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TIROS-N SPACECRAFT JITTER CALCULATIONS

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DECEMBER 1972

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TIROS-N SPACECRAFT JITTER CALCULATIONS

INTRODUCTION

The purpose of this report is to examine the TIROS-N (Television Infrared Observatory System) primary payload sensor characteristics and to develop the attitude control system jitter specification needed for satisfactory performance of the sensor. The primary sensor is the AVHRR (Advanced Very High Resolution Radiometer).

The TIROS-N spacecraft is an orbital platform carrying a number of earth-observation sensors. It requires a three-axis attitude control system which maintains the roll axis along the velocity vector, the yaw axis along the local vertical, and the pitch axis normal to the orbit plane. The TIROS-N orbit is sun synchronous and has an altitude of 1678 km.

DISCUSSION

Based on the parameters given in Figure 1, it is possible to compute the maximum allowable body rates about all three spacecraft axes. From these rates, it is then possible to compute the spacecraft angular deviation from the nominal attitude which will yield ground motion of 0.2 km. The 0.2 km value is the allowable ground motion due to spacecraft jitter and is 20 percent of one scan advance.

Once the maximum body rates are obtained, the next problem is to define the frequency response of the allowable body motion. The TIROS-N control system specification states that the square root of the sum of the squares of the roll and pitch errors cannot exceed ± one degree at any instantaneous time in the steady state (no large transients such as orbit adjust thrusters firing). Also the yaw position error cannot exceed ± one degree. A worst case condition will be used for this analysis, which implies roll and pitch errors of 0.7 deg occurring simultaneously. One can intuitively see that at very low body jitter frequencies, the 0.7 deg allowable pointing error is adequate, because in one scan advance the amplitude of the body motion will be sufficiently small to limit the ground motion to less than 0.2 km. However, at high body jitter frequencies, the body position motion must be attenuated in order to meet the 0.2 km requirement. The following analysis attempts to describe a method of defining body motion as a function of jitter frequency.

Figure 1 represents the orbital geometry of a spacecraft in a TIROS-N orbit. The angle of 41.4 deg is the scan angle for orbit-to-orbit contiguity. This is the value of the scan angle at which the subtended angles at the spacecraft are computed. The spacecraft is allowed to rotate about each of its three axes so that ground deviations of 0.2 km occur on the surface of the earth in three orthogonal directions. From Figure 1, the following calculations give the subtended angles at the spacecraft:

Pitch $$E_p = \frac{0.2 \text{ km} \times 57.3}{1895.325 \text{ km}} = 0.006 \text{ deg}$$

Yaw $$E_y = \frac{0.2 \text{ km} \times 57.3}{1650.648 \text{ km}} = 0.007 \text{ deg}$$

Roll $$E_r = \frac{0.11039 \text{ km} \times 57.3}{2542.8589 \text{ km}} = 0.0025 \text{ deg}$$

If these angles are divided by the instrument scan period, body rates are obtained which limit the ground motion to 0.2 km in each of three directions. Therefore, the body rates corresponding to these subtended angles are:

$$R_p = \frac{0.006 \text{ deg}}{(1/6) \text{ sec}} = 0.036 \text{ deg/sec}$$

$$R_y = \frac{0.007 \text{ deg}}{(1/6) \text{ sec}} = 0.042 \text{ deg/sec}$$

$$R_r = \frac{0.0025 \text{ deg}}{(1/6) \text{ sec}} = 0.015 \text{ deg/sec}$$

Since pitch and yaw rates are essentially the same, 0.036 deg/sec is used for the maximum allowable rate for both pitch and yaw. The roll rate is specified as 0.015 deg/sec.

CALCULATION OF JITTER ANGLE VERSUS FREQUENCY

The following assumes that the spacecraft body motion is periodic. This is a valid assumption, because when one talks of a jitter frequency, periodic motion is implied. Therefore, the instantaneous position of the spacecraft can be written as a Fourier series:

$$\text{Position} \qquad P(t) = \sum_{k=1}^{N} C_k \sin(k\omega t) \text{ deg}$$

The body rate is the time derivative of the position function.

