COR-2248

COPY 3 OF 5

STAT [redacted]

29 July 1963

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[redacted] Project 9051 - Gamma I Rectifier

Progress Report No. 1 - 1 April 1963 to 23 July 1963

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A telegram authorization was received during the last week of March 1963 by [redacted] Contracts Manager, which re-instated the Gamma I program. This telegram allowed the expenditure of funds remaining of the original [redacted] authorization.

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The specifications submitted to [redacted] were modified and revised to the extent necessary to insure satisfactory performance of the Gamma I instruments. The modifications and revisions reflect the findings of [redacted] investigation and analysis of the original specifications which were ambiguous or inconclusive in certain areas. These modifications and revisions were submitted to W.W. and they received his concurrence.

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A second telegram was received on 20 May 1963 by [redacted] authorizing additional funding of [redacted] and the development and fabrication of two Gamma I instruments. This brought the total funding on this program to [redacted]

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The contract was definitized verbally in a telephone conversation between [redacted] and J.C. on 25 June 1963 and the formal contract was forwarded to [redacted] for appropriate signatures.

Initial planning and scheduling operations (including a PERT network) were completed during the early stages of the program. The initial schedule indicated a nine-week slippage beyond the nine-month development period starting on 1 April 1963. Re-evaluation of the planning concept at that time indicated it would be possible to bring the schedule back to a nine-month period, barring unforseen problems.

The major cause of the indicated slippage was found to be in the area of the projection lens design and fabrication. The extreme field angle combined with the resolution requirements presents complex design problems. Preliminary designs were investigated and a promising solution was obtained. The design of the surrounding housings and mechanisms proceeded on the basis of this lens configuration.

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A visit was made by W.W. to our [redacted] facility on 2 July 1963. The purpose of this visit was review of the progress and a technical discussion of our design approaches. W.W. requested slight modifications of our designs in the areas of:

1. Slit width--desirous of having a permanently attached slit capable of variable width.

2. Nadir offset--desirous of having a witness mark that would slide over the film and be retractable during printing.

3. $9\frac{1}{2}$" film transport--desirous of having capability of variable amount of film transported to reduce film waste caused by 80° scan angle.

These changes are not expected to be of sufficient magnitude to adversely affect the existing designs.

STAT [redacted] continued their investigations into the lens design with respect to availability of glass and the generation of the element surfaces. They decided that the optimum theoretical design was not the best approach due to the need for fabrication of deep curvature non-spherical elements. A new design for an eight-element lens was initiated. This design increased the physical size of the lens, thereby necessitating a redesign of the housings and mechanisms to accommodate the lens.

For sharp rectification it is necessary that the lens rotate about a point between the front and rear nodal points that is located in the same ratio as the system conjugates. This point can be fixed if the nodal separation is small, but if it is large, it becomes necessary to translate the lens axially to maintain the proper proportionality. The nodal separation for the eight-element lens was too large and this necessitated a further design analysis in an effort to bring the nodes together. An arrangement has been devised by the optics department whereby the addition of two more elements allows us to position the nodal points where we want them to be without reducing the optimum performance of the lens. In this case we are going to bring the nodal points into coincidence or as nearly so as necessary to meet the specifications with respect to resolution and image quality of the system.

The procurement of the glass blanks takes about three months and the final stages for lens calculation cannot start until all the glass and pertinent data are in hand. This procurement cycle is impeding the progress of the overall design and it appears that delivery of the first unit will be from nine to twelve weeks late. Every effort will be made to reduce this anticipated slippage.

The original computations were based on a single fixed altitude. The new specifications call for a different and variable altitude range. The new parameter necessitated the need for a new and more detailed computer program. This program had to be specially coded so as to prevent any breach in security. [redacted] has prepared the needed programs and encoded them. The computer runs should be available within the next two to three weeks. STAT

STAT [redacted] has reprogrammed the computer and coded it to prevent any security breach. The final computer runs should become available within another two to three weeks.

STAT It was also desirous for [redacted] to recompute the central magnification and lens focal length according to the new variable parameters so as to obtain optimum system performance. A small difference between the new figures and those originally calculated was obtained; however, these differences are not of sufficient magnitude to warrant any concern.

During the first two weeks in July, releases were made for fabrication and procurement of approximately 12% of the parts necessary for development of the Gamma I instruments. It is anticipated that another 10% of the parts will be released by the end of July.

The basic design concepts of the balance of the instrument are nearly completed. The physical arrangement and location of the various assemblies and the overall configuration of the instrument is proceeding in good manner. It is anticipated that the final design concept will be established and the design layouts completed during the month of August.

STAT

[redacted]
Project Manager

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COPY 6 OF 7

Design Study

GAMMA I And II PRINTERS

AUGUST 17, 1962

CONTENTS

FIGURES

TABLES

1. INTRODUCTION

This report and its accompanying budgetary supplements represents Task Order No. 5 to the present contract.

It contains the results of a six week design investigation which has been performed to determine the optimum approaches to the development of two models of rectifying projection printers which are designated Gamma I and Gamma II.

2. SCOPE OF INVESTIGATION

The report outlines, and where necessary specifies, the concepts which will guide the development of the Gamma instruments.

The reasons for the selection of particular concepts are stated and substantiated, as are the reasons for the rejection of various alternate concepts which, at first appraisal, would seem to merit attention and/or investigation.

In keeping with the manifest intent of the contract, the report defines the method of development of basic laboratory type instruments and the methods for the development of more complex instruments which incorporate the additional capabilities and/or components which were suggested by the customer as areas of supplementary design investigation. In addition, an optimum design concept, based on an evaluation of the system requirements correlated with the experience gained from the development of previous rectifying instruments, has been formulated. The optimum design is considered the most satisfactory choice for the customer's requirements and it is strongly recommended that the contract specifications be based on development of instruments in accordance with the optimum design concept as outlined in Section 5 of this report.

3. PURPOSE OF THE GAMMA INSTRUMENTS

The Gamma I and Gamma II instruments herein discussed are rectifying projection printers capable of transforming the panoramic distortions of tilted panoramic aerial photography and producing enlarged rectified copy on roll film.

Two taking systems are involved in the production of the panoramic photography. One system will furnish the input film to Gamma I, the other will furnish the input film to Gamma II. The taking systems contain dissimilar cameras. For the purposes of the rectifier development, the significant dissimilarities are in lens focal length, and film width.

Primary design requirements of the Gamma instruments specify that both models (I and II) produce rectified copy to the same map scale. This requirement transposes directly into a requirement for dissimilar printer magnifications.

The contractor's knowledge of the Gamma II input is (of necessity) somewhat less than complete. For this reason, we point out here that it is incumbent on the customer to be particularly critical in the evaluation of the Gamma II design concepts so as to detect possible inconsistancies resulting from erroneous hypotheses which might be inadvertently developed by the contractor.

4. DESIGN PARAMETERS

The parameters which control the design concepts outlined in this report are listed in Tables 1 and 2.

Table 1 — Input Specifications

	Gamma I	Gamma II
Input focal length	24	36
Input film length	500 ft	500 ft
Input film width	70 mm (58 mm format)	168 mm (155 mm format)
Scan angle	70°	70
Primary pitch	15°	11.7°
Pitch range	Primary ± 5°	Primary ± 5°
Maximum input resolution	200 L/mm	200 L/mm
Pitch and roll	± 5°	± 5°
Camera altitude	Variable	Variable

Table 2 — Rectifier Output Specifications

Format size	Full format (not segmented)
Output scale	1.875 Gamma I 1.250 Gamma II
Resolution design goal	80 L/mm at nadir across width of format, no point on format less than 50 L/mm — measured at negative scale and printed on duplicating film (5427).
Auxiliary data to be recorded	Data block contained on input
Earth curvature	Compensated for by printer

Table 2 (Cont.)

Pitch and roll	Compensated for by printer
Panoramic and Convergent Tilt distortions	Compensated for by printer
Velocity and IMC distortions	Not compensated for
Overall printer accuracy	The projection of a grid that has been constructed to duplicate taking case panoramic distortions shall be accurate within 0. 01 inch as to location of projected points relative to actual grid points.

5. RECOMMENDATIONS

In order to amplify the statement in Section 3 of this report in regard to a recommended optimum design concept, a definition of the concept is made in this section.

In general, the recommended optimum instruments combine the basic laboratory type design with selected additional features. A tabular list of both recommended and non-recommended features is given below.

Recommended

a. Basic laboratory type design
b. Automatic copy film transport
c. Exposure control
d. Single copy easel

Not Recommended

a. Automatic input film transport
b. −5 to 20 pitch angle rectification (Gamma I)
c ± 0. 5% variable magnification

It is felt that manual transportation of the input film is desirable. The nature of the printing operation is such that no purpose would be served by the inclusion of an automatic transport for this function. Only a minimum of physical effort is required to transport the negative film manually, the time required for either manual or automatic transport is essentially the same, and the exposure control system suggested is compatible with a manual transport system. As an automatic transport system would be an extra cost item, its inclusion in the design does not seem to be justified.

On the other hand, the size of the copy film is such that manual transport of it would require the expenditure of considerable physical effort and time; therefore, the extra cost of including an automatic copy film transport does seem to be justified.

The exposure control system which is described in this report is relatively inexpensive and does considerably enhance the printers' capabilities. For this reason, its inclusion is recommended.

Use of a single copy easel (for each model) appears feasible based on the most authoritative altitude range information that is available at this time. It is certain that single easel construction is the most economical; however, if later information discloses a broader altitude range requirement, two or more easels must be included with a consequent cost increase.

Investigation has shown that the inclusion of a variable magnification capability, and a capability to accommodate -5 to 20° pitch angles would greatly increase the cost and to some extent degrade the resolution capabilities of the instruments. We therefore recommend that they not be included unless a positive requirement for them has been established by the user.

6. RECTIFICATION DESIGN PRINCIPLES

In order to design instruments capable of performing the required rectification functions, the theory and principles of rectification have been applied to the specific cases of the Gamma instrument parameters. The paragraphs of this section state the theory, principles, design approaches, and applications.

6.1 RECTIFICATION THEORY

The following types of distortion are contained in a Tipped Panoramic Photograph:

a. Panoramic Distortion — the displacement of images from their true, or expected, orthographic position due to the geometry of the focal plane and the scanning action of the lens.

b. Scan Positional Distortion — the displacement of images from their true, or expected, geometric position due to the forward displacement of the vehicle during the scan period of the lens. This distortion is in addition to and modifies the position of points due to panoramic distortion.

c. IMC Distortion — the displacement of images from their true, or expected, geometric position due to the lens motion which is used to compensate for image motion during the exposure period. This distortion is in addition to and modifies the position of points due to both panoramic and scan positional distortion.

d. Convergent Tip Distortion — the displacement of images from their true, or expected, geometric position due to the introduction of a tipped optical axis in the line of flight. This distortion is in addition to and modifies the position of points due to panoramic, scan positional, and IMC distortions.

6.2 APPROACH TO RECTIFICATION

The general approach to rectification that is planned for the Gamma instruments is optical reprojection of the panoramic photography, analogous (in part) to the taking case.

