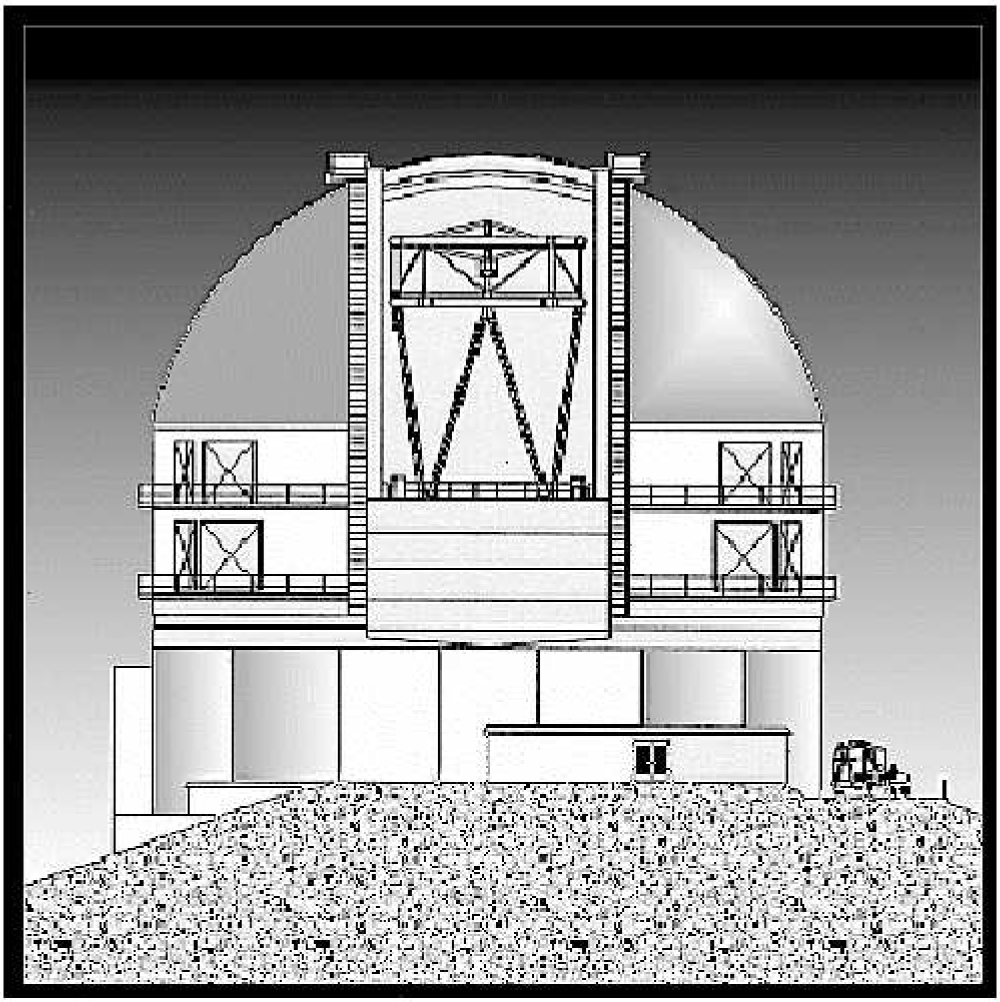
GEMINI
8-M Telescopes
Project

RPT-O-G0052

Effects of Chopping Magnitude and Frequency on Telescope Performance for the Tip-Tilt Mechanism



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February 5, 1994

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Section 1
Introduction

This document was assembled to present information that is thought to be useful in assessing the effects of chopping requirements on telescope performance. The information presented considers only the effects produced by the tip-tilt mechanism. Other telescope subsystems and subassemblies will also contribute to telescope performance degradation as a function of chopping requirements. Some considerations will effect all operating modes of the telescope while others only affect telescope performance while chopping. The effects have been approximated as linear functions of chopping frequency, sky motion amplitude and the observing duty cycle, when possible. These relationships are only approximate.

Our current conceptual design for the tip-tilt mechanism was used to assess some of the effects. This concept was developed only to the extent necessary to assess design implications of performance requirements. The actual device designed and built may not be the same.

The present requirements are fifteen arcseconds total sky motion at ten Hertz and thirty seconds total sky motion at five Hertz. The observing duty cycle for both frequencies is eighty percent. The approximations should remain good for small excursions outside of this performance envelope. Increases in the requirements may require further analysis.

Mechanical non-repeatability is a function of the maximum chopping excursion required. It is not directly related to chopping frequency or observing duty cycle. This has performance implications for all other operating modes (not just chopping) and its effect at other wavelengths and other operating modes should be considered.

Mechanical harmonic oscillations only apply during chopping operations. The power and force requirements in this document only apply in the chopping mode of operation.

Performance of the f/16 R-C telescope for wavelengths of 2.2µm, 3µm, 5µm, 8µm and 10µm was evaluated. The nominal encircled energy diameters for these wavelengths are listed in the table below.

Diffraction Based Encircled Energy Diameters for the Nominal f/16 Telescope										
Wavelength	**2.2µm**		**3µm**		**5µm**		**8µm**		**10µm**	
percent encircled energy	50%	85%	50%	85%	50%	85%	50%	85%	50%	85%
diameter, arcsecond	0.0651	0.1973	0.0889	0.2694	0.1482	0.4490	0.2371	0.7183	0.2960	0.8965

Section 2
Non-Repeatability Effects as a Function of Chopping Magnitude

Introduction

Presented here are predictions of the contributions to telescope system image degradation due only to non-repeatability in the tip-tilt mechanism. The tip-tilt mechanism will also contribute to image quality degradation due to effects other than non-repeatability. In addition, there are errors due to other subsystems and subassemblies of the telescope system that are not presented here.

Non-repeatability of the secondary mirror caused by the tip-tilt mechanism is related directly to the maximum mirror excursion required. The mechanism has a resolution and a non-repeatability that is a fraction of the total measurement range it is required to perform over. Under good to ideal conditions, the sensors at each mirror mounting point have a resolution/non-repeatability of .01 % of the total range they must perform over. Under good to ideal conditions, control systems may control to four times the non-repeatability/resolution of the sensors. This factor may go to ten times the non-repeatability/resolution as conditions depart from good to ideal. The non-repeatability will appear as mirror tilt and focus errors. All *telescope operations*, not just chopping, will be effected by the maximum excursion required.

