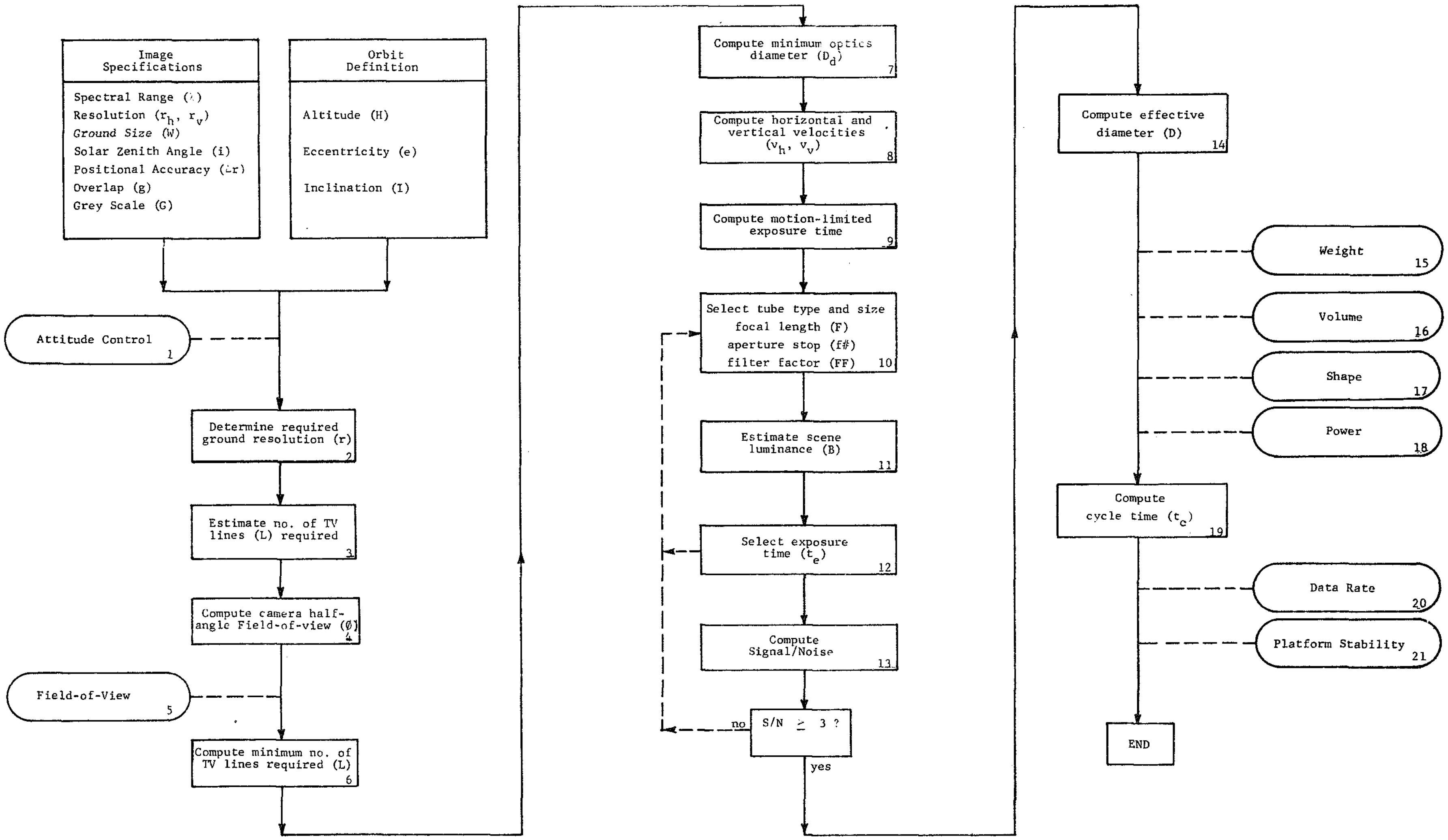

FIGURE 3. LOGIC DIAGRAM FOR TELEVISION SYSTEMS

$$\Delta\theta = \frac{\Delta r}{H}$$

①

If no vertical resolution required, $r = r_h$.
For shadow measurement, r is the smaller of $r_v \tan i$ or r_h.
For stereo, r is the smaller of $0.4 W r_v / H$ or r_h.