Because it is necessary to work with finite conjugate distances in an operational printer rather than with an infinite conjugate (as in the taking case), the distances used for the reprojection are proportional to, rather than identical with, those of the taking system. In addition, some geometrical changes are required to achieve the analogous reprojection.

6.3 SCAN POSITIONAL AND IMC DISTORTION RECTIFICATION

Where the residual-distortion S-curve of the combined scan positional movement and IMC distortions is of sufficient magnitude to require its rectification (as is the case of low altitude – high velocity camera flight), a complex mechanical solution is utilized whereby the motions of the taking system are proportionately duplicated. In a design of this nature, the negative platen is moved to simulate IMC and the printing easel is moved to simulate the scan positional movement (camera vehicle velocity).

The magnitude of the residual-distortion S-curve is determined by the application of the following formula:

$$X = CF(\sin \alpha - \alpha \cos \alpha)$$

where $C = V/H/W$
V = apparent ground velocity
H = altitude (or altitude/cos (tip angle))
W = scan rate (radians/sec)
F = focal length
X = residual distortion in original film

Applying the S-curve formula to the case of the Gamma instruments we get:

$$C = 0.165$$

therefore for the maximum off-axis scan angle of 35

$$X = 0.0165\ (610\ \text{mm})\ \left(\sin 35^\circ - \frac{35\ \pi}{180} \cos 35^\circ\right)$$

$$X \approx 0.7\ \text{mm}$$

This value (X) is a plus and minus value on respective sides of the longitudinal film center line, it varies slightly from one side to the other due to the tipped attitude of the scan axis.

The magnitude of the derived distortion is not considered sufficient to warrant the additional expense required for including the complex optical-mechanical distortion limiting motions in the Gamma design. As this uncorrected distortion component is highly predictable, it will require a minimum effort to apply a correction factor in the cases where removal of the S-curve is considered desirable

6.4 PANORAMIC AND CONVERGENT TIP DISTORTION RECTIFICATION

The Gamma instruments will be designed to rectify panoramic and convergent tip distortions by the geometric relationships of the various components of the optical system. The approach to the geometric design is contained in the following paragraphs.

6.4.1 Object Space Consideration (Fig. 1)

The cameras at altitude (H) above the mean earth radius (R) has a tip angle (t). The camera axis intersects the sphere at point B in the line of flight forming the arc A-B. This arc intercepts the angle δ at the earth's center (0). A plane (E), tangent to the sphere at point B, approximates the earth curvature in the line of flight. It then becomes necessary to consider a new tip angle (t′).

$$\sin (t + \delta) = \sin t' = \frac{R + H}{R} \sin t \qquad (1)$$

then

$$t' - t = \delta$$

Our total object distance (D_0) is then

$$D_0 = \frac{H \cos \delta/2}{\cos (t - \delta/2)} \qquad (2)$$

The initial tip reference (H) is replaced by (H′)

$$H' = D_0 \cos t' \qquad (2a)$$

If we then consider (D_0) to be lying in the scanning plane, this plane would cut the sphere in a circle whose circumference would contain points B and C. The circle with radius (P-B) would necessarily contain the scan center line on the surface of the sphere.

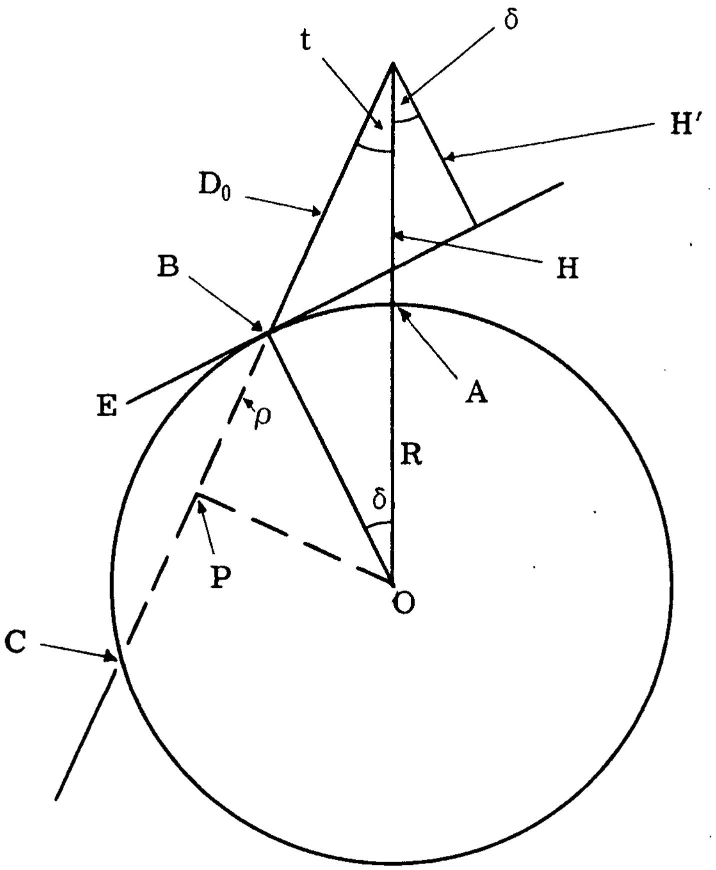

Fig. 1 — Object space geometry

This radius P-B or ρ is

$$\rho = R \cos t' \tag{3}$$

6. 4. 2 Image Space Considerations

It is specified that the resultant photographic output of rectifiers Gamma I and Gamma II be of nearly the same image scale. If standard 9-inch film is used as output, the Gamma II input of 6. 6-inch film will have a magnification factor of 1. 25×. If then the Gamma I and Gamma II focal lengths have a factor of 1. 5 the resultant Gamma I magnification is 1. 875×.

With the magnification m_0 (1. 875) given as a starting parameter we can then derive the principle plane rectifier dimensions (Fig. 2).

m_0 = Central magnification
F = Camera focal length or rectifier lens-film distance
d_0 = Lens — rectifier easel distance
t' = Rectification tip angle
E' = Easel plane
f = Rectifier lens focal length
θ_0 = Rectifier lens tip for any easel tip (t') satisfying the Scheimpflug Condition
V = Rectifier vanishing point

then

$$d_0 = \frac{m_0 F}{\cos t'} \tag{4}$$

$$\tan \theta_0 = \frac{F}{F\left(\cot t' + \frac{m_0}{\sin t'}\right)}$$

$$= \frac{\sin t'}{\cos t' + m_0} \tag{5}$$

and

$$f = \frac{m_0 F}{\sin t'} \sin \theta_0 \tag{6}$$

It is apparent that for any new tip angle (t') the focal length changes. In the case of Gamma I where t' varies by approximately 10 degrees, f would be required to change by 0. 2 inch. This would create optical problems which should not be considered for a finite conjugate high resolution lens.

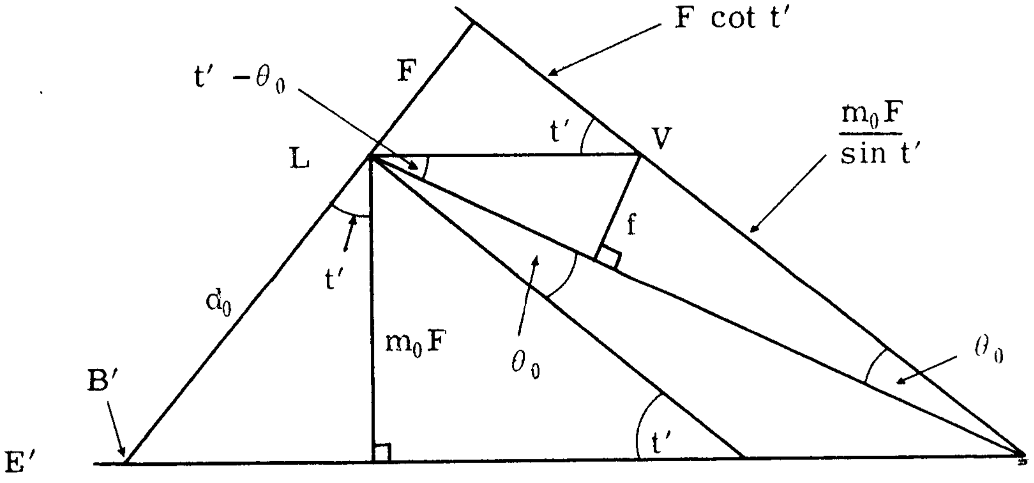

Fig. 2 — Rectification geometry

Instead, a fixed optimum focal length is chosen and the above dimensions are recalculated with the value for f given.

then

$$\sin (t' - \theta_0) \quad \frac{f}{F} \sin t'$$

and

$$\theta_0 \cdot t - (t' - \theta_0) \qquad (4a)$$

$$\frac{m_0 F \sin \theta_0}{\sin t'} = \frac{F}{\sin t'} \sin (t' - \theta_0)$$

and

$$m_0 = \frac{\sin (t' - \theta_0)}{\sin \theta_0} \qquad (5a)$$

and

$$d_0 \quad \frac{m_0 F}{\cos t'} \qquad (6a)$$

6.4.3 Object – Image Scale Relationships

Paragraphs 6.4.1 and 6.4.2 have provided a basis for scale determinations in the principle plane of the rectifier (Fig. 3).

$$M_{\text{map scale}} \quad \frac{d_0}{D_0} \text{ or } 1: \frac{D_0}{d_0} \qquad (7)$$

$$R'_{\substack{\text{easel radius of} \\ \text{curvature}}} \quad R \cdot M \qquad (8)$$

$$\rho_{\text{map scale}} \quad \rho M \text{ or } R' \cos t' \qquad (9)$$

It is apparent that for changes in easel tip (t') d_0 varies accordingly, therefore, changing the map scale M. In the Gamma I rectifier with tip angles varying by ±5 degrees the maximum change in scale is less than 1.5 percent. For a fixed altitude parameter the easel radius of curvature changes by a similar

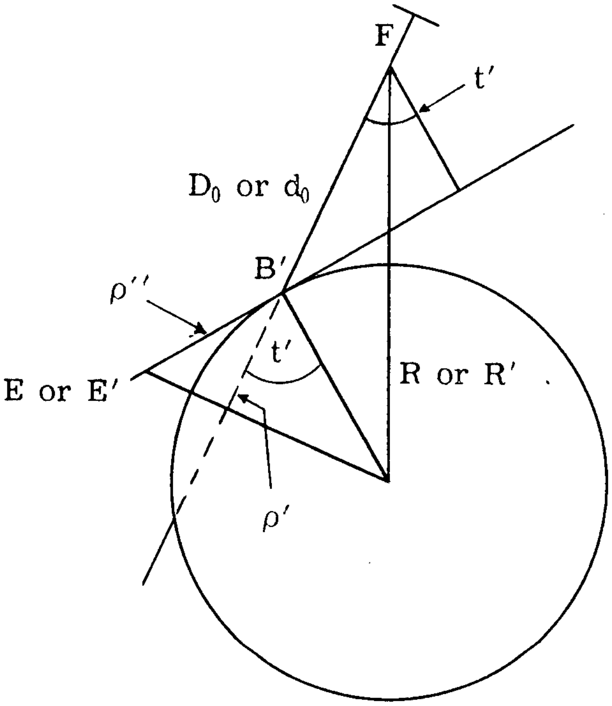

Fig. 3 – Object image comparison

percentage. If a mean radius of easel curvature is selected, the deviation from this mean can be computed (Fig. 4).

$$h = \frac{Y^2}{2\,R''}$$

where Y = maximum image distance on easel
R'' = mean radius
h = deviation from flat easel

then

$$dh = h\,\frac{(P)}{100}$$

where dh = true deviation
$\frac{P}{100}$ = maximum percentage change

In the Gamma I rectifier dh is less than 0.1 mm.

