SPACE SYSTEMS

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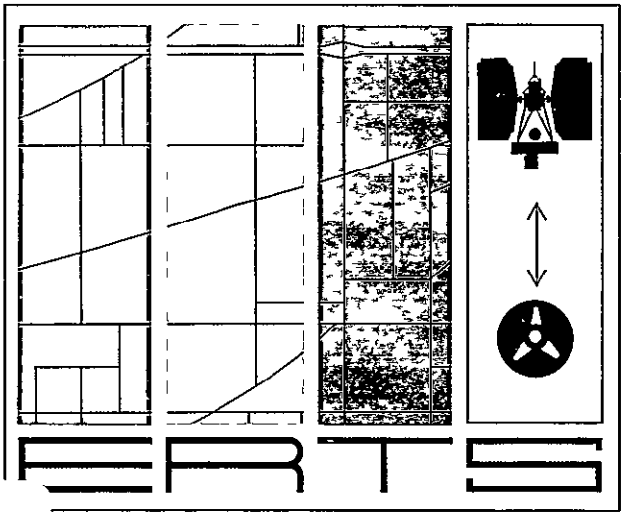
17 April 1970

EARTH RESOURCES TECHNOLOGY SATELLITE OPERATIONS CONTROL CENTER AND DATA PROCESSING FACILITY FINAL REPORT

SYSTEMS STUDIES

BOOK 3



Prepared For
GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND 20771

GENERAL ELECTRIC

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UNDER
CONTRACT NO NAS 5-11529

GENERAL ELECTRIC
SPACE SYSTEMS ORGANIZATION
Valley Forge Space Center
P O Box 8555 • Philadelphia, Penna 19101

17 April 1970

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ERTS A - AND - B
TERRAIN ALTITUDE REPORT

by

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28 February 1970

Prepared by

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ABSTRACT

This study investigates the effects of terrain altitude variations on the accuracy of the grid rectification of ERTS satellite photographs It also presents an investigation of image location inaccuracies due to errors in satellite height and satellite attitude It has been shown that image location errors due to errors in attitude determination will be of considerably greater magnitude than that due to ephemeris errors or terrain altitude variations However, precision location and rectification of ERTS picture imagery to account for variations in the terrain can be enhanced by implementing terrain altitude contour maps of the United States in the software preprocessing

SECTION 1 0

EFFECTS OF TERRAIN VARIATIONS ON PRECISION IMAGERY

1.1 THE EARTH'S GEOID AND REFERENCE ELLIPSOIDS

The accurate reduction of satellite photographic data from the two experimental Earth Resources Technology Satellites, ERTS A-and-B, requires knowledge of the sub-satellite point at the center of the picture and the actual height of the satellite above the terrain on the Earth's surface Basically the sub-satellite point is specified by a latitude (ϕ) and longitude (λ).

The latitude and longitude information is determined from accurate tracking data reduction analysis of the GSFC R/R transponder and from Minitrack data Standard data reduction - orbit analysis programs such as the WOLF NONAME package can provide precise information on these parameters along the satellite ground track However, the height above the terrain is another matter entirely since all orbit programs determine the height above either a reference spheroid (e g , SAO 1967) or a mean geoid.

The three surfaces considered in geodetic computations are (a) the actual topographic surface of the Earth, (b) the geoid or sea-level surface, and (c) a reference spheroid. Only one of these three is completely real, the topographic surface. The geoid is considered to be the mean surface of the sea extended under the continents, and is an equipotential surface The geoid hardly deviates from the spheroid by more than 100 meters, whereas the topographic surface departs from the spheroid by as much as five miles. The reference spheroid is assumed to be an equipotential surface of the same volume and flattening as the geoid

Actual physical measurements such as gravity, deflections of the vertical and triangulation are all made on the topographical surface, and reduced to the mean geoid, however computations are made on the reference spheroid

