Air War College

AIRBORNE OPTICAL TRACKING

RESEARCH REPORT

No. 77 By Kingdon R. Hawes

AIR WAR COLLEGE
AIR UNIVERSITY
UNITED STATES AIR FORCE
MAXWELL AIR FORCE BASE, ALABAMA

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REPORT NO. 77

AIRBORNE OPTICAL TRACKING

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AIR WAR COLLEGE RESEARCH REPORT SUMMARY

NO. 77

TITLE: AIRBORNE OPTICAL TRACKING

AUTHOR: Kingdon R. Hawes, LT. Colonel, USAF

The Air Force has a mission which requires airborne photography of a high speed moving target. Optical data is collected with several different types of cameras simultaneously by using a servo system and electro-optical tracker. This report deals with the problem of tracking accuracy between the tracking sensor and recording cameras. Tracking problems of the RC-135S (Rivet Ball) are identified and two alternative solutions are proposed. One proposal is to engineer a modified servo system with fewer moving parts that will reduce tracking errors to an acceptable limit. The second proposal is to mount the cameras in a stationary position and use periscopes mounted on top of the fuselage.

BIOGRAPHICAL SKETCH

Lieutenant Colonel Kingdon R. Hawes has sixteen years of operational experience in the field of electronic warfare. Operational assignments include strategic bombing (B-52), strategic reconnaissance (RC-135S), and tactical reconnaissance (EB-66). Colonel Hawes has 4000 hours of flying experience and held staff positions at squadron, wing, and headquarters level. His most recent staff position was as Headquarters SAC as a reconnaissance/operations and training inspector for the Inspector General. Colonel Hawes has more than two years experience with the RC-135S (Rivet Ball) program as a crew member and was responsible for writing the first classified technical operators manual on RC-135S airborne optical tracking systems. He is a graduate of the University of Nebraska Omaha (management), Squadron Officers School, Air Command and Staff College, Air War College, and holds a certified Airframe and Powerplant license (FAA no. 1434489) from the Academy of Aeronautics.

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CHAPTER I

INTRODUCTION

Background

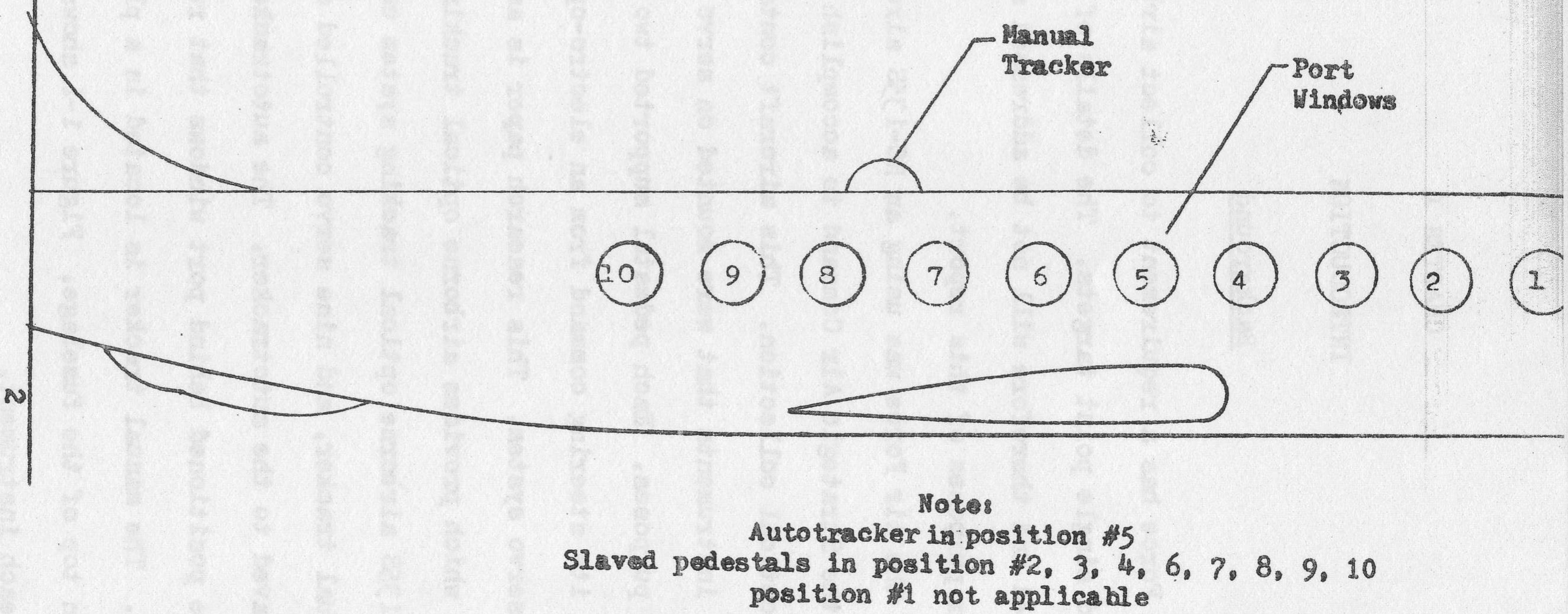
The Air Force has a requirement to collect airborne optical data on high speed single point targets. The details of this requirement are classified and therefore will not be addressed since it is not necessary for purposes of this report.

In 1969 the Air Force was using an RC-135S aircraft (Rivet Ball) assigned to the Strategic Air Command to accomplish its unique mission of airborne optical collection. This aircraft contained several primary optical instruments that were mounted on servo driven pedestals for tracking purposes. Each pedestal supported two optical instruments and received its steering command from an electro-optical autotracker by way of a servo system. This research paper is an analysis of the servo system which provides airborne optical tracking.

The RC-135S airborne optical tracking system consists of an autotracker, manual tracker, and nine servo controlled camera pedestals which are slaved to the autotracker. The autotracker and slaved pedestals are positioned behind port windows that run the length of the fuselage. The manual tracker is located in a plastic dome which is mounted on top of the fuselage. Figure 1-1 shows the relative position of each instrument.

The manual tracker is a modified B-50 gunsight (12:3). This tracker position is manned by an operator who sits directly beneath the

Figure 1-1
RC-135S Profile Position



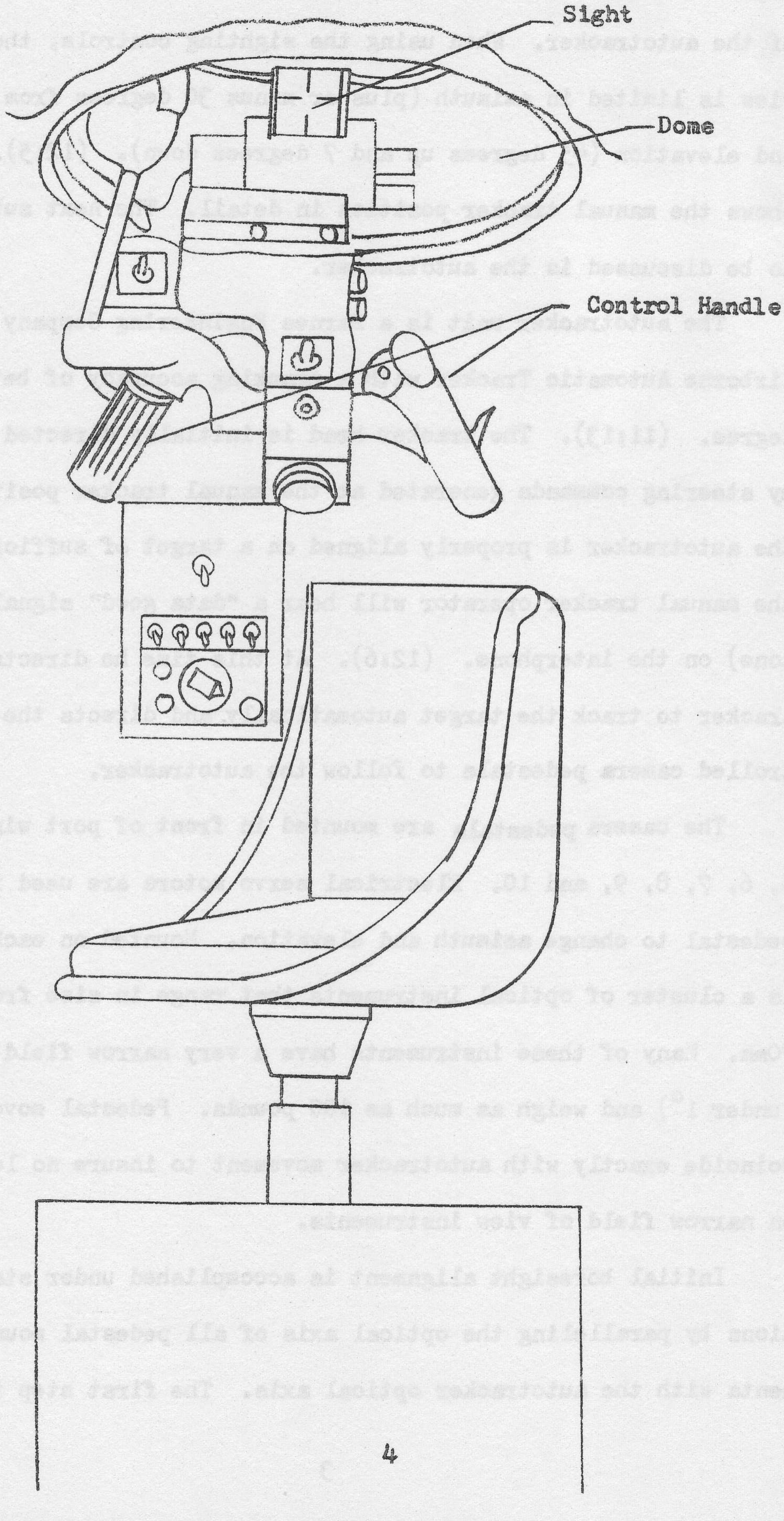
observation dome. The sighting controls mounted within the dome are used by the operator for target acquisition and directional control of the autotracker. When using the sighting controls, the field of view is limited in azimuth (plus or minus 30 degrees from starboard) and elevation (45 degrees up and 7 degrees down). (12:5). Figure 1-2 shows the manual tracker position in detail. The next sub-system to be discussed is the autotracker.

The autotracker unit is a Barnes Engineering Company Model 21-122 Airborne Automatic Tracker with a tracking accuracy of better than 0.1 degree. (11;13). The tracker head is initially directed on target by steering commands generated at the manual tracker position. When the autotracker is properly aligned on a target of sufficient energy, the manual tracker operator will hear a "data good" signal (50 cps tone) on the interphone. (12:6). At this time he directs the autotracker to track the target automatically and directs the servo controlled camera pedestals to follow the autotracker.

The camera pedestals are mounted in front of port windows 2, 3, 4, 6, 7, 8, 9, and 10. Electrical servo motors are used for each pedestal to change azimuth and elevation. Mounted on each pedestal is a cluster of optical instruments that range in size from 16mm to 70mm. Many of these instruments have a very narrow field of view (under 1°) and weigh as much as 100 pounds. Pedestal movement must coincide exactly with autotracker movement to insure no loss of data on narrow field of view instruments.

Initial boresight alignment is accomplished under static conditions by paralleling the optical axis of all pedestal mounted instruments with the autotracker optical axis. The first step in this pro-

Figure 1-2
Manual Tracker Position



cedure is to align the pedestal mounted instruments with each other on their respective pedestals. This is accomplished by sighting through the optics with a boresight lens and making appropriate adjustments to each mount. When this step is complete, the instrument cluster may be aligned with the autotracker by making appropriate adjustments to each pedestal servo system. When boresighting is completed, all instruments are accurately pointed at one stationary target.

Problem

The servo controlled pedestals have a history of not following the autotracker with sufficient accuracy and reliability to insure collection of optical data on narrow field of view instruments. This problem was of such a magnitude that replacement aircraft (RC-135S, Cobra Ball) was equipped with only one tracking instrument. This restriction severely reduces the range of optical data which can be collected. The problem of tracking multiple instruments to one autotracker is the subject of this study.

Objective

The objective of this report is to analyze the RC-135S servo tracking system for possible modifications or alternatives that might provide the necessary tracking accuracies needed in developing future airborne optical tracking platforms that use more than one instrument. The complexity of this problem coupled with limited data and time impose several limitations.

