Space Station Orbit Selection

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This paper presents a review of the techniques, considerations, and parametric flight mechanics data developed recently for the Space Station Phase B study to improve orbit selection. Typical experiment requirements for an Earth orbital Space Station mission are described and operational guidelines defined. These requirements were postulated based on the Space Station Phase B Experiment Program summary and were amplified by Skylab and other current reference data which proposed various ground truth sites, sensors, film resolution, ground swaths, etc. Starting with these requirements, the orbit selection techniques are then used to illustrate how an acceptable orbit regime is selected for a preliminary design. The concepts and objectives described within this paper reflect the opinion of the author and do not necessarily constitute endorsement by the NASA or any other U.S. Government organization.

Introduction

THERE are many considerations involved in the final selection of an operational orbit (or orbit maneuvering schedule) for a manned Space Station. Some of the considerations relate to orbital behavior in the form of ground coverage sensitivity and its associated performance in providing Earth viewing coverage, and frequency of observations, to an orbital experiment program. Other considerations relate to orbital behavior in the form of operational functions such as rendezvous and communications/observations opportunities which directly affect the total system design of the Space Station.

Orbit Behavior

The behavior or performance of potential orbits as they relate to satisfying various Earth viewing requirements can best be determined by evaluating their ground coverage sensitivity. The nature, extent and frequency of ground coverage of features of the Earth's surface are best evaluated by examining a candidate orbit's trace pattern. The trace pattern describes the locus of subsatellite points generated on the surface of the rotating Earth by the satellite in the course of its orbital motion.

The ratio (N/M) of Number of nodal orbits per revolution of the Earth (relative to the Orbit Plane) was established as a useful design tool for evaluating traces. This ratio was expressed as the "satellite trace repetition parameter," using the term Q, in Ref. 1. The equation is straightforward:

$$Q = N/M = 360°/\Delta\lambda_0 = 360°/(\omega_E - \dot{\Omega})\tau_n$$

where N = number of nodal revolutions; M = number of Earth rotations relative to the orbit plane; $\Delta\lambda_0$ = longitudinal shift along the equator per nodal revolution (deg); ω_E = Earth rotation rate (0.2507 deg/min); $\dot{\Omega}$ = nodal regression rate (deg/min); and τ_n = nodal period (minutes).

The reader is referred to Ref. 1 for a more detailed explanation of satellite repetition parameter and trace pattern development. The satellite repetition parameter sensitivity with altitude is shown in Fig. 1 for orbit inclinations of 50° and 55°.

The satellite trace repetition parameter "tells" how long it will take for an orbit to complete its cycle and return to an arbitrary starting point [e.g., directly overhead Kennedy Space Center (KSC)]. It also defines how close the ground tracks will appear to each other (and how fine a mapping coverage separation is available) in this cycle. To illustrate the interpretation of the values of this design tool, some typical cases for a 50° inclination are shown.

The Q value of 15.25 ($15\frac{1}{4}$ nodal orbits per "day") can be read from Fig. 1 at a 50° inclination and 229 naut miles altitude. The lowest integers of N "orbits" and M "days" whose ratio equals the 15.25 value are then the number of orbits and days necessary to complete the orbit's coverage or repeatibility cycle. In the 229 naut miles case, the lowest integers are $N = 61$ and $M = 4$ or every 4 days. When $Q = 15\frac{1}{4}$, expressed with a fractional remainder, the fraction indicates the amount of the daily ground track shift (e.g., $\frac{1}{4}$ of the separation between two successive orbits) and the denominator indicates the days required for the orbit to repeat (e.g., 4 days.

The trace behavior of some orbits allows for a resupply vehicle to be launched and then to arrive within close proximity to the target vehicle (i.e., the second flight's terminal location exactly matches the first's). Such orbits are called Rendezvous Compatible Orbits (RCO). Their ground trace behavior allows certain Earth truth sites to be directly overflown every M days. These days are not 24-hr periods because the orbits are precessing (KSC encounters the orbit

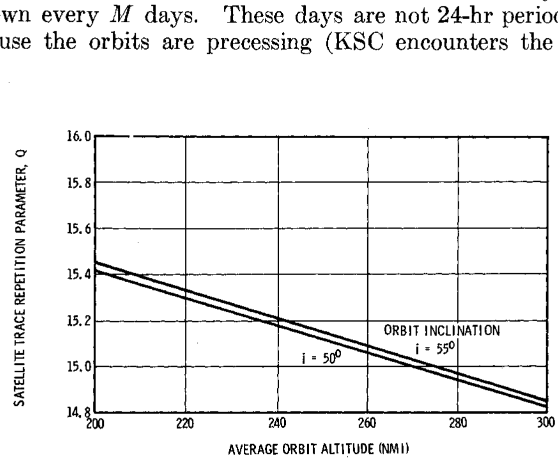

Fig. 1 Satellite trace repetition parameter (50° and 55° inclination).

Presented as Paper 70-1063 at the AAS/AIAA Astrodynamics Conference, Santa Barbara, Calif., August 19–21, 1970; submitted October 9, 1970; revision received March 31, 1971. The work described in this paper has been conducted under the sponsorship of NASA under Contract NAS8-25140.