To consider the significance of ρ' it must first be explained that the rectification easel E' will be in the shape of a cylinder, tangent at B' with radius R'. E' will be one element lying in the cylinder parallel to the cylinder axis. Since the scanning plane cuts the cylinder at an angle t', the developed section of the cylinder or output format will contain the scan center line.

In the plane of the developed format the scan center line will have a radius ρ''. At the extreme ends of the Gamma I output format this deviation from a straight line is in the order of 1.5 mm.

$$\rho'' = \frac{\rho'}{\sin t'}$$

6.4.4 Image Space — Off Principle Plane

6.4.4.1 Vertical Section (Fig. 5)

With the fixed dimensions for rectifier distances, tilts, and radii, the off-principle plane (scan angle) image geometry and quality are dependent on the motions of the scanning arm and lens.

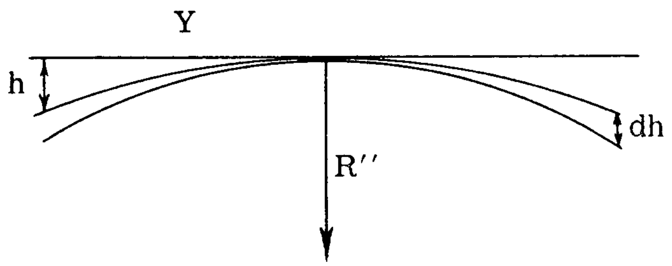

Fig. 4 — Rectifier easel geometry

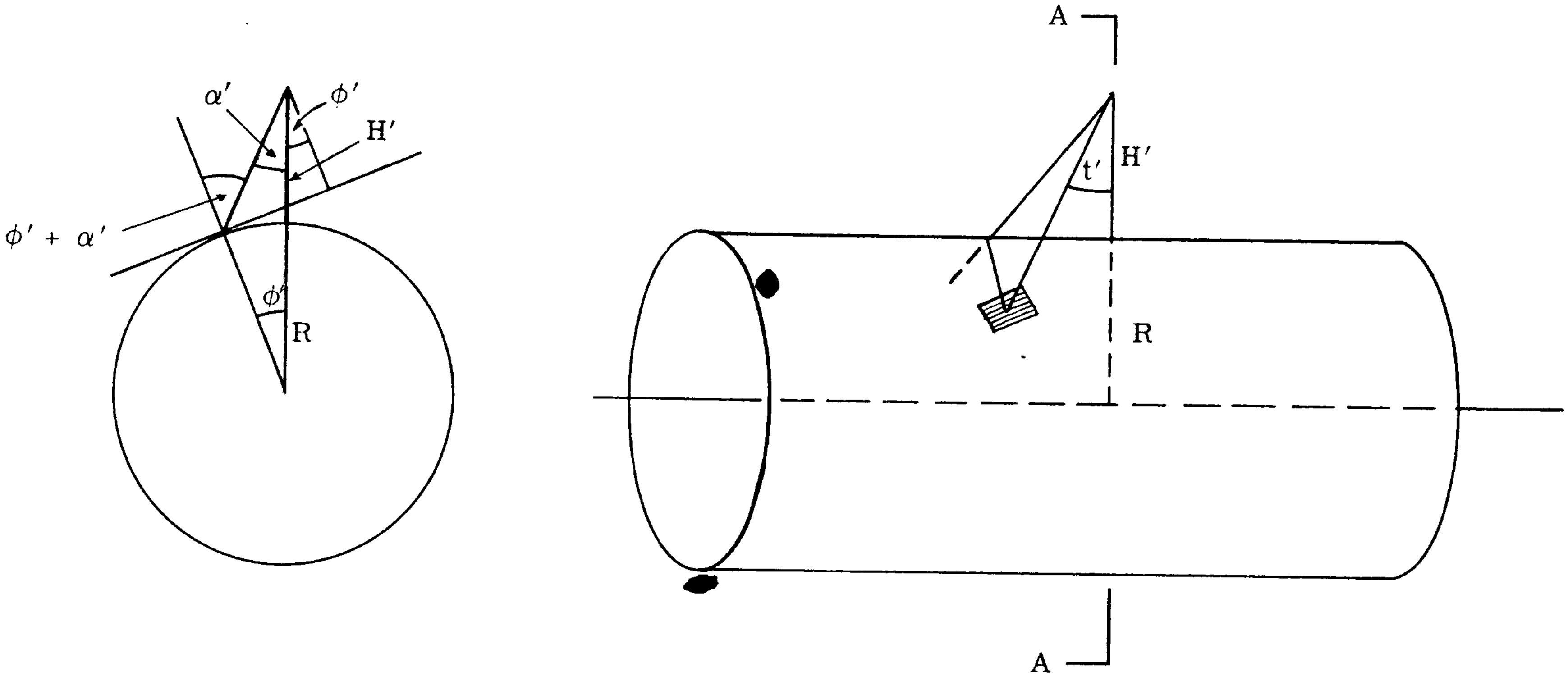

Fig. 5 — Rectification cylinder

The scan angle α is in the tipped plane and to compute the scan angle in the vertical reference plane.

$$\tan \alpha' = \frac{\tan \alpha}{\cos t'} \tag{10}$$

The cylinder easel shape suggests that each angle α' has a new reference ϕ'.

$$\sin (\alpha' + \phi') = \frac{R + H'}{R} \sin \alpha'$$

$$\phi' = (\alpha' + \phi') - \alpha' \tag{11}$$

The angle of maximum tilt (t) formed by angles t' and α can then be computed according to the Law of Cosines in Spherical Trigonometry.

$$\cos t = - \sin \phi' \sin \alpha + \cos \phi' \cos \alpha \cos t' \tag{12}$$

C. 4. 4. 2 Oblique Section (Fig. [illegible])

In the tipped or oblique plane the analysis is similar to that of the vertical plane but using rectifier dimensions

$$\sin (\alpha + \phi) = \frac{\rho' + d_0}{\rho} \sin \alpha$$

$$\phi = (\alpha + \phi) - \alpha \tag{13}$$

The lens to easel distance (d) for any scan angle α is:

$$d = \rho \frac{\sin \phi}{\sin \alpha} \tag{14}$$

With known values for f (rectifier focal length), F (camera focal length and rectifier image conjugate) and now d (rectifier object conjugate), the total focusing tilt angle η can be computed.

$$\cos \eta = \frac{f (F + d)}{F d} \tag{15}$$

This is a theoretical solution for a perfect lens system. Optical characteristics of a chosen lens system would require that angle η be determined on the finite conjugate testing bench.

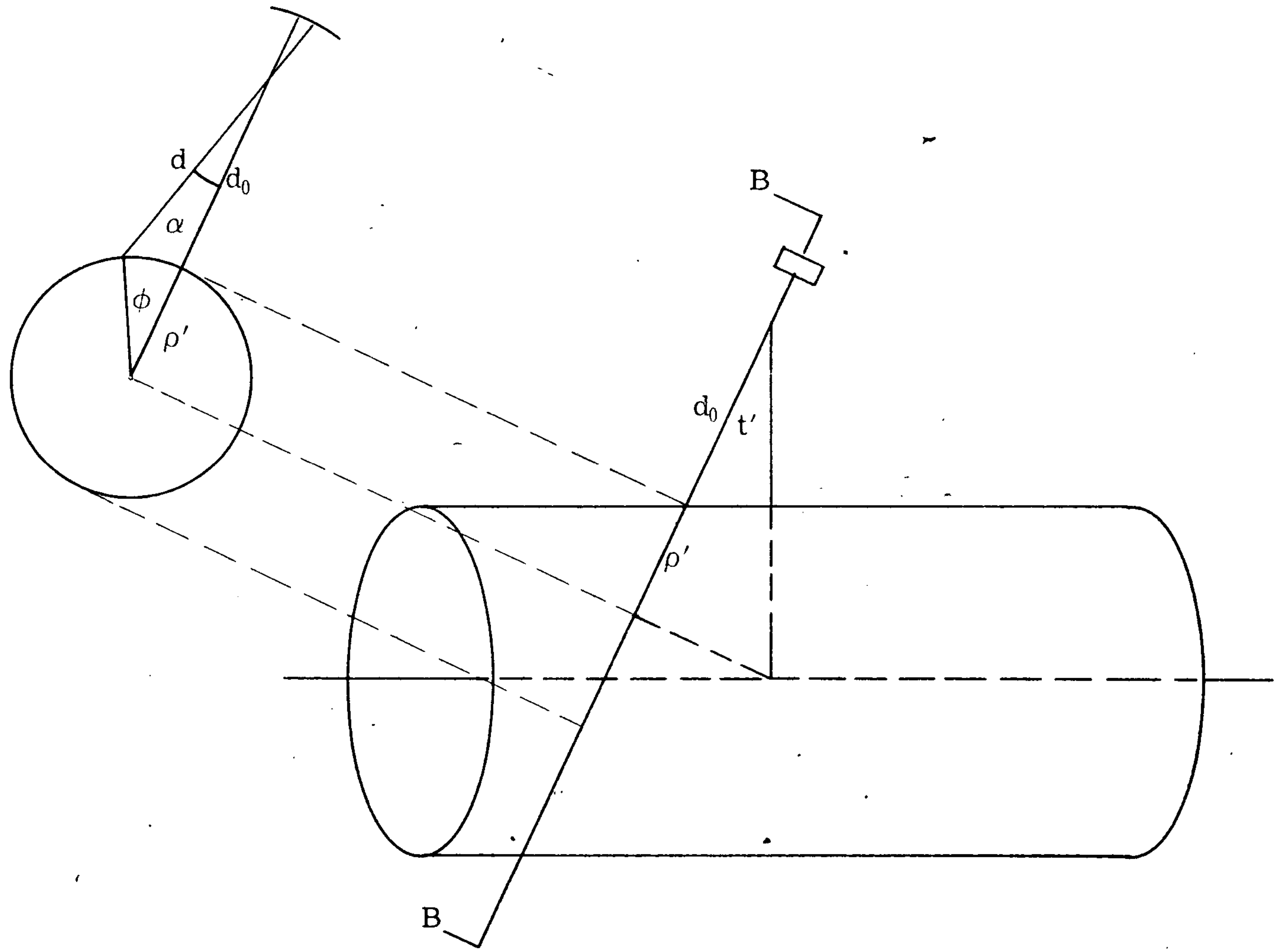

Fig. 6 — Scanning plane related rectification cylinder

6. 4. 5 Differential Lens Functions

The values of primary lens tilt (θ_0) can be computed for any easel tilt (t') with equation 4a to satisfy the Scheimpflug Condition of optical rectification, and the total focusing tilt angle η can be computed (15) to satisfy the Newton Lens Equation. What remains is the small variations of both of these lens functions made necessary by the curved easel shape. These small changes are the key to the expected high photographic image quality.