Limitations

The limitations placed on this research study are:

1. Analysis is limited to optical tracking problems of the

RC-135S (Rivet Ball) aircraft between the autotracker head and servo controlled instrument pedestal.

2. Attention is focused on the servo system for slaved pedestals #4, #10, and autotracker position #5.

3. The electrical and mechanical functions of the synchro follow-up assemblies are studied in detail.

4. Measurements for tracking accuracy are made under static conditions with aircraft on ground power.

5. Servo tracking problems are limited to elevation only due to availability of measuring equipment.

6. Proposed design changes and concepts are theoretical and beyond the author's capability to prove.

Because of the above limitations, certain assumptions must be made.

Assumptions

There are four assumptions made in this study. Each assumption is followed by support based on standardization of all slaved pedestals.

1. Tracking problems in elevation can apply to azimuth since the synchro follow-up assemblies, servo amplifiers, and servo motors are identical for all pedestals.

2. Tracking problems between pedestals #4, #10, and autotracker position #5 can apply to slaved pedestals #2, #3, #6, #7, #8, and #9. These additional pedestals are identical in electrical and mechanical operation.

3. Tracking errors will be essentially the same under static and dynamic conditions. This assumption excludes the effects of pedestal

lag and overshoot. The electrical input and mechanical configuration of all slaved pedestals are the same for both static and dynamic conditions.

4. The two servo amplifiers for each pedestal may be connected in parallel and driven by one control transformer without degrading tracking accuracy.

The assumptions listed above are only applicable to the RC-135S (Rivet Ball) optical tracking system. The sources of data will now be covered.

Sources

The primary source of data is based on the experiences and observations of the author while assigned to the RC-135S (Rivet Ball) project. Engineering support and guidance was also provided by the following individuals:

1. Mr. John V. Tumas (Optical Systems Engineer), Electro Optics section of Ling Tempco Vought Electro systems (LTVE), Greenville, Texas.

2. Mr. Douglas Prince (Electrical Engineer), Electronics section of LTVE, Greenville, Texas.

3. Mr. Joseph Zufall (Physicist), TDDCO, Foreign Technology Division, Wright Patterson AFB, Ohio.

Additional references were obtained from the Air University Library.

Organization

The body of this report consists of six chapters. Chapter Two identifies the servo tracking path between autotracker and pedestals. Chapter Three identifies the tracking error problem in detail and points out the cause. Chapter Four proposes some modifications that would reduce tracking error considerably. Chapter Five is the author's proposal of a radically new concept in tracking that uses periscopes and stationary instruments. The last chapter presents the author's conclusions and recommendations for improved tracking.

CHAPTER II

SERVO TRACKING PATH

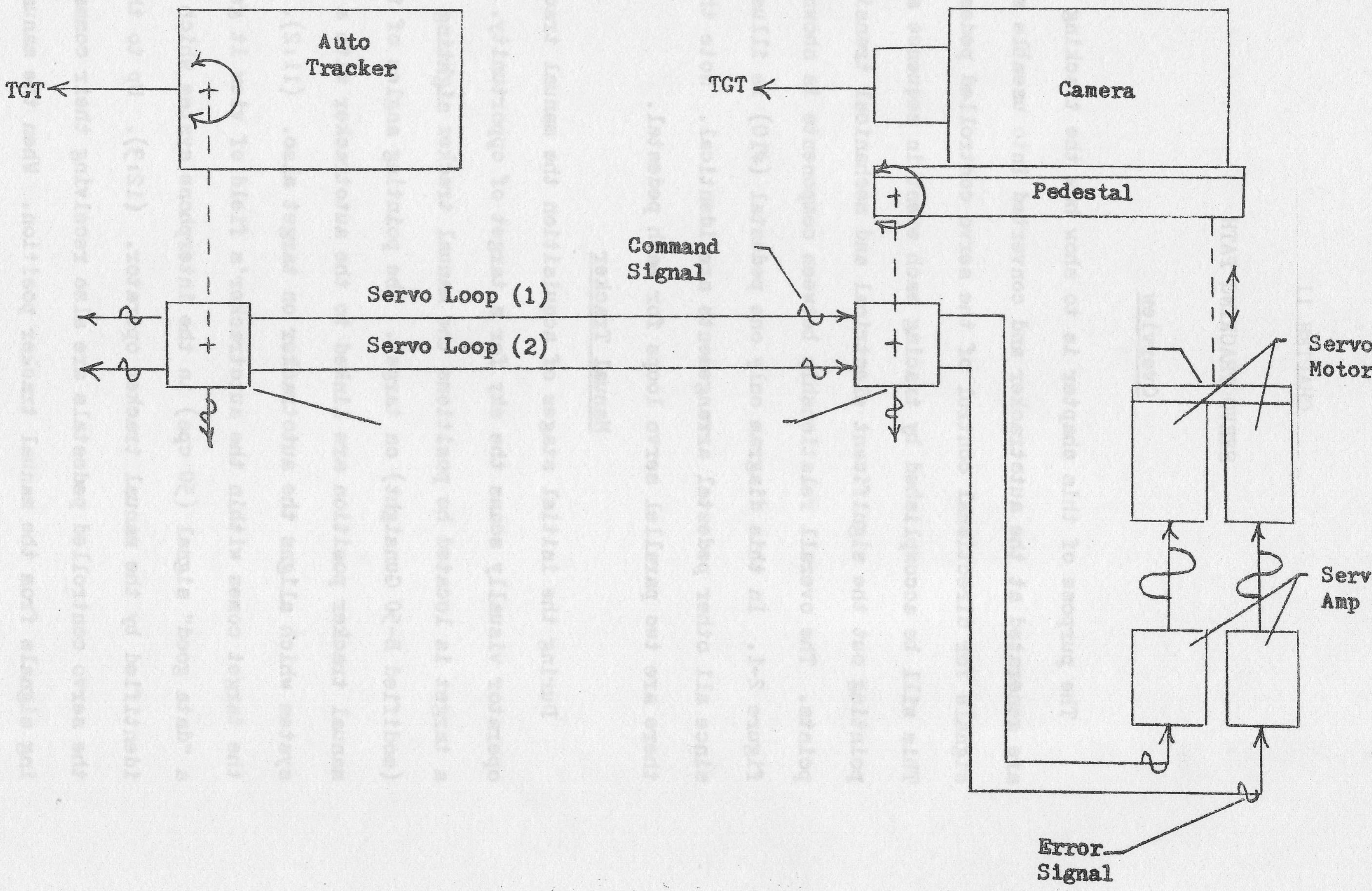
Overview

The purpose of this chapter is to show how the tracking signals are generated at the autotracker and converted into useable steering signals for directional control of the servo controlled pedestals. This will be accomplished by tracing each event in sequence and pointing out the significant electrical and mechanical transition points. The overall relationship between components is shown in figure 2-1. In this diagram only one pedestal (#10) is illustrated since all other pedestal arrangements are identical. Note that there are two parallel servo loops for each pedestal.

Manual Tracker

During the initial stages of acquisition the manual tracker operator visually scans the sky for a target of opportunity. When a target is located he positions the manual tracker sighting controls (modified B-50 Gunsight) on target. The pointing angles of the manual tracker position are linked to the autotracker with a servo system which aligns the autotracker on target also. (11:2). When the target comes within the autotracker's field of view it generates a "data good" signal (50 cps) in the interphone system which is identified by the manual tracker operator. (12:3). Up to this point the servo controlled pedestals are also receiving their command steering signals from the manual tracker position. When the manual tracker operator receives a "data good" signal, he depresses a button which allows the autotracker to track the target on its own and transfers

Figure 2-1
Servo System Block Diagram



steering control of the pedestals from the manual tracker servo system. (13:41). From this point on the cameras are directed by command signals from the autotracker position. Now for a detailed look at how this is accomplished.

Autotracker

Radiant flux from the target is collected by the optical system (Figure 2-2) and focused on a position encoding reticle assembly. (11:3). The rotating reticle modulates this signal in a manner determined by the location of the target in respect to the optical axis. The modulated signal is intercepted by one of two detectors and is converted into a modulated electrical signal. (11:2). This signal is interpreted by two electronic units that send appropriate correcting signals to the autotracker servo motors. The servo motors move the tracker head on target and maintain alignment within (0.1) degree. Any change in azimuth and elevation will be transmitted to slaved pedestals by a servo system. To understand how this system works a 10° change in elevation will now be traced from the autotracker to the pedestal.

Autotracker Servo System

Movement of the tracker head is transferred through a linkage to the synchro follow-up assembly which converts this angle into an electrical command signal for pedestal direction. The first step in this process starts at the autotracker elevation pivot point (reference Figure 2-3). A linkage, consisting of a connecting rod and two pivot arms, connects this point to a synchro follow-up assembly drive gear. (16:3). Five synchro control transmitter rotors (type EGC 11-FS-4) are connected to the drive gear. Both