$$\text{Rate} \qquad R(t) = \sum_{k=1}^{N} k\omega C_k \cos(k\omega t) \text{ deg/sec}$$

where

C_k is the k^{th} Fourier coefficient of the position function

and

ω is the fundamental frequency of the body motion

For the roll axis, the maximum allowable position error is ±0.7 deg and the maximum allowable body rate is ±0.015 deg/sec. Therefore, for k = 1 (the fundamental frequency of body motion), the following expressions can be written:

$$C = 0.7 \text{ deg}$$

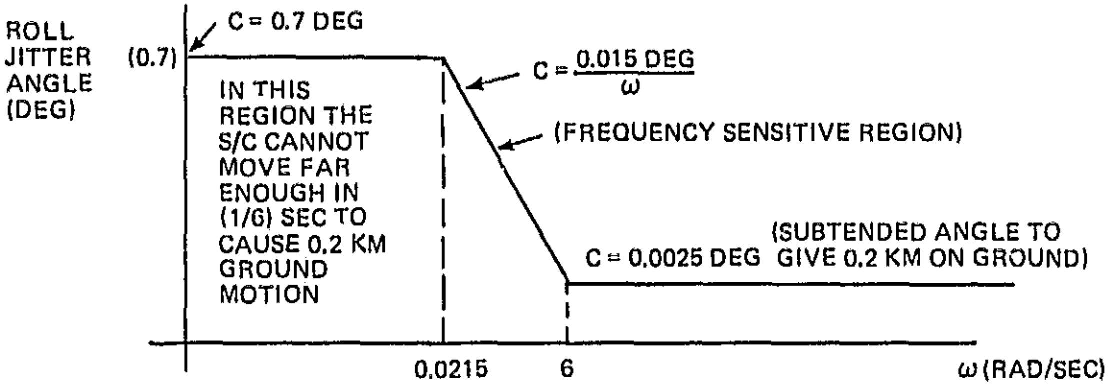
and

$$C\omega = 0.015 \text{ deg/sec}$$

or

$$C = \frac{0.015 \text{ deg/sec}}{\omega \text{ rad/sec}} \text{ deg}$$

These two expressions for C are plotted and found to intersect at $\omega = 0.0215$ rad/sec. For frequencies above this valve of ω, the jitter amplitude becomes frequency sensitive. The allowable amplitude continues to decrease until the jitter angle corresponds to 0.2 km of ground motion. At this frequency and above, the allowable jitter cannot exceed an amplitude of 0.0025 degrees. In other words, beyond $\omega = 6$ rad/sec one does not care how high the jitter frequency becomes, as long as the jitter amplitude does not exceed 0.0025 degrees. This relationship is shown in the following diagram:



The expressions for yaw are:

$$C = 1.0 \text{ deg}$$

$$C = \frac{0.036}{\omega \text{ rad/sec}} \text{ deg}$$

Maximum high frequency amplitude = 0.006 deg.

The expressions for pitch are:

$$C = 0.7 \text{ deg}$$

$$C = \frac{0.036}{\omega \text{ rad/sec}} \text{ deg}$$

Maximum high frequency amplitude = 0.006 deg.

Figures 2, 3, and 4 show the plotted jitter amplitude versus jitter frequency curves for motions about the roll, pitch, and yaw axes.