Unfortunately, no known analytical relationships exist which allow a reasonable estimate of the topographic elevation above the spheroid to be computed for any point on the Earth's surface This is because the topographical surface must be computed point by point and cannot be specified by a few parameters since it is not a mathematical surface but depends on the irregular distribution of visible and invisible masses near the Earth's surface However, accurate geoid contour maps on a global basis are available from satellite - terrestrial data analysis studies These maps give the iso-elevation differences between the mean geoid and a selected reference spheroid

The heights of the topological surface of the Earth above mean sea-level (msl) is known fairly accurately particularly over the continental United States from geodetic survey data We will show that the effect of variations in terrain altitude has a relatively minor effect on the accuracy of the grid rectification process and that because ERTS A/B will be concerned primarily with data over the U S , it would be desirable to use an integrated average height above msl in grids per a table look-up procedure as an approximate correction to the nadir point latitude and longitude This procedure will be more fully discussed in Section 1 4 of this report

1.2 EARTH - SATELLITE VIEWING GEOMETRY

Variations in the topography of the Earth can most easily be accomplished by describing the terrain variations from a mean spheroid of revolution. A spheroid of the Earth can be determined which is described mathematically as representing the best figure of the Earth's surface and is an approximation to the mean geoid.

Consider the Earth-satellite viewing geometry above a reference spheroid as illustrated in Figure 1 The radius of a point on the Earth's reference spheroid R can be described as a function of latitude and is given by

$$R = \frac{a\sqrt{1-e^2}}{\sqrt{1-e^2 \cos^2 \phi_c}} \tag{1}$$

where

R = geocentric radius vector

ϕ_c = geocentric latitude

a = semi-major axis of reference spheroid

e = eccentricity of reference ellipse $= 1 - \frac{b^2}{a^2} = \sqrt{2f}$

f = flattening

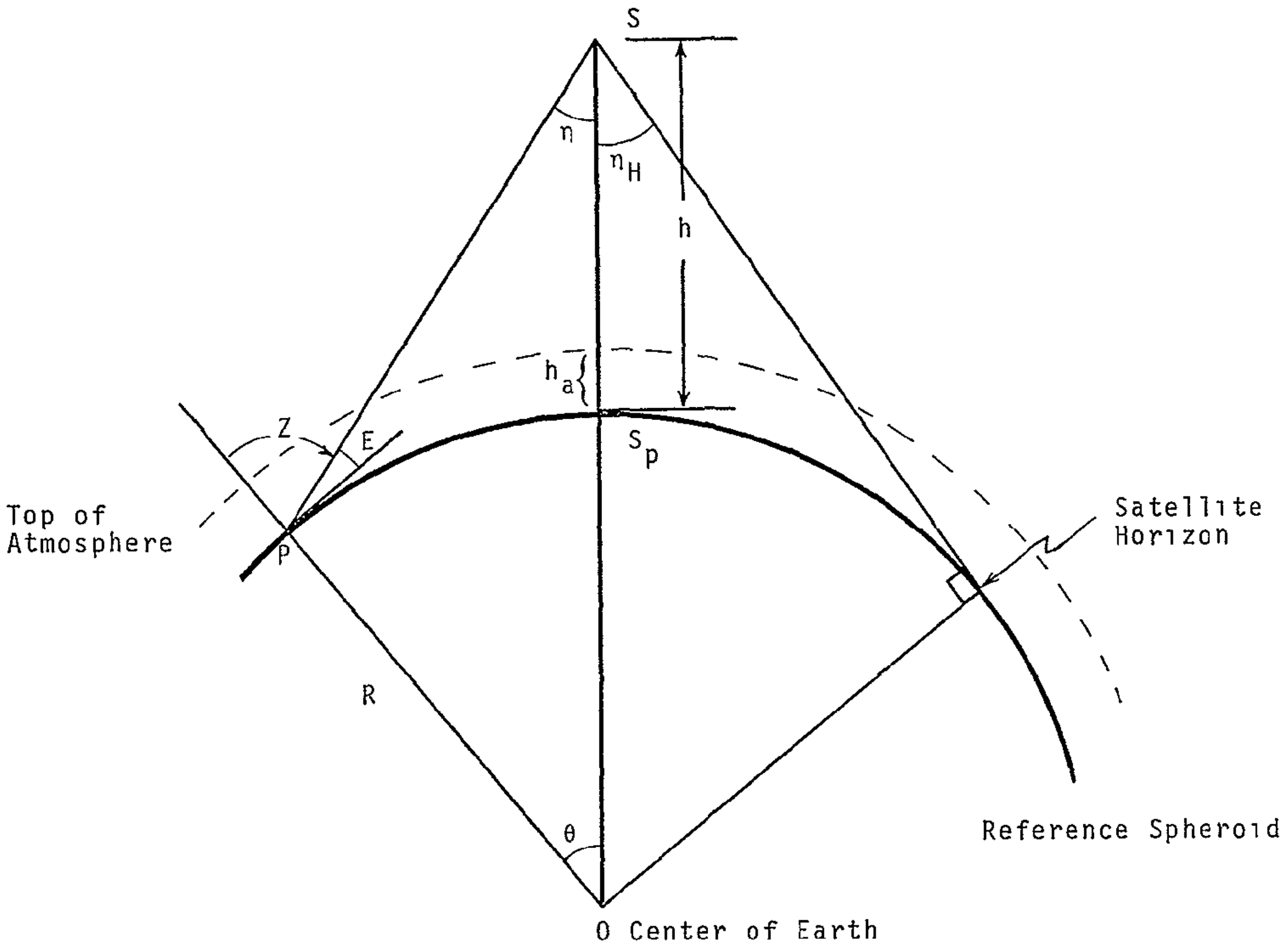
S
η
η_H
h
h_a
Z
E
S_p
Top of Atmosphere
P
Satellite Horizon
R
θ
Reference Spheroid
O Center of Earth