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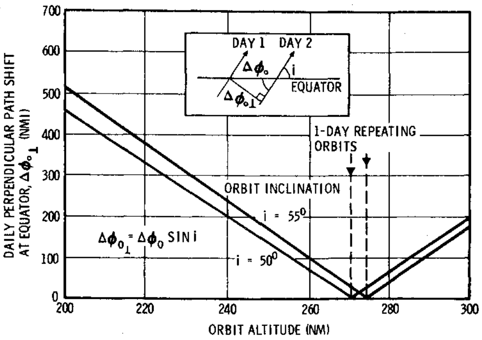

Fig. 2 Daily ground track separation.

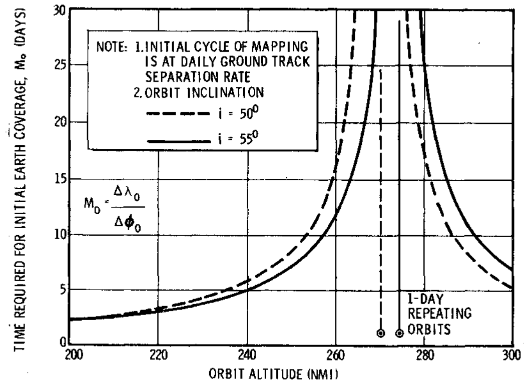

Fig. 5 Time to complete initial cycle of total Earth mapping.

plane earlier on each succeeding day). The RCO altitudes for 1–6 days are listed in Table 1 for 50° and 55° inclinations for illustration.

The longitudinal separation of adjacent ground traces of the N orbits provides the final measure of how fine a ground coverage is obtained. This separation distance can be estimated using the following equations:

$$\Delta\lambda' = \Delta\lambda_0/M, \quad \Delta\lambda_\perp' = \Delta\lambda' \sin i$$

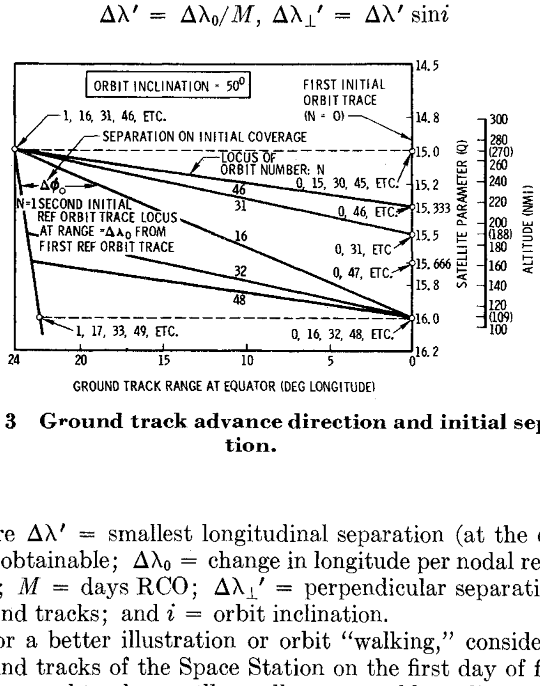

Fig. 3 Ground track advance direction and initial separation.

where $\Delta\lambda'$ = smallest longitudinal separation (at the equator) obtainable; $\Delta\lambda_0$ = change in longitude per nodal revolution; M = days RCO; $\Delta\lambda_\perp'$ = perpendicular separation of ground tracks; and i = orbit inclination.

For a better illustration or orbit "walking," consider the ground tracks of the Space Station on the first day of flight. The ground tracks are all equally separated by a distance $\Delta\lambda_0$

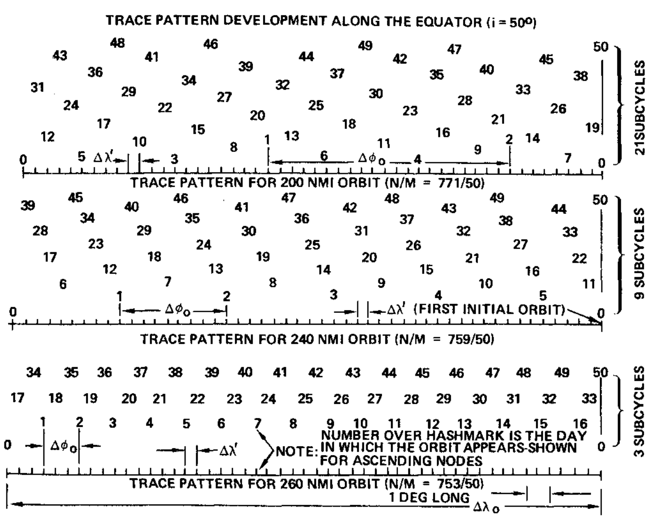

Fig. 4 Trace pattern development along the equator.

(e.g., 1424 naut miles as shown in Fig. 13) along the equator on this first day. On the next day, and when an orbit (ascending node) ground track appears between these two initial bordering tracks, its separation from the closest bordering track establishes the daily longitudinal walk direction and distance. This daily rate or first subcycle establishes how fine an orbital coverage is obtained on the first pass. Because the orbit may not exactly repeat (directly overfly the initial bordering tracks) at the end of the first pass, subsequent (second, third, etc.) cycles are initiated until the orbit finally appears to repeat after M days. The fineness of the ground coverage obtained after these M days is $\Delta\lambda'$, whose value is the simple ratio $(\Delta\lambda_0/M)$ which is valid because of the symmetry with which the orbit traces fully develop. This symmetry of the M final adjacent tracks (equally spaced) is shown (see Fig. 4) and discussed in the remainder of this section.