The slit used to scan the input film is parallel to the axis of the cylinder of the input film. This cylinder with radius F and the easel cylinder with radius R' intersect at an angle t'. This condition causes the imaging slit to be projected onto the easel with a continually changing azimuth when being used at any scan angle other than $\alpha = 0$.

The following geometrical conditions are most easily illustrated with spherical trigonometry (Fig. 7).

First, to compute the azimuth (β) of the line of the angle of maximum tilt ν'.

$$\sin \phi' = - \sin \alpha \cos \nu' + \cos \alpha \sin \nu' \cos \beta$$

then

$$\cos \beta = \frac{\sin \phi' + \sin \alpha \cos \nu'}{\cos \alpha \sin \nu'} \qquad (16)$$

With given angles of ν' and β the angle (ξ) included between the scanning plane and easel plane at any scan angle can be determined:

$$0 = \cos \nu' \cos \xi - \sin \nu' \sin \xi \sin \beta$$

then

$$\cos \nu' \cot \xi = \sin \nu' \sin \beta$$

and

$$\cot \xi = \tan \nu' \sin \beta \qquad (17)$$

This value in turn must be divided into components in order to achieve a mechanical solution:

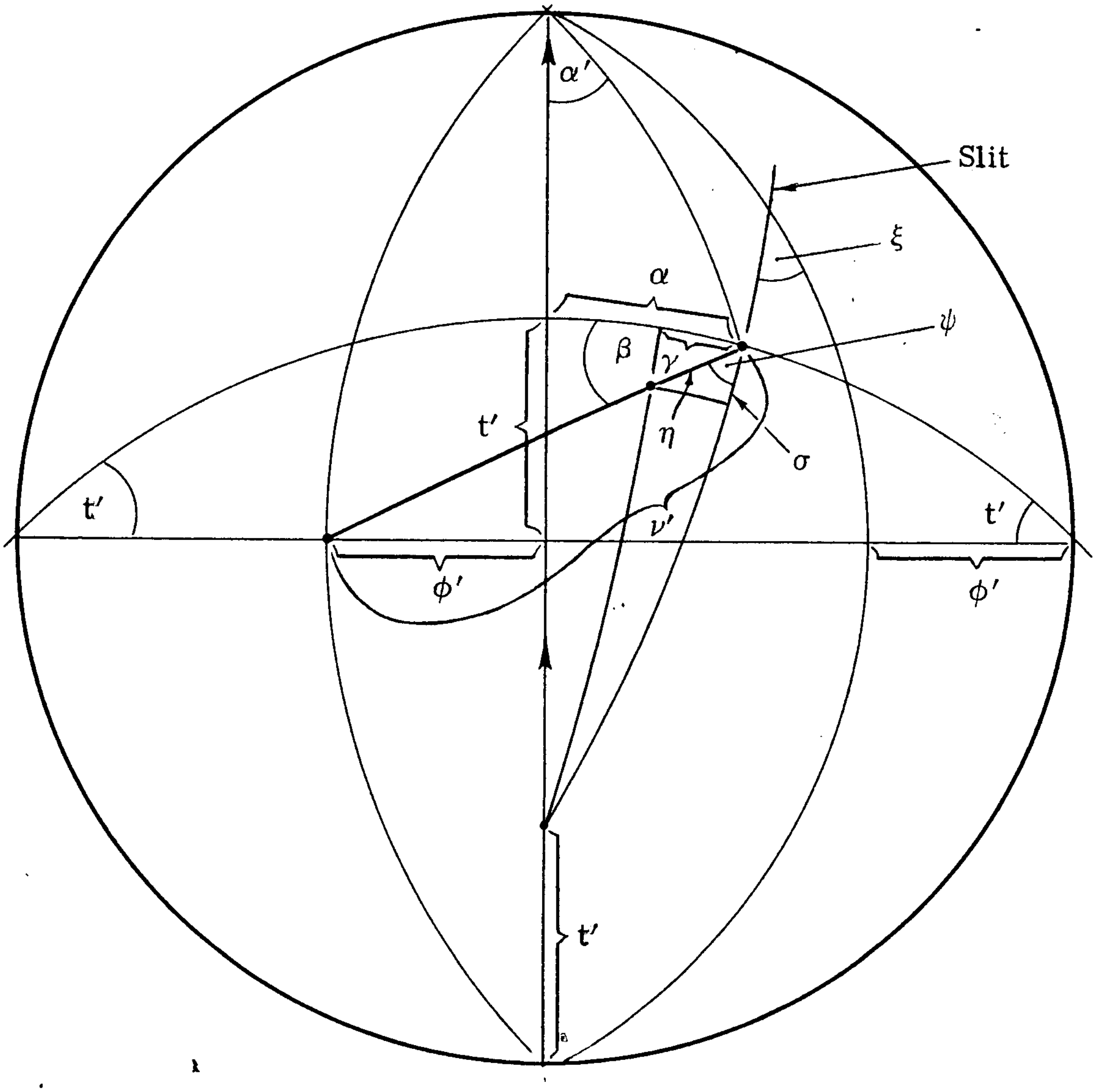

Fig. 7 — Spherical relationship of functions

$$\tan\sigma = \frac{F}{(F + d)\tan\xi}$$

$$= \frac{F}{(F + d)}\tan\nu'\sin\beta \qquad (18)$$

The lens already has values for the total focusing tilt η and the value of one tilt component (σ) can be computed by equation 18. Before finding the second lens tilt component the azimuth of the total focusing tilt must be determined.

$$\cos\psi = \frac{\tan\sigma}{\tan\eta} \qquad (19)$$

or

$$\sin\psi = \frac{\tan\gamma}{\tan\eta}$$

where γ is our second tilt component.

Therefore

$$\tan\gamma = \tan\eta\ \sin\psi \qquad (20)$$

In the rectifier, the angle γ is the included angle between the scan axis and the "active" optical axis of the lens. The term "active" was used to qualify the optical axis because of the influence of the Scheimpflug tilt θ.

Because of the azimuth of the slit image on the curved easel the values for θ_0 determined with equation 4a are modified slightly as can be determined as follows:

$$\frac{\cos\psi}{\sin\theta} = \frac{\sin 90^\circ}{\sin\eta}$$

then

$$\sin\theta_{new} = \sin\eta\ \cos\psi$$

$$= \tan\sigma\cos\eta$$

$$= \frac{F}{F + d}\cot\xi\ \frac{f\,(F + d)}{F\,d}$$

$$\sin \theta_{new} = \frac{f}{d} \cot \xi \qquad (21)$$

The value for θ and γ determined by the above formulation are theoretical values for a lens assumed to have a flat optical field. The true functions can only be determined by physically testing the chosen lens at the required conjugates on the optical test bench.

To determine the total field angle (η') required of the rectifier lens, the total focusing tilt angle η and one half the taking camera lens field ϵ must be considered together with the azimuth angle β as follows:

$$\cos \eta' = \cos \epsilon \cos \eta - \sin \epsilon \sin \eta \cos \beta \qquad (22)$$

This value is used as a prime factor together with the focal length, f-number, resolution, distortion, conjugates and wavelength of the projection light, to specify the required rectifier lens.

6.5 LENS POSITION

To retain and reproject rigidly the geometry of the input film, the rectifier lens will be positioned exactly where the camera lens was positioned — a distance equivalent to the acquisition camera focal length. Gamma I — 24 inches. Gamma II — 36 inches.

6.6 IMAGE FORMAT, SHAPE AND POSITION

The input film, or negative image, will retain the original radius of curvatures, i.e., the acquisition camera focal length. Because the image geometry distortion due to image motion correction will not be removed, the image format will not move during rectification.

6.7 OBJECT FORMAT, SHAPE AND POSITION

The object format will simulate, as closely as possible, the earth's surface in map, or rectification, scale. In the direction of flight, the easel will be a plane tangent to the sphere at the image scan center line.

In the scan direction the surface will be a cylinder of radius R', as computed with equation 8 in the rectification theory. An average R' was used for all tip angle conditions. The maximum deviation from the average is explained in paragraph 6.4.3 Object-Image Scale Relationships.

The true R' values (in feet) can be found in lines 30 of Gamma I and Gamma II calculation sheets.

The earth's radius was assumed to be 20.9×10^6 feet which is the radius of a sphere having the same volume as the earth.

The object format position varies as a function of the tip variation. The easel setting is computed with equation 6a. This is the rectifier-lens to easel-center distance (in inches); the values of which can be found in lines 28 of the calculation sheets.

6. 8 EASEL CURVATURE FOR RANGE OF ALTITUDE

Probably the most critical flight parameter is the range of flight altitudes. The value of t′ (the true easel tilt) and the easel radius of curvature are primarily a function of altitude. This can be seen in equations 1, 2, 7, and 8. A variation of plus and minus 5 or 10 percent from a mean altitude has little influence on the above factors, and the resulting errors are well within the geometric tolerance. One altitude was used for the calculations of both the Gamma I and Gamma II analysis. This altitude parameter was obtained through an authoritative source. Since making the enclosed analysis, another source indicates a new range of altitudes. It will suffice to say that the rectification theory holds regardless of the magnitude of the parameters.

6. 9 PRIMARY EASEL TILT

The primary tilt will be the intentional camera tip plus the influence of earth curvature in the direction of flight. For the Gamma I this will be 15 degrees plus approximately 23 minutes. The value t′ is computed with equation 1.

6. 10 VARIABLE EASEL TILT

The variation specified is plus or minus 5 degrees from the nominal. The true easel tilt range for Gamma I is approximately 10 degrees, 10 minutes to 20 degrees, 30 minutes.

For Gamma I and Gamma II the t′ values can be found in lines 5 of the calculation sheets.

6. 11 SMALL SCALE CHANGE

For variations in camera tip of ± 5 degrees, at the same flight altitude, the scale changes by less then 1. 5 percent. Since for any series of 10 photos, or less, this total tip variance is unlikely and an altitude change is even more unlikely, scale variations greater than 0. 5 percent will not be considered. A magnification "zoom" feature (optional) on the rectifier lens will compensate for the half percent "scale fitting" error.

6. 12 LENS SELECTION

6. 12. 1 Focal Length

The rectifier lens focal lengths were determined by rectification theory as seen in Fig. 2. If a magnification constant is used as a starting parameter, the changes in t will bring about similar changes in lens focal length. The average value is chosen for each rectifier. The Gamma I lens has a focal length of 15. 78 inches, and the Gamma II lens has a focal length of 20. 11 inches. This number is expected to be held to ± .005 inch during design and fabrication.

The average focal lengths were determined with equations 4, 5, and 6 and used in 4a. Values can be found in lines 21 of the calculations.

6. 12. 2 Field Angle

The required angular field of the printer lens is a function of the total focusing tilt as computed with equation 15 (found in lines 117, 118, and 119) and the angular field of the acquisition camera The half field is computed with equation 22.

For the Gamma I lens the minimum full field is 47 degrees. For the Gamma II lens the minimum full field is 55 degrees. These angles are used at maximum t′ and scan (α) angles.

