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STELLAR ATTITUDE STUDY

MISSION 1010-1

5 February 1965

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ABSTRACT

The observed distortion of images in the J-system stellar photography have been analytically correlated with the scan phase relationship of the two panoramic instruments. It is concluded that the incomplete momentum balancing of these instruments, when combined with their unsynchronized operation, creates varying degrees of vehicle disturbances which can result in a panoramic image ground smear contribution of up to 4½ feet. It is further observed that the scan phase relations of the two instruments are so erratic as to warrant a complete review and improvement of the scan control system design.

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INTRODUCTION

Throughout the history of the J program there have been reports of distortion and double imagery in the stellar photography. These reports were generally attributed to a smear caused by the normal vehicle pitch rate, or to a double exposure resulting from a secondary opening of the stellar shutter when being "cocked." These somewhat superficial explanations failed to seriously relate these disturbances to potential panoramic image quality degradation, or to the sporadic resolution performance experienced both between separate frames and within individual frames of panoramic photography.

An analysis of the dynamics of the panoramic instrument[1] indicated a dynamic unbalance capable of imparting sufficient disturbance into the vehicle such as to create a potentially image-smearing rate of motion. This analysis was considered briefly, and was left unresolved pending "further analysis" by Boston. The concensus was generally that "... unbalance may contribute to, or be associated with, photographic degradation due to the resulting vehicle disturbances; even though present photographic results cannot be used as conclusive proof for this degradation."[2]

Not until mission 1010 (J-11) was the total effect of the unbalance disturbances realized. The cyclic disturbances of moving particles in successive stellar formats not only effectively demonstrated the phenomenon, but provided the clues to the photographic recording of the distortions. It then became evident that the displaced, or "double", images often encountered in the stellar photography were in reality actual image distortions created by vehicle movements in excess of the normal pitch rate (which, by itself, should create only an extremely minor image distortion). At last there was a rational explanation for the stellar imaging behavior, and there was visual evidence of the unbalance disturbances.

ANALYSIS

The complete mission 1010-1 stellar record was carefully analyzed for presence and magnitude of distortion. Several frames containing records of the moving particles mentioned above were inspected in detail, and the location, size and shape of all images observed were noted. The measured distortion of the images in successive frames were geometrically analyzed and compared with the dynamics of the panoramic instruments at the corresponding time. The rate

1 [redacted] to [redacted] "Dynamic Unbalance in M, J Instrument System dated 3 June 1964.

2 [redacted] to [redacted] "Dynamic Unbalance in the M-J Instrument System", dated 6 July 1964

of motion and displacement profile of each distorted image was calculated, and found to be very directly related to the main instrument operation.

In order to positively verify the correlation of image motion with panoramic instrument operation, the magnitude of distortion in each of the stellar frames was compared with the phase relationships of the two scan arms. These comparisons were plotted both in a distortion frequency distribution as a function of phase angle, and in a sequential pattern of phase angle and distortion as functions of time (i.e., panoramic frame number) showing overall trends of instrument operation and accompanying distortion.

CONCLUSIONS

The detailed attitude analysis study shows a very distinct correlation of the observed vehicle pertubations with the predicted performance.[3] Maximum rates of vehicle motion were measured to be approximately 300 degrees per-hour, which is sufficient to create a panoramic image degradation of the order of $3\frac{1}{2}$ to 4 feet of smear with exposure times of 1/300 to 1/250 second. In establishing this basic conclusion, the following characteristics and analytical findings were observed:

1. There is a very distinct correlation between the observed occurrence of stellar distortion and the phase relationship of the two panoramic instruments. The stellar images were consistently grossly distorted at phase relationships of $+70^\circ$ to $+100^\circ$ (forward instrument leading the slave) and again, but to a lesser magnitude, at -70° to -100° (forward instrument lagging behind the slave). The explanation of the reduced distortions when the instruments are 180° out of phase is not readily apparent, but is believed to be a result of the deviations of the actual instrument operation profile from the theoretical.

2. The shape and proportional magnitude of the large distorted images observed correspond to the cyclic motion and rates of the panoramic instrument operations. The two second exposure time of the stellar instrument recorded approximately 90% of a full panoramic instrument operation cycle (about 2.2 seconds per cycle), graphically indicating the resultant vehicle motions.