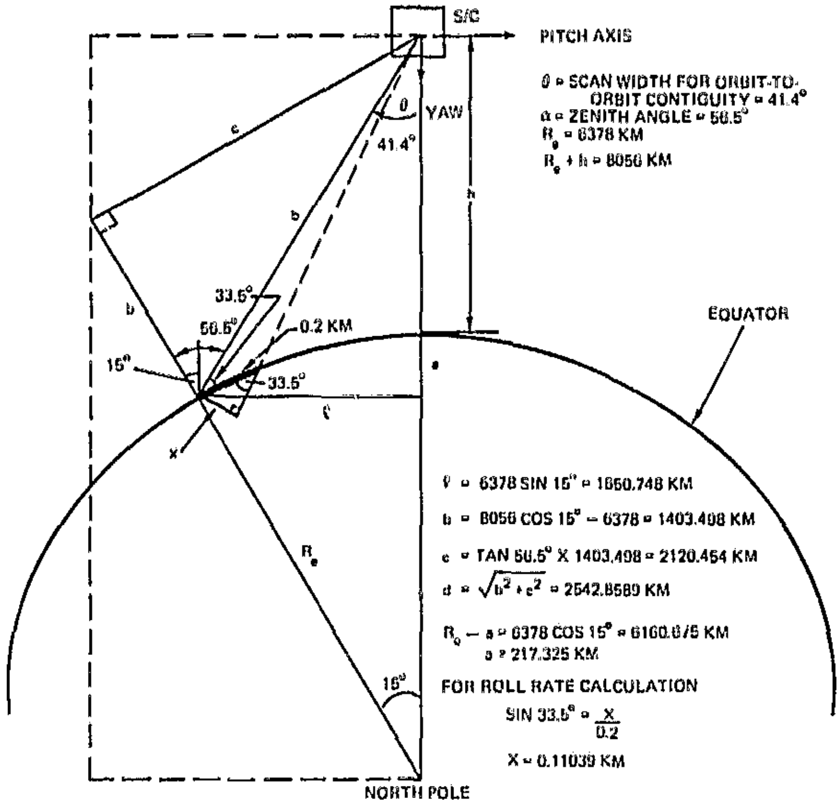


Figure 1. Geometry for Jitter Rate Calculation

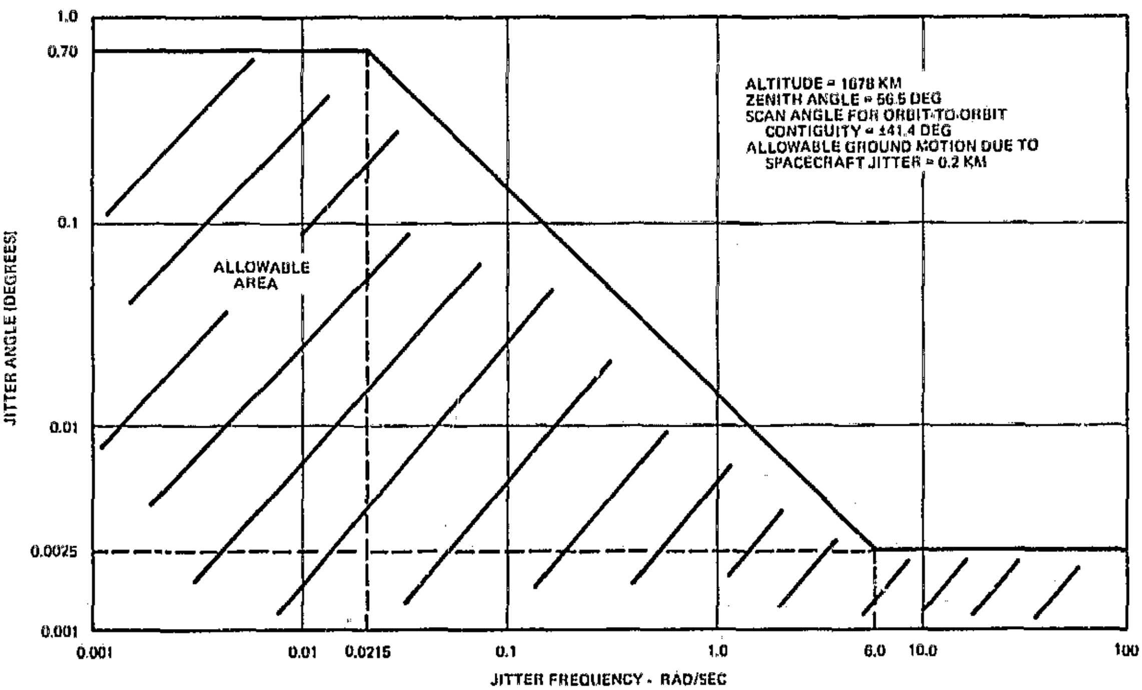


Figure 2. Roll Jitter Angle Versus Jitter Frequency

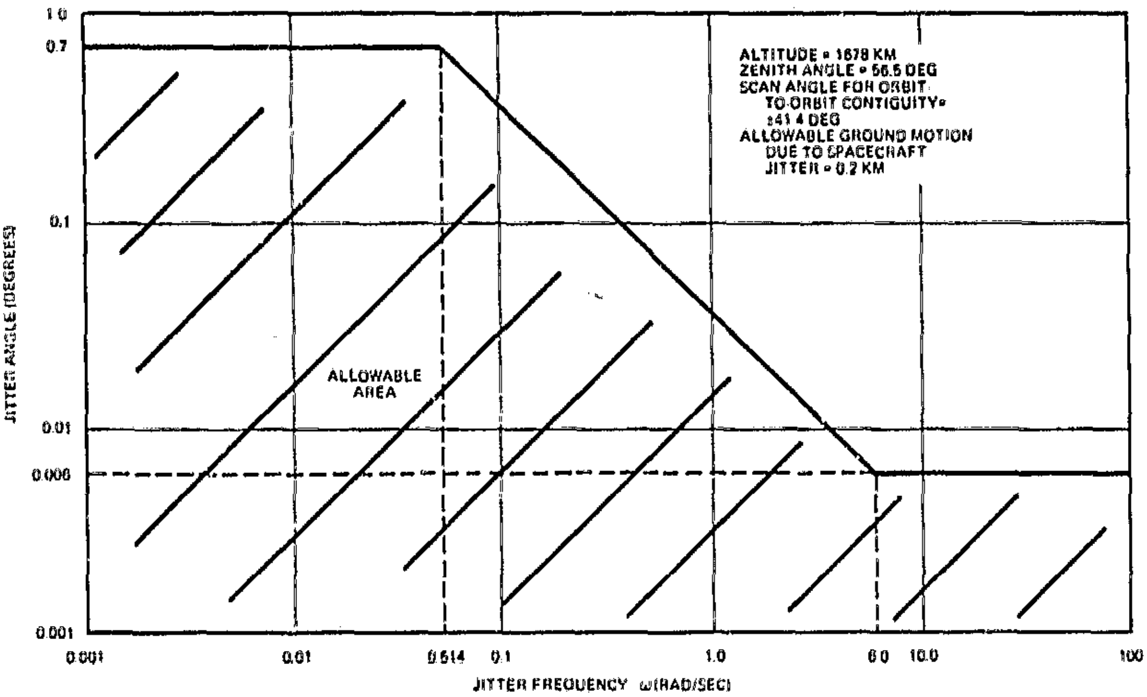