Figure 2-2
Autotracker Optical Block Diagram

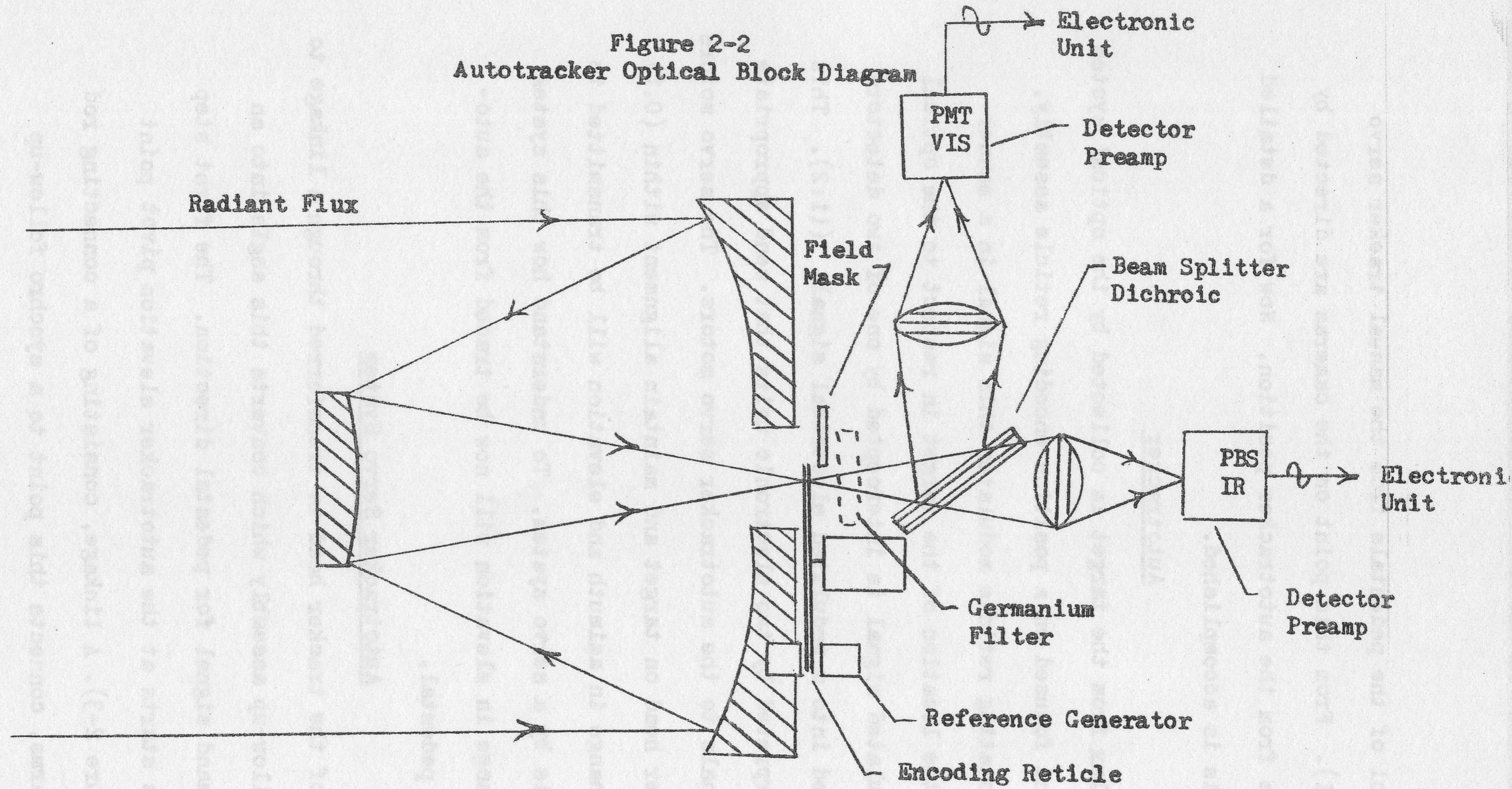
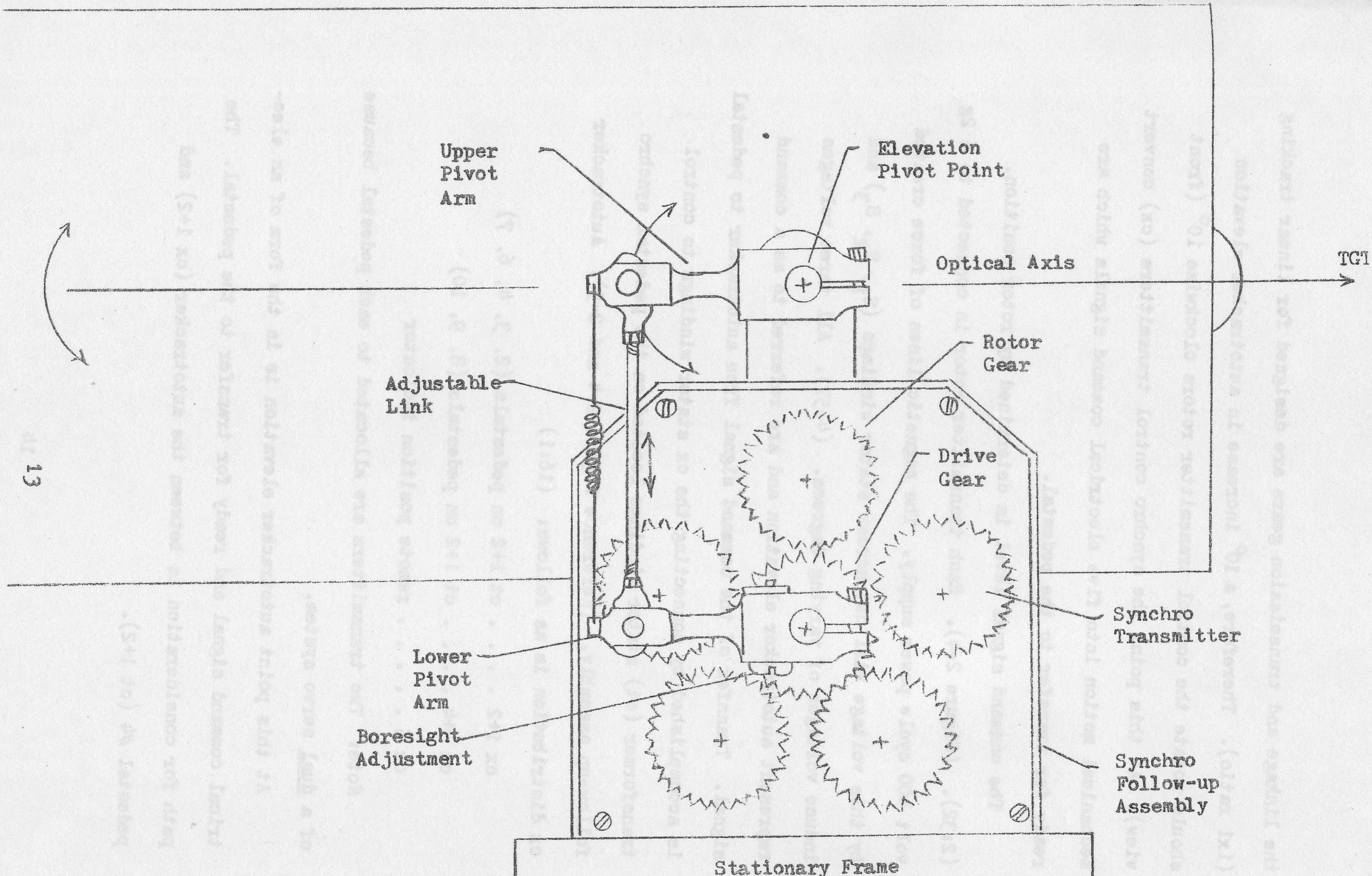


Figure 2-3
Autotracker Synchro Assembly



the linkage and transmission gears are designed for linear tracking (1x1 ratio). Therefore, a 10° increase in autotracker elevation should rotate the control transmitter rotors clockwise 10° (front view). At this point the synchro control transmitters (cx) convert mechanical motion into five electrical command signals which are ready for transfer to the pedestal.

The command signal level is determined by rotor position. (2:32). (Figure 2-4). Each transmitter rotor is connected to a 2g volt 400 cycle power supply. The magnetic lines of force created by this voltage will cut across stator windings (S_1, S_2, S_3) and induce voltages of varying degrees. (4:57). All three voltages represent autotracker elevation and are referred to as a command signal. Transfer of the command signal from autotracker to pedestal is accomplished by connecting the cx stator windings to control transformer (ct) stator windings located on the pedestal synchro follow-up assembly. (Reference Figure 2-4 and 2-5). Autotracker cx distribution is as follows: (16:1)

cx 1+2 . . . . ct 1+2 on pedestals (2, 3, 4, 6, 7)

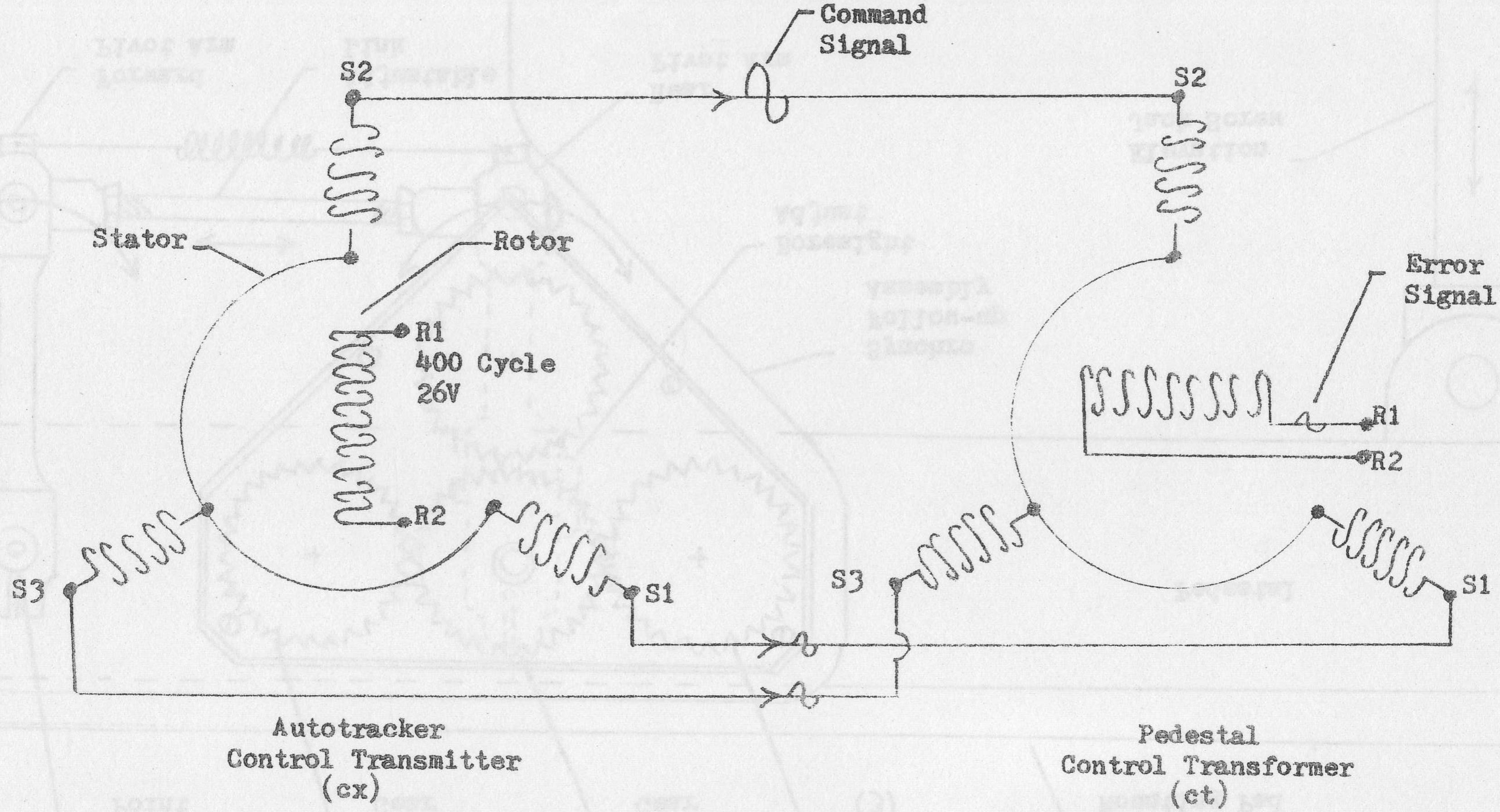
cx 3+4 . . . . ct 1+2 on pedestals (8, 9, 10)

cx 5 . . . . . remote position indicator

Note: Two transmitters are allocated to each pedestal because of a <u>dual</u> servo system.

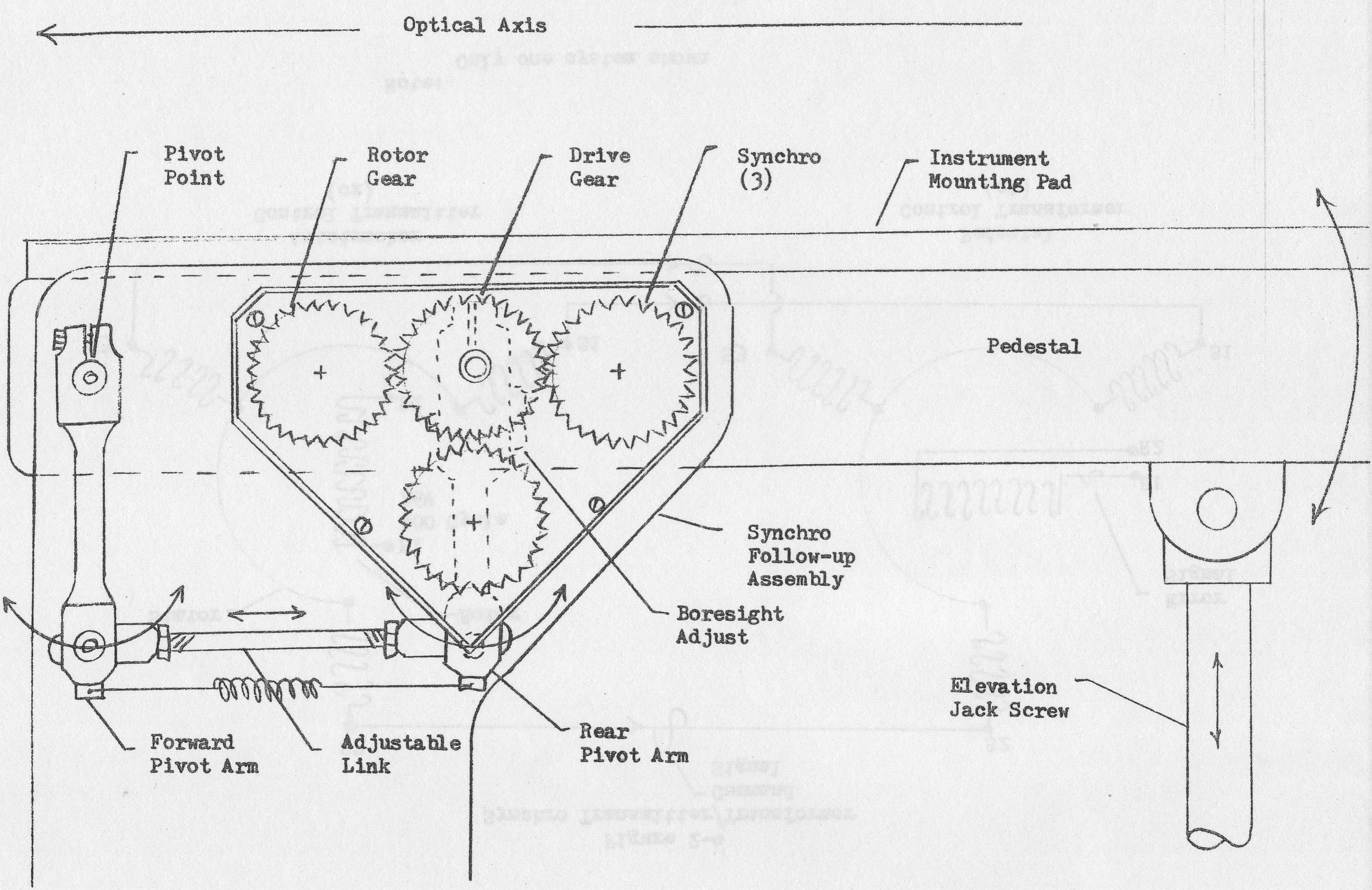
At this point autotracker elevation is in the form of an electrical command signal and ready for transfer to the pedestal. The path for consideration is between the autotracker (cx 1+2) and pedestal #4 (ct 1+2).