[3] [redacted] op. cit.

3. The maximum angular displacement of the vehicle, creating the image distortion, was determined to be of the order of $4\frac{1}{2}$ to 5 minutes of arc, achieved in approximately 900 milliseconds. This rate of displacement is in excess of 300 degrees per hour, which can be degradable to panoramic image quality; however, since the resulting absolute displacement is well within the vehicle attitude control system dead-band, no overall vehicle reaction to these motions would be expected unless the vehicle has drifted to the edge of the control dead-band.

4. There is evidence of larger, but much slower, pertubations induced into the vehicle. The correcting action of the vehicle attitude control system appears as a reversal in direction of the successive displacements as the cumulative motion exceeds the control dead-band. The attitude errors about the pitch axis are not easily discernable inthe stellar photography, whereas the significant roll and yaw errors observed are very readily evident for analysis.

5. The variations of panoramic instrument scan rates with control (proportional V/H) voltage varies between the two instruments to the extent that the trends in the sean phase relationships will actually reverse (sometimes more than once) during continuous operation. It is quite common to find one instrument running faster than the other, constantly increasing the phase angle between them, but before the end of the sequential operation it will actually be running slower than the second, the accumulated phase relationship being diminished.

6. The large images observed in several of the stellar formats are moving particles, possibly self-luminous, which can be tracked through consecutive frames. The particles appear to be completely independent, each moving at a velocity and in a direction differing from any of the others. Only the velocity components in the image plane could be determined; the apparent velocity of each of the particles was steadily increasing with consecutive frames (i.e., accelerating).

DISCUSSION

The theoretical analysis of M and J instrument system dynamic unbalance by [redacted] in June 1964 illustrated the potential vehicle motions, and accompanying image degradation, that could be induced by the lack of full momentum balancing of the instruments drums. The mission 1010-1 stellar record provided a source of empirical data by which the actual effects of the characteristic momentum imbalance in an actual flight could be determined and compared with the predicted theoretical performance. The distorted images contained in the 1010-1 record provided a general verification of [redacted] analysis, even though there are some areas of explanation that are not adequately documented with useable empirical data to understand completely.

Stellar Frames 8 - 14

Several frames near the beginning of the mission included smeared records of moving particles. These particles were shown to be traveling in a straight line across the image plane by plotting the relative image movement from successive frames in which the traces were observed. Stellar frame numbers 8 through 14 contained a large sampling of these particle traces, as well as several distinct star images. Both the stellar images and the particle traces show varying degrees of distortion; appearing as "double-image" smears for the stars, and as lateral displacements of the particle from its straight velocity vector. The images observed in frames numbered 8 through 14 are plotted on a common format in Figure 1.

By simple analytical geometry, it was found that the direction and magnitude of the distortion of the stellar images were in agreement with the resultant lateral displacement component of the more complex particle trace distortion. Or, more simply, the distortion of the particle trace is of the same magntiude and direction as that of the stellar images. From this analysis, it was determined that the maximum displacements were of the order 4½ to 5 minutes of arc, consisting of approximately 4½ minutes of arc in the vehicle roll directio and 1 or 2 minutes of arc in the vehicle yaw direction. The rates of this cyclic motion was observed to be somewhat greater in one direction than in the other, the more rapid rate requiring approximately 0.85 seconds to move through the 4½ minutes of arc for an average angular velocity in excess of 300 degrees per hour. This observed maximum velocity agrees with [redacted] analytical predictions.