Non-repeatability, hysteresis and position resolution will all be lumped into one category, non-repeatability. The non-repeatability values used are $\pm 3\sigma$, 6σ total, of a Gauss-Laplacian distribution.

Tracking

The tracking error contribution of the tip-tilt mechanism is a direct result of the mechanical non-repeatability of tilt of the secondary mirror. The error is .04% to .10% of the largest chopping amplitude. For example, if the largest range desired is 30 arcseconds total sky motion, the tracking error that results *for all operations* is .012 to .030 arcsecond due only to tip-tilt mechanism non-repeatability. The tracking error for the conceptual design tip-tilt system due to tip-tilt mechanism non-repeatability may not be improved beyond .0015 to .0039 arcsecond total, regardless of chopping requirements. The *Gemini System Error Budget Plan* allowance for the tip-tilt system is .024 arcsecond total.

Image Smear

The image smear contribution of the tip-tilt mechanism due to non-repeatability is due to two effects, image motion due to tilt and effective enlargement due to defocus. Image quality degradation from the tilt magnitudes considered are small compared to the image degradation due to motion of the image and were not included in this analysis. Non-repeatability in tilt is related directly to the maximum chopping amplitude required. In calculating the effect of non-repeatability in tilt, image motion in one direction only was considered.

The mirror is articulated in tilt and defocus by axial motion at its three attachment points on a 677.33 mm diameter. Sensors are also located at this diameter. Non-repeatability in the axial position of the three mirror attachment points leads to non-repeatability in mirror position in defocus.

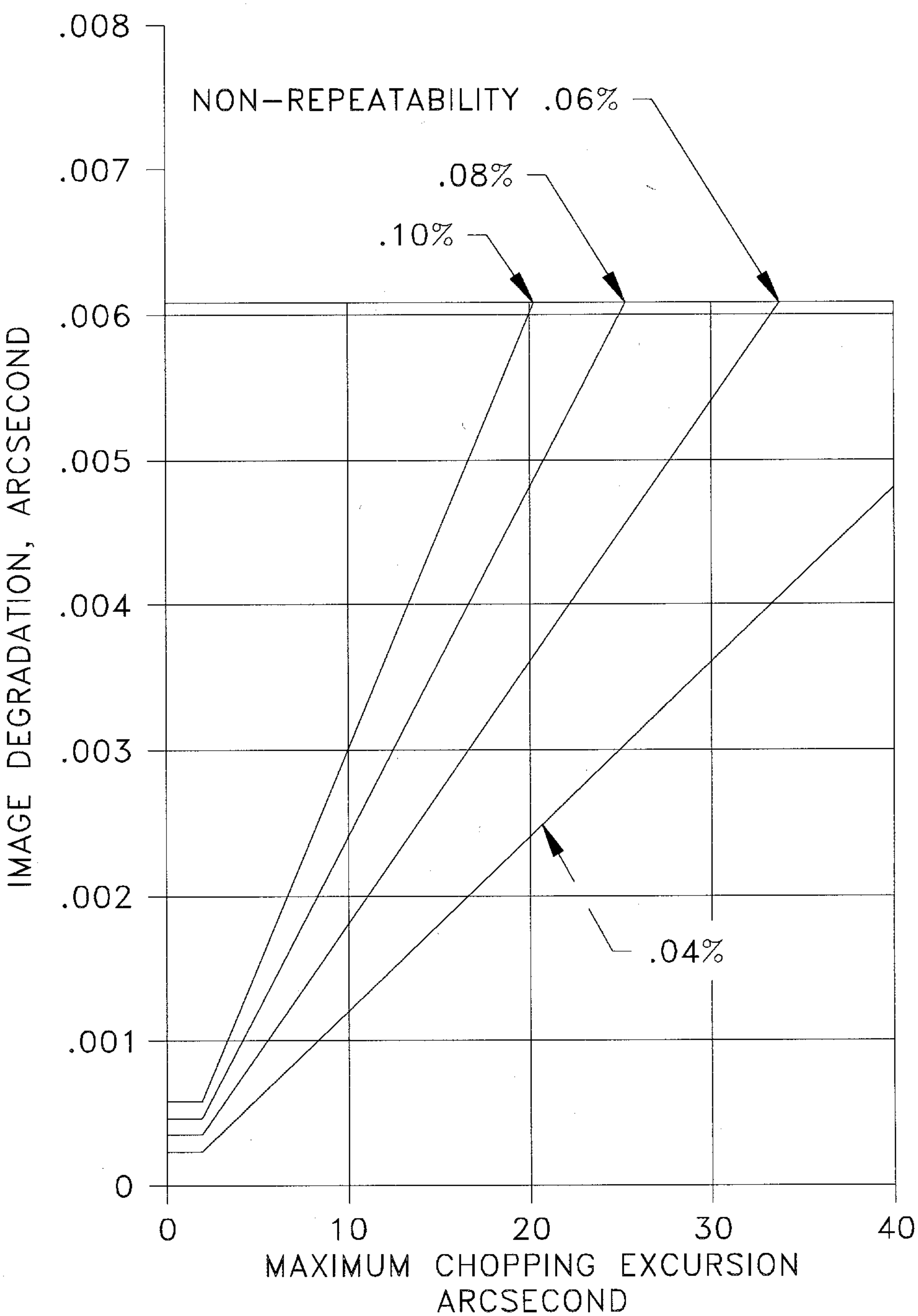
The degradation due to image smear and defocus for non-repeatability is obtained by multiplying the maximum chopping range by a constant.

