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Orbit Selection for
Earth Observation Missions

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ORBIT SELECTION

FOR EARTH OBSERVATION MISSIONS

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ABSTRACT

The orbit selection process is simplified for most earth-oriented satellite missions by a restriction to circular orbits, which reduces the primary orbit characteristics to be determined to only two: altitude and inclination. A number of important mission performance characteristics depend on these choices, however, so a major part of the orbit selection task is concerned with developing the correlating relationships in clear and convenient forms to provide a basis for rational orbit selection procedures. The present approach to that task is organized around two major areas of mission performance, orbit plane precession and coverage pattern development, whose dependence on altitude and inclination is delineated graphically in design chart form. These charts provide a visual grasp of the relationships between the quantities cited above, as well as other important mission performance parameters including viewing time of day (solar), sensor swath width (and fields of view), swath sequencing, and pattern repeat condition and repeat periods. These relationships and the accompanying discussion provide a general approach to the orbit selection aspect of earth-oriented satellite mission design.

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GENERAL

In earth observation applications, the orbit selection process is usually simplified by a restriction to circular orbits, imposed by the need to maintain uniform viewing conditions. With that restriction, the primary orbit characteristics remaining to be determined reduces to only two: the altitude (h) and the inclination (i). A number of other important mission parameters depend on these choices, however, so a major part of the orbit selection task is concerned with developing these relationships in suitable forms to provide a basis for rational orbit selection procedures. The brief discussion of that subject which follows is organized around two important areas of mission performance which depend on h and i, namely, orbit plane precession and coverage pattern development.

ORBIT PLANE PRECESSION

The dependence of orbit plane precession on h and i is shown graphically in Figure 1. The graph gives the basic nodal precession rate ($\dot{\Omega}$) as a function of h and i, along with several other useful precession-dependent quantities. The latter are largely self-explanatory, except for the "nodal day" (D_n), which is defined as the earth rotation period relative to the (precessing) orbit plane. This parameter is useful in determining coverage pattern characteristics, as described later in this section.

The specific procedures to be followed in applying design aids such as Figure 1 to particular orbit selection problems varies considerably from case to case. Some applications, Landsat for example, require sun-synchronous orbits to maintain solar illumination of the sensor fields of view (Reference 2), and this requirement restricts the inclination value to a narrow range near 100°, as indicated by Figure 1.

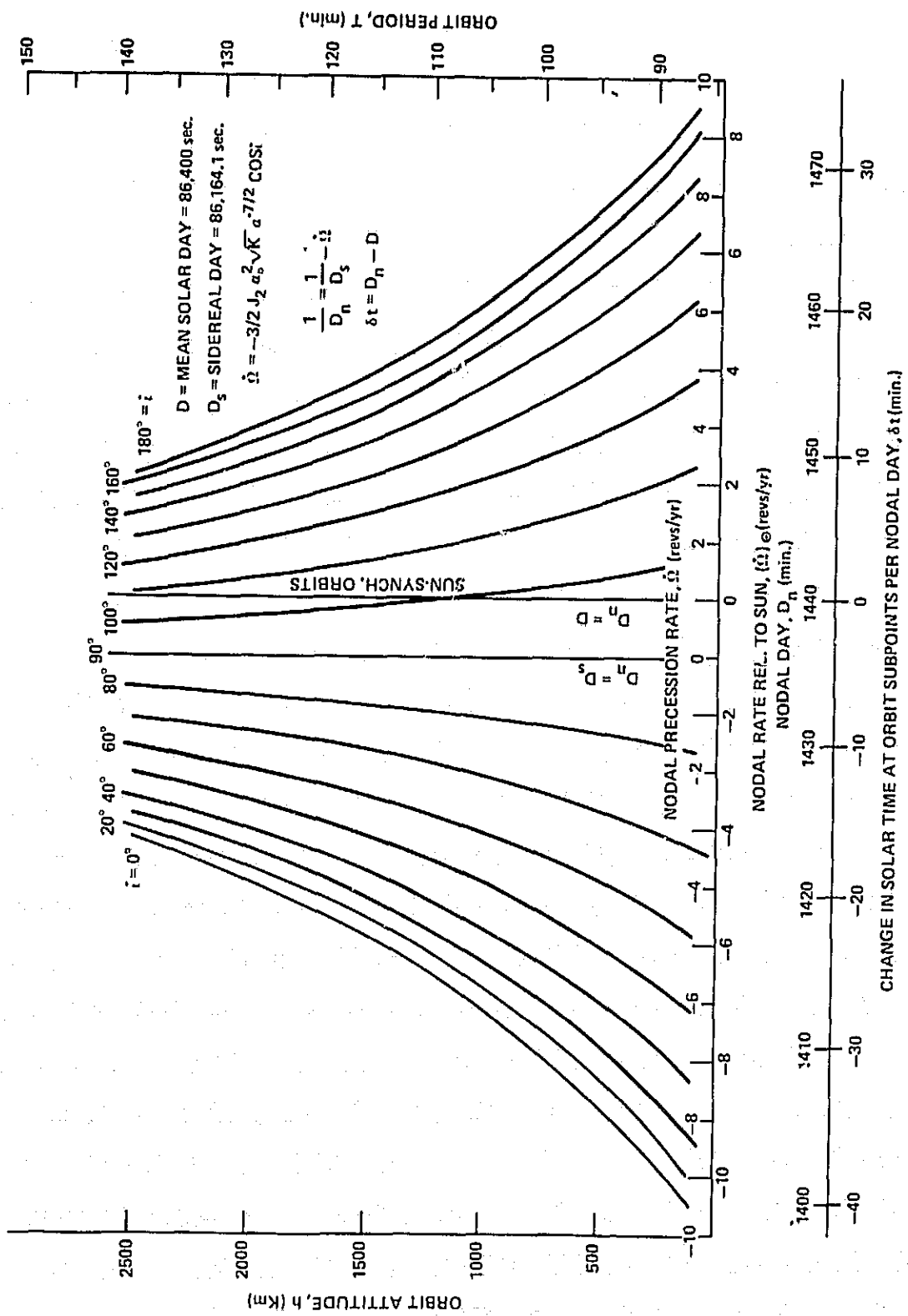*Contribution to the Final Report of the Applications Review Panel on High Resolution Passive Microwave Satellites.