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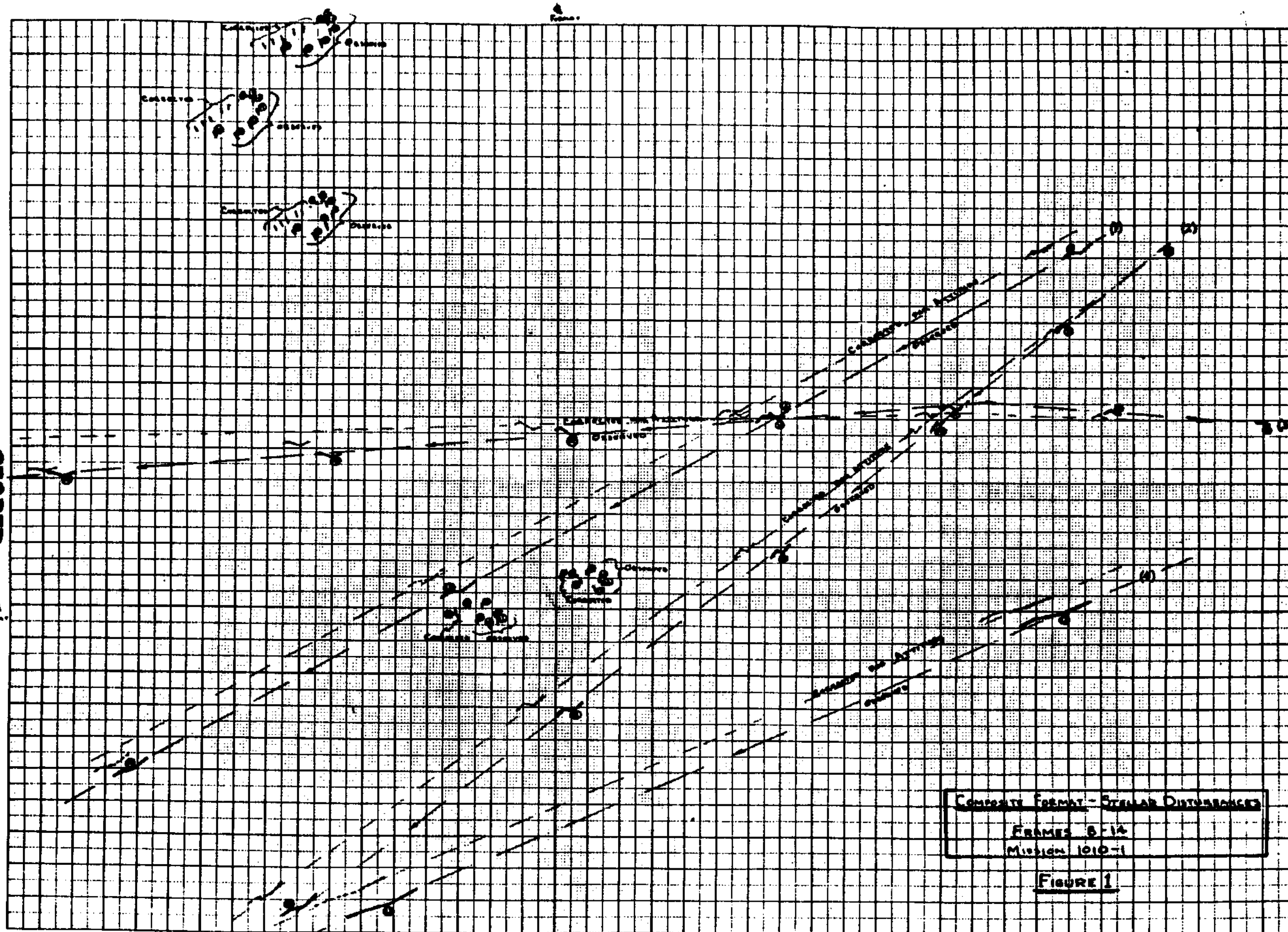

Figure 1

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In making this analysis of the distortions, it was observed that the particle traces appear to be accelerating. This may be merely a geometrical phenomenon associated with the particles approaching the vehicle, or may be something far more complex, such as an accelerating force created by a reaction of materials in the particle mass, or an "outgassing" or degradation of the mysterious particle's material.

It is suspected that these same types of particles are the source of the so-called "light-leak" streaks appearing in the stellar photography sporadically throughout the mission. Detailed examination of these large, blurred streaks reveals that these too have an apparent lateral displacement in agreement with the accompanying distortion of the stellar images in the respective frames. If the particles were very close to the vehicle, they would be recorded as quite large, blurred (out of focus) streaks, moving across the image plane at a very high rate; these, indeed, are the characteristics of the randomly occurring streaks.