(image degradation, arcsecond) = b x (maximum chopping range, arcsecond total)

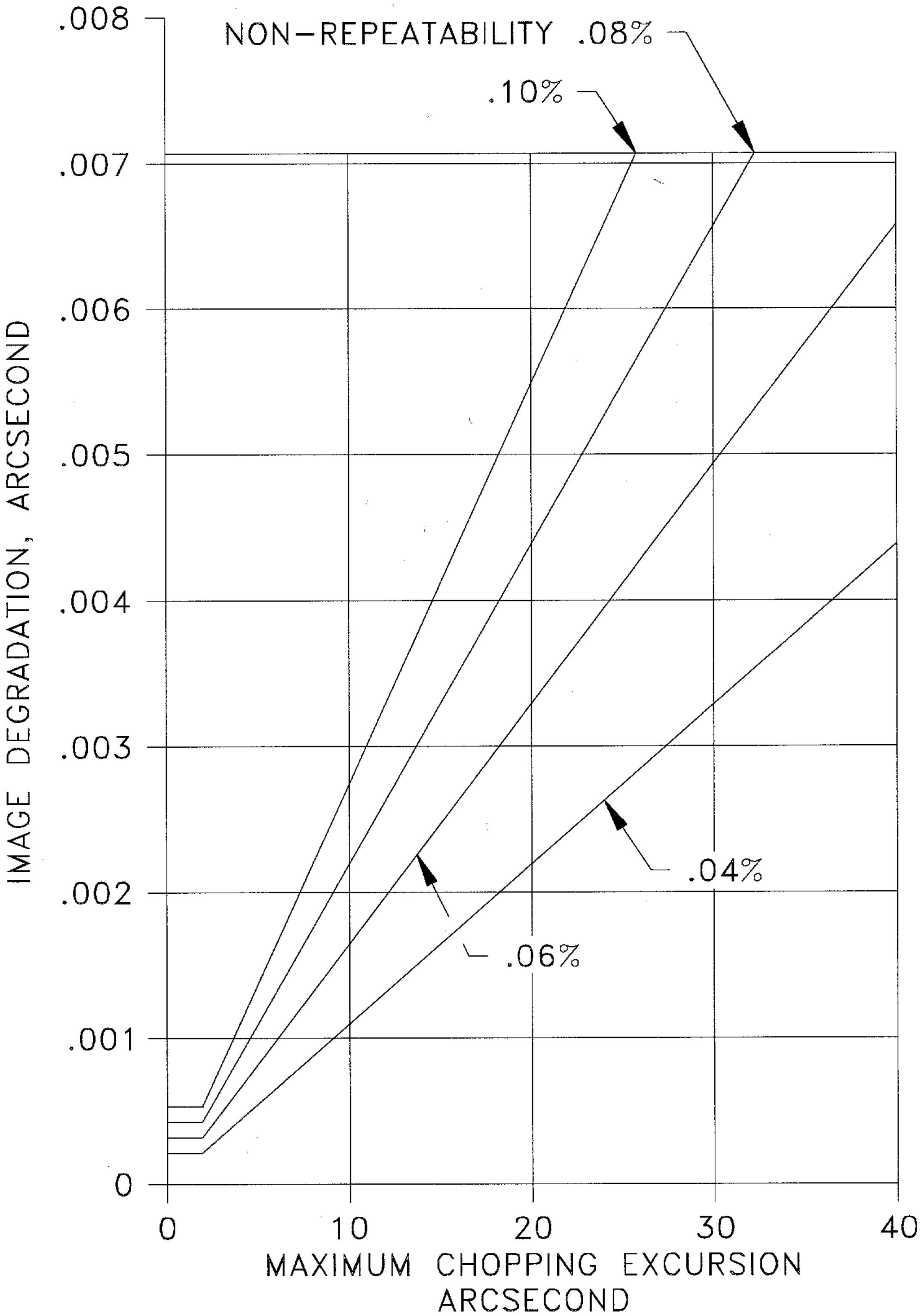
A range of constants, b, for each wavelength for fifty percent encircled energy for several wavelengths is given in the following table. This constant was obtained by combining the effects of non-repeatability in tilt and defocus. Also given in the table is the range of image degradation for the best non-repeatability expected. These values are derived from the best resolution of the sensors used in the conceptual design. Reducing the maximum range of motion will not improve image degradation beyond these values. The maximum allowed image degradation is also included where a requirement exists.

Constant to Obtain Image Degradation from Maximum Chopping Range						
Wavelength	2.2µm		3µm	5µm	8µm	10µm
percent encircled energy	50%	85%	50%	50%	50%	50%
b, .10% non-repeatability	0.00030058	0.0002742	0.00030421	0.0031022	0.00031300	0.00031909
b, .04% non-repeatability	0.00012023	0.0001096	0.00012168	0.00012409	0.00012520	0.00012764
best degradation, maximum, arcsecond	0.00364	0.00332	0.00369	0.00376	0.00379	0.00387
best degradation, minimum, arcsecond	0.00146	0.00133	0.00147	0.00150	0.00152	0.00155
maximum allowance, diameter, arcsecond	0.00608	0.00707				0.05001