Figure 2-4
Synchro Transmitter/Transformer



Note:
Only one system shown

Figure 2-5
Slaved Pedestal Synchro Assembly



Pedestal

The autotracker command signals indicating a 10^{o} increase in elevation are impressed on stator windings of control transformers ct 1+2. This change in stator voltages induces an error signal into the ct rotors because of the angular difference between cx and ct rotors. (9:3). The equation below reflects this relationship. (3:38).

Er=Emr x cos θ

Er=control transformer rotor output (error voltage).

Emr=maximum control transformer rotor voltage

θ=relative angle separation of cx and ct rotors.

No matter what the values are, the ct rotor output will always be zero as long as there is a 90^{o} angular difference between rotors. (3:38). Any change will generate an error signal and result in pedestal movement. In this case the pedestal must move down 10^{o} to reduce the error signals back to zero (null) and reestablish a 90^{o} angular difference between rotors.

The error signal from ct 1+2 are fed into two separate servo amplifiers to provide the necessary power for servo motor control. The speed and direction of both motors will depend on the signal phase and voltage level. (3:55). At this point the two separate electrical signals are converted into one common mechanical motion. This is made possible by a transmission and jack screw. The jack screw, powered by both motors in parallel, moves the pedestal down until the error signal drops to zero. Refer to figure 2-5 for angular transfer to the synchro follow-up assembly.

Downward movement of the pedestal is transferred through a linkage to the synchro follow-up assembly drive gear and synchro rotors. The control transmitter (cx) command signal provides input to a remote position indicator for monitoring elevation. (16:6). The linkage arrangement and gear ratios are designed to duplicate autotracker movement (1x1 ratio). Therefore, a 10^{o} downward movement of the pedestal will cause all rotors to move in a counter clockwise direction (rear view). Pedestal movement will continue until the pedestal ct and autotracker cx rotor relationship is 90^{o}. When this occurs the error signal will drop to zero. (1:20). Any additional changes to autotracker elevation will create a new command signal and result in additional pedestal movement.

This completes the servo tracking path from target acquisition to pedestal tracking. The complexity of this path is quite evident and involves several transitions between electrical and mechanical points. The accuracy of angular transfer can be effected by any one of these transfer points between the autotracker and pedestal. A progressive breakdown of all transition points is listed below in sequence starting with the autotracker pivot point. A transition point is defined as any mechanical or electrical break in the angular path that may induce tracking error. Astericks (*) represent two separate paths provided by the dual servo system.

Transition Points

LINKAGE

1. Autotracker pivot point

   Pivot arm

2. Pivot arm

   Adjustable link

3. Adjustable link

   Pivot arm

4. Pivot arm

   Drive gear shaft

5. Drive gear shaft

   Drive gear

*6. Drive gear

   Rotor gear

SYNCHRO ASSEMBLY

*7. Rotor gear

   Rotor (cx)

*8. Rotor (cx)

   Stator (cx)

*9. Stator (cx)

   Stator (ct)

*10. Stator (ct)

   Rotor (ct)

*11. Rotor (ct)

   Servo amplifier

*12. Servo amplifier

   Servo motor

*13. Servo motor

Transmission

14. Transmission

Jack screw drive

15. Jack screw drive

Pedestal

16. Pedestal

Pedestal pivot point

17. Pedestal pivot point

Pivot arm

LINKAGE

18. Pivot arm

Adjustable link

19. Adjustable link

Pivot arm

20. Pivot arm

Drive gear shaft

21. Drive gear shaft

Drive gear

SYNCHRO ASSEMBLY

*22. Drive gear

Rotor gear

*23. Rotor gear

Rotor (ct)

*24. Rotor (ct)

Stator (ct)

At this point in the report the author has presented the details involved in transferring autotracker pointing angles to the remotely controlled servo driven instrument pedestals. The complexities involved in accomplishing this task are many and varied which offer considerable opportunity to inject tracking error. Chapter III will now reveal the degree of error that existed and identify one of the major contributing factors.

CHAPTER III

SERVO TRACKING ERRORS

Many factors must be considered when examining tracking accuracy; however, the importance of tracking accuracy should be understood before a detailed examination is begun.

Changing Mission Requirements

When the RC-135S (Rivet Ball) was originally designed, the optical tracking tolerances required were no greater than two degrees. Many of the cameras used had a field of view (FOV) on the order of ten degrees which made it relatively easy to track a moving target. Wide angle lenses and two degree tracking tolerances were permissable because the targets were photographed and tracked at night with a dark background which highlighted the subject and prevented light saturation of the film. However, these ideal conditions did not continue which caused considerable problems.

During the mid 60's (1965-66) mission requirement changed from a nighttime environment to daytime. This meant that the target had to be acquired, tracked, and photographed against an intense sky background. Many times the sun's rays were directly within the camera FOV which literally saturated the film and made it impossible to collect any useful data.

Narrow Field of View

In order to collect any useable data on a moving target with intensive background lighting it was necessary to modify the cameras to a narrow FOV. (17:1). By reducing the FOV the background lighting effects are reduced which allows detection and collection of useable data on the target. Camera FOV was reduced to one degree in order to permit target discrimination. The reduction in camera FOV compensated for the intense sky background but tasked the tracking accuracies of the system itself. For example, an instrument with a one degree (1°) FOV will not collect data if permitted to drift more than a half degree ($\frac{1}{2}^{\circ}$) off target.

While assigned to the RC-135S (Rivet Ball) project, the author was responsible for operation of all the photographic equipment as a signal monitor and tactical coordinator. During the early phases of daytime collection missions, it became apparent that the narrow FOV (1°) instruments were collecting very little data despite successful autoracker operation. This situation continued for more than two years before any cause was identified. (19J:2). Some of the methods used in checking tracking accuracy will now be discussed.

Detection

The normal procedure for checking tracking accuracy was to activate the servo system and visually observe pedestal movement through various changes in azimuth and elevation. If a station position appeared questionable then it was switched into a remote position indicator at the tactical coordinator station for comparison with the autotracker. This indicator had two servo driven needles which duplicated the pointing angle of the autotracker and any one selected pedestal. The accuracy of this indicator was only within two degrees (2°) and therefore not suitable for a one degree (1°) FOV instrument. Only major discrepancies could be identified. (15:1).

Another check of tracking accuracy involved comparison of boresight camera film. All camera positions including the autotracker were equipped with a wide angle boresight camera which was theoretically aligned with each instrument independently. This meant that when the target appeared in the center of the boresight camera film for position nine it should also appear in the center of the primary instrument film for position nine. Since all boresight film was encoded with a time reference, it would be possible to compare the pointing angle of all instruments relative to the autotracker at any one time. This would permit an ideal comparison and check, provided all boresight cameras were properly aligned, operating, and had an identifiable target within its FOV. Unfortunately, this situation very seldom if ever existed. The first indication of any significant tracking problem resulted from an improvised technique of boresight examination.

Boresight

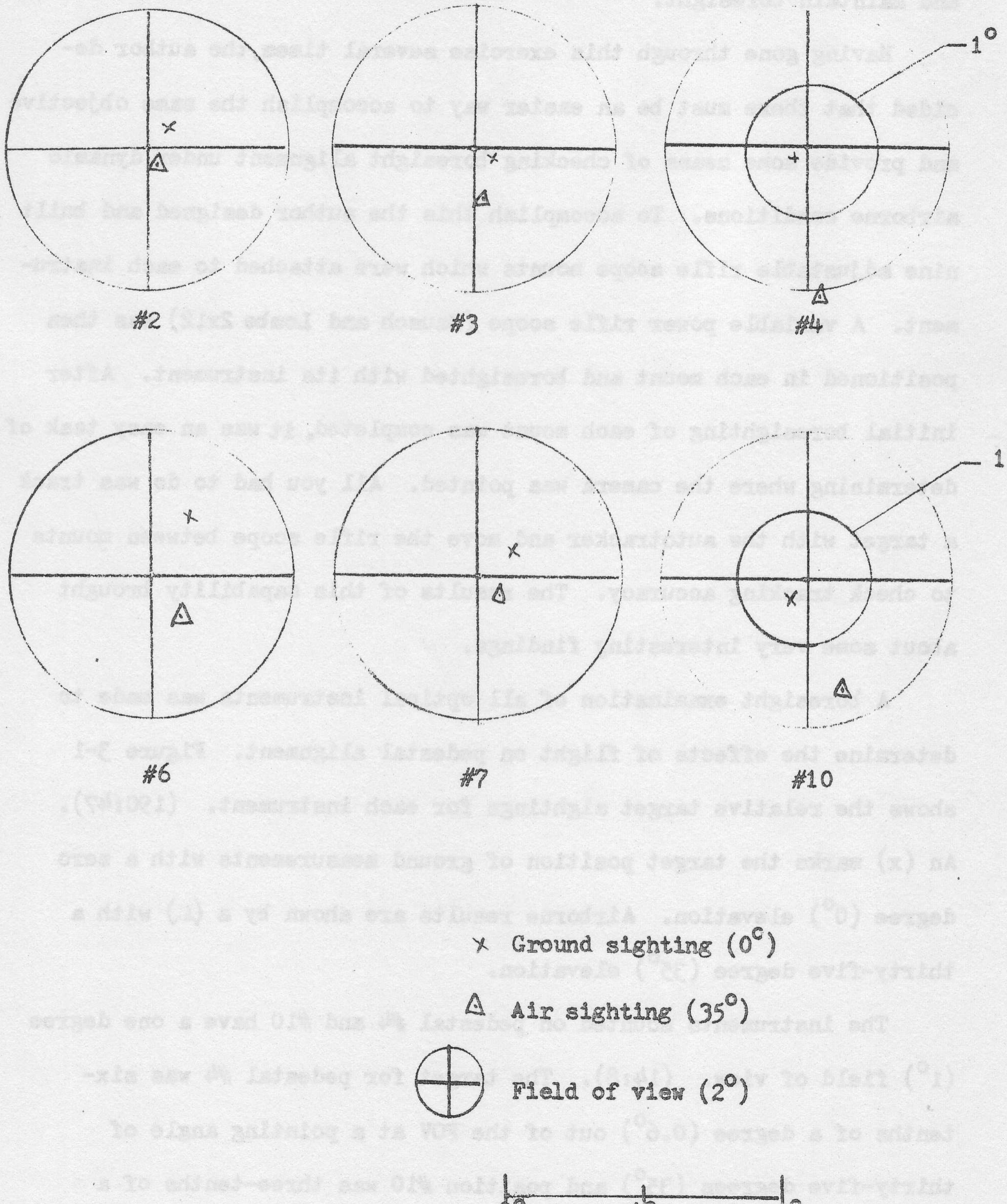
Boresight alignment of all instruments is normally done on the ground and involves several hours since all instruments must be down-loaded. After removing the film from all cameras, a boresight tool is inserted which allows the operator to sight through the optics of each instrument. When the boresight tools for each instrument are installed, the operator selects a distant target to track with the autotracker. When autotrack is established the servo controlled pedestals are slaved to the autotracker. Now the operator sights through the instrument boresight tool and makes whatever adjustments are necessary to each camera until all instruments are properly aligned. This is usually accomplished by shifting the mounts and using shim stock. After all instruments are aligned the cameras are loaded and the aircraft is returned to normal operation. The limitations to this exercise are rather obvious. The only conclusion that can be made from this boresight procedure is that at the time of boresighting all instruments are properly aligned along one stationary axis under ground environment conditions. It is assumed that once boresighting is complete that all instruments will track together and maintain boresight.