Phase Angle Correlation

Each of the frames of stellar photography from mission 1010-1 were reviewed, and a relative evaluation of distortion estimated. The distribution of image disturbances is shown in sequencial order for the entire 1010-1 mission on Figure 2a. Also, shown in Figure 2 are plots of the relative phase relationships between the two main instruments, determined from the time words actually recorded on the mission panoramic photography. The rates of change, the reversing of the phase change trend, and the correlation between the phase relationship and image distortion are evident from these curves.

In order to more fully illustrate the correlation of image distortion with the instruments' phase relationships, the respective values from Figure 2 were replotted in Figure 3a, showing estimated relative distortion as a direct function of the phase relationship. As an alternate approach, the frequency distribution of only the medium and large disturbances were plotted also as a function of the phase (Figure 3b). The distinct similarity between the two curves in Figure 3 very strongly reinforces the direct correlation of these observed distortions with the dynamic operation of the panoramic instruments.

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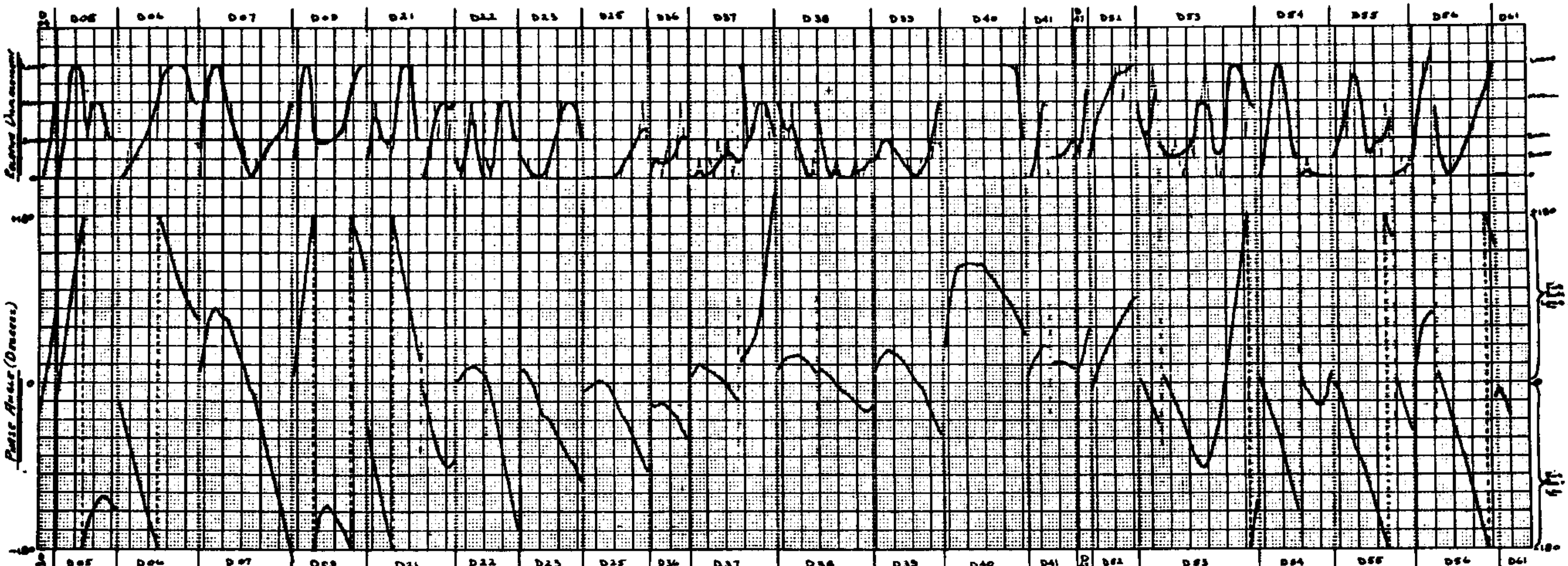