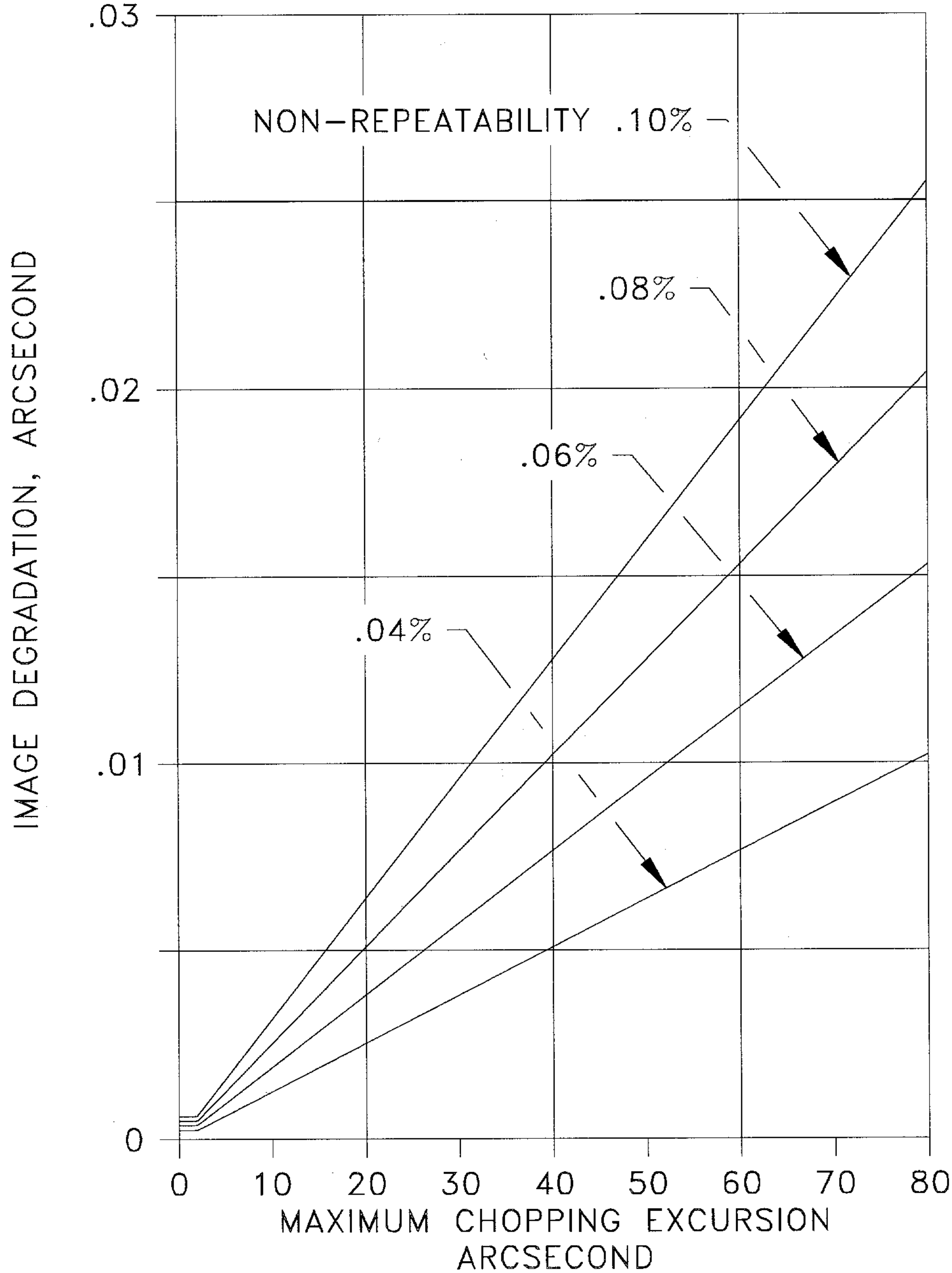
Image degradation due to non-repeatability of the tip-tilt mechanism is shown in the following graphs. Each graph has four plots. Each plot is for a different fractional non-repeatability, .04%, .06%, .08% and .10%. The horizontal line at the top of the plots for 2.2µm and 10µm wavelengths is the maximum image degradation allowed by the *Gemini System Error Budget Plan.* The horizontal portion of each plot near the origin represents the best performance of the sensors used in the conceptual design.



NON-REPEATABILITY EFFECTS ON IMAGE QUALITY
2.2 MICRON, 50% ENCIRCLED ENERGY



NON-REPEATABILITY EFFECTS ON IMAGE QUALITY
2.2 MICRON, 85% ENCIRCLED ENERGY



NON-REPEATABILITY EFFECTS ON IMAGE QUALITY
10 MICRON, 50% ENCIRCLED ENERGY

Section 3
Effects of Harmonic Oscillations as a Function of Chopping Magnitude and Frequency

The chopping motion will produce harmonic oscillation of the secondary mirror. This "ringing" motion will smear the image and increase the effective image size. The amount of effective image enlargement is a function of the mechanical oscillation of the mirror. The oscillations are proportional to the maximum force required by the mirror articulation. The maximum force required will be determined by the chopping magnitude, the chopping frequency and the observing duty cycle. Image smear is calculated from the expression

$$\phi = b \bullet a \bullet \left(\frac{f}{1-d} \right)^2$$

where:

- ϕ is the effective enlargement of encircled energy diameter in arcsecond
- b is a coefficient for the particular wavelength and encircled energy percentage, $\frac{arc\sec ond}{arc\sec ond \bullet hz^2}$
- a is the chopping magnitude in arcsecond total
- f is the chopping frequency in Hz
- d is the observing duty cycle

Coefficients, *b*, are listed in the following table. They are the results of structural analysis for the telescope secondary support structure and the dynamic response of the positioning mechanism and the tip-tilt mechanism to unbalance in the mirror/tip-tilt combination. These responses are then combined with the deformation of the miff or due to accelerations experienced during chopping. These numbers were generated assuming force and moment cancellation of better than 98%.

Coefficients for Assessing Effects on Image Quality Due to Harmonic Oscillation				
wavelength	3µm	5µm	8µm	10µm
percent encircled energy	50%	50%	50%	50%
coefficient b	1.30054×10^{-6}	1.26907×10^{-6}	1.22836×10^{-6}	1.24857×10^{-6}

Image degradation due to harmonic oscillation as a function of chopping range and frequency is shown in the following graphs. This degradation only occurs in chopping operation and will change with chopping amplitude and frequency. All plots are for an observing duty cycle of eighty percent.