Figure 1

where

S_p = known subsatellite point

Z = zenith distance measured from the vertical

E = elevation angle measured from the horizontal

We want to evaluate the effect of variations in R due to the terrain on the satellite photographic grid rectification process

The diagonal field of view of the ERTS RBV camera is 16 25°. This will enable photographs to be made of an area on the Earth's surface of 100 x 100 n mi We will further assume that the angle η is fixed and remains constant at 8 125 degrees

With the camera pointed vertically toward the nadir point on the Earth's surface the effect of terrain variations on center-of-picture resolution will be a minimum, however, at the picture edges, the effects of perspective and terrain error will contribute to much larger errors in the grid rectification process In addition, errors in satellite or sensor orientation, as well as errors in satellite height, will also contribute to rectification errors in the satellite photographs As a primary consideration we will investigate the effects of terrain variations on the grid rectification process and give secondary consideration to the effects of satellite orientation and height errors

In this analysis we will assume that the TV camera has a vertical optical axis, and a surface parallel to the Earth at the sub-satellite point Section 2 will develop the camera to Earth photographic relations in the general case for the camera optical axis inclined at an angle to the vertical We will further assume that the TV lens is non-distorting and that no geometric distortion is introduced by the TV electronics, transmission or recording system

1 3 ERROR ANALYSIS

Considering triangle SPO from Figure 1 and the law of similar triangles, we can obtain a relation for the the in-plane angle θ along the sub-satellite track

$$\theta = \sin^{-1}\left[\left(\frac{R+h}{R}\right) \sin \eta\right] - \eta \qquad (2)$$

Notice that θ is a function of three variables expressed in functional form as

$$\theta = \theta\ (R,h,\eta) \qquad (3)$$

Thus θ depends upon the radius of curvature of the reference spheroid R, the satellite altitude h and the nadir angle η To evaluate the total error in the along-track ground angle θ, the total derivative of equation (3) is taken

$$\Delta\theta = \frac{\partial\theta}{\partial R}\Delta R + \frac{\partial\theta}{\partial h}\Delta h + \frac{\partial\theta}{\partial\eta}\Delta\eta \qquad (4)$$