Figure 2

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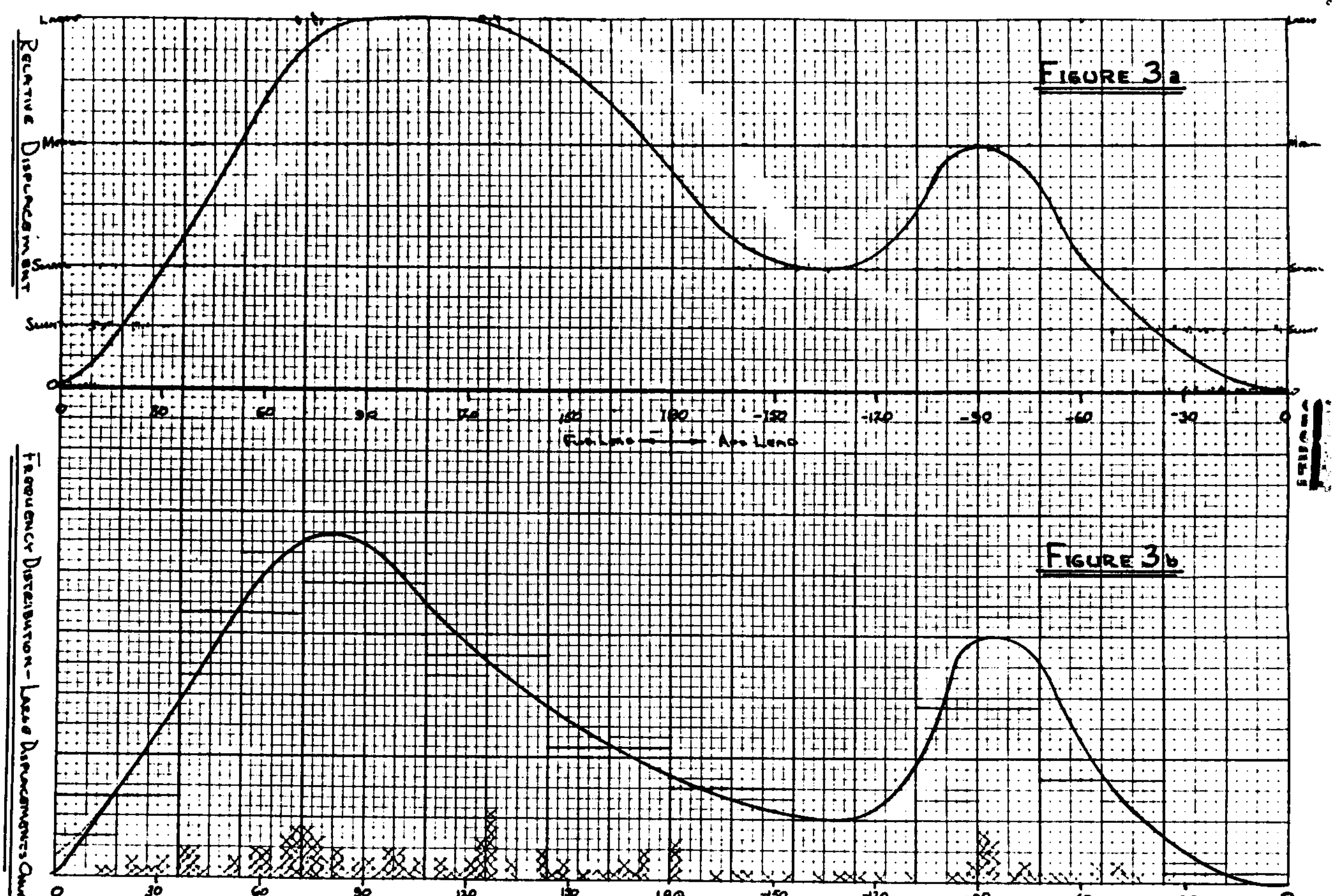

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Although no general conclusion is drawn at this time, one might venture to speculate on the significance of the profile of curves in Figure 3. The hint of symmetry with the two peaks of distortion at +75° to 100° and -75° to -100° respectively, plus the decrease in distortion as the instruments become directly opposed (180° out of phase), presents a minor mystery which will require even further empirical investigation to explain confidently. An analysis of the geometric relationships of the two scan arms shows that the maximum combined momentum imbalance occurs when the phasing is such that one instrument is just completing a scan as the other is just starting. This occurs when the instruments are approximately 80 to 100 degrees out of phase with each other (both directions). A series of plots showing the theoretical net combined unbalanced momentum imparted into the system for several representative phase relationships are presented in Figure 4.