②

$$L \geq \frac{W}{0.7r}, \text{ but } L \leq 3400$$

③

$$\gamma = \frac{W}{2R}$$

If $\gamma < 0.1$, $\phi = \tan^{-1} \frac{W}{2H}$, otherwise

$$\phi = \cot^{-1}\left(\frac{R + H}{R \sin \gamma} - \cot \gamma\right)$$

④

FOV is 2ϕ by 2ϕ

⑤

$$L \geq \frac{W(r_\phi / r_0)}{0.7r}, \text{ but } \leq 3400, \text{ where}$$

$$\frac{r_\phi}{r_0} = \frac{R}{H} \cdot \left\{ \frac{\cos \phi}{\left[\left(\frac{R}{R+H}\right)^2 - \sin^2 \phi\right]^{\frac{1}{2}}} - 1 \right\}$$

which is given in Table 4-1.

⑥

$$D_d = \frac{1.83 \times 10^{-4} L}{\tan\phi} \text{ cm}$$

but limited to two meters.

⑦

$$a = R + \tfrac{1}{2}(H_p + H_a)$$

$$v_p = \frac{R}{R+H_p}\left[\mu \left(\frac{2}{R+H_p} - \frac{1}{a}\right)\right]^{\frac{1}{2}}$$

$$v_h = (v_p^2 + v_r^2 - 2 v_p v_r \cos I)^{\frac{1}{2}}$$

$$v_v = \left[\frac{\mu e^2}{a(1 - e^2)}\right]^{\frac{1}{2}}$$

Planet	R(km)	μ(km^3/sec^2)	v_r(km/sec)
Moon	1740	4.90×10^3	-
Mercury	2420	2.17×10^4	-
Venus	6100	3.25×10^5	-
Mars	3380	4.30×10^4	0.24
Jupiter	71350	1.27×10^8	12.7

⑧

$$t_e \leq \frac{r}{3(v_h + v_v \tan\phi)} \quad \text{w/o IMC}$$

$$t_e \leq \frac{r}{3(0.1 v_h + v_v \tan \phi)} \quad \text{w/ IMC}$$

⑨

Use Figure 4-8 to select tube type and size.
Image format size (*ℓ*) from Figure 4-9.

$$F = \frac{\ell}{2 \tan \phi} \text{ mm}$$

$$1 \leq f\# \leq \frac{F}{D_d}$$

Filter	FF
500mμ	3.7
Wratten 47 blue	3.3
Wratten 58 green	9.8
Wratten 25A red	27

⑩

$$B = f B_o$$

Planet	B_o	Zenith Angle (i)	f
Moon	1400	20°	0.49
Mercury	8300	40°	0.31
Venus	15,500	60°	0.15
Mars	800	75°	0.06
Jupiter	200		

Use f = cos i for Venus, Jupiter

⑪

$$t_e \geq \frac{4S(f\#)^2 \cdot FF}{\eta B}$$

See step #9 above, S given in lower right table.
Use η of 0.8 for zoom lens, 0.9 otherwise.

⑫

$$\frac{S}{N} = \frac{4.6 \times 10^5 M \ell}{L\,(f\#)\,k} \left(\frac{q \eta B t_e}{FF}\right)^{\frac{1}{2}}$$

⑬

$$D = \frac{F}{f\#}$$

limited to 2 meters

⑭

Weight is 16 lbs./ inch of TV tube diameter.

If IMC used, add 15 lbs.
If D > 10 cm, add $0.037D^2$ lbs, D in cm.
If zoom lens used, add $25 + 0.047\,D^2$ lbs, D in cm.

⑮

Volume is 560 cu in/inch of TV tube diameter
If IMC used, add 800 cu in.
If F > 20 cm, or D > 10 cm, add FD^2.
If zoom lens used, add 1000 cu in for altimeter.

⑯

TV tube length from Figure 4-15.
System length > tube length + F
System diameter > tube diameter or D.

⑰

Input power is 16 watts/inch of TV tube diameter.
If IMC used, add 15 watts.
If zoom lens used, add 10 watts.

⑱

$$t_c = \frac{W(1-g)}{v_h}$$

⑲

$$DR = \frac{GL^2}{t}$$

where $t = t_c - 0.1$ sec or 100 sec, whichever is smaller.
For 3 color filters, $t = \frac{1}{3} t_c - 0.1$ sec or 100 sec, whichever is smaller.