Having gone through this exercise several times, the author decided that there must be an easier way to accomplish the same objective and provide some means of checking boresight alignment under dynamic airborne conditions. To accomplish this the author designed and built nine adjustable rifle scope mounts which were attached to each instrument. A variable power rifle scope (Bausch and Lombe 2x12) was then positioned in each mount and boresighted with its instrument. After initial boresighting of each mount was completed, it was an easy task of determining where the camera was pointed. All you had to do was track a target with the autotracker and move the rifle scope between mounts to check tracking accuracy. The results of this capability brought about some very interesting findings.

A boresight examination of all optical instruments was made to determine the effects of flight on pedestal alignment. Figure 3-1 shows the relative target sightings for each instrument. (19C:47). An (x) marks the target position of ground measurements with a zero degree (0°) elevation. Airborne results are shown by a (Δ) with a thirty-five degree (35°) elevation.

The instruments mounted on pedestal #4 and #10 have a one degree (1°) field of view. (14:8). The target for pedestal #4 was six-tenths of a degree (0.6°) out of the FOV at a pointing angle of thirty-five degrees (35°) and position #10 was three-tenths of a degree (0.3°) out. Neither instrument would collect any data under

Figure 3-1
Boresight Observations



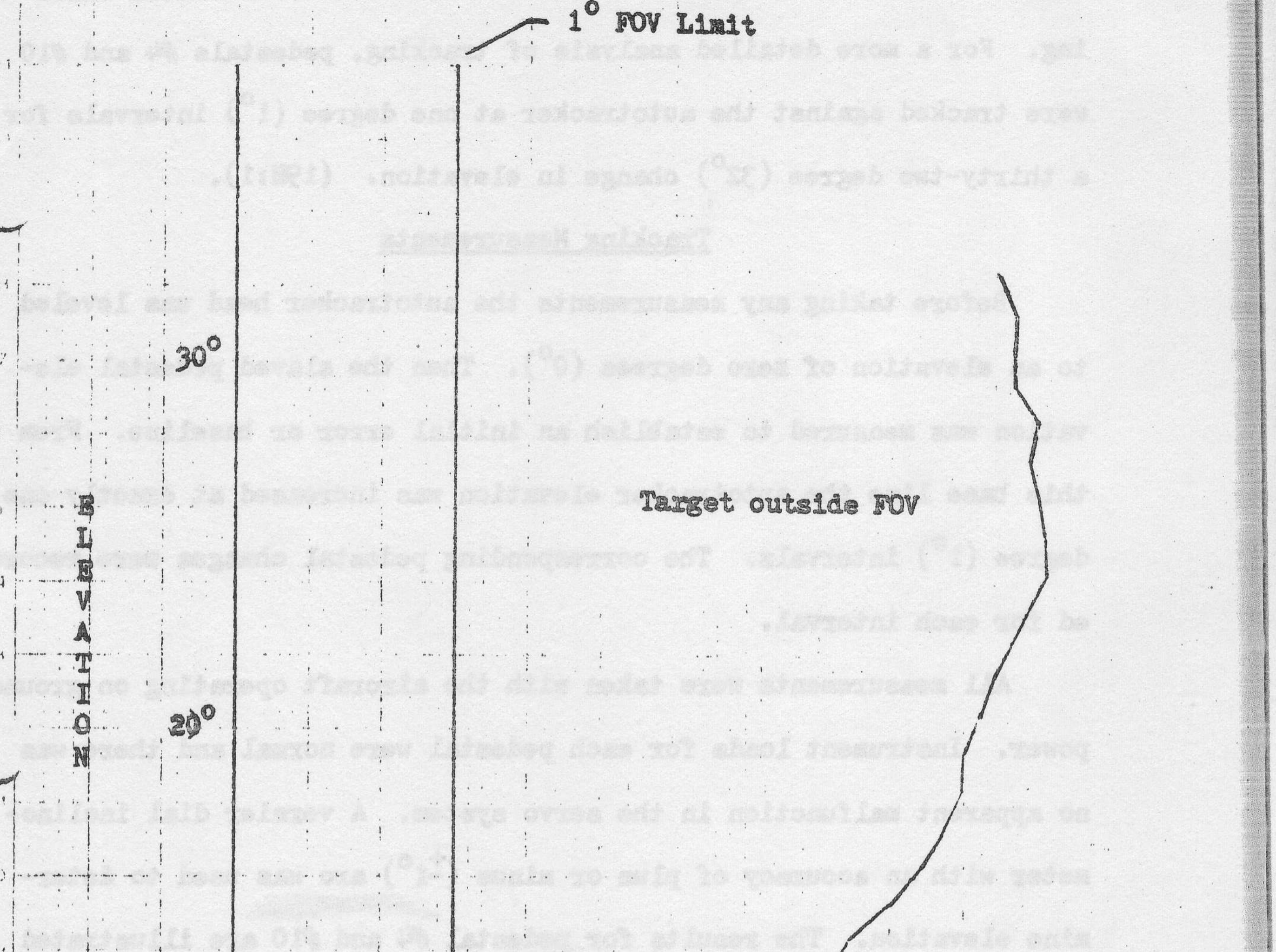
these conditions. This was the first indication of nonlinear tracking. For a more detailed analysis of tracking, pedestals #4 and #10 were tracked against the autotracker at one degree (1°) intervals for a thirty-two degree (32°) change in elevation. (19H:1).

Tracking Measurements

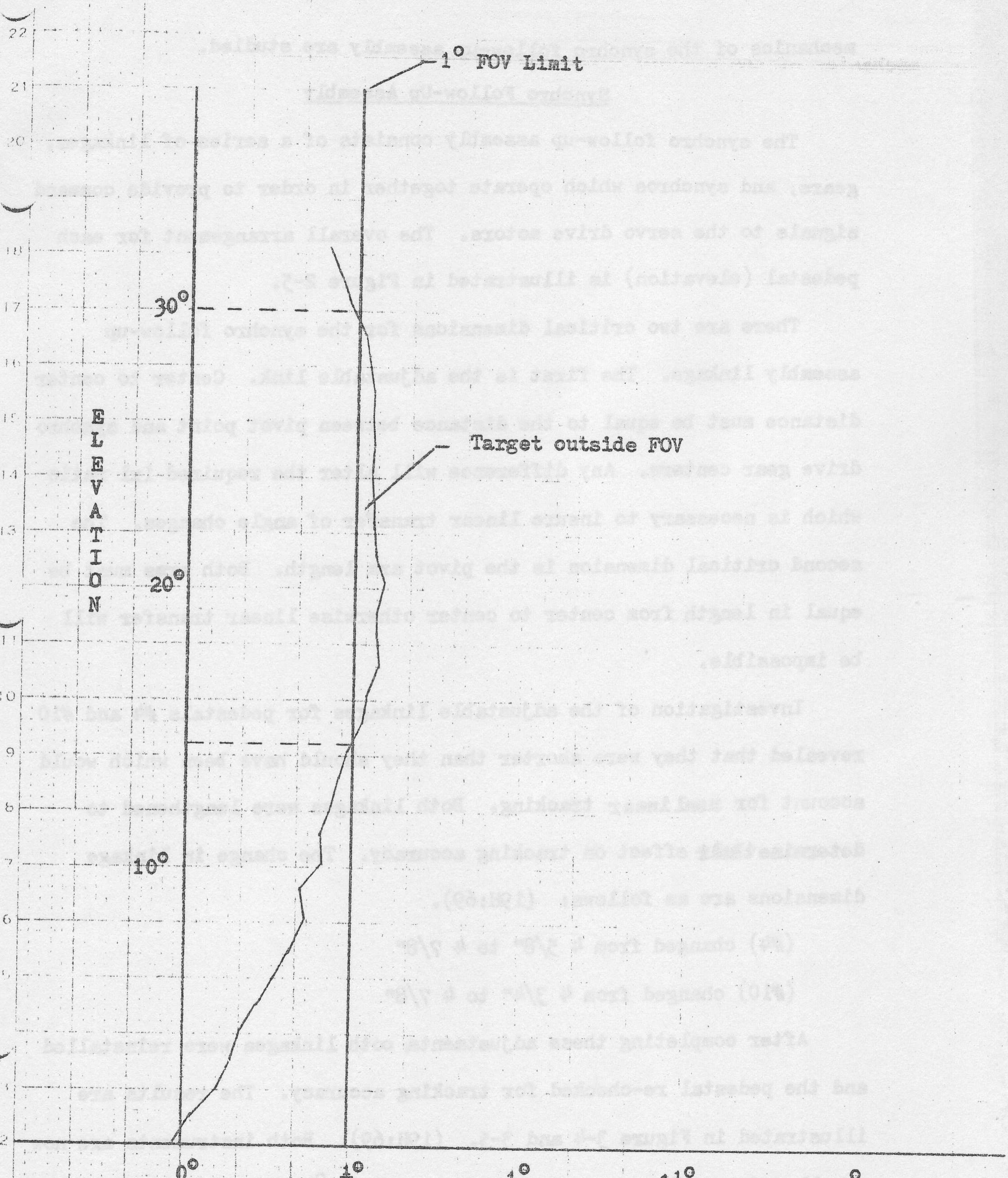
Before taking any measurements the autotracker head was leveled to an elevation of zero degrees (0°). Then the slaved pedestal elevation was measured to establish an initial error or baseline. From this base line the autotracker elevation was increased at exactly one degree (1°) intervals. The corresponding pedestal changes were recorded for each interval.

All measurements were taken with the aircraft operating on ground power. Instrument loads for each pedestal were normal and there was no apparent malfunction in the servo system. A vernier dial inclinometer with an accuracy of plus or minus ($\pm 1°$) arc was used to determine elevation. The results for pedestal #4 and #10 are illustrated in Figures 3-2 and 3-3. (19H:63)

The results of this test revealed that pedestal #4 and #10 did not track the autotracker on a linear path. The instrument mounted on pedestal #4 with a one degree (1°) FOV would not collect data above an elevation of three and one-half degrees ($3\frac{1}{2}°$). At this point the pedestal was pointing one-half degree ($\frac{1}{2}°$) higher than the autotracker. Pedestal #10 exceeds the limit for a one degree (1°) FOV instrument at thirteen degrees (13°) elevation and reenters at thirty-one degrees (31°). In both cases pedestal elevation increases at a faster rate than the autotracker and tends to slow down at higher pointing angles. This is a problem of nonlinear tracking which can be explained when the



1° FOV Limit
30°
ELEVATION
20°
10°
Target outside FOV
0°
½°
1°
1½°
2°
Tracking Error


1° FOV Limit
Target outside FOV
ELEVATION
30°
20°
10°
0°
½°
1°
1½°
2°
Tracking Error

mechanics of the synchro follow-up assembly are studied.

Synchro Follow-Up Assembly

The synchro follow-up assembly consists of a series of linkages, gears, and synchros which operate together in order to provide command signals to the servo drive motors. The overall arrangement for each pedestal (elevation) is illustrated in Figure 2-5.

There are two critical dimensions for the synchro follow-up assembly linkage. The first is the adjustable link. Center to center distance must be equal to the distance between pivot point and synchro drive gear centers. Any difference will alter the required 1x1 ratio which is necessary to insure linear transfer of angle changes. The second critical dimension is the pivot arm length. Both arms must be equal in length from center to center otherwise linear transfer will be impossible.

Investigation of the adjustable linkages for pedestals #4 and #10 revealed that they were shorter than they should have been which would account for nonlinear tracking. Both linkages were lengthened to determine their effect on tracking accuracy. The change in linkage dimensions are as follows: (19H:69).