It might further be reasoned that one instrument has in reality a greater degree of momentum balancing than the other, thus not only contributing to the lopsided distribution, but also offering some additional explanation of the predominantely one-direction occurrence (in Yaw) of the observed distortion velocity vector. Other contributing possibilities might be the varying extent of deviation of the scan dynamics from the theoretical (which has been demonstrated several times by [redacted], and the tendency for the vehicle to have greater inertia in one direction of motion than in another (such as might result from induced minute gyroscopic effects). The detailed investigation of these characteristics is beyond the intention of this report, but should definitely be studied further.

General Observations

The observations and analyses of the stellar image distortion correlation wit panoramic instrument operation generally substantiate the analytical predictions, but also indicate a need for an even better understanding of the actual instrument dynamics. In review, these general observations were:

A. The cycle rates of the two instruments appear to be significantly inconsistent with respect to each other. The differences in rate from one to the other varies not only from pass to pass, but also within a pass. The variations in sequential scans within one pass are so extensive that the relative scan rates actually reverse (more than once in some passes). Note these relationships on the plots shown in Figure 2.

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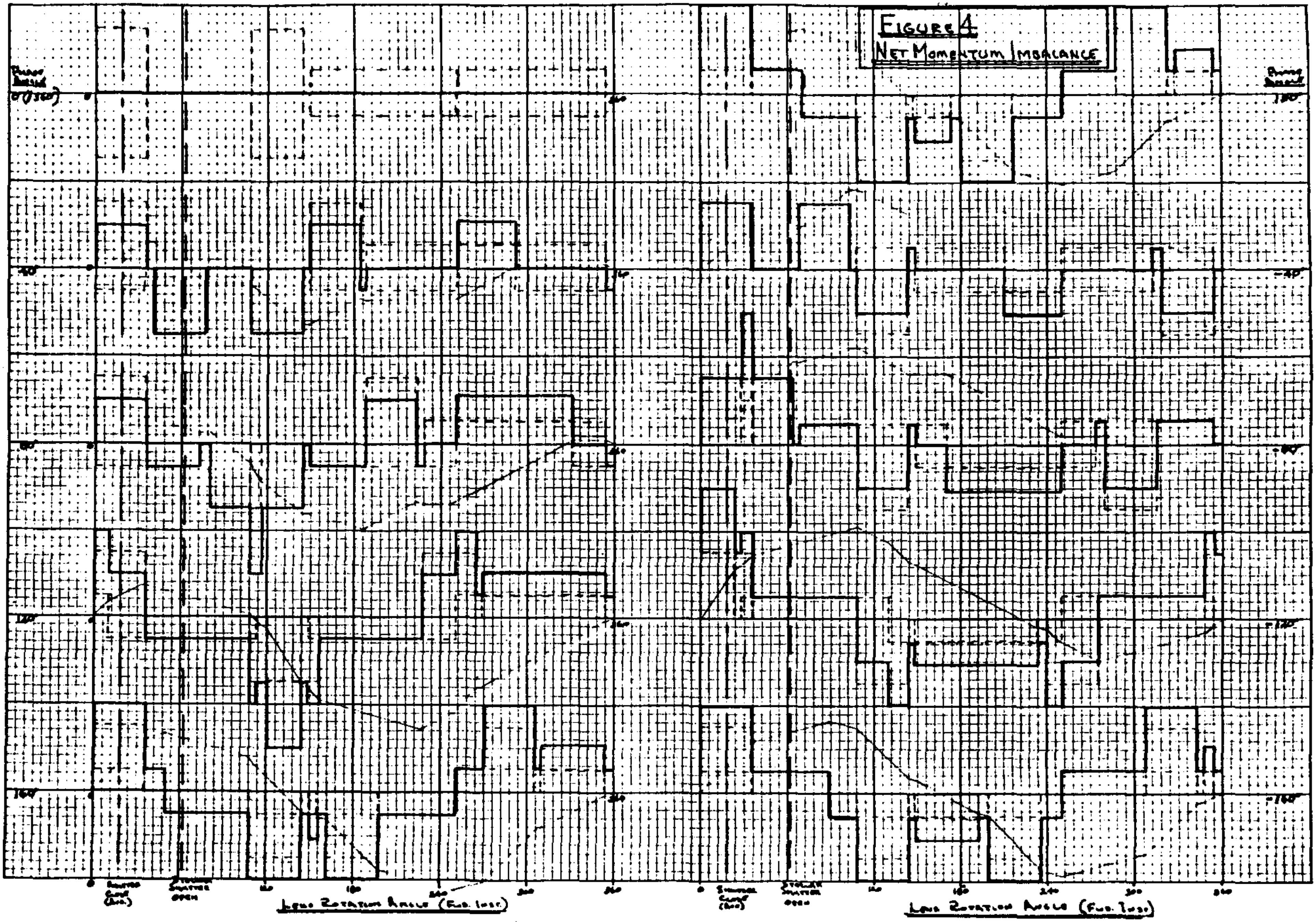