6. 12. 3 F-numbers

The lens will be used between f/9 and f/11 at the required conjugates. This requires the lenses to be designed for infinity conjugates with stops at f/5 to f/8.

6. 12. 4 Resolution

Resolution at short conjugate is to be 80 lines per millimeter across the width of format at nadir determined by value of resolution on the specified output film, multiplied by the magnification factor for any scan angle.

6. 13 LENS MOTION

6. 13. 1 Lens Position

The lens is rotated for scanning and Scheimpflug focusing, about its conjugate design nodal point. The rotation axis has a fixed attitude. A "fork" arrangement will allow the independent Scheimpflug tip of the lens.

6. 13. 2 Lens Scan

It is obvious that a lens rotating about its nodal point with an angular displacement coincident with that of the scan arm cannot maintain focus throughout the entire scan between the input cylinder and the easel cylinder. The method of maintaining focus is to rotate the lens through an angle γ (as determined by equations 19 and 20) that is a function of the total focusing tilt that is a function of the scan angle. For scan angles of 35 degrees the lens scan is approximately 20 degrees, as seen in lines 137 of the calculations.

6. 13. 3 Lens Tilt for Easel Tilt

The lens tilt required to satisfy the Scheimpflug condition for any one easel tilt is determined through classical rectifier theory and is computed by equation 4a. The lens tilt is approximately one-third of the easel tilt as shown in lines 24 of the calculations.

6. 13. 4 Variable Lens Tilt for Easel Curvature

Because the lens tilt is a function of the angle intercepted by an element on the input cylinder and the projected element on the easel, a change in this angle results in a lens tilt change. Because of the easel curvature, this angle does change during the scan. The lens tilt, as a function of scan, is computed with equation 21. The calculations based on the assumptions to date require a change, from zero to maximum scan, of less than one minute and therefore need not be mechanically solved once the indicated easel-lens tip components are set.

6. 14 LENS DESIGN

STAT

Investigation has disclosed that commercially manufactured lenses with the optical capabilities and the physical properties required for satisfactory operation in the Gamma instruments are nonexistent. This being the case, [redacted] will design and construct lenses in accordance with the parameters outlined in subsection 6. 12 of this report.

6. 15 FILM

In accordance with the recommendations of the customer, Kodak Aerographic Duplicating Film-Emulsion 5427 (Military Type 1A, Class G2) has been selected for use in the Gamma instruments.

Aero Dup has a blue-sensitive fine grain emulsion which can be used with 0A or 1A safelights. It is capable of 100 L/mm resolution of high contrast targets. Normally it is a high contrast film but, with the proper developing technique, the processing gamma may be controlled to give a range of from 0. 75 to 3. 0 gamma. It is a clear base film with a very low fog level. Spectral response is between 400 and 550 angstroms. The projection light sources and the exposure control system will be designed for compatability with Aero Dup 5427 film.

6. 16 EXPOSURE CONTROL

Due to the conditions under which the input film is exposed, it seems reasonable to assume that variations in the illumination of the ground scene will cause the exposure of discrete areas in individual frames to vary over considerable range, i. e. , from the maximum illumination characteristic of an area receiving direct sunlight, to a minimum illumination associated with an area in the shadow of a dark cloud. Fortunately, some compensation for these wide variations in exposure can be effected during development by controlling the effective emulsion speed of gross areas on the film as a function of their sensed exposure.

To produce the maximum amount of useful information in the reproduction cycle, some method of varying the illumination is required. The proposed system of printing incorporates a moving light source passing the light through a 2 mm printing slit and subsequently illuminating a 2 mm lateral area of the input negative photography. To measure density and compensate for density variation during the actual printing operation would be the equivalent to automatically dodging a small finite area. Automatic dodging is expensive and complex, and requires the use of considerable amounts of extra bulky components. It is not felt that a system for automatically adjusting exposure over a 2 mm slit area is a definite requirement. Therefore, we propose a system which permits the operator to measure an area of prime reproduction interest, and to adjust the illumination at the printing station prior to starting the exposure sweep. The operator will be able to measure the quantity of illumination being transmitted through the negative with a mobile photocell probe. The spot size of the photocell probe will be developed with respect to the expected photography. The measurement of illumination passing through the negative can be converted by adjusting appropriate dials, into actual units of light passing through the slit and negative when the measured frame is transported to the printing operation.

A considerable number of physical methods for controlling the illumination passing the slit have been investigated. Of these methods one was selected as being most economical, reliable, and easy to operate. This is a system utilizing a continuous tone gradient neutral density belt mounted under the printing aperture and controlled by two knobs, one on either side of the lamp housing. This gradient belt will be produced by either a vacuum deposit technique or recorded on a special photographic sensitized material. It is proposed to have the gradient continuously range in transmission value from 1.5 percent to 80 percent transmission along the longitudinal axis. In addition to being uniform in transmission values, the important design criteria will be in the total length of the gradient belt. The longer the belt, within limits, the smaller the change in transmission value; therefore, the less critical the adjustment or position of the belt.

Automatic compensation for the inherent difference in exposure required from nadir to ends of frame will be designed into the unit by automatically changing the rate of speed of the light housing unit.

Table 3 — Rectifier Calculations for Gamma I

	Tip Angle, degrees										
1 t°	10	11	12	13	14	15	16	17	18	19	20
2 sin t	0. 17364818	0. 19080900	0. 20791169	0. 22491505	0. 24192190	0. 25881905	0. 27563736	0. 29237170	0. 30901699	0. 32556815	0. 34202014
3 (R + H)/R	1. 024727	1. 024727	1. 024727	1. 024727	1. 024727	1. 024727	1. 024727	1. 024727	1. 024727	1. 024727	1. 024727
4 2 × 3 = sin t′	0. 17794198	0. 19552713	0. 21305272	0. 23051341	0. 24790390	0. 26521887	0. 28245304	0. 29960117	0. 31665805	0. 33361847	0. 35047727
5 $\sin^{-1}$ t′ = t + δ	10-14-59. 5*	11-16-32. 0*	12-18-05. 0*	13-19-38. 0*	14-21-13. 0*	15-22-48. 0*	16-24-24. 0*	17-26-01. 0*	18-27-39. 5*	19-29-19. 0*	20-30-59. 5*
6 cos t′	0. 98404100	0. 98069817	0. 97704041	0. 97306946	0. 96878419	0. 96418804	0. 95928112	0. 95406474	0. 94853950	0. 94270782	0. 93657100
7 t′ − $\delta/2$	10-07-30. 0*	11-08-16. 0*	12-09-02. 5*	13-09-49. 0*	14-10-36. 5*	15-11-24. 0*	16-12-12. 0*	17-13-00. 5*	18-13-50. 0*	19-14-39. 5*	20-15-30. 0*
8 cos $\delta/2$	0. 99999762	0. 99999711	0. 99999654	0. 99999592	0. 99999524	0. 99999450	0. 99999370	0. 99999284	0. 99999190	0. 99999091	0. 99998984
9 H(cos $\delta/2$)	516798. 77	516798. 50	516798. 21	516797. 89	516797. 54	516797. 16	516796. 74	516796. 30	516795. 81	516795. 30	516794. 75
10 cos(t′ − $\delta/2$)	0. 98442657	0. 98116551	0. 97759689	0. 97372373	0. 96954407	0. 96506224	0. 96027745	0. 95519150	0. 94980535	0. 94412180	0. 93814099
11 9/10 = D_0	524974. 4	526718. 9	528641. 4	530743. 8	533031. 5	535506. 5	538174. 3	541039. 4	544107. 0	547382. 0	550871. 0
12 6 × 11 = H′	516596. 33	516552. 26	516504. 01	516450. 58	516392. 49	516328. 96	516260. 44	516186. 61	516106. 98	516021. 29	515929. 80
13 R cos t′ = ρ	20, 566456. 9	20, 496591. 7	20, 420144. 6	20, 337151. 7	20, 247589. 6	20, 151530. 0	20, 048975. 4	19, 939953. 1	19, 824475. 5	19, 702593. 4	19, 574333. 9
14 [45]/cos t′	45. 730	45. 886	46. 057	46. 245	46. 450	46. 671	46. 910	47. 167	47. 441	47. 735	48. 048
15 cos t′ + m_0	2. 85904100	2. 85569817	2. 85204041	2. 84806946	2. 84378419	2. 83918804	2. 83428112	2. 82906474	2. 82353950	2. 81770782	2. 81157100
16 4/15 = tan θ_0	0. 0622383	0. 0684691	0. 0747018	0. 0809367	0. 0871739	0. 0934136	0. 0996559	0. 1059011	0. 1121493	0. 1184006	0. 1246553
17 $\sin^{-1} \theta_0$	03-33-41. 0*	03-55-01. 0*	04-16-20. 0*	04-37-38. 0*	04-58-55. 5*	05-20-12. 0*	05-41-28. 0*	06-02-45. 0*	06-23-56. 0*	06-45-09. 0*	07-06-20. 0*
18 sin θ_0	0. 06211794	0. 06831034	0. 07449527	0. 08067250	0. 08684450	0. 09300779	0. 09916538	0. 10532399	0. 11144966	0. 11758073	0. 12369770
19 cos θ_0	0. 99806882	0. 99766412	0. 99722137	0. 96674066	0. 99622190	0. 99566538	0. 99507097	0. 99443796	0. 99377008	0. 99306333	0. 99231995
20 [45]/4	252. 8914	230. 1470	211. 2153	195. 2164	181. 5219	169. 6711	159. 3185	150. 1996	142. 1091	134. 8846	128. 3963
21 18 × 20 = f	15. 7091	15. 7214	15. 7345	15. 7486	15. 7642	15. 7807	15. 7989	15. 8196	15. 8380	15. 8598	15. 8823
22 f/F × 4	0. 11699685	0. 12855909	0. 14008216	0. 15156257	0. 16299681	0. 17438141	0. 18571287	0. 19698777	0. 20820267	0. 21935414	0. 23043880
23 $\sin^{-1}$ of 22	06-43-08. 0*	07-23-11. 0*	08-03-09. 0*	08-43-03. 0*	09-22-51. 0*	10-02-33. 5*	10-42-10. 0*	11-21-39. 0*	12-01-01. 5*	12-40-16. 0*	13-19-22. 5*
24 5 − 23 = θ_0	03-31-51. 5*	03-53-21. 0*	04-14-56. 0*	04-36-35. 0*	04-58-22. 0*	05-20-14. 5*	05-42-14. 0*	06-04-22. 0*	06-26-38. 0*	06-49-03. 0*	07-11-37. 0*
25 sin of 24	0. 06158800	0. 06782665	0. 07408915	0. 08036806	0. 08668242	0. 09302000	0. 09938729	0. 10579163	0. 11223013	0. 11870725	0. 12522260
26 22/25 = m_0	1. 89967	1. 89541	1. 89072	1. 88585	1. 88039	1. 87466	1. 86858	1. 86203	1. 85514	1. 84786	1. 84023
27 m_0 × F	45. 592	45. 490	45. 377	45. 260	45. 129	44. 992	44. 846	44. 689	44. 523	44. 349	44. 166
28 27/6	46. 331	46. 385	46. 443	46. 513	46. 583	46. 663	46. 749	46. 841	46. 938	47. 044	47. 157
29 1: D_0/d_0 = M	1:135968. 5	1:136279. 1	1:136599. 8	1:136930. 8	1:137308. 4	1:137697. 7	1:138135. 0	1:138621. 4	1:139122. 2	1:139638. 2	1:140170. 7
30 R × M = R′	153. 7121	153. 3617	153. 0017	152. 6318	152. 2121	151. 7818	151. 3013	150. 7704	150. 2276	149. 6725	149. 1039
31 R′ × cos t′ = ρ'_M	151. 2590	150. 4015	149. 4888	148. 5213	147. 4607	146. 3462	145. 1405	143. 8447	142. 4968	141. 0974	139. 6464
32 tan 10°	0. 17632698	0. 17632698	0. 17632698	0. 17632698	0. 17632698	0. 17632698	0. 17632698	0. 17632698	0. 17632698	0. 17632698	0. 17632698
33 tan 20°	0. 36397023	0. 36397023	0. 36397023	0. 36397023	0. 36397023	0. 36397023	0. 36397023	0. 36397023	0. 36397023	0. 36397023	0. 36397023
34 tan 35°	0. 70020754	0. 70020754	0. 70020754	0. 70020754	0. 70020754	0. 70020754	0. 70020754	0. 70020754	0. 70020754	0. 70020754	0. 70020754
35 32/6	0. 1791866					0. 1828761					0. 1882686
36 33/6	0. 3698730					0. 3774888					0. 3886200
37 34/6	0. 7115633					0. 7262147					0. 7476288
38 $\tan^{-1}$ 35 = α'	10-09-32. 0*					10-21-49. 0*					10-39-44. 0*
39 $\tan^{-1}$ 36 = α'	20-17-53. 0*					20-40-51. 5*					21-14-14. 0*
40 $\tan^{-1}$ 37 = α'	35-26-03. 0*					35-59-16. 0*					36-46-58. 0*
41 sin of 38	0. 17637851					0. 17989444					0. 18501869
42 sin of 39	0. 34690382					0. 35316400					0. 36223018
43 sin of 40	0. 57976715					0. 58761266					0. 59878288
44 (R + H′)/R	1. 024717					1. 024704					1. 024685
45 41 × 44	0. 18069479					0. 18433855					0. 18958588
46 42 × 44	0. 35539315					0. 36188856					0. 37117183
47 43 × 44	0. 59395504					0. 60212904					0. 61356383
48 $\sin^{-1}$ 45	10-24-37. 0*					10-37-21. 0*					10-55-43. 0*
49 $\sin^{-1}$ 46	20-49-03. 0*					21-12-58. 5*					21-47-16. 5*
50 $\sin^{-1}$ 47	36-26-17. 5*					37-01-21. 0*					37-50-51. 5*