Figure 1. Satellite Orbit Precession and Related Viewing Parameters

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Other applications, such as those involving microwave sensing, may be free of the sun-synchronism restriction and call instead for some other precession-dependent characteristic, such as a desired rate of change of viewing time of day (solar), e.g., Seasat (Reference 3). It is feasible, for example, to obtain a complete sweep of viewing times of day each month by selecting a nodal rate relative to the sun of 6 revolutions per year, i.e., $(\dot{\Omega})_\oplus = \pm 6$, since the ascending and descending portions of the orbit each make separate complete (24-hr) time sweeps with every orbit plane revolution. The above sign choice might be made based on other considerations, such as the more economical launch into the low-inclination, direct (eastward) orbit obtained by choosing $(\dot{\Omega})_\oplus = -6$.

Still other applications may require particular ranges or values of both h and i, with the resulting precession rate assuming only secondary importance.

COVERAGE PATTERN SELECTION

A second important mission characteristic which depends on h and i is the earth coverage sequence and pattern. The desired pattern characteristics are usually determined by the sensor fields of view (swath width), the earth latitude zones of interest, and any sequencing or repetition requirement, such as a need to re-view each area of coverage every N days (References 2 and 3).

Pattern Characteristics

Figure 2 (from Reference 4) provides a convenient means of correlating the various types and rates of periodic coverage with orbital period (or altitude). A 5-day repeat cycle period, for example, is obtainable at any of an extended series of orbital altitudes, as indicated by the points along the N = 5 ordinate line. Each point (dot) is defined by simultaneous integral values of the revolution numbers N and R, the number of nodal days and orbital revolutions, respectively, per complete pattern repetition cycle. Pattern repetition is guaranteed by the integral value constraint on N and R.

Apparent omissions in the array of points in Figure 2 occur where the integral values of N and R are not relatively prime and therefore represent redundant multiples of shorter
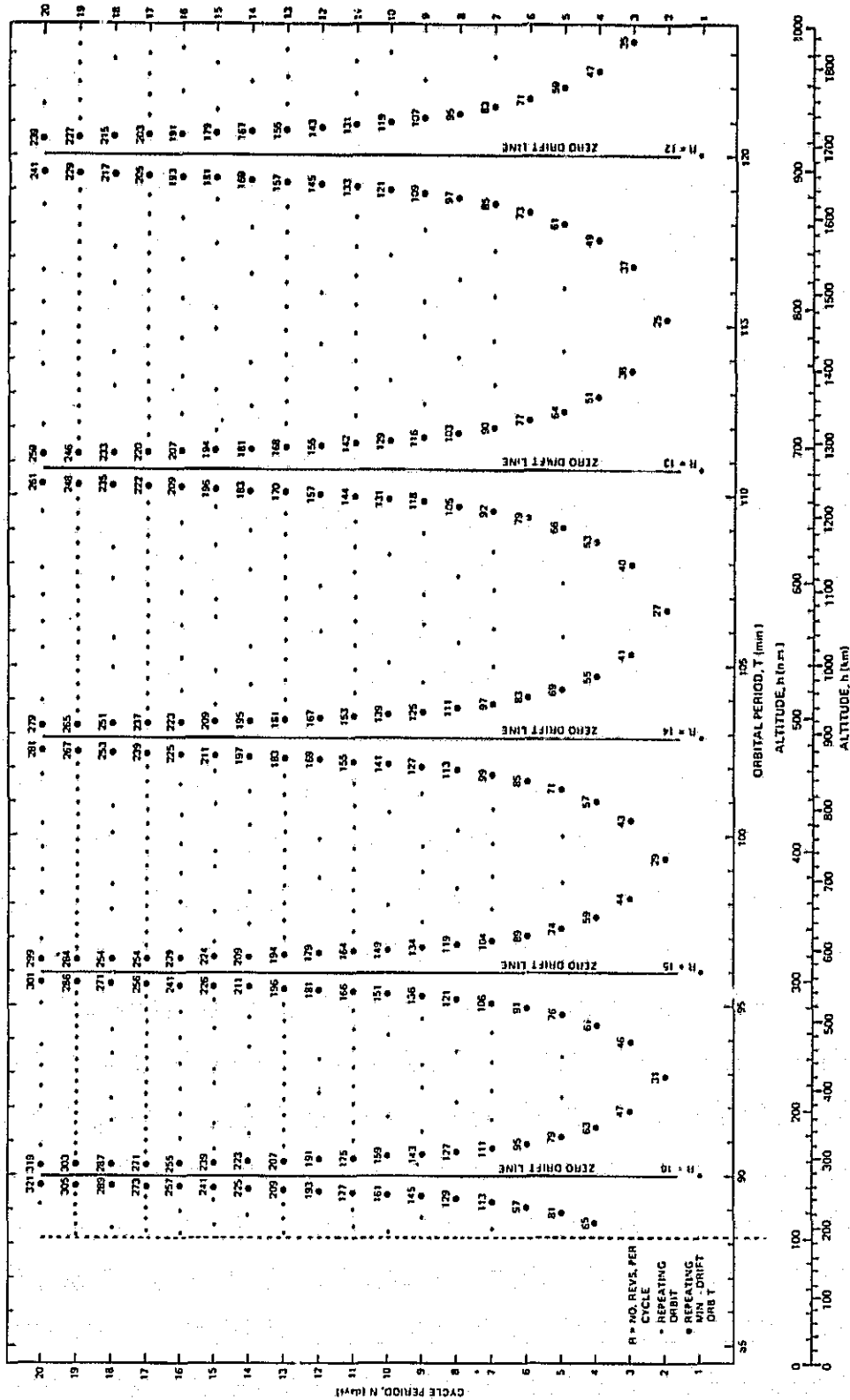
3