The effect of altitude on the behavior of an orbit can be related to its daily longitudinal path shift at the equator. Figure 2 shows the sensitivity of altitude to the daily perpendicular path shift $(\Delta\phi_{0\perp})$ which is the shift along the equator reduced by the sine of the orbit inclination. This perpendicular distance is presented here as a reference for mapping rate and separation distance. In using the orbit mechanics data, it is more convenient to use longitudinal and nodal travel measurements and the (Sine i) multiplication must always be made for establishing the true mapping separation.

The coverage direction and separation distance for the "initial coverage" subcycle (the daily path shift) is illustrated in Fig. 3 for 50° orbits. This figure shows the orbital altitude effect on the locus of the 16th orbit (on the second day) as it varies a distance $(\Delta\phi_0)$ from the nearest initial reference trace. At 270 naut miles altitude (Q = 15) the 16th orbit trace is located 23.98° (along the equator) beyond the first trace (and exactly on the second trace) and at 109 naut miles (Q = 16) is 0° (exactly on) the first trace. Figure 3 is meant to illustrate the placement behavior of the first, second, and third orbits whose tracks appear between two initial reference ground tracks (e.g., orbit number 0 and 1 on the first day).

Table 1 RCO orbits

M days RCO	Q	Altitude, naut miles $i = 50°$	Altitude, naut miles $i = 55°$
1	15, 16	270, 109	274, 113
2	$15\frac{1}{2}$	188	191
3	$15\frac{1}{3}, 15\frac{2}{3}$	214, 161	219, 164
4	$15\frac{1}{4}, 15\frac{3}{4}$	229, 148	233, 152
5	$15\frac{1}{5}, 15\frac{2}{5}$	237, 203	241, 208
	$15\frac{3}{5}, 15\frac{4}{5}$	171, 140	176, 144
6	$15\frac{1}{6}, 15\frac{5}{6}$	242, 134	247, 139

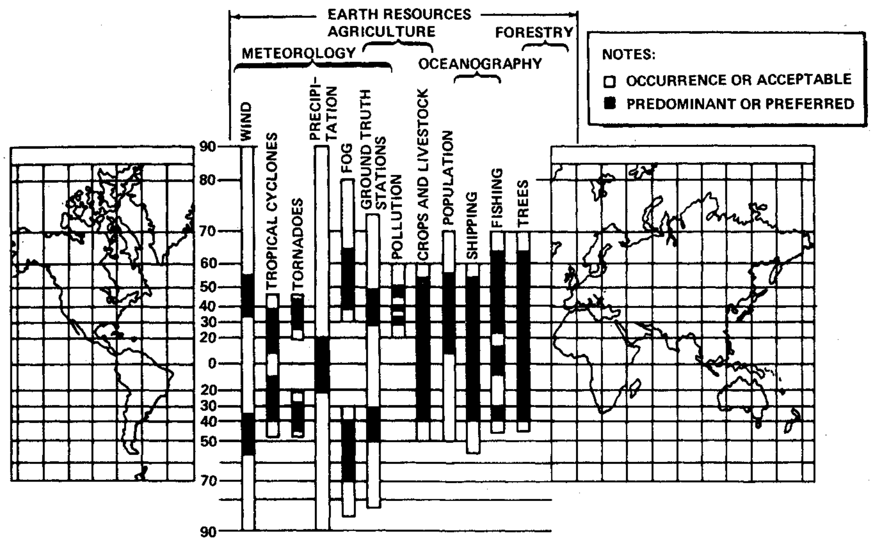

Fig. 6 Earth resources distribution.

Table 2 shows three altitudes (200, 240 and 260 naut miles) at a 50° inclination where the coverage cycle repeats approximately every 50 days. The trace pattern development for these orbits is shown in Fig. 4. Close inspection of this pattern development will show the behavior characteristics of these orbits as summarized in Table 2.

The numbers over the "hashmarks" of the orbit traces in Fig. 4 indicate the orbit overfly position (ascending nodes only) on the *n*th day which appear within the initial interval ($\Delta\lambda_0$). Since the initial traces are shown as day 0 the 50-day RCO is obtained 50 days (or appearances) after the initial traces. The term M_0 in Table 2 is the time to complete the initial coverage (or to sweep across $\Delta\lambda_0$ at the $\Delta\phi_0$ daily rate and spacing). This is shown in Fig. 5. Figures 2 and 5 together, yield both the initial spacing and the time required to obtain initial Earth coverage at the daily shift rate. The term M_1 in Table 2 is the time required to complete the initial mapping of total Earth coverage (within visible latitudes) down to a specified level, which in this example was a 200 × 200 naut miles area ground swath (with or without excess overlap). M_1 was interpolated from Fig. 4.