Table 3 (Cont.)

	10	11	12	13	14	15	16	17	18	19	20
51 48 − 38 = φ'	00-15-05.0*					00-15-32.0*					00-15-59.0*
52 49 − 39 = φ'	00-31-10.0*					00-32-07.0*					00-33-02.5*
53 50 − 40 = φ'	01-00-14.5*					01-02-05.0*					01-03-53.5*
54 sin of 51	0.00438755					0.00451845					0.00464935
55 sin of 52	0.00906589					0.00934222					0.00961150
56 sin of 53	0.01752300					0.01805833					0.01858426
57 cos of 51	0.99999037					0.99998979					0.99998919
58 cos of 52	0.99995890					0.99995636					0.99995380
59 cos of 53	0.99984646					0.99983694					0.99982730
60 cos 10°	0.98480775					0.98480775					0.98480775
61 cos 20°	0.93969262					0.93969262					0.93969262
62 cos 35°	0.81915204					0.81915204					0.81915204
63 57 × 60 × 6	0.96908186					0.94953016					0.92233240
64 58 × 61 × 6	0.92465805					0.90600084					0.88004847
65 59 × 62 × 6	0.80595542					0.78968780					0.76706155
66 sin 10°	0.17364818					0.17364818					0.17364818
67 sin 20°	0.34202014					0.34202014					0.34202014
68 sin 35°	0.57357644					0.57357644					0.57357644
69 54 × 66	0.00076189					0.00078462					0.00080735
70 55 × 67	0.00310072					0.00319523					0.00328733
71 56 × 68	0.01005078					0.01035783					0.01065949
72 63 − 69	0.96831997					0.94874554					0.92152505
73 64 − 70	0.92155733					0.90280561					0.87676114
74 65 − 71	0.79590464					0.77932397					0.75640206
75 [(31 + 28)/31] × 66	0.1780806					0.1782622					0.1785348
76 [(31 + 28)/31] × 67	0.3507503					0.3511060					0.3516448
77 [(31 + 28)/31] × 68	0.5882171					0.5888179					0.5897173
78 $\sin^{-1}$ 75	10-15-29.0*					10-16-07.0*					10-17-04.0*
79 $\sin^{-1}$ 76	20-31-59.8*					20-33-18.0*					20-35-17.0*
80 $\sin^{-1}$ 77	36-01-50.0*					36-04-23.0*					36-08-13.0*
81 78 − 10° = φ	00-15-29.0*					00-16-07.0*					00-17-04.0*
82 79 − 20° = φ	00-31-59.5*					00-33-18.0*					00-35-17.0*
83 80 − 35° = φ	01-01-50.0*					01-04-23.0*					01-08-13.0*
84 sin of 81	0.0045039					0.00468813					0.00496447
85 sin of 82	0.00930586					0.00968643					0.01026333
86 sin of 83	0.1798562					0.01872726					0.01984212
87 (84/66) × 31 = d	47.0783					47.4124					47.9086
88 (85/67) × 31 = d	49.3864					49.7364					50.2861
89 (86/68) × 31 = d	56.9163					57.3384					57.9706
90 [f(F + d)]/Fd	0.9926865					0.9903240					0.9868775
91 [f(F + d)]/Fd	0.9770206					0.9747723					0.9713047
92 [f(F + d)]/Fd	0.9347494					0.9327080					0.9297069
93 $\cos^{-1}$ 72 = ν'	14-27-37.8					18-25-24.2					22-50-58.0
94 $\cos^{-1}$ 73 = ν'	22-50-41.6					25-28-14.4					28-44-44.2
95 $\cos^{-1}$ 74 = ν'	37-15-33.2					38-48-42.6					40-51-07.1
96 sin of 93	0.2497127					0.3160364					0.3883119
97 sin of 94	0.3882377					0.4300440					0.4809212
98 sin of 95	0.6054221					0.6266138					0.6541070
99 60 × 96	0.2459190					0.3112351					0.3824126
100 61 × 97	0.3648241					0.4041139					0.4519177

Table 3 (Cont.)

	10	11	12	13	14	15	16	17	18	19	20
101 62 × 98	0.4959327					0.5132920					0.5358131
102 (66 × 72 + 54)/99	0.7015910					0.5438538					0.4306095
103 (67 × 73 + 55)/100	0.8888038					0.7872036					0.6848167
104 (68 × 74 + 56)/101	0.9558457					0.9060411					0.8443964
105 $\cos^{-1} 102 = \beta$	45-26-43.0*					57-03-13.0*					64-29-37.5*
106 $\cos^{-1} 103 = \beta$	27-16-36.0*					38-04-30.0*					46-46-44.0*
107 $\cos^{-1} 104 = \beta$	17-05-23.0*					25-02-10.0*					32-23-34.0
108 tan of 93	0.2578832					0.3331081					0.4213771
109 tan of 94	0.4212801					0.4763449					0.5485194
110 tan of 95	0.7606702					0.8040446					0.8647602
111 sin of 105	0.7125807					0.8391798					0.9025383
112 sin of 106	0.4582876					0.6166924					0.7287164
113 sin of 107	0.2938689					0.4231894					0.5357204
114 $\{[24]/([24] + 87)\} \times (108 \times 111)$	0.06204850					0.0929459					0.1269308
115 $\{[24]/([24] + 88)\} \times (109 \times 112)$	0.0631400					0.0956135					0.1291380
116 $\{[24]/([24] + 89)\} \times (110 \times 113)$	0.0663018					0.1003993					0.1356398
117 $\cos^{-1} 90 = \eta$	06-56-01.0*					07-58-37.0*					09-17-32.0*
118 $\cos^{-1} 91 = \eta$	12-18-24.0*					12-53-10.0*					13-45-32.0*
119 $\cos^{-1} 92 = \eta$	20-48-44.0*					21-08-20.5*					21-36-39.0*
120 tan of 117	0.1216086					0.14013051					0.1636169
121 tan of 118	0.2181572					0.2289795					0.2448629
122 tan of 119	0.3801085					0.386650					0.3961467
123 114/120	0.5102312					0.6632810					0.7757805
124 115/121	0.2894243					0.4175636					0.5273890
125 116/122	0.1744286					0.2596645					0.3423999
126 $\cos^{-1} 123 = \zeta$	59-19-15.0*					48-26-58.0*					39-07-27.0*
127 $\cos^{-1} 124 = \zeta$	73-10-35.0*					65-19-09.0*					58-10-14.5*
128 $\cos^{-1} 125 = \zeta$	79-57-16.0*					74-56-59.5*					69-58-37.0*
129 sin of 126	0.8600378					0.7483708					0.6310031
130 sin of 127	0.9572010					0.9086479					0.8496243
131 sin of 128	0.9846702					0.9656990					0.9395549
132 120 × 129	0.1045880					0.1048696					0.103243
133 121 × 130	0.2088203					0.20806174					0.2080415
134 122 × 131	0.3742815					0.3733875					0.3722016
135 $\tan^{-1} 132 = \gamma$	05-58-15.0*					05-59-12.0*					05-53-40.0*
136 $\tan^{-1} 133 = \gamma$	11-47-42.0*					11-45-12.0*					11-45-08.0*
137 $\tan^{-1} 134 = \gamma$	20-31-12.0*					20-28-30.0*					20-24-55.0*