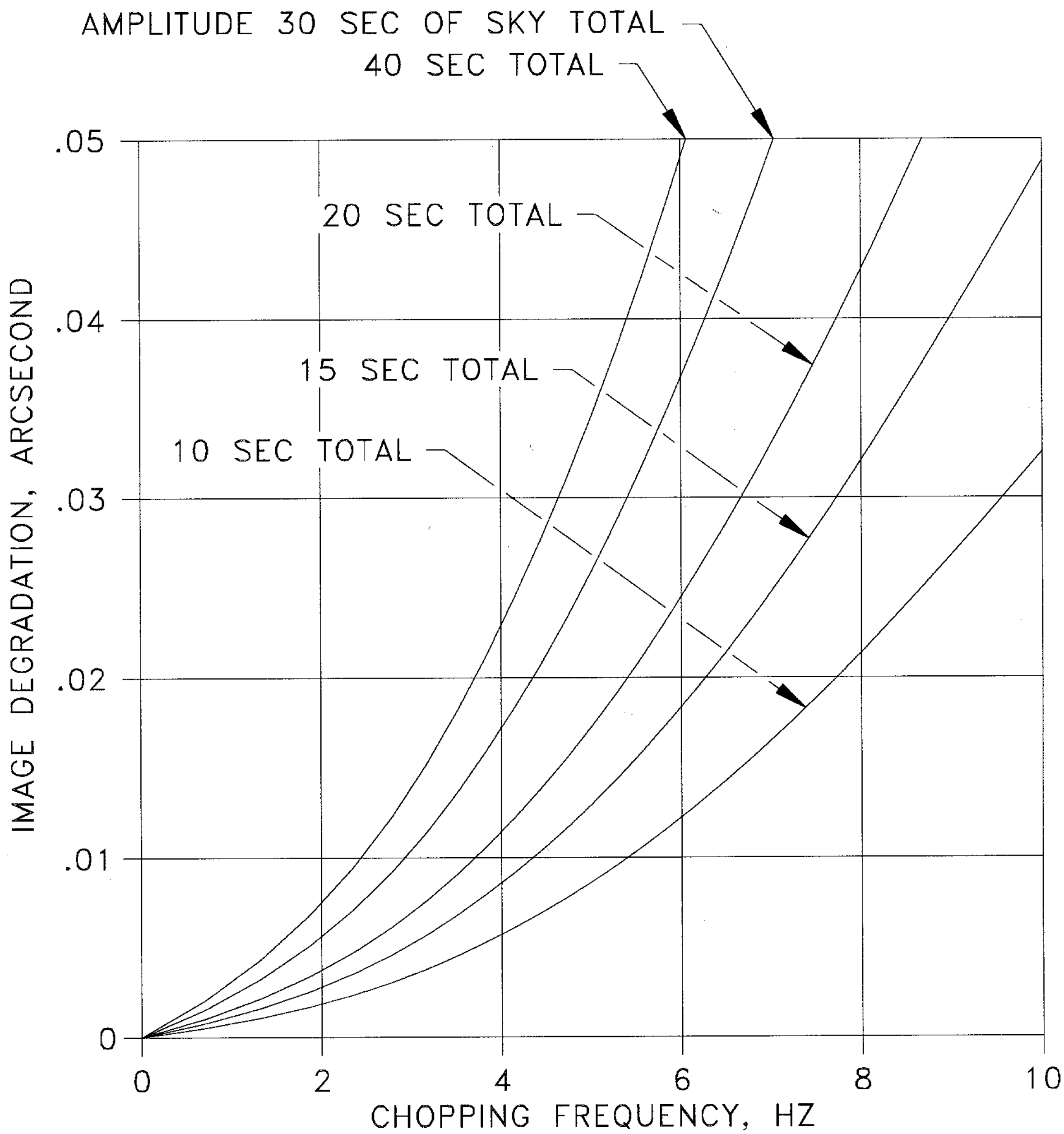


IMAGE DEGRADATION FOR 3 MICRON, 50% ENCIRCLED ENERGY
FOR CONSTANT AMPLITUDE AND DUTY CYCLE OF 80%

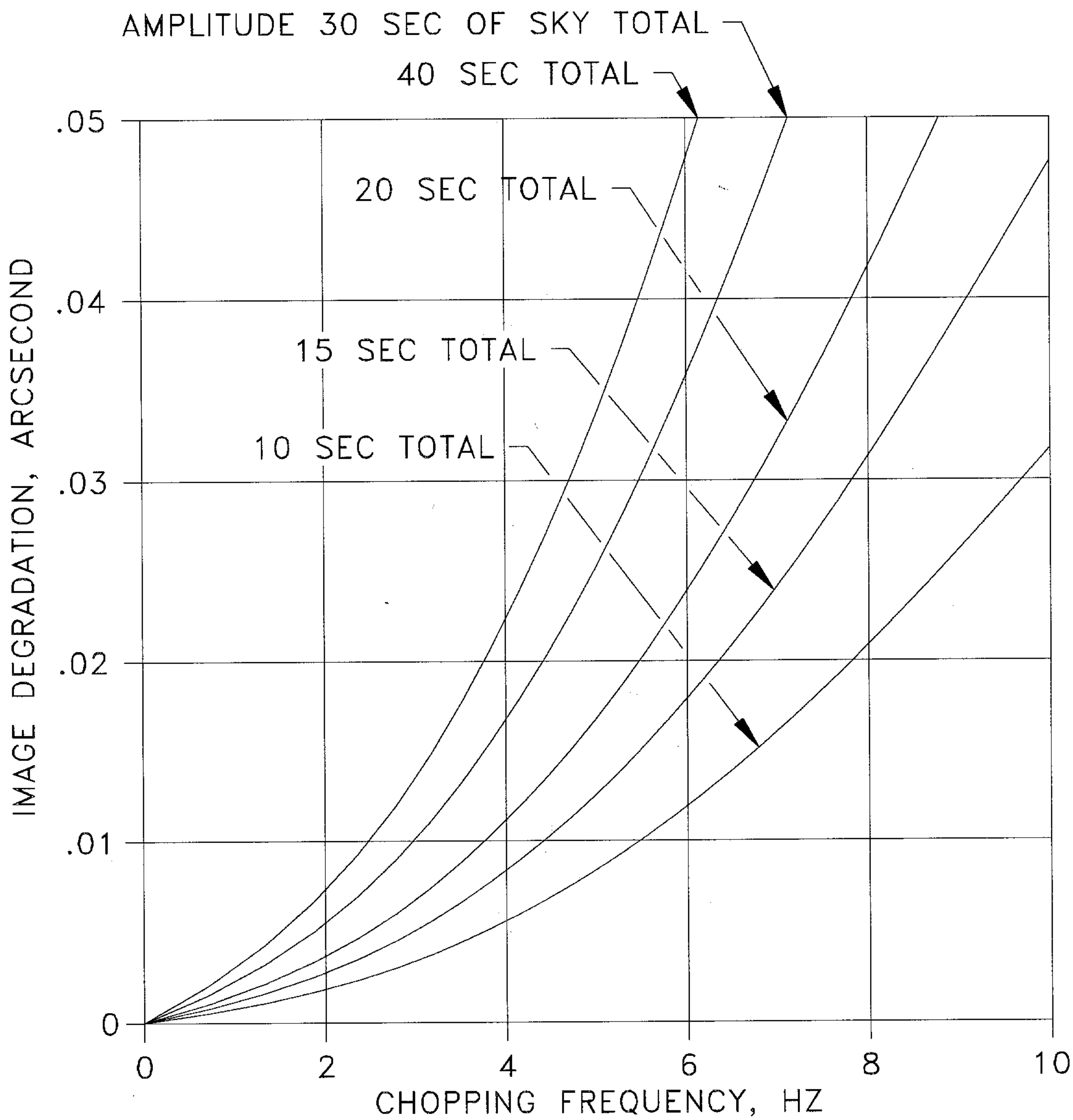


IMAGE DEGRADATION FOR 5 MICRON, 50% ENCIRCLED ENERGY
FOR CONSTANT AMPLITUDE AND DUTY CYCLE OF 80%

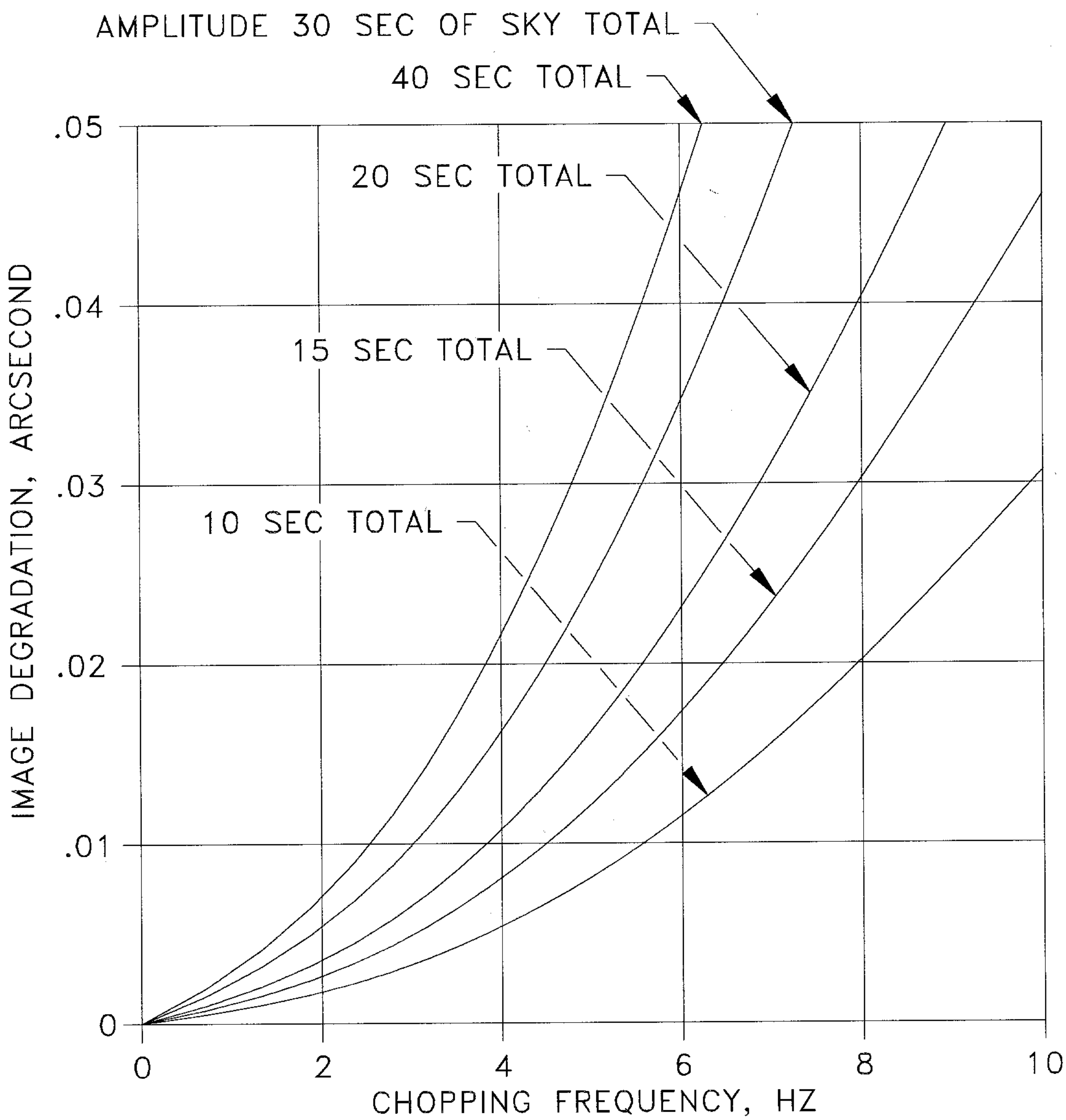


IMAGE DEGRADATION FOR 8 MICRON, 50% ENCIRCLED ENERGY
FOR CONSTANT AMPLITUDE AND DUTY CYCLE OF 80%

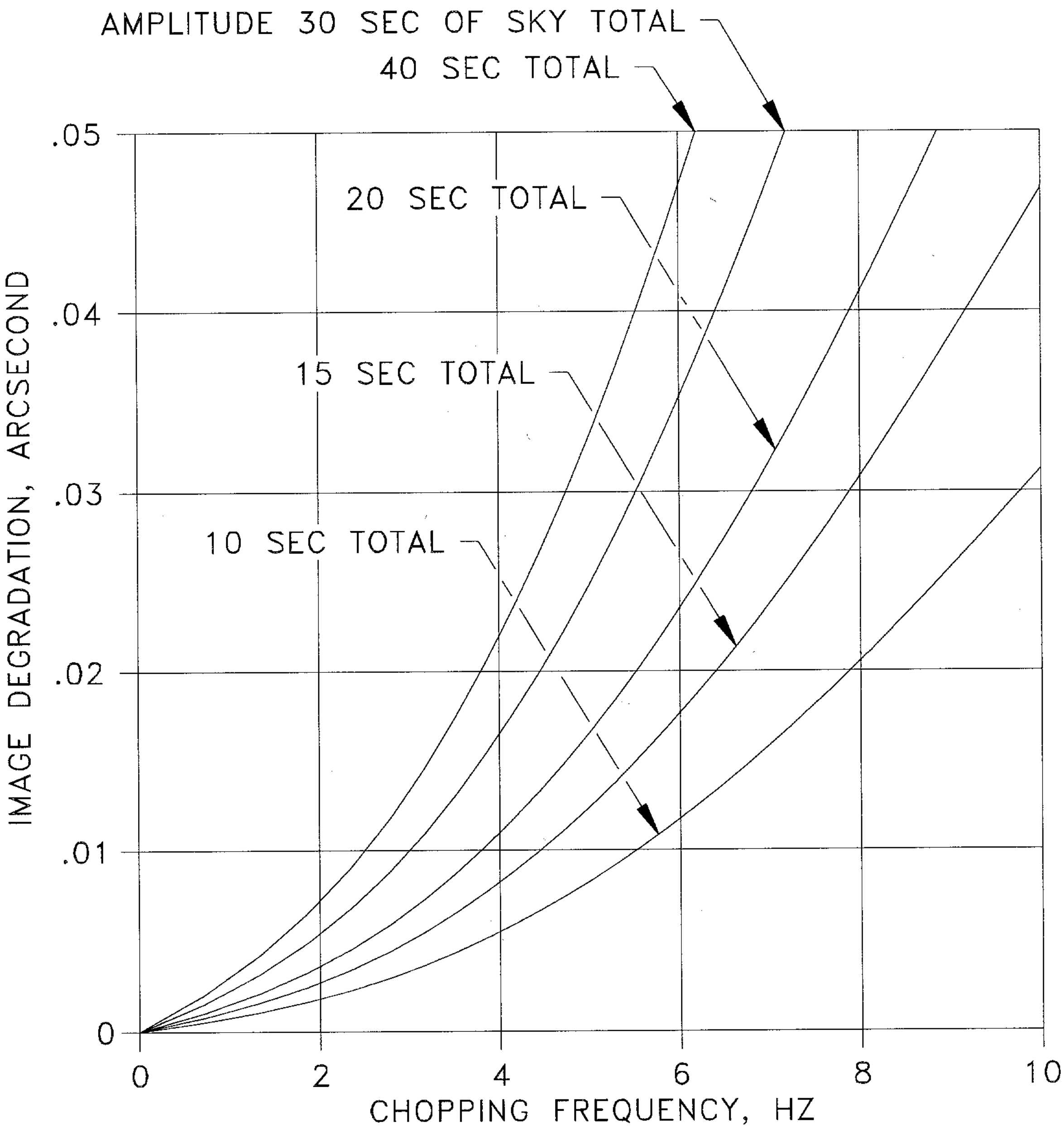


IMAGE DEGRADATION FOR 10 MICRON, 50% ENCIRCLED ENERGY
FOR CONSTANT AMPLITUDE AND DUTY CYCLE OF 80%

Section 4