Space Station Experiment Requirements

The recommended baseline experiments program (Refs. 2 and 3) requirements can all be satisfied (to a varying degree) within the Space Station study orbit envelope of 200 to 300 naut miles and 28.5° to 55° inclination. Earth surveys were determined to be the orbit selection driver since their requirements overlap the others and providing a satisfactory orbit for them would be acceptable to the rest. The altitude choice will also affect Earth surveys the most, due to the nature of the ground coverage rate differences with altitude.

The distribution of 12 typical Earth resources with Earth latitude is shown in Fig. 6. A cumulative distribution of these Earth resources covered by various orbit inclinations is illustrated in Fig. 7. This cumulative plot indicates that a 30° orbit contains about 42% and a 55° orbit contains 84% (twice the 30° coverage) of the resources considered.

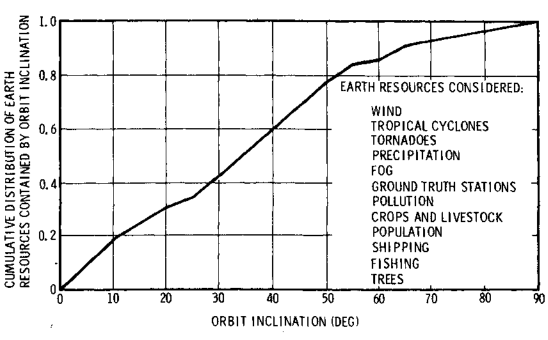

Fig. 7 Cumulative distribution of typical Earth resources with inclination.

The effect of orbital inclination on the percent of an orbit exceeding or conversely lying between latitude regions is shown in Fig. 8. Some Earth phenomena are indicated on

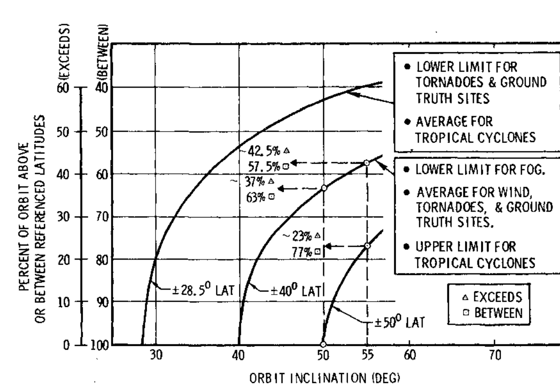

Fig. 8 Percent of orbit at various latitudes.

this figure as they occur between the referenced latitude regions. As indicated, the percent of an orbit exceeding a ±40° latitude region is 37% for a 50° orbit and 42.5% for a 55° orbit inclination. This sensitivity is more pronounced near higher latitudes where, for example, regions above ±50° latitude are covered 23% of the time by an orbit at a 55° inclination and not at all if the orbit is inclined at 50°.

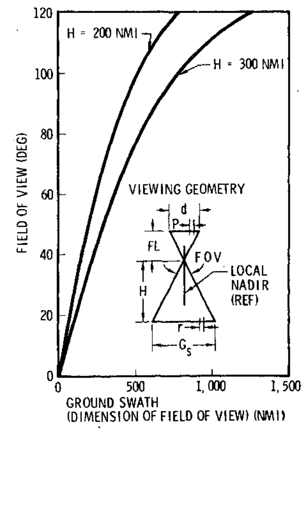

Fig. 9 Ground swath viewing geometry: where H = altitude measured at local nadir; FOV = field-of-view; G_S = ground swath (diam); r = ground resolution, FL = lens focal length; d = dimension of sensitive surface; P = dimension of 1 line pair; $H/FL = G_S/d$; and $d/P = G_S/r$.

Table 2 Trace pattern development characteristics at 50° inclination

Altitude, naut miles	$\Delta\lambda_0$ deg	$\Delta\lambda_0$ naut miles	Q	M, days	$\Delta\lambda'$ deg	$\Delta\lambda'$ naut miles	$\Delta\phi_0$ deg	$\Delta\phi_0$ naut miles	$\Delta\phi_{0\perp}$, naut miles	M_0, days	Number of subcycles	M_1 1st total coverage, days[a]	Lens angle field-of-view, deg[a]
200	23.23	1400	$15.42 = 15\frac{21}{50}$	50	0.46	28	9.9	594	455	2.3	21	6	53
240	23.7	1422	$15.18 = 15\frac{9}{50}$	50	0.47	29	4.4	261	200	5.4	9	5	45
260	23.89	1434	$15.06 = 15\frac{3}{50}$	50	0.48	29	1.4	86	66	16.6	3	14	42

[a] Referenced to a 200 x 200 naut miles area ground swath.

Table 3 Candidate sensor field-of-view

	Candidate sensors	Typical field-of-view, deg
1	Metric camera	70
2	Multispectral camera	41
3	Multispectral IR scanner	20
4	IR interferometer spectrometer	3
5	IR atmospheric sounder	12.5
6	IR spectrometer/radiometer	0.2
7	MW scanner radiometer	100
8	Multifrequency MW radiometer	120
9	MW atmospheric sounder	120
10	Radar imager	8.6
11	Active-passive MW radiometer	10
12	Visible wavelength polarimeter	3
13	VHF sferics	120
14	Absorption spectrometer	1 for spect., 18 for imager
15	Laser altimeter	6×10^{-8} steradian
16	UV imager/spectrometer	1 for spect., 15 for imager
17	Photo-imaging camera	Less than 16
18	Radar altimeter/scatterometer	1
19	Data collection	20

Earth Viewing Requirements

The Earth surveys will employ many of the sensors contained in the NASA Candidate Experiment Program (Blue Book). Typical fields-of-view of these sensors are shown in Table 3. The effect of sensor field-of-view on ground swath width is illustrated in Fig. 9 for two altitudes. Viewing geometry and resolution/focal length, etc., relationships are also indicated.