Figure 2. Array of Orbits Which Produce Repeating Swath Patterns

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period cycles (obtained by removing common factors from N and R). The "minimum-drift" orbits (large dots) are those in which the swath progression sequence is consecutive, i.e., adjacent swaths are covered on consecutive days. Patterns represented by the smaller dots exhibit increasing values of the "daily drift", which produces a skipping motion in the daily progression, in which the skipped-over swath positions are covered later in the cycle in subsequent sweeps across the area. The characteristic number of positions skipped in a given pattern is determined by the difference between its R-number and that of the nearest minimum-drift pattern. The apparent direction of daily drift is eastward for points (patterns) situated to the left of the nearest zero drift line and westward for points to the right.

Note that the abscissa scales in Figure 2 are strictly applicable only to sun-synchronous orbits. This restriction can be circumvented, however, if the integer N is defined in nodal days, and the abscissa scales are adjusted using the relationship

$$T = T_{ss}D_n/D$$

where T is the correct period for the unrestricted orbit precessing at a rate corresponding to D_n, and T_{ss} is the value indicated directly in Figure 2 for sun-synchronous orbits (having $D_n = D = 1440$ min., the mean solar day). In actual practice, the procedure consists of selecting the desired pattern (N, R) in Figure 2 and reading the corresponding T_{ss} directly, entering that T_{ss} value into Figure 1 and reading the value of D_n corresponding to the inclination or precession rate desired. The correct period T would then be obtained using the above correction formula, and the corresponding h value obtained using the abscissa scales of Figure 2. The cycle period is known to be N nodal days (of D_n minutes each).

Selection Factors

The characteristic revolution numbers N and R are of primary importance in the pattern selection process, since they effectively define (for a given i) the complete pattern of the nadir trace (Reference 5). The significance of N, the repetition cycle period, is already

clear — it defines the time interval between successive passes (in the same direction)[1] over a given site. The orbital revolution number R is also of primary importance in that it determines the "fineness" of the pattern, i.e., the interval $s = 360°/R$ between adjacent nadir trace crossings of the equator (in one direction) in the complete pattern (Reference 5). Thus R also determines the minimum swath width w needed to obtain full coverage (in one direction) at the equator, via the relation

$$w_{min} \cong s/\sin i = 360°/R \sin i$$

Conversely, given an available swath width, this equation will yield a minimum value of R required for full coverage in one direction. This number, along with the desired number for N, serves to guide the selection of a particular pattern (and corresponding orbit in an acceptable altitude range) from Figure 2.

OVERVIEW

The above discussion outlines some of the principal relationships between parameters important in the selection of orbits for earth observation missions. Because of the wide variations in the form in which actual selection problems occur, it is not practicable to prescribe specific design procedures. In most cases, however, suitable procedures will be suggested by the requirements and constraints given. The approaches and relationships provided herein can then be applied selectively and in sequences suited to the particular problem under consideration.

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[1] Complete periodic patterns always exhibit two symmetric (mirror-image) sets of passes, ascending and descending, over all latitudes traversed. Local correlation and mapping of the two sets require more detailed analysis.

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