⑳

$$\dot{\theta} = \frac{r}{3 t_e W}$$

$$\dot{\phi} = \frac{r}{6 t_e H} \quad \text{w/o IMC}$$

$$\dot{\phi} = \frac{r}{0.6 t_e H} \quad \text{w/ IMC}$$

㉑

NOMENCLATURE

a-orbit semi-major axis, km
B-scene luminance, ft-lambert
D-optics diameter (F/f#), cm
D_d-minimum optics diameter, cm
DR-data acquisition rate, bits/sec
e-orbit eccentricity
f-scene photometric function
f#-optics aperture stop (f-number)
F-focal length, cm
FF-filter factor
FOV-field-of-view
g-fractional overlap along orbit
G-bits per resolutuion element (normally 6)
H-camera altitude, km
H_a-orbit apoapse altitude, km
H_p-orbit periapse altitude,km
i-solar zenith angle
I-orbit inclination
k-number of grey *levels (normally 64)*
ℓ-image format size, mm
L-number of TV lines
M-maximum density difference
q-quantum efficiency
r-desired ground resolution, km
r_h-desired horizontal resolution, km
r_v-desired vertical resolution, km
R-planet radius, km
S-min. tube illumination, ft-candle-sec
S/N-signal-to-noise ratio
t_c-camera cycle time, sec
t_e-exposure time, sec
v_h-apparent horizontal speed, km/sec
v_p-camera ground speed at periapse, km/sec
v_r-planet equatorial rotation speed, km/sec
v_v-camera vertical speed, km/sec
W-image width (length) on ground, km
γ-image half-angle subtended at planet center
Δr-desired image ground positional accuracy, km
$\Delta\theta$-allowable camera pointing error, radians
η-optical system transmission factor
$\dot{\theta}$-allowable camera yaw rate, rad/sec
λ-wavelength
μ-planet gravitational constant, km^3/sec^2
ϕ-camera half-angle field-of-view
$\dot{\phi}$-allowable camera pitch or roll rate, rad/sec

Tube type	S(ft-candle-sec)	M	q
Vidicon	3×10^{-3}	2.0	0.2
Plumbicon	2×10^{-3}	2.3	0.2
RBV	1×10^{-3}	2.0	0.2
SEC	5×10^{-5}	1.8	0.3
Image Orthicon	2×10^{-6}	2.0	0.3

FIGURE 4. SCALING LAWS FOR TELEVISION SYSTEMS

Such freedom of choice may be used by the experiment designer to effect tradeoffs between the support requirements. The performance of such tradeoffs was beyond the scope of the study, and hence the experiment support requirements actually estimated must be regarded as representative, not optimum or minimized.

A complete derivation of scaling laws for ultraviolet, visual (TV and film), infrared scanning, passive microwave, and radar systems is provided in Volume IV-Imaging Sensor System Scaling Laws. Scaling laws for infrared television systems are presented in a classified appendix to Volume IV.

6. EXPERIMENT SUPPORT REQUIREMENTS

Once the measurement specifications were defined, and an orbit selected for achievement of the measurements, subsystem support requirements were estimated for imaging experiments at Mars, Venus, Mercury, and Jupiter using the sensor system scaling laws. Each experiment consists of a specific imaging system operating in a specific mode providing imaging data to achieve a specific objective. Thus the experiment support requirements represent a synthesis of exploration objectives, orbital mechanics, and sensor system design.

In general, the estimated support requirements are sensitive to the orbital parameters, the imaging system design, and, of course, the scientific requirements. For each experiment, the support requirements reflect minimal achievement of the scientific objective (with due regard to orbital mechanics constraints) as defined by the worth curves associated with the measurement specifications. Different support requirements may be obtained by selecting a different orbit, or by changing the design of the sensor system. If such changes are skillfully made, the measurement achievement need not suffer. No attempt was made in this study to define explicitly the limits of support requirement flexibility for each experiment. Therefore the support requirements obtained must be regarded as representative of requirements demanded in an actual mission. In some individual cases, similar experiments were compared with one another as a test of representativeness.