(#4) changed from 4 5/8" to 4 7/8"

(#10) changed from 4 3/4" to 4 7/8"

After completing these adjustments, both linkages were reinstalled and the pedestal re-checked for tracking accuracy. The results are illustrated in Figure 3-4 and 3-5. (19H:69). Both instruments are now capable of tracking through thirty degrees (30°) elevation and remaining on target. It is obvious from this test that the major contribution to nonlinear tracking is incorrect adjustment of the synchro follow-up

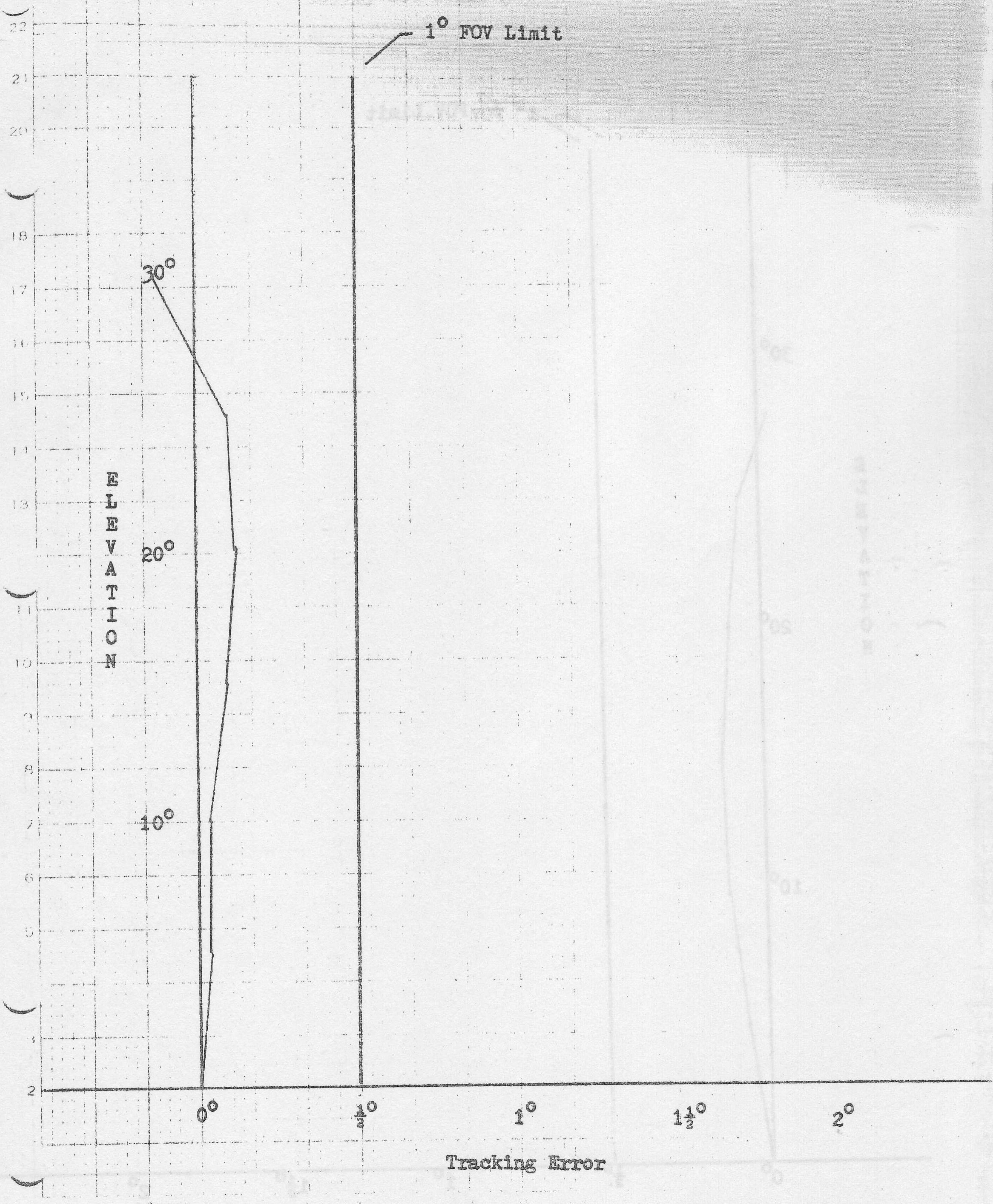
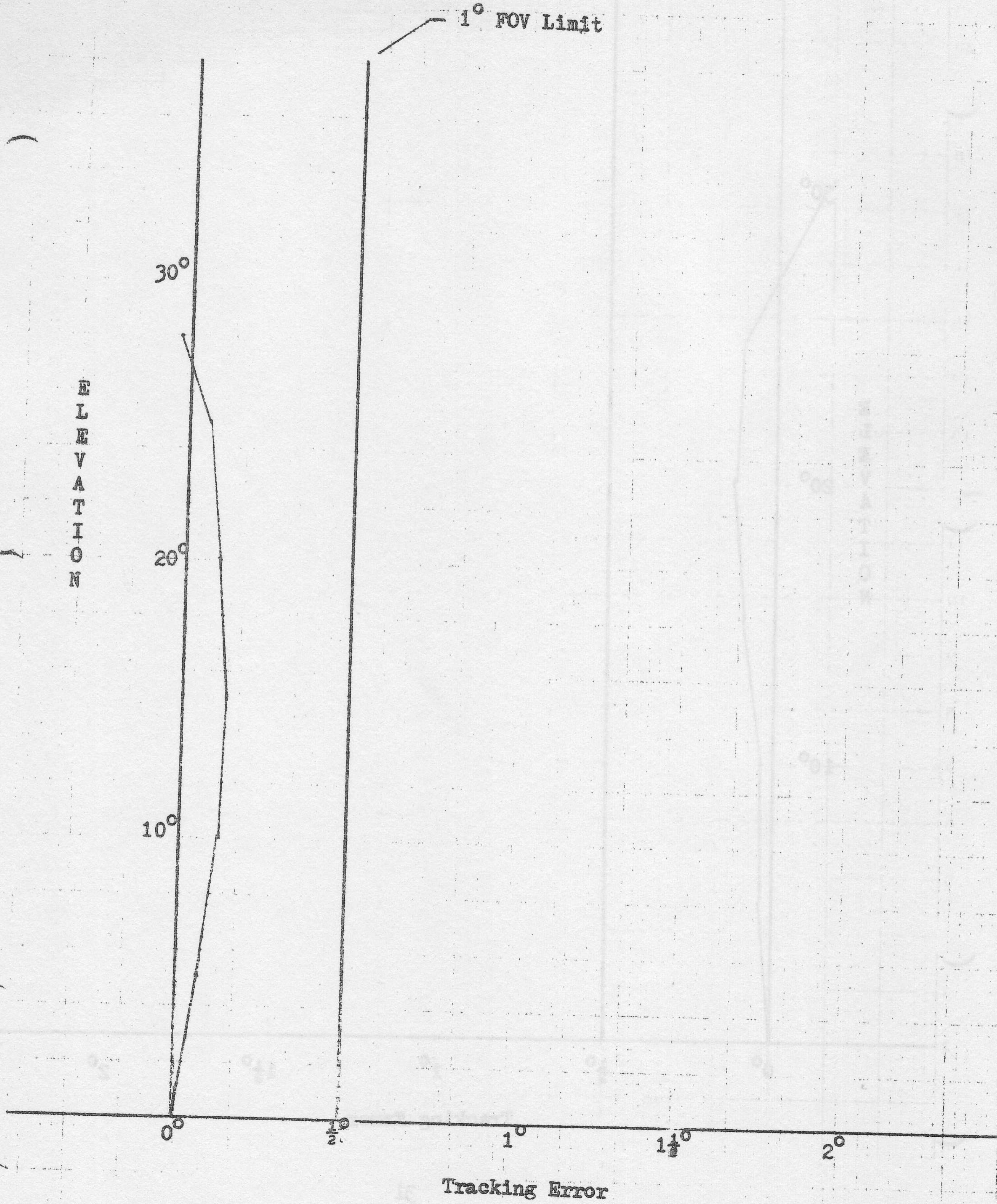

1° FOV Limit
ELEVATION
30°
20°
10°
0°
½°
1°
1½°
2°
Tracking Error

Figure 3-5
Tracking Error #10 (after



assembly linkage. Based on this finding the author will now present an alternative design which will eliminate this possibility.

CHAPTER IV

SERVO SYSTEM MODIFICATIONS

The previous chapter pointed out that the major cause of tracking error for pedestals #4 and #10 was incorrect adjustment of the synchro follow-up assembly linkage. The main subject of this chapter is to propose a design change which will eliminate the need for such a linkage and suggest additional modifications which may enhance tracking accuracy and boresight procedures.

Dual Servo System

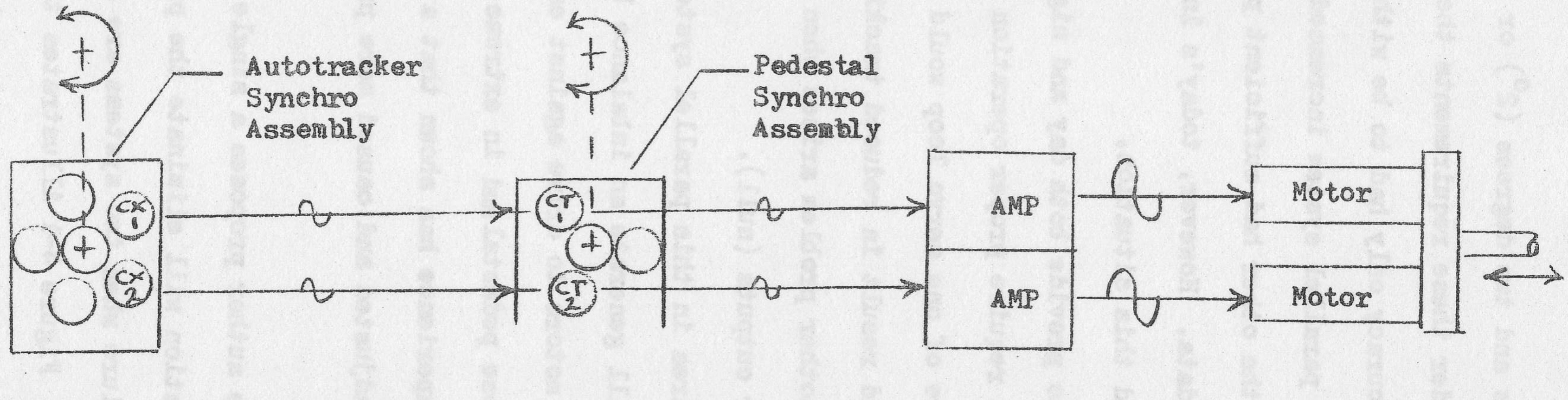
The heart of the entire servo system discussed so far is the synchro follow-up assembly. Its primary function is to convert the autotracker positon and motion into an electrical signal (error) for pedestal direction. The accuracy of this signal will determine instrument field of view and collection capability.

The synchro follow-up assembly for the RC-135S (Rivet Ball) optical tracking system employs two parallel single speed (1x1 ratio) servo loops for each plane of rotation (azimuth and elevation). Figure 4-1 illustrates this principle.

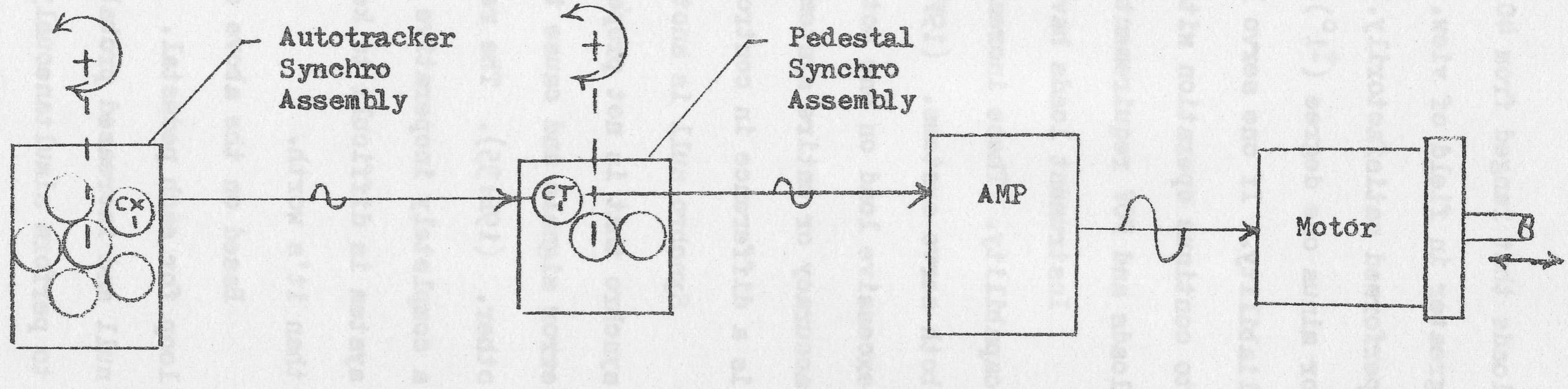
There are two control transmitters on the autotracker synchro follow-up assembly that detect motion for each pedestal. The signal from each of these transmitters is linked to a corresponding control transformer mounted on the appropriate pedestal synchro follow-up assembly. The resulting error signals (two) are then amplified separately and used to control the sevo drive motor which moves the pedestal.