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B. The distortions of the stellar images correlate very directly with the scan phase relationships (i.e., momentum imbalance) of the two panoramic instruments. Peak distortions occurred most frequently at phase angles of approximately $+100^{\circ}$ and -100°, which are the relationships in which the deceleration of one scan coincides with the acceleration of the other. This effect could be accentuated by the suspected deviations of the actual scan velocity profile from ideal, and by the apparent variations in relative scan rates reiterated in A. above.

C. The magnitude of the distorted images is sufficient to cause significant contribution to image smear of the panoramic photography. Since the motion is cyclic, the contributions are additive to image smear created by earth rotation in one direction, but are counter acting it in the other. Thus, depending upon the net combined momentum imbalance and the resultant induced motion, the panoramic photography could have an enlarged apparent cross-track smear, no smear, or an apparent "reverse-crab" smear (i.e., when opposing disturbance is greater than earth rotation contribution). Since the maximum smear for each of the two contributors (crab and imbalance) is of the order of four feet for typical panoramic exposures, a constructive reinforcement could result in a total smear of eight feet, whereas a coincident contribution (destructive reinforcement) would result in zero smear.

In addition to these basic observations there are the many related observations and conclusions previously presented in this discussion, plus a few somewhat unrelated observations, the most interesting of which is the occurrence and behavior of the moving particles. Since this discussion has already described the observed velocities, distortion, acceleration, size and relative distance of these particles, no further comments will be presented here, except a suggestion that these particles be investigated further (on other missions) to determine if there is any scientific significance to their existence, character (illumination and behavior.

RECOMMENDATIONS

From the preceeding discussion of the observations and analyses of the vehicle dynamics, and the resulting image degradation, it is appropriate to suggest, or recommend, possible courses of action to fully resolve this important issue.

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A. The most obvious recommendation is a reiteration of previous recommendations that all instrument momentum imbalance be eliminated by either synchronizing the instruments with one another (at 0-degree phase angle), or by providing a precise 100% momentum balancing system. It is interesting to note that there has not yet been any action taken on the earlier recommendation, despite a valid technical justification (which is now reinforced with empirical observations). A secondary aspect of this recommendation would be the correction of the linearity of the scan arm during photography, an improvement also suggested in previous recommendations.

B. More practical for immediate action, it is recommended that the entire dynamics of the panoramic instrument be thoroughly investigated under precisely controlled laboratory conditions to obtain sufficient empirical data by which the observations discussed in this report might be completely understood. The net imbalance imparted to the vehicle as a function of phase and of cycle rate, etc., should be thoroughly measured empirically. This should be superimposed on the measured effects of the system non-linearities (i.e., deviations of actual scan arm velocities from theoretical profile) and discrepancies in relative cycle rates for the two instruments. The ultimate recommendation to satisfy the questions raised by this report would be the natural consequence of the suggested empirical investigation.

C. The incorporation of yaw programming will preclude the addition of the earth rotation and imbalance effects and result in the reduction of peak smear factors. This solution will however result in the loss of the subtractive effect where the earth rotation and imbalance are of opposite sign.

Distribution:

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