Figure 3. Pitch Jitter Angle Versus Jitter Frequency

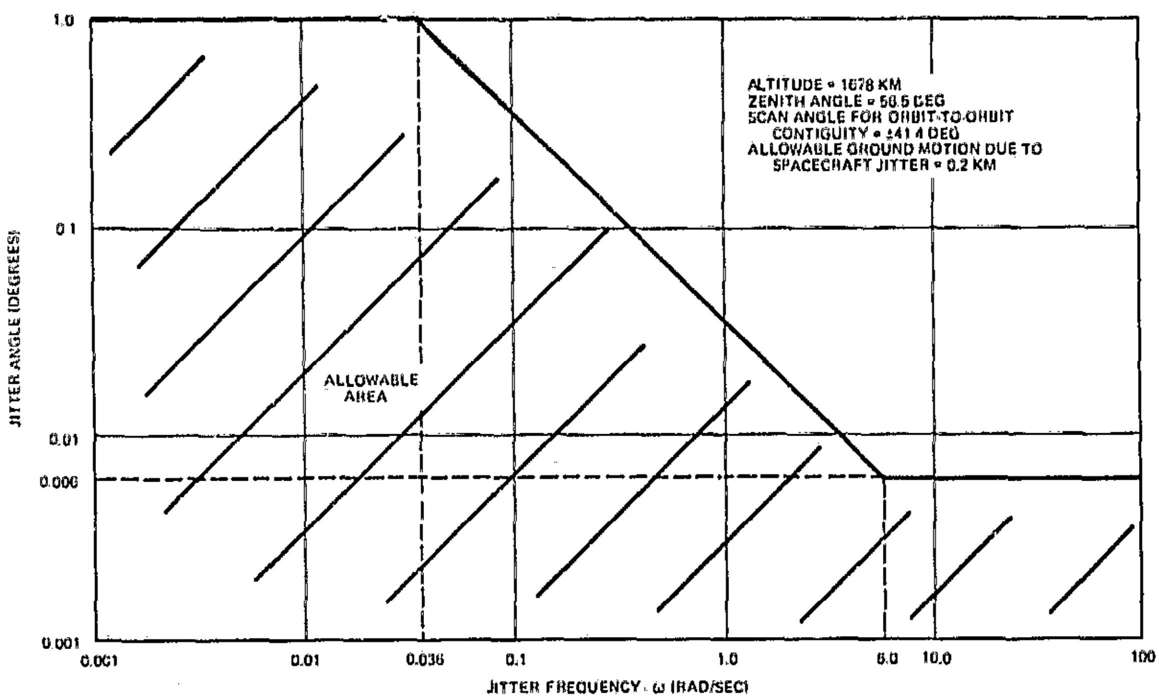


Figure 4. Yaw Jitter Angle Versus Jitter Frequency

REFERENCE

1. TIROS-N Phase A Report. Volumes 1, 2, and 3. March 1971.