The Earth viewing requirements of the Skylab program were reviewed and the scientific disciplines of that program have been related to experiment objectives and ground truth sites. Table 4 presents these relationships and identifies the instruments to be utilized in meeting these objectives. Representative ground swaths for these instruments were estimated based on fields-of-view and ground resolution limitations for these sensors and are included in Table 4. The ground truth targets for the U.S. zone of interior reach to 49°N latitude. Total coverage of the U.S. is generally desirable from the multisensor test viewpoint because this provides a broader geographical base for ground truth data correlation. The altitude preferences of some of the Skylab ex-

Table 4 Proposed skylab Earth viewing requirements

Scientific discipline	Experiment objective/application	Proposed Ground truth site	Sensor to be utilized	Coverage, naut miles
Agriculture	Map extensive farm areas and identify large area crops Measure large distressed crop areas	Central Calif. Central Grain Belt Texas Corn Belt	6-in. camera Multispec camera IR scanner IR spect (0.4 to 2.5μ)	350 × 350 200 × 200 100 × 100 150 × 150
Forestry	Map heavily forested areas and identify major tree types Measure forest fire and burned areas	Sierra, Nevada Pacific N.W. East Texas So. Michigan	6-in. camera Multispec camera IR scanner IR spect (0.4 to 2.5μ)	350 × 350 200 × 200 100 × 100 150 × 150
Geography	Compile/revise topographic maps of the world Prepare thermatic land use maps including US test sites	No. Illinois, Michigan & Indiana, E. Tenn., N. Georgia, & Carolinas So. Calif. & Nevada	6-in. camera Multispec camera	350 × 350 200 × 200
Geology	Map geologic features over wide areas (faults, folds, earthquake belts, etc.) Rock types Map thermal anomalies	San Andreas Fault Mt. Lassen Arizona Copper Belt So. W. Volcanic Basin Yellowstone Park	6-in. camera Multispec camera IR scanner IR spect (5 to 22μ) Imaging radar	350 × 350 200 × 200 100 × 100 10 × 10 40 × 40
Hydrology	Correlation of geomorphology and stream flow Snowfield and glacier inventory Surface temperature and diffusion patterns of lakes Soil moisture measurements	Everglades So. Cascade Glacier Colorado River Basin Imperial Valley Weslaco, Texas	Metric camera Multispec camera IR scanner	150 × 150 200 × 200 100 × 100
Meteorology	Surface mapping thru cloud cover Atmosphere sounding thru cloud cover Thunderstorm detection and mapping Surface mapping with IR Atmosphere sounding with IR	All weather reporting stations	IR scanner IR spect (5 to 22μ) MW scanner MW radiometer UHF sferics Day-night camera Dielectric tape IR profile radio	100 × 100 10 × 10 170 × 170 650 × 650 1000 × 1000 100 × 100 100 × 500 3 × 3
Oceanography	Hydrographic charting River discharge and sediment patterns Sea state measurements Sea surface temperature measurements	North Atlantic (Argus Island) Gulf of Mexico Pacific (Scripps) Mississippi River Delta Florida Straits	6-in. camera IR scanner Multispec camera IR spect (5 to 22μ) IR radiometer Scatterometer MW radiometer MW scanner	350 × 350 100 × 100 200 × 200 10 × 10 1 × 1 80 × 80 650 × 650 170 × 170

periments were evaluated and found to be often conflicting as illustrated in Fig. 10. The number of experiments "satisfied" at any altitude is also indicated on this figure and shows that the most preferred region was between 125 and 150 naut miles with less experiments satisfied with increased altitude.

The Earth viewing requirements of a representative summary of Earth survey experiments were synthesized using data from Ref. 4. This summary is presented in Table 5. Several important characteristics should be pointed out concerning these requirements for the purposes of using the data to support the orbit selection analysis; as such, each column is explained below.

1) Preferred latitude coverage. Desired latitude coverage ranges from ±45° to ±90° latitude, with many users re-

Table 5 Representative summary of Earth viewing requirements[c]