The following paragraphs summarize, in gross terms, the experiment support requirements of orbital imagery as might be used in unmanned planetary exploration. Only the weight, average power, and peak data acquisition rate requirements are emphasized here. Additional support requirements for individual experiments are tabulated in Volume V-Support Requirements for Planetary Orbital Imaging. The support requirements quoted here, and in Volume V, are based upon imaging system capabilities consistent with the current or near-future state-of-art. Some speculation on likely advances in the state-of-art have been provided in Volume IV, but the support requirements summarized here do not reflect these speculations.

All the visual imaging experiments suggested by the study employ imaging systems which are within reach of the current state-of-art, except for those few experiments which require ground resolutions of less than five meters. In fact, it appears that ground resolutions on the order of one meter are not currently feasible with any type of orbital imaging system. Most of the atmospheric imaging experiments at Mars and Venus can be performed by one-half-inch vidicon systems each weighing eight pounds, consuming eight watts of power (average), and acquiring data at a rate of 25,000 bits/sec, or less, assuming six binary bits per resolution element. At Jupiter, high imaging altitudes and elliptic orbits require a two-inch RBV (return beam vidicon) system using about 30 watts of power and a data rate of 4×10^5 bits/sec. For 20 km ground resolution, the system weighs about 50 pounds, but for 3 km ground resolution, the system grows to 300 pounds because of the large optical subsystem required. Support requirements for surface imagery at Mars and Mercury are 15-30 pounds, 15-30 watts, 5,000-500,000 bits/sec for regional scale imagery; 30-60 pounds, 30-100 watts, 10^6-10^7 bits/sec for local scale imagery; and 300-500 pounds, 30-300 watts, 10^7-10^8 bits/sec for detailed scale imagery.

Orbital radar imaging experiments are not feasible at Jupiter, at least from the orbital altitudes considered here, and enormous amounts of power are required. At Mars, Venus, and Mercury, the weight, average power, and peak data acquisition rates are 200-300 pounds, 300-500 watts, about 10,000 bits/sec for regional scale imagery; 300-400 pounds, 200-300 watts, 10^5-10^6 bits/sec for local scale imagery; and about 1000 pounds, 1000 watts, and 10^6 bits/sec for detailed scale imagery. Ground resolutions of less than five meters are not feasible.

Except at Jupiter, all the atmospheric infrared imaging experiments can be performed by scanning systems weighing two to six pounds, consuming about two watts of power, and collecting data at a peak rate of less than 7,000 bits/sec. Regional scale surface imagery at Mars and Mercury requires 2-10 pounds, about five watts, and less than 15,000 bits/sec, while local scale surface imagery requires 50-100 pounds, 5-30 watts, and about 10^6 bits/sec. Detailed scale imagery and atmospheric imagery at Jupiter do not appear to be feasible.

Surface passive microwave imagery from orbit is feasible only at Mars and Mercury, and then only for regional scale imagery. A typical imaging system is estimated to weigh about 500 pounds, consume 100 watts of power, and collect about 2000 data bits/sec. Atmospheric imaging experiments are applicable only to Venus and Jupiter. At Venus the atmospheric experiments require 20-100 pounds, 20-80 watts, and 200-2,000 bits/sec. At Jupiter the experiments desired are not feasible.

Ultraviolet scanning systems can be used at Mars, Venus, and Mercury. For three km ground resolution, a typical system weighs about two pounds, consumes only one watt of power, and collects data at rates from 2,000 to 250,000 bits/sec, depending upon the orbit. A ground resolution of 200 meters can be achieved by a 50 pound system with a 10^6 bit/sec data rate and one watt average power.

Multispectral scanning systems are likely to be very useful at Mars, Venus, and Mercury. Support requirements for such systems will be similar to those for infrared scanning systems, although the data acquisition rates will depend upon the number of spectral channels required. Multifrequency radar systems might be useful at Mars and Venus, especially for study of atmospheric precipitation. The support requirements are likely to be somewhat more demanding than for monochromatic radar systems. Passive radiofrequency imaging systems would be especially useful at Jupiter, but the design of such systems is so speculative that scaling laws have not been derived during this study.

One of the more important tradeoffs found common to all the imaging systems studied is that imagery obtained from an elliptic orbit over any significant altitude range results in increased weight, power, and data acquisition rates as compared to use of a constant, or nearly constant, imaging altitude. Thus experiment support requirements can frequently be traded off against the velocity change of the orbit capture maneuver and the mission duration required to achieve the desired amount of planetary coverage.