Originally this servo system was designed to work with instrument

Figure 4-1
Servo System



Dual Single Speed Servo System (original)



Single Speed Servo System (modified)

loads that ranged from 40 to 153 pounds and two degrees (2°) or greater in field of view. (15:1). Under these requirements the system performed satisfactorily. Tracking accuracy only had to be within plus or minus one degree ($\pm 1^{\circ}$), and using a parallel system increased reliability. If one servo loop failed, the other had sufficient power to continue operation with no loss of data. However, today's instrument loads and FOV requirements have altered this situation.

Instrument loads have increased to provide both day and night capability. These increased loads now require proper operation of both servo systems. (19F:61). Failure of one servo loop would place excessive load on one motor which would result in reduced tracking accuracy or entire system failure. Another problem arises when there is a difference in control transformer outputs (null).

Synchro null is another problem area in this parallel system. A synchro that is not properly nulled will generate an imbalance between error signals and cause the two servo motors to drive against each other. (19B:35). The result is a loose pedestal and in extreme cases a completely inoperative pedestal. Experience has shown that a dual system is difficult to keep properly adjusted and caused more problems than it's worth.

Based on the above experience, the author proposes a single servo loop for each pedestal. This modification will eliminate the problem of null and increased probability of failure when two systems are required to perform simultaneously. (19E:60). Figure 4-1 illustrates the basic arrangement. This arrangement also facilitates major design changes to the synchro follow-up assembly that will eliminate adjustable linkages.

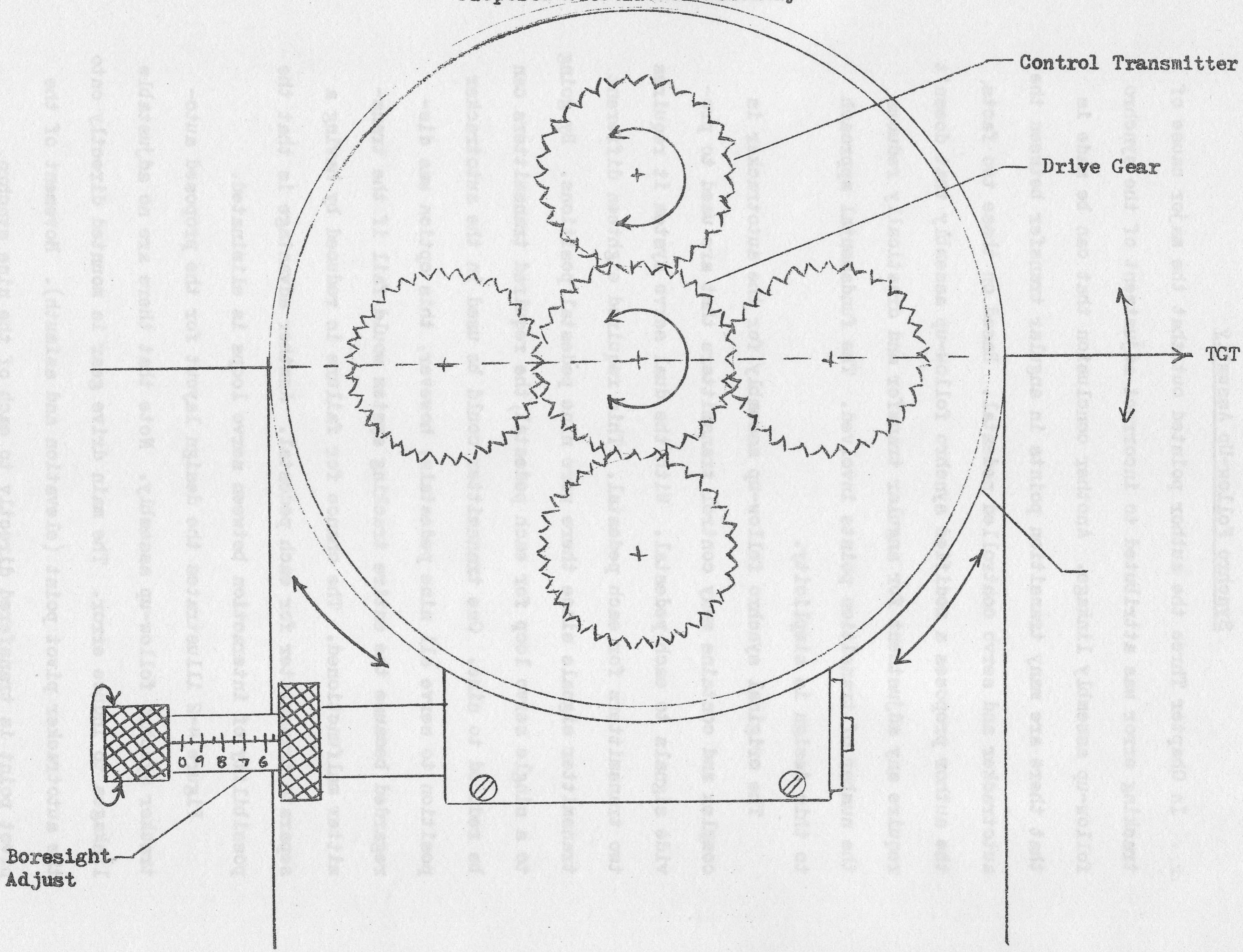
Synchro Follow-Up Assembly

In Chapter Three the author pointed out that the major cause of tracking error was attributed to incorrect adjustment of the synchro follow-up assembly linkage. Another conclusion that can be made is that there are many transition points in angular transfer between the autotracker and servo controlled pedestal. Based on these two facts, the author proposes a modified synchro follow-up assembly that doesn't require any adjustment for angular transfer and drastically reduces the number of transition points involved. The fundamental approach to this design is simplicity.

The original synchro follow-up assembly for the autotracker is complex and contains many control transmitters that are used to provide signals to each pedestal. With the dual servo system it requires two transmitters for each pedestal. This required eighteen different transmitter signals since there were nine pedestal positions. By going to a single servo loop for each pedestal, the required transmitters can be reduced to nine. One transmitter could be used in the autotracker position to serve all nine pedestals; however, this option was disregarded because the entire tracking system would fail if the transmitter malfunctioned. The chance for failure is reduced by having a separate transmitter for each pedestal. Another advantage is that the possibility of interaction between servo loops is eliminated.

Figure 4-2 illustrates the design layout for the proposed autotracker synchro follow-up assembly. Note that there are no adjustable linkages to induce error. The main drive gear is mounted directly onto the autotracker pivot point (elevation and azimuth). Movement of the pivot point is transfered directly to each of the nine synchro

Figure 4-2
Proposed Autotracker Assembly



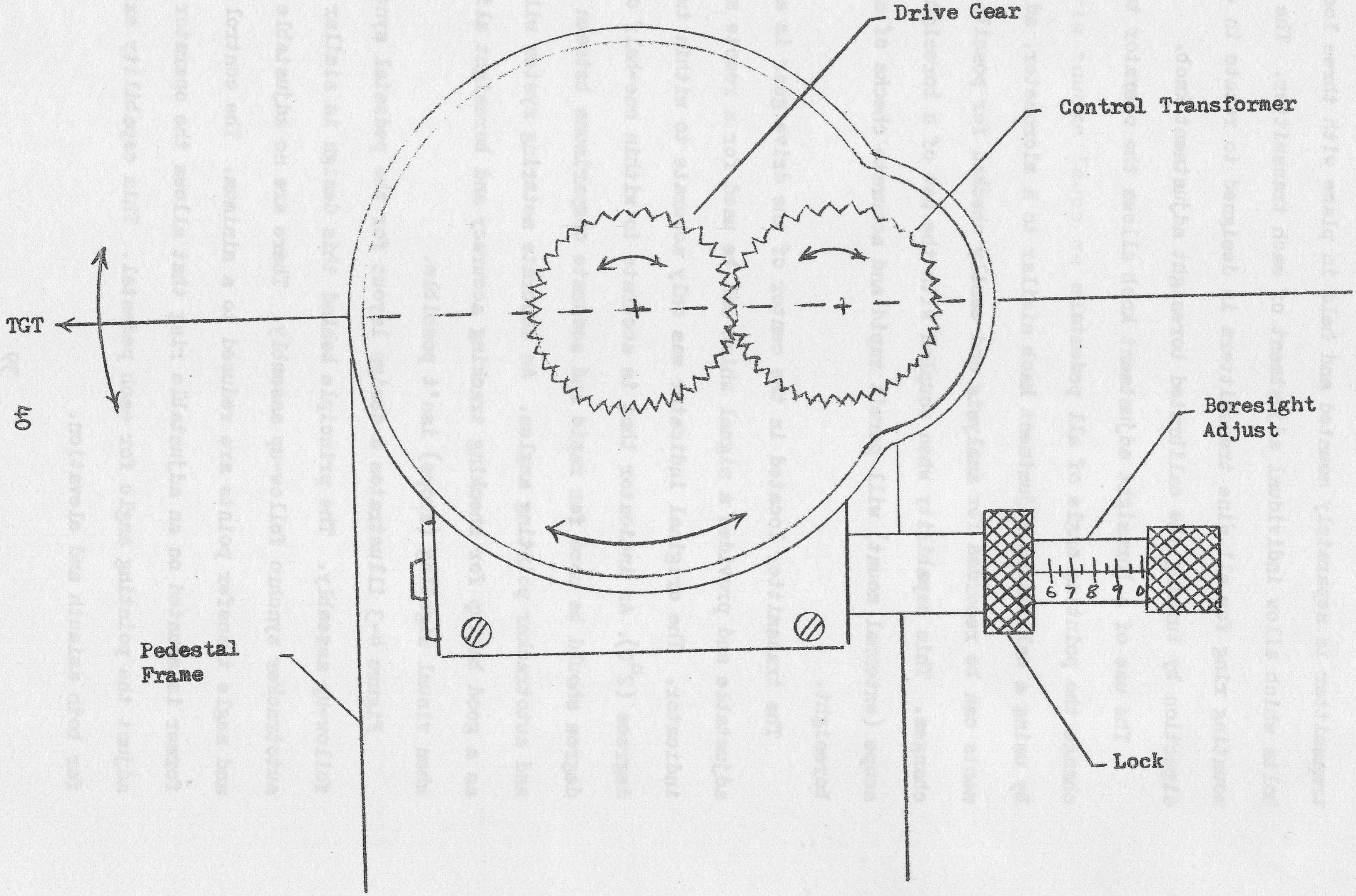
transmitters through a gear arrangement with a ratio of 1x1. Each transmitter is separately mounted and held in place with three locking bolts which allow individual adjustment of each transmitter. The mounting ring for all nine transmitters is designed to rotate in either direction by turning the calibrated boresight adjustment knob.

The use of a boresight adjustment knob allows the operator to change the pointing angle of all pedestals an equal amount simultaneously. By using a calibrated adjustment knob similar to a micrometer, adjustments can be recorded for analysis and easily checked for possible changes. This capability when coupled with the use of a boresight scope (external mount) will permit rapid and accurate checks of system boresight.

The transmitter located in the center of the drive gear is also adjustable and provides a signal which can be used for a remote angle indicator. The original indicator was only accurate to within two degrees ($2^{o}0$). An indicator that is accurate to within one-half of one degree should be used for rapid and accurate comparisons between pedestal and autotracker pointing angles. An accurate metering system will serve as a good backup for checking tracking accuracy and boresight alignment when visual sighting (scope) isn't possible.

Figure 4-3 illustrates a design layout for the pedestal synchro follow-up assembly. The principle behind this design is similar to the autotracker synchro follow-up assembly. There are no adjustable linkages and angle transfer points are reduced to a minimum. The control transformer is mounted on an adjustable ring that allows the operator to adjust the pointing angle for each pedestal. This capability exists for both azimuth and elevation.