Earth viewing tasks	Preferred latitude coverage, ± deg	Nominal solar illumination angle,[a] deg	Minimum[b] elevation angle,[a] deg	Sensors to be utilized	Frequency of observations (once per)	Duration	Desired ground area coverage, stat. mi.
Agriculture/forestry							
Land use survey	60	30 to 90	45	Oc, IRr	5 yr	N/C	100 × 100
Soil survey	50	30 to 90	45	Oc, IRr	5–10 yr	N/C	100 × 100
Rangeland survey	50	60 to 90	35	Oc, IRr	6 months	4–8 weeks	50 × 50 min
Crop identification	47	60 to 90	45	Oc, MSOr	14 days	6–30 days	25 × 25
World timber inventory	70	60 to 90	45	Oc, MSOr	5 yr	N/C	100 × 100
Forest fire detection	50	N/C	30	IRr	1 day	1–6 hrs	50 × 50
Timber inventory	70	60 to 90	45	O	5 yr	Spring	100 × 100
Atmospheric sciences							
Cloud observation (day & night)	90	45 to 90	45 to 55	O, IRr	Continuous	Continuous	Horizon × horizon
Storm tracking	90	45 to 90	45 to 55	O, IRr, SF, RW	Continuous	Continuous	1,000 × 1,000
Wind velocity measurements	90	45 to 90	45	TV, IRr, SF, RW	6 hr	Continuous	600 × 600
Atmospheric temperature	90	45 to 90	45	IRs, MWr	12 hr	Continuous	200 × 200
Atmospheric density	90	N/C	N/A	S	12 hr	Continuous	N/A
Atmospheric humidity	90	45 to 90	45	IRs, MWr	12 hr	Continuous	600 × 600
Atmospheric ozone	90	45 to 90	45	IRs, UVs	12 hr	Continuous	600 × 600
Atmospheric heat budget	90	45 to 90	N/C	Or, Sr	12 hr	Continuous	1,000 × 1,000
Global precipitation distribution	90	N/A	N/A	R, MWr, IRr	12 hr	Continuous	1,000 × 1,000
Global atmospheric pollution	90	45 to 90	45	Oc, MWr	6 hr	Continuous	200 × 200
Geography							
Mapping, 1:1,000,000, scale	90	30 to 60	45	Omc	(Once only)	N/C	200 × 200 min
Mapping, 1:250,000, scale	90	30 to 60	45	Omc	5 yr	N/C	70 × 70 min
Mapping, 1:62,500, scale	90	30 to 60	45	Omc	5 yr	N/C	20 × 20
Mapping, 1:24,000, scale	90	30 to 60	45	Om	5 yr	N/C	20 × 20
Transportation survey	60	60 or more	70	O	1 yr	N/C	25 × 25
Industrial survey	70	60 to 90	60 to 70	O, IRr	6 months	N/C	25 × 25
Urban survey	70	60 to 90	60 to 70	O, IRr	1 yr	N/C	25 × 25
Settlement planning	70	60 to 80	45	O, IRr	(Once only)	N/C	100 × 100
Geology/hydrology:							
Geological mapping, 1:1,000,000	90	30 to 60	45	Oc	(Once only)	N/C	100 × 100 min
Geological mapping, 1:250,000	90	30 to 60	45	Oc	(Once only)	N/C	50 × 50 min
Magnetic mapping	90	N/A	N/A	RVM	(Once only)	N/A	N/A
Radiant temperature mapping	90	N/A	N/C	IRr	Season	Sundown + 1 hr	100 × 100
Mineral/petroleum survey	70	30 and 60	45	IRr, Oc	(At least twice)	N/C	100 × 100
Heavy metal survey	70	60 to 90	30 to 45	IRr, Oc	Season	N/C	100 × 100
Volcanic belt reconnaissance	70	N/A	N/C	IRr	7 days	N/A	100 × 100
Volcanic eruption damage	70	N/C	N/C	O	1–2 days	N/A	10 × 10
Earthquake belt reconnaissance	70	60 to 90	45	Oc, IRr	(Once)	N/C	100 × 100
Earthquake damage assessment	70	N/C	30	O, R	1 day	N/A	10 × 10
River basin mapping	70	60 to 90	45	Oc, IRr	Season	N/C	30 × 30 max
Water pollution survey	70	60 to 90	45	Oc, IRr	7 days	73 hr max	30 × 30 min
Snow/ice survey	90	30 to 60	30 to 70	O, IRr	1 month	14–30 days	100 × 100
Soil moisture survey	70	60 to 90	45	O, IRr	Season	N/C	100 × 100
Groundwater survey	70	60 to 90	45	Oc, IRr	(Twice/season)	N/C	25 × 25
Hydrological station monitoring	90	N/A	N/A	D	1 day	3–12 hr	N/A
Atmospheric water loss survey	50	60 to 90	45	O, IRs, LA	7 days	N/A	25 × 25 min
Sedimentation survey	70	60 to 90	45	Oc, LA	(Twice/season)	7–30 days	50 × 50 min
Erosion survey	70	60 to 90	45	Oc, LA	(Twice/season)	N/C	50 × 50 max
Flood mapping	70	30 to 70	45	O, IRr	1–3 days	1–14 days	25 × 25 min
Oceanography							
Ocean mapping	80	45 to 55	45	Oc	(Once)	N/C	50 × 50
Buoy/satellite data collection	80	N/A	N/A	D	2 hr	N/A	N/A
Commercial fish location	75	60 to 90	N/C	Oc, IRr	1 day	N/C	50 × 50
Sea/ice surveillance	90	30	30 to 90	O, MWr, R	2 days	Period of thaw	100 × 100
Sea state survey	75	N/A	30 to 45	O, LA, Rs	2–6 hr	2 hr	100 × 100
Coastal mapping	70	30 to 90	45	Oc, LA	(At least twice)	N/C	50 × 50
Coastal engineering survey	70	60 to 90	45	Oc	(Twice/season)	N/C	50 × 50 min
Coastal damage assessment	70	30 to 90	45	Oc	(At least twice)	N/A	100 × 100
Navigational hazard survey	70	60 to 90	45	Oc	1 month	N/C	50 × 50
Marine pollutant survey	50	60 to 90	45	Oc, IRr	1 week	N/A	30 × 30 min