OTHER CONSIDERATIONS

Power Requirements

The average power dissipated in the actuator coils of the tip-tilt mechanism during chopping operation is related to the chopping frequency, the chopping amplitude and the observing duty cycle. The maximum power allocation for the tip-tilt mechanism for any operations is fifty watts. The power dissipation may be approximated by

$$P_{avg} = b \bullet a \bullet \left(\frac{f^4}{(1-d)^3} \right)$$

where

P_{avg} is the average power in watts
a is the chopping magnitude in arcseconds sky motion total
f is the chopping frequency in Hertz
d is the observing duty cycle
b is a constant of proportionality, .1778 x10^{-6} $\frac{watts}{arc\sec ond^2 - Hz^4}$

Plots of the average power dissipation as a function of chopping magnitude and frequency follow. The graph is for an observing duty cycle of eighty percent.

Force Limit

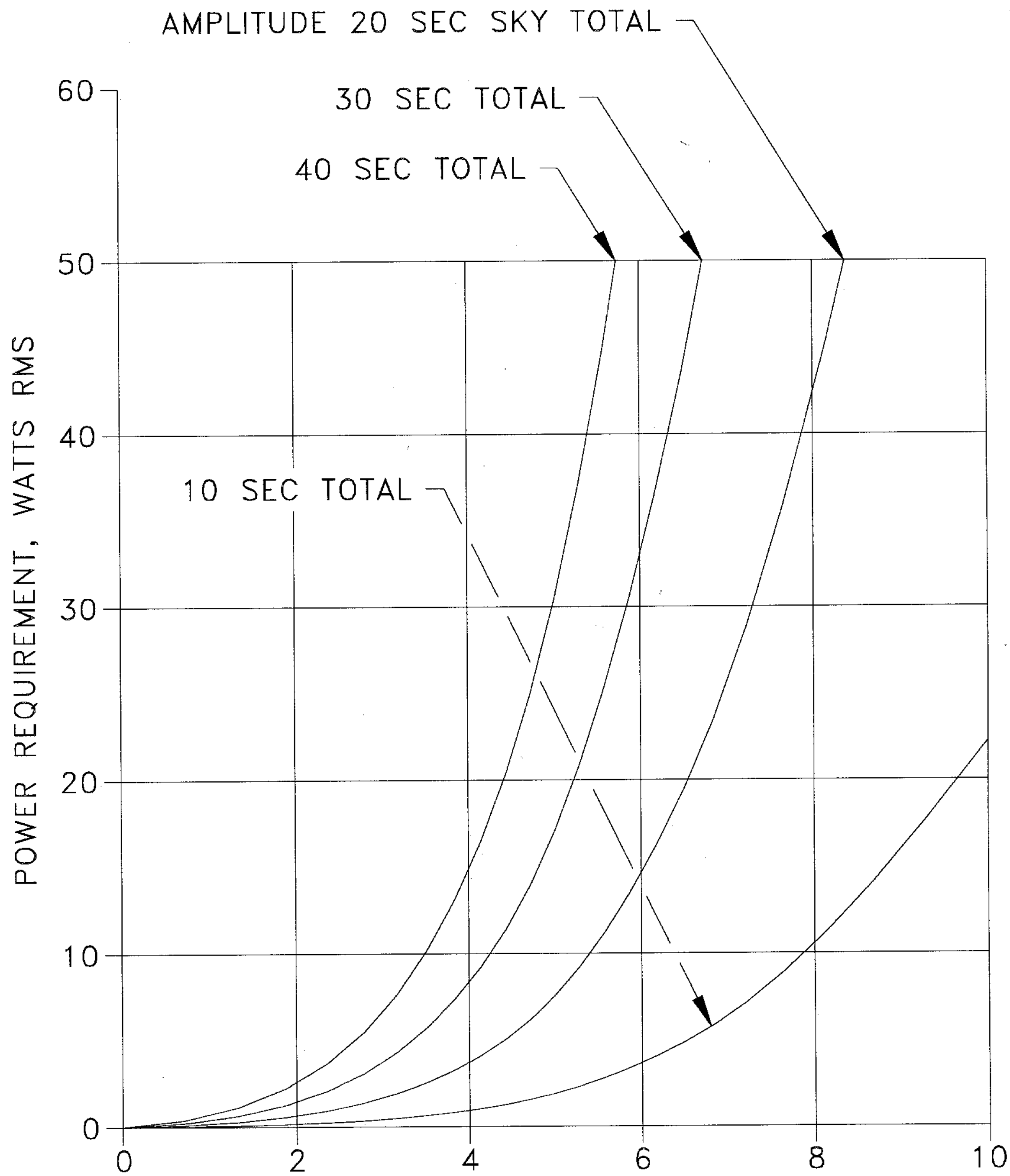
The conceptual design uses three voice coil actuators to articulate the mirror in the fast modes of operation. The maximum force rating of the actuators is 667 N. The force required for chopping may be calculated from the relationship