* Deg-Min-Sec

Table 4 – Rectifier Calculations for Gamma II

Tip Angle, degrees

1 t°	06-42-00.0	07-42-00.0	08-42-00.0	09-42-00.0	10-42-00.0	11-42-00.0	12-42-00.0	13-42-00.0	14-42-00.0	15-42-00.0	16-42-00.0
2 sin t	0.11667074	0.13398619	0.15126082	0.16848938	0.18566662	0.20278730	0.21984620	0.23683815	0.25375794	0.27060045	0.28736052
3 $(R + H)/R$	1.0247273	1.0247273	1.0247273	1.0247273	1.0217273	1.0247273	1.0247273	1.0247273	1.0247273	1.0247273	1.0247273
4 $2 \times 3 = \sin t'$	0.1195569	0.13729930	0.15500109	0.17265566	0.19025765	0.20780168	0.22528240	0.24269451	0.26003268	0.27729166	0.29446616
5 $\sin^{-1} t'$	06-51-59.0*	07-53-30.0*	08-55-01.0*	09-56-32.0*	10-58-04.0*	11-59-37.0*	13-01-10.0*	14-02-44.0*	15-04-13.0*	16-05-55.0*	17-07-32.0*
6 $\cos t'$	0.9928276	0.99052944	0.98791407	0.9849824	0.9817343	0.9781708	0.97429367	0.97010307	0.96560764	0.96078588	0.9556618
7 $\delta = t' - t$	00-09-59.0*	00-11-30.0*	00-31-01.0*	00-14-32.0*	00-16-04.0*	00-17-37.0*	00-19-10.0*	00-20-44.0*	00-22-13.0*	00-22-58.0*	00-25-32.0*
8 $\delta/2$	00-05-00.0*	00-05-45.0*	00-06-30.0*	00-07-16.0*	00-08-02.0*	00-08-48.0*	00-09-35.0*	00-10-22.0*	00-11-06.0*	00-11-29.0	00-12-46.0*
9 $\cos \delta/2$	0.9999989	0.99999860	0.99999821	0.99999777	0.99999727	0.99999672	0.99999611	0.99999545	0.99999479	0.99999442	0.99999310
10 $t' - \delta/2$	06-46-59.0*	07-47-45.0*	08-48-31.0*	09-49-16.0*	10-50-02.0*	11-50-49.0*	12-51-35.0*	13-52-22.0*	14-53-07.0*	15-54-26.0*	16-54-46.0*
11 $\cos (t' - \delta/2)$	0.99300048	0.99075771	0.98820538	0.98534512	0.98217716	0.97869951	0.97491789	0.97083051	0.96644212	0.9617068	0.95674873
12 $H \cos \delta/2 = D_0$	520,442.3	521,620.0	522,967.0	524,485.0	526,176.0	528,045.9	530,093.9	532,325.3	534,742.1	537,374.9	540,159.0
13 $6 \times 12 = H'$	516,709.0	516,680.0	516,646.0	516,608.5	516,565.5	516,519.0	516,467.1	516,410.4	516,351.1	516,302.2	516,209.3
14 $R \times \cos t' = \rho$	20,750100	20,702060	20,627400	20,586130	20,518250	20,443770	20,362740	20,275150	20,181200	20,080420	19,973330
15 $[45]/\cos t'$	45.32509	45.43025	45.55052	45.68610	45.83725	46.00424	46.18730	46.38682	46.60278	46.83666	47.08779
16 $\cos t' + m_0$	2.2428276	2.2405294	2.2379141	2.2349824	2.2317343	2.2281708	2.2242937	2.2201031	2.2156076	2.2107859	2.2056618
17 $4/16 = \tan \theta_0$	0.05330579	0.06127985	0.06926141	0.07725146	0.08525103	0.09326111	0.10128267	0.10931678	0.11736405	0.12542674	0.13350467
18 $\sin^{-1} \theta_0$	03-03-05.0*	03-30-24.0*	03-57-43.0*	04-25-03.0*	04-52-22.0*	05-19-41.0*	05-47-00.0*	06-14-19.0*	06-41-38.0*	07-08-57.0*	07-36-15.0*
19 $\sin \theta_0$	0.05323161	0.06116468	0.06909388	0.07702356	0.08494353	0.09285814	0.10076689	0.10866928	0.1165648	0.12445297	0.13232847
20 $\cos \theta_0$	0.99858219	0.99812769	0.99761016	0.99702927	0.99638577	0.99567935	0.99491006	0.99407796	0.99318309	0.99222551	0.99120592
21 $(19 \times [45])/4 = f$	20.03606	20.04679	20.05937	20.07499	20.09096	20.10867	20.12811	20.14927	20.17214	20.19673	20.22229
22 $f/F \times 4$	0.06678514	0.07669691	0.08658533	0.09644737	0.10628004	0.11608033	0.12584525	0.13557185	0.14525714	0.15489820	0.16449207
23 $\sin^{-1}$ of 22	03-49-46.0*	04-23-55.0*	04-58-02.0*	05-32-05.0*	06-06-03.0*	06-39-57.0*	07-13-46.0*	07-47-30.0*	08-21-08.0*	08-54-39.0*	09-28-04.0*
24 $5 - 23 = \theta_0$	03-02-13.0*	03-29-35.0*	03-56-59.0*	04-24-27.0*	04-52-01.0*	05-19-40.0*	05-47-24.0*	06-15-14.0*	06-43-05.0*	07-11-16.0*	07-39-28.0*
25 sin of 24	0.05297986	0.06092756	0.06888107	0.07684954	0.08484209	0.09285332	0.100882661	0.10893435	0.11698371	0.12512159	0.13325588
26 $22/25 = m_0$	1.2605760	1.2588213	1.2570265	1.2550156	1.2526806	1.2501473	1.247442	1.244528	1.241687	1.237981	1.2344076
27 $m_0 \times F$	45.38074	45.31757	45.25295	45.18056	45.09650	45.00530	44.90791	44.80301	44.70073	44.56732	44.43867
28 27/6	45.70858	45.75085	45.80657	45.86941	45.93555	46.00966	46.09278	46.18376	46.29285	46.38633	46.50042
29 1: $D_0/d_0 = M$	1:136,633.2	1:136,815.9	1:137,002.2	1:137,211.7	1:137,456.0	1:137,722.2	1:138,007.0	1:138,314.9	1:138,615.5	1:139,017.3	1:139,394.6
30 $R \times M = R'$	152.96429	152.76002	152.55252	152.31937	152.04865	151.75476	151.44159	151.10447	150.77679	150.34100	149.93407
31 $R' \times \cos t' = \rho_M$	151.8672	151.3133	150.7088	150.0319	149.2714	148.4421	147.5486	146.5869	145.5912	144.4455	143.2863

Step by step calculations for Gamma II are similar to those for Gamma I, therefore only significant values are listed, as in the Gamma I calculation sheets

α_{10} (scan)	10-00-00.0*					10-00-00.0*					10-00-00.0*
α_{20} (scan)	20-00-00.0*					20-00-00.0*					20-00-00.0*
α_{35} (scan)	35-00-00.0*					35-00-00.0*					35-00-00.0*
38 α'_{10}	10-04-15.0*					10-13-07.0*					10-27-14.0*
39 α'_{20}	20-07-58.0*					20-24-35.0*					20-50-59.0*
40 α'_{35}	35-11-38.0*					35-35-47.0*					36-13-48.0*
51 φ'_{10}	00-15-06.0*					00-15-19.0*					00-15-40.0*
52 φ'_{20}	00-31-12.0*					00-31-40.0*					00-32-24.0*
53 φ'_{35}	01-11-57.0*					01-36-59.0*					02-16-26.0*
81 φ_{10}	00-15-12.0*					00-15-40.0*					00-16-24.0*
82 φ_{20}	00-31-26.0*					00-32-22.0*					00-33-54.0*
83 φ_{35}	01-00-45.0*					01-02-35.0*					01-05-32.0*
87 d_{10}	46.4281					46.7486					47.2372
88 d_{20}	48.7196					49.0348					49.5739
89 d_{35}	56.1440					56.5338					57.1494

Table 4 (Cont.)

	06-42-00.0	07-42-00.0	08-42-00.0	09-42-00.0	10-42-00.0	11-42-00.0	12-42-00.0	13-42-00.0	14-42-00.0	15-42-00.0	16-42-00.0
93 ν'_{20}	12-19-11.0*					15-44-06.0*					19-53-24.0*
94 ν'_{20}	21-35-41.0*					23-29-12.0*					26-31-18.0*
95 ν'_{35}	36-45-55.0*					38-18-02.0*					40-35-01.0*
105 β_{10}	34-04-40.0*					50-01-12.0*					59-56-16.0*
106 β_{20}	18-57-18.0*					31-11-38.0*					41-15-19.0*
107 β_{35}	11-31-12.0*					19-34-54.0*					26-53-25.0*
117 η_{10}	07-21-47.0*					08-35-21.0*					10-09-17.0*
118 η_{20}	13-44-26.0*					14-22-00.0*					15-21-46.0*
119 η_{35}	23-32-16.0*					23-53-22.0*					24-25-34.0*
126 ψ_{10}	65-34-10.0*					51-32-56.0*					40-52-41.0*
127 ψ_{20}	77-05-21.0*					68-09-41.0*					59-44-33.0*
128 ψ_{35}	82-18-32.0*					76-33-21.0*					70-45-02.0*
135 γ_{10}	06-42-36.0*					06-44-46.0*					06-41-09.0*
136 γ_{20}	13-24-21.0*					13-22-26.0*					13-21-01.0*
137 γ_{35}	23-20-56.0*					23-18-20.0*					23-12-31.0*

* Deg-Min-Sec
00-00-00.0

7. MECHANICAL DESIGN CONCEPTS

This section of the investigation report contains descriptions of the designs of the various mechanical components and functions of the Gamma instruments.

7.1 FRAME

The frame will be fabricated of heavy-gauge aluminum-alloy structural shapes, welded to form a rigid unitized support for all components of the machine. Gussetts and framing members will be located so as to provide maximum strength, commensurate with minimum weight, and access to component assemblies.

The frame will be mounted on casters to facilitate moving and positioning of the unit. Leveling jacks will be provided at three points so that the casters may be raised off the floor while simultaneously leveling the machine.

Machined pads will be located upon the frame for mounting and alignment of the component assemblies.

7.2 COMPONENT MATERIALS

The majority of fabricated components will be constructed of aluminum alloys and corrosion resistant steel alloys. The appropriate alloy will be selected for each application with respect to usage, stresses, and manufacturing techniques. All parts will be black anodized or black passivated (where necessary) to enhance corrosion resistance and to minimize reflections within the instrument.

7.3 EXTERIOR COVERING

The exterior covering of the machine will be kept to a minimum commensurate with appearance and protection of the internal components. The covering will be fabricated of sheet metal panels, formed and welded, (where necessary) into such configuration as to provide easy removal of any or all sections for ease of access and/or maintenance. The outer surfaces will be painted conventional contemporary color (s).

7.4 9 $^1/_2$-INCH FILM TRANSPORT

7.4.1 General Description

The transport system is to be an integral unit of the printing plane easel assembly, and it will be possible to rotate the entire assembly about a horizontal axis. The rotation of this assembly will allow for the accommodation of variable pitch angles within the specified ranges. In addition, the entire assembly will have the capacity of lateral translation to compensate for the change in optical path length due to the lens tilt in conjunction with the easel tilt.

The transport system will have the capability to handle 9 $^1/_2$-inch wide film or paper wound on spools of up to 500-foot capacity. The length of film to be transported after each exposure will be approximately 65 inches. This length will provide a gap between exposures that will eliminate the possibility of overlapping exposures.

The length of film transported during each cycle will be metered and interlocked so that an exposure cannot be initiated until the correct amount of film has been moved into the printing area. The design of the metering device will preclude involved mechanisms.

The threading of the film will not be a complex problem because the use of idler rolls, drive rolls, and guide rolls will be kept to a minimum. The printing plane easel will be designed so that a vacuum system, coupled to the easel, will draw the film flat against the easel surface during exposure period.