[a] Angle measured from horizontal.
[b] Minimum where phenomena can still be observed.
[c] N/C = not critical, N/A = not applicable, optical band sensors: O = optical band imagery, Oc = (color), Om = (metric), Omc = (metric color); radiometry: Or = optical, MSOr = multispectral optical, MWr = microwave, IRr = infrared, Sr = incident solar flux; spectrometry: UVs = ultraviolet, IRs = infrared; misc. sensors: LA = laser altimeter, TV = TV camera, R = radar, Rs = radar scatterometer, RW = weather radar, D = data collection system, RVM = rubidium-vapor magnetometer, S = star tracker sensor system, SF = sferics receiver.

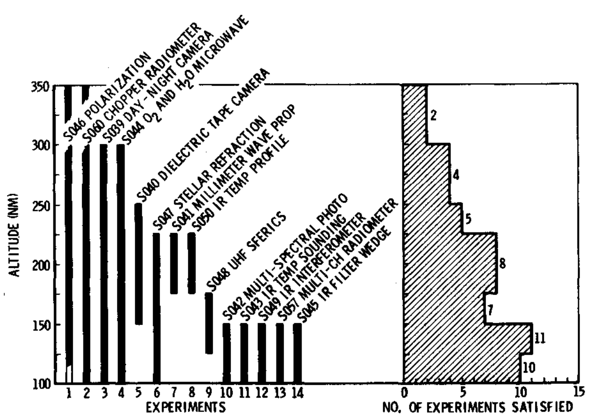

Fig. 10 **Experiment altitude preferences.**

quiring sun-synchronous imagery to obtain the similar sun angles for adjacent coverage strips on successive passes of the same latitude.

2) Illumination angle: the desired angle of solar illumination measured from the horizontal, expressed as degrees. Sometimes two illumination angles are recommended, e.g.,

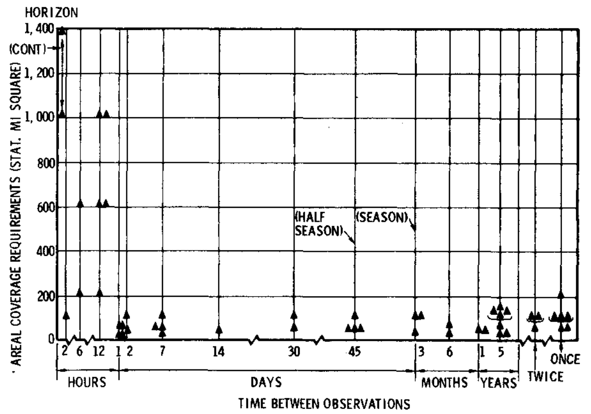

Fig. 11 **Areal coverage requirements vs time between observations.**

for color photography. In the limits presented, some sensor measurements desire a range including the high-noon zenith, whereas others cut off this no-shadow region.

3) Minimum elevation angle: referenced limiting angle measured from the horizontal at which phenomena can still be satisfactorily observed, expressed as degrees. For clarification, it should be pointed out that while the solar illumination of a target may be satisfied, the target distance (min. elevation angle) cannot be less than this limit.

4) Sensors to be utilized. Over 60% of the sensing tech-

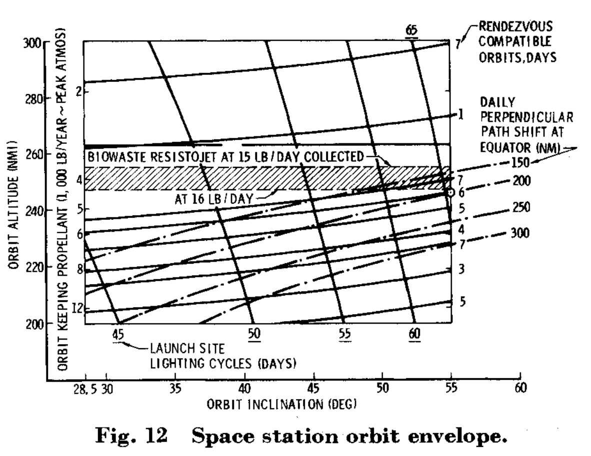

Fig. 12 **Space station orbit envelope.**

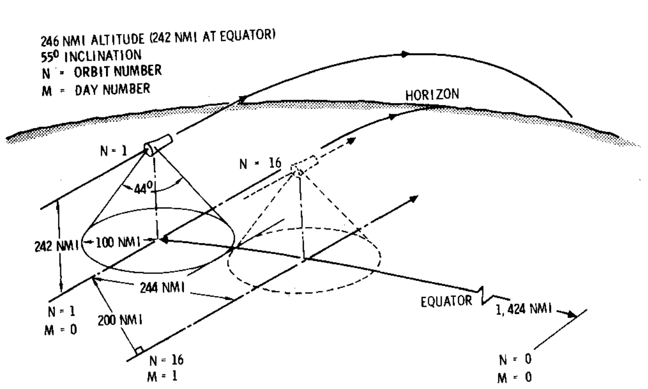

Fig. 13 **Earth coverage profile.**

niques identified are by Optical Imagery. Radiometry was required 13%, while spectrometry and active techniques such as radar, laser altimeters and radar scatterometers were required 18%.