$$F = b \bullet a \bullet \frac{f^2}{(1-d)^2}$$

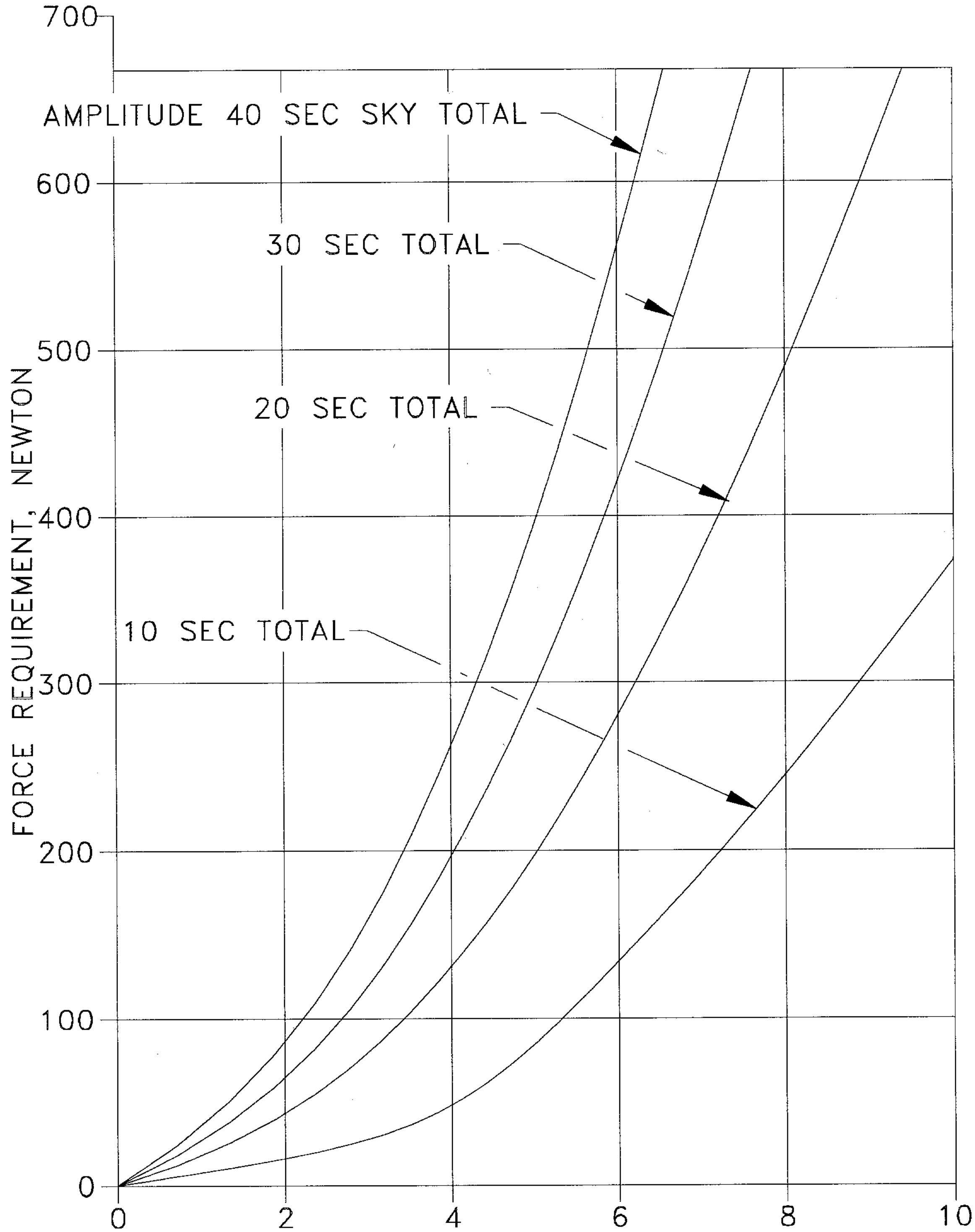
where

F is the maximum force required
b is a constant of proportionality, .0149333 $\frac{N}{arc\sec ond - Hz^2}$
a is the chopping magnitude in arcseconds of sky total
f is the chopping frequency in Hertz
d is the observing duty cycle

Plots of the maximum force required as a function of chopping magnitude and frequency follow. The graph is for an observing duty cycle of eighty percent.



AVERAGE POWER REQUIREMENT FOR CONSTANT AMPLITUDE
OBSERVING DUTY CYCLE 80%



MAXIMUM FORCE REQUIREMENT, CONSTANT AMPLITUDE
OBSERVING DUTY CYCLE 80%