Figure 4-3
Proposed Pedestal Assembly



The control transmitter located in the center of the synchro follow-up assembly is used to drive a remote indicator pointing needle which is used in comparison with the autotracker remote indicator to compare pointing angles. In designing the remote indicator, the autotracker and pedestal indicator needles should be superimposed over each other for easy comparison.

Boresight Scope

Another modification which should be incorporated is the installation of an external boresight scope. A variable power (2x8) sighting scope should be mounted on all pedestal positions including the autotracker. By doing this, cameras would not require downloading for boresight adjustments and passive targets (nonradiating) may be used by manually directing the autotracker. Real time tracking accuracy may be checked by observing operational events through individual scopes.

Pedestal Balance

The last suggested design change involves pedestal balance. The original pedestal had its pivot point on the foward portion of the pedestal (see figure 2-5) closest to the optical viewing port mounted in the fuselage. This allowed for smaller window design (22 inches in diameter) and a more compact installation. In order to compensate for camera load and balance the pedestal, a series of springs were installed. When the springs were in good working order the platform was fairly well balanced and offered very little resistance to the servo motors. Spring balance was only necessary for elevation control. After two or three months of operation, the springs lost some of their tension which placed an additional load on the elevation servo motors. This additional load could contribute to sluggish reaction for the heavier instruments and certainly decrease the service life of the servo motor.

To alleviate the problem of pedestal balance the author proposed the installation of adjustable spring mounts. The mounts should be designed in such a manner that they can be adjusted by one man without the use of any tools. A device similar to a turnbuckle would be satisfactory. With adjustable spring tension, the pedestals can be maintained in a balanced condition and insure optimum performance of the servo system.

Modification Summary

The design changes proposed above are relatively inexpensive and require no major alterations. The basic equipment is available today and could be tested on a trial basis with little difficulty. The main feature of the proposal is to use a single loop servo system that incorporates very few moving parts and is easy to adjust. Proposals which follow in the next chapter involve a radical design change but offer considerable advantage in the author's opinion.

CHAPTER V

PERISCOPE TRACKING CONCEPT

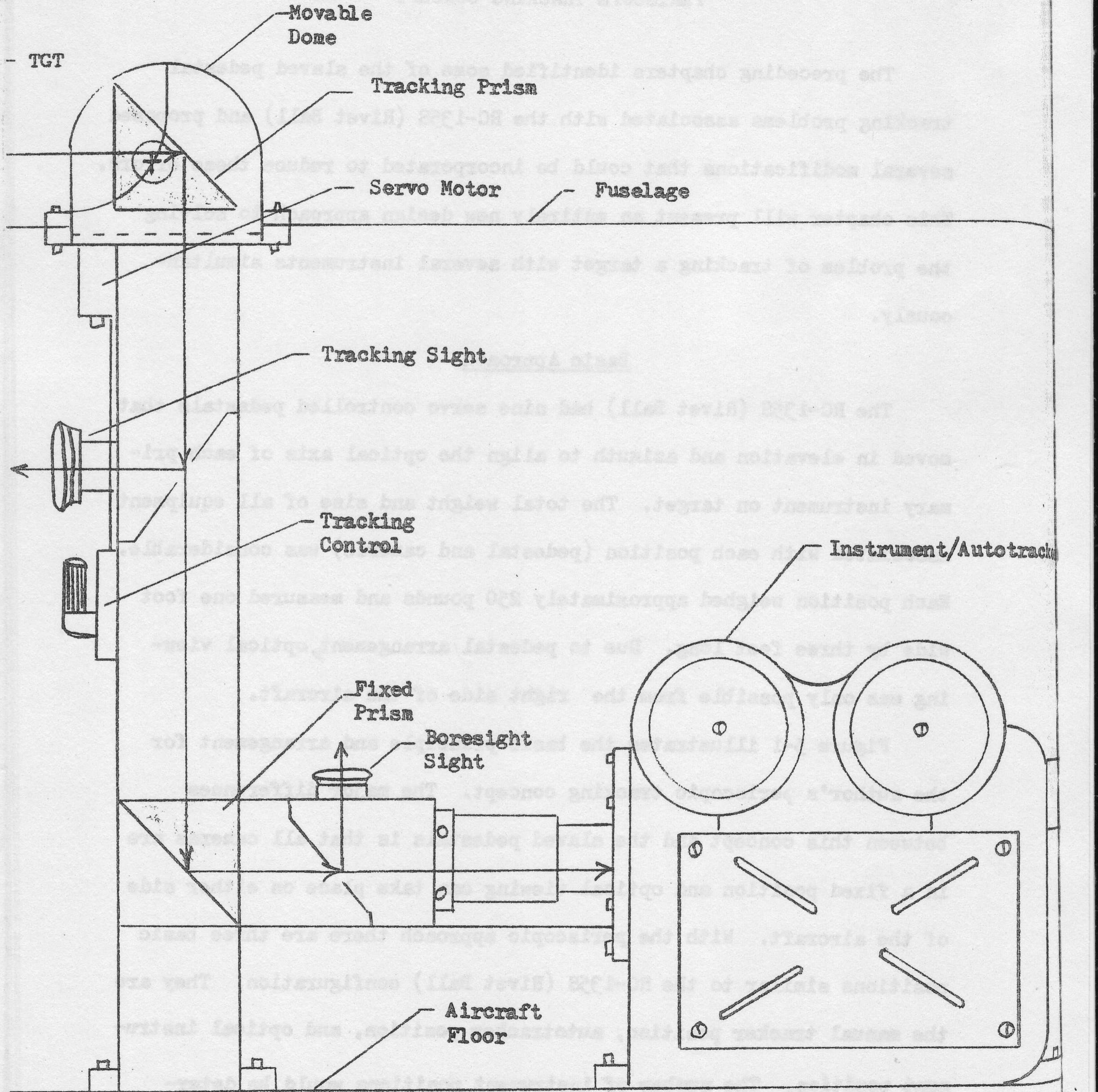
The preceding chapters identified some of the slaved pedestal tracking problems associated with the RC-135S (Rivet Ball) and proposed several modifications that could be incorporated to reduce these errors. This chapter will present an entirely new design approach to solving the problem of tracking a target with several instruments simultaneously.

Basic Approach

The RC-135S (Rivet Ball) had nine servo controlled pedestals that moved in elevation and azimuth to align the optical axis of each primary instrument on target. The total weight and size of all equipment associated with each position (pedestal and cameras) was considerable. Each position weighed approximately 250 pounds and measured one foot wide by three feet long. Due to pedestal arrangement, optical viewing was only possible from the right side of the aircraft.

Figure 5-1 illustrates the basic principle and arrangement for the author's periscopic tracking concept. The major differences between this concept and the slaved pedestals is that all cameras are in a fixed position and optical viewing can take place on either side of the aircraft. With the periscopic approach there are three basic positions similar to the RC-135S (Rivet Ball) configuration. They are the manual tracker position, autotracker position, and optical instrument position. The number of instrument positions would be determined by space available and mission requirements.

Figure 5-1
Tracking Periscope



Periscope

The periscope consists of a tracking prism and stationary prism. The tracking prism is mounted in a protective housing atop the fuselage and allows for 360° rotation. The prism within this housing moves in elevation which allows for tracking of the target. Motion of the prism housing and prism is accomplished with a servo system that gets its directional command from the manual tracker or autotracker position. The physical size of this housing is relatively small and on the order of six inches in diameter and six inches high. This relatively small size is made possible because of the narrow field of view instruments required.

Periscopic Tracking Head

The prism assembly within the periscopic tracking head will require very little power to drive in azimuth and elevation due to its relatively low weight and size. The optical elements including the port window are made of quartz in order to minimize any filtering effects. A prism is used instead of a mirror because is can be designed to permit total internal reflection. (5:50). When the tracking prism has aquired the target its image is directed down an optical tube to another prism (90°) which directs the image into the instrument lens for recording.

The optical tube and lower prism are fixed in position along with the instrument. Coupling of the instrument to the optical tube assembly is adjustable and allows for ease in changing instruments for a particular mission. It also allows for easy removal to perform maintenance and make adjustments. By using a ninety degree (90°) lower prism the instruments can be positioned in such a way that they offer maximum unobstructed floor space and compact installation. All of the instruments can be mounted on one side of the aircraft and relatively close to each other since they are stationary. Due to motion of the pedestals in the RC-135S (Rivet Ball), a separation distance of approximately five feet was necessary to avoid interference. Another problem with moving instruments is the danger of an accident to crew personnel.

Acquisition and Tracking

The manual tracker and autotracker positions are unique in that they are combined with one common periscope. By using this approach it eliminates the need for a servo tracking system between positions. A periscope arrangement also allows the manual tracker operator to stay in a fixed position and scan the sky on either side of the aircraft by merely operating hand controls.

Initially the manual tracker operator sights through a fixed eyepiece in order to align the rotating prism head of the periscope with the incoming target. Movement of the operator hand controls direct the tracker prism and position the target within the field of view of the elector-optical autotracker. When the target is within the autotracker FOV, the operator transfers directional control of the tracker prism over to the autotracker. From this point on tracking is accomplished automatically.

Slaved Periscopes

Pointing angles from the tracking periscope are linked to each of the slaved instrument periscopes by a servo system. The response and accuracy of this system is considerably greater than that on the RC-135S (Rivet Ball) because of the small size and lightweight equipment involved. (7:35). The only element in motion is the prism in the head of each periscope.

Boresighting of the instrument periscopes to the tracker position is made simple by using a sighting scope which is incorporated between the fixed prism and instrument. (6:64). During autotrack the operator sights through the instrument scope and makes whatever adjustments are necessary to the servo system. These adjustments can be made during ground operation or inflight. Passive targets may be used by tracking a target in the manual mode.

Angular Recording

Another feature which is unique to this tracking concept is the ability to record the pointing angle for all periscopes. The azimuth and elevation axis for each periscope is converted into an analog voltage which is tape recorded. A record of pointing angles enables easy comparison of tracking accuracy between all periscopes. A visicorder printout of all positions can be made simultaneously and analyzed within a matter of minutes if necessary. The ability to detect tracking errors easily is very important when considering how long it took to detect those that existed in the RC-135S (Rivet Ball).

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

The author's conclusions parallel the sequence of events in this study. They begin with the servo tracking path and conclude with overall tracking accuracy. From these conclusions the author offers his recommendations for an improved tracking system.

Conclusions

1. The RC-135S (Rivet Ball) servo tracking system is complex, bulky, and contains an excessive number of angular transition points (35) between the autotracker and slaved pedestals. Every point of transition increases the probability of tracking error and by reducing the number of these points it will reduce the probability of error.

2. The adjustable linkages on the synchro follow-up assemblies is a major contributor to tracking error between the autotracker and slaved pedestals. The length of each linkage must be exactly the same dimension as the distance between pivot points. Any error in adjustment will result in nonlinear tracking. Incorrect adjustment of the autotracker linkage will cause all slaved pedestal to track in error even if each pedestal is adjusted properly.

3. The ability to detect tracking error with conventional procedures is difficult and time consuming which contribted to the long delay in identifying this problem. A simple and accurate means of calibration is needed, this includes boresighting.

4. The use of a dual servo system increases the probability of system failure since both sytems must be fully operational and properly adjusted to provide accurate tracking.

5. A multiple instrument tracking system that requires directional movement of the instruments is difficult to engineer, requires considerable area to accomodate tracking movements, and must use a high powered servo system. Rapid motion of precision instruments is not conducive to reliable performance and may present a safety hazard.

6. The RC-135S (Rivet Ball) tracking system can be modified to provide tracking accuracies suitable for instruments with a one degree (1°) field of view.

7. The periscope concept is feasible and offers more advantages than a modified RC-135S (Rivet Ball) tracking system. It offers coverage on both sides of the aircraft, more accurate tracking due to smaller size and width, more room for equipment installation, and an easy means of detecting and correcting instrument tracking.

Recommendations

1. The author recommends the periscope concept over system modifications. This recommendation is based on the above conclusion, personal experience, and the need for a system with expanded capability. A small scale ground based system should be developed first to prove its feasibility before aircraft installation.

2. The need for a wide range of airborne spectral data still exists. If the periscope concept can be proven, then consideration should be given either to modifying the RC-135S (Cobra Ball) for installation or building an entirely new system with emphasis on a wide range of airborne optical tracking instruments.

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