5) Frequency of observation: the desired or acceptable repetation of surveillance, which varies from continuously to once only.

6) Duration: the time period in which a phenomenon takes place and within which observations should be made before significant changes occur. Some phenomena change continuously such as clouds, winds, density, etc.

7) Desired ground area coverage: area dimensions on the ground desired by users to be covered by a single sensor record (e.g., optical coverage per image) expressed in statute miles.

The areal coverage requirements for these Earth viewing tasks were compared to their desired frequency of observation. This requirements summary was cross-plotted and is presented in Fig. 11. From this summary, and a review of the Blue Book experiment sensors, a 200 naut miles swath width would satisfy all of the observation requirements that are repeated at daily intervals or longer. The high frequency observations require areal coverage up to horizon to horizon. The field-of-view for these areas are very large (~140°) and are within the capability of only a few sensors.

The other area of concern is the amount of time between repetitions of the ground track. Desired repetitions for operational resource measurements range from several times per day (sea state, meteorology, etc.) to 2–5 times per year in the case of some agricultural measurements to geology which is relatively insensitive to ground track repetition times and hence remeasurement.

Orbit Selection

The selection of an orbit regime for the Space Station involves considerations affecting both the inclination (which

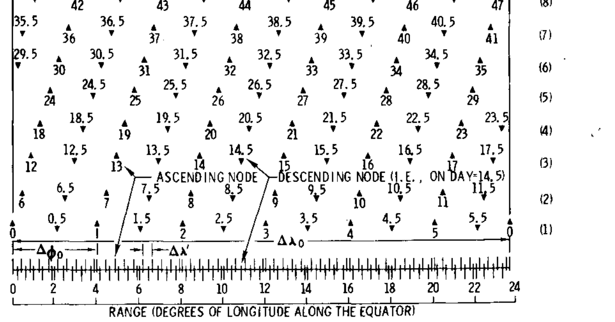

Fig. 14 **Space station orbit trace pattern development.**

will probably remain fixed) and the altitude (which can be changed). The baseline orbit inclination was selected as 55° (study limit) to maximize earth resources coverage. A 200 naut miles value for ground swath mapping was selected as representative of sensor requirements. A 200 naut miles daily perpendicular (equatorial) ground track shift was then established as a candidate for satisfying this mapping in the minimum time. The additional requirements were that the orbit possess a repetition cycle of coverage appropriate to seasonal variations with a nonrepeating orbit specified to allow mapping down to smaller areal coverages. A 246 naut miles altitude candidate was then established (see Fig. 2) as possessing these features and this was subsequently evaluated against the operational and design requirements.

The Space Station orbit envelope shown in Fig. 12 is a convenient tool on which to evaluate operational and design factors such as radiation shielding and drag makeup propellant both of which change with the solar cycle. Satellite ground trace behaviors for various orbital repetition and launch site lighting cycles are added to the envelope to provide further trend data. At the 246 naut miles candidate altitude, station keeping, assuming a Resistojet system, is provided essentially free during peak atmospheric density years by using the expected amount of biowaste from the 12-man crew. The propellant requirements are representative of the 33-ft diam Space Station in a local horizontal orientation with four attached modules (broadside area approximately 600 ft^2 each) present.

The operational requirements imposed on the logistics system and the Space Station were evaluated in detail (Ref. 5) as to payload, launch, rendezvous, and target illumination opportunities, communications, and other considerations and found to be satisfied at the baseline orbit.

Space Station Baseline Orbit Behavior

The Earth coverage profile of the Space Station in the baseline orbit is illustrated in Fig. 13. The ground trace behavior pattern for this orbit along the equator is presented in Fig. 14. Included in this trace summary are the effects of the north as well as the south nodal crossings of the orbit. The orbit repeat parameter corresponds to a repeat every 5.89 or 58.924, etc., days. Accordingly, the orbit appears to repeat at nearly 59 days. Inherent in this orbit behavior is the operation of a resistojet propulsion system which continuously cancels drag. If the orbit were allowed to decay, the trace pattern development would only be slightly affected over the first 59 days, however, and the coverage behavior would be approximately the same.

Conclusions

In the early Space Station studies, the tried and proven operational techniques of the Mercury, Gemini, and Apollo manned hardware programs were employed which dictated that only certain operational orbits could be considered (e.g., the rendezvous compatible orbits). Later, as experiment program definition progressed and their requirements emerged, more attention has been given to satisfying these experiments by picking an orbit appropriate for their use and then imposing the resulting operational requirements on the station and logistics systems.

This paper has indicated some of the considerations involved in the mission design task of orbit selection. As each subsystem of the program hardware evaluates the environment of a candidate orbit, another iteration is performed in the process of converging on the best compromise.

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