A study of two transport methods (manual and automatic) has been conducted. Consideration has been given to the development costs, reliability, and maintenance requirements, for each method. The two methods are described in the following paragraphs:

7.4.2 Manual Drive Method

The basic transport system will be composed of a film supply, vacuum easel, metering device, take-up, and drive. Operation of the system will be accomplished by means of a hand crank.

7.4.2.1 Supply

The supply mechanism will embody a means of attaching a fully loaded, 500-foot capacity spool such that the material may be threaded directly into the easel printing plane with the emulsion facing the lens. The material will be unwound from the spool in a direction that will allow the emulsion to face inward towards the axis of rotation.

A spindle will be connected to the supply spool and a friction brake will act on the spindle to prevent film spillage when the transport system stops.

Baffling will be provided around the supply spool to prevent accidental exposure of the raw material by stray or reflected light. The entire supply area will also be enclosed to prevent inadvertent exposure by control panel illumination. Access panels will be provided to facilitate loading and unloading.

A means of detecting and signaling a low-film condition will be embodied in the supply mechanism. Appropriate audio or visual indications will be provided to alert the operator.

7.4.2.2 Vacuum Easel

A vacuum easel will be provided to hold the sensitized material at the printing plane. The system will utilize the pressure differential principle to hold the material in contact with the easel.

Physically the easel will consist of a grooved and orficed plate mounted to a cast vacuum plenum. The printing plane will be formed into an arc representative of scaled down earth curvature. The easel plate will be provided with edge guides to maintain the material position during the transport cycle when the pressure in the plenum is equal to ambient atmospheric.

Pressure differential will be provided by an oil-less vacuum pump and an accumulator tank, and controlled by a relief valve, a solenoid valve, and switches. One switch will function to remove the pressure differential, as required by the operator, for test and alignment of the instrument.

Use of the accumulator tank makes it possible to employ a constantly operating low-capacity vacuum pump. The relief valve ensures the capability of adjusting the vacuum pressure as required for optimum operation.

Thick walled latex tubing will be used for pneumatic connection of the various components of the vacuum system.

The vacuum pump will be mounted on vibration isolators to prevent the transmission of mechanical vibrations which could cause photographic degradation.

7.4.2.3 Metering

A rubber covered roller of an appropriate diameter to make a specified number of revolutions per frame length of transported film will be geared to a single lobe cam. The gear ratio will be such that the cam will complete a single revolution for each frame length transported. The cam will activate a roller-lever-actuator type switch that will be electrically connected to the vacuum solenoid valve.

At the completion of a transport cycle the switch will cause the solenoid valve to be energized through a holding relay. The holding relay will be controlled by switches so mounted as to be activated by the exposure arm.

When the solenoid valve is energized, vacuum will be placed in the easel chamber and the film will be drawn against the easel surface. This is a self-braking feature of the system and the film will remain braked until a new cycle is initiated.

7.4.2.4 Take-up

A light-tight cassette will be provided to contain the exposed film on a standard spool. A thorough market survey has indicated that commercial or military cassettes that will operate satisfactorily in the proposed attitude are not available; therefore a cassette will be designed and developed specifically for this contract.

The cassette will be located near the vacuum easel so that the unprotected portion of the previously recorded frame will be as short as is possible. Sufficient friction will be included in the cassette rollers to preclude the possibility of film spillage within the cassette.

7.4.2.5 Drive

The manual drive will consist of a removable hand crank fitted directly to the drive shaft of the cassette. The cassette and hand crank will be located within convenient reach of the operator.

7.4.3 Automatic Drive Method

Previous rectifiers have used an automatic film transport system that embodied a sinusoidal drive mechanism. This mechanism starts and stops the film with very low accelerations so that the motion is extremely smooth and consequently excessive forces are not imposed on the film. Experience has indicated that such sophistication is unnecessary for an instrument of this type; therefore, the design has been simplified. This approach increases reliability and decreases design and fabrication costs.

The proposed automatic transport system will be similar in concept to the manual system previously discussed in paragraph 7.4.2 except for the means used to impart motion to the film. The same components will be utilized for film supply, vacuum easel, and take-up cassette. The metering principle will be the same but the physical arrangement will differ.

The film will pass around a rubber-coated drive/metering roller with an angle-of-wrap greater than 200 degrees. The drive roller will be directly coupled to a gearhead motor. The output shaft of the motor will be geared to a single lobe cam that will trip a switch. The switch will serve the dual function of de-energizing the motor windings, and of energizing the vacuum solenoid valve to provide braking of the film. The switch will actuate the components through holding relays.

The film will be wound onto the take-up spool (mounted in the cassette) by a torque motor coupled to the cassette drive shaft. The torque motor will be stalled by the interaction of a tight wrap of film on the take-up spool and the locked film on the vacuum easel. The automatic system will include all wiring and components necessary for proper response of the two motors.

7.5 NEGATIVE FILM HANDLING SYSTEM

The various assemblies necessary for handling of the negative film will be mounted on a large aluminum alloy platen. This plate will be supported by a series of large castings so that the optical axis of projection will be inclined from the vertical at an angle of 30 degrees. This inclination results from folding the optical path to keep the overall dimensions of the machine to a minimum.

The areas encompassed in the negative handling system are:

1. Supply spindle and associated drag brake and rollers
2. Negative film platen and supports
3. Nadir positioning device
4. Film drive
5. Take-up spindle and associated components.
6. Densitometer

7.5.1 Supply

The negative film is to be supplied on standard U.S. Air Force spools, MS24343-6 (500-foot capacity). The film will be wound on the spool so that the emulsion side of the film faces inward toward the axis of rotation. The spool will be placed on the supply spindle so that the film will unwind when the spool is rotated in a counter-clockwise direction.

A dancer-roll that will control the braking on the supply spindle, to prevent film spillage, is provided. If the film leaves the spool too fast, the dancer roll will cause the brake to be applied to the spindle, and conversely, if the film does not leave the spool fast enough, the braking force will be diminished.

7.5.2 Platen and Supports

The platen will be designed to guide and maintain the negative film in the same position that the original film is in when exposed by the camera system. The configuration of the platen will be an 80 degree segment of a 24 inch radius circle.

The film will be supported along its edges. The center portion of the film will support itself by the inherent characteristics of the cylindrical surface it follows. Rollers will be located at both ends of the circular segment so that the film will enter and leave the curved portion tangentially.

The platen will be supported from the main plate and it will be spaced from the plate so that the centerline of the film format will coincide with the optical axis of the projection system.

7.5.3 Nadir Positioning

The operator will manually position the nadir prior to initiating an exposure of any particular frame. Upon receipt of data which specifies the offset of the nadir indication with respect to the format centerline (in the direction of flight) the operator will position a pointer which is mounted to the platen in such a manner that it is free to move at the proper radius. A scale indication to which the pointer may be aligned will be provided.

The operator will then manually position the film nadir fiducial mark so that it coincides with the nadir pointer which has been previously set. This alignment is necessary for uniform rectification on either side of the true vertical between the vehicle and the target.

7.5.4 Film Drive

A study of two methods of transporting the negative film has been made and a fully manual system has been compared with an automatic system embodying a manual positioning feature. A cost comparison of the two methods has been prepared and is being submitted under seperate cover.

7.6 EASEL TILT MECHANISM (15° 5', 11.7° 5° or – 5 to 20°)

As stated in section 6 of this report, it is necessary to tilt the copy easel in order to rectify the tilt component of the panoramic photography.

To accomplish this physically, it is necessary to tilt not only the easel, but the entire $9\frac{1}{2}$-inch film transport system including the take-up spool, the supply spool, the drive mechanism and the easel.

All of the above mentioned components will be fastened to a single rigid body. The rigid body will be mounted in a cradle type support which will allow the easel (and the other components) to be rotated about the horizontal centerline axis of the 9 $^1/_2$-inch copy film.

Rotational force will be applied through a manually operated worm and wheel. A graduated scale and pointer arrangement will be included in the mechanism so that the operator may readily determine the angular setting of the easel.

7.7 EASEL TRANSLATION MECHANISM

The requirement to translate the easel along the optical center line results directly from the easel tilt. Calculations have shown that the maximum translation required to maintain focus through the given range of tilt angles is approximately 0.7 inch.

In the Gamma instruments, the translation will be accomplished by mounting the entire film transport mechanism (including the tilt mechanism) on dovetail ways. The assembly will be driven on the ways (along the optical path) by a manually operated lead screw drive. A scale and pointer will be included in the drive system so that the operator may readily determine the location and setting of the easel.

7.8 SCHEIMPFLUG TILT MECHANISM

In order to satisfy the Scheimpflug Condition (as explained in section 6 of this report) it is necessary to tilt the projection lens in a plane 90 degrees to the scan-sweep plane.

To accommodate this requirement, the lens will be mounted in a gimbal type mounting. A manually operated gear and sector drive mechanism, which will include a scale and pointer indicator device, will serve to furnish the required Scheimpflug settings.

7.9 PROJECTION LENS DRIVE

In order to maintain the projected image in focus during the proportional panoramic sweep, it is necessary that the lens and the projection lamp head have a differential angular movement.

To accomplish the required differential motion, the lens will be rotated about an axis coincident with the rotational axis of the exposure arm. The arm will rotate a focusing cam through a gear train. The cam follower will drive the lens through a rack and pinion so that the lens rotation will be a function of the exposure arm rotation.

The focusing cam configuration will be generated in such a manner as to provide the correct differential rate of angular displacement for the various easel tilt settings.

The differential rate of angular displacement will be symmetrical about the optical centerline, and the only point of coincidence between the lens and the projection head slit will be at the nadir point of the sweep.

7.10 EXPOSURE ARM DRIVE

The configuration of the printing easel is such that the image conjugate distance is minimum at the nadir point and maximum at the ends of the scan sweep. This condition causes a light fall-off that increases from the nadir point to either end; therefore, if the exposure arm were to be rotated at a constant angular velocity the print would be correctly exposed only at the nadir location, with constantly increasing underexposure toward either end of the frame.

The inherent light fall-off described above will be compensated for by varying the angular velocity of the exposure arm. Two variables will be introduced by the driving mechanism to give a velocity curve which approximates the reciprocal of the light fall-off curve.

The arm will be driven through its scan arc by means of a friction wheel located to give a peripheral drive motion to the arm. A drive motor will be connected to the friction wheel in such a manner as to convert rotation to translation. The translation will be transmitted to the arm through a sliding linkage which will impart angular velocity to the arm. Because of the sliding linkage, the translation force will be applied tangentially at constantly varying arm radii, thus varying the arm's angular velocity so that it is minimum at the ends of the sweep and maximum at nadir.

In addition to the velocity variation induced by the sliding linkage mechanism, another variable will be introduced by varying the armature voltage of the drive motor. The drive mechanism will be coupled mechanically to a variable transformer electrically connected to the motor through a control rectifier such that the position of the arm will determine the armature voltage. Voltage (and consequently motor speed) will be minimum at the beginning of the exposure sweep and will increase to maximum at the nadir point. Here the transformer reference will be reversed by automatic switching so that the voltage will decrease to minimum at the end of the exposure sweep.

The arm will travel approximately 75 degrees to print the full format, plus overtravel at each end. The overtravel will allow for controlled acceleration and deceleration rates before and after exposure to reduce mechanical transient vibrations.