The variation of θ with radius of curvature, satellite height and nadir angle is determined by differentiating equation (2) with respect to each parameter while holding the other two parameters fixed. These partials are respectively,

$$\frac{\partial\theta}{\partial R} = \frac{-h}{R(R+h)} \tan(\eta+\theta) \qquad (5)$$

$$\frac{\partial\theta}{\partial h} = \frac{\sin\eta}{(R+h)\sqrt{\left(\frac{R}{R+h}\right)^2 - \sin^2\eta}} \qquad (6)$$

and

$$\frac{\partial\theta}{\partial\eta} = \frac{\cos\eta}{\sqrt{\left(\frac{R}{R+h}\right)^2 - \sin^2\eta}} - 1 \qquad (7)$$

The corresponding grid errors in latitude and longitude can be determined by resolving the in-plane angular error $\Delta\theta$ into a latitude $\Delta\phi$ and longitude $\Delta\lambda$ error by the following relations,

$$\Delta\phi = \Delta\theta \sin i \qquad (8)$$

$$\Delta\lambda = \Delta\theta \cos i$$

where i is the inclination of the satellite orbit with respect to the equatorial plane. Because of the near-polar orbit chosen for ERTS, the grid rectification error will be mostly latitudinal

Multi-parameter calculations of equations (5), (6) and (7) have been performed for the northern and southern extremeties of the United States These calculations have been resolved into latitude and longitude errors in nautical miles on the photograph and are displayed in Tables 1, 2 and 3 Table 1 presents the terrain altitude error per kilometer of terrain altitude variation for three nadir angles and three satellite altitudes A nominal satellite altitude of 500 n mi. (926 5 km) has been assumed for the ERTS orbit Table 2 presents the satellite altitude error per kilometer of satellite altitude variation in a similar arrangement, and Table 3 presents the satellite orientation error effects on sub-satellite latitude and longitude per degree of camera nadir angle error

1.4 MAPPING PROCEDURE FOR DETERMINING SATELLITE ALTITUDE ABOVE TERRAIN

The image location accuracies that may be expected considering errors in satellite ephemeris (height), satellite attitude and variations in terrain altitude have shown that terrain errors are about a factor of three smaller than satellite attitude errors With the camera pointed vertically towards the sub-satellite point the image locations error at the picture edge is about 0.012 n mi. per km. error in terrain height, thus the maximum error is less than 0 20 n mi For precise image location, the effects of terrain errors on the grid rectification process can be included as a correction

TABLE 1

TERRAIN ALTITUDE ERROR (PER KM)

LATITUDE	SATELLITE ALTITUDE (KM)	η = 10°		η = 20°		η = 30°	
		LATITUDE (N MI)	LONGITUDE (N MI)	LATITUDE (N MI)	LONGITUDE (N MI)	LATITUDE (N MI)	LONGITUDE (N MI)
NORTHERN UNITED STATES (ϕ=70°)	916 5	0 01329	0 00209	0 02574	0 00406	0 03682	0 00581
	926 5	0 01344	0 00212	0 02602	0 00411	0 03721	0 00588
	936 5	0 01358	0 00215	0 02629	0 00415	0 03761	0 00594
SOUTHERN UNITED STATES (ϕ=30°)	916 5	0 01324	0 00209	0 02563	0 00405	0 03666	0 00579
	926 5	0 01338	0 00211	0 02590	0 00409	0 03706	0 00585
	936 5	0 01353	0 00214	0 02618	0 00413	0 03745	0 00591

TABLE 2

SATELLITE ALTITUDE ERROR (PER KM)

LATITUDE	SATELLITE ALTITUDE (KM)	$\eta = 10°$		$\eta = 20°$		$\eta = 30°$	
		LATITUDE (N MI)	LONGITUDE (N MI)	LATITUDE (N MI)	LONGITUDE (N MI)	LATITUDE (N MI)	LONGITUDE (N MI)
NORTHERN UNITED STATES (ϕ=70°)	916 5	0 06952	0 01098	0 12856	0 02030	0 16749	0 02645
	926 5	0 06933	0 01095	0.12817	0 02024	0 16692	0 02636
	936 5	0 06913	0 01092	0 12779	0 02018	0 16635	0 02627
SOUTHERN UNITED STATES (ϕ=30°)	916 5	0 06941	0 01096	0 12835	0 02027	0 16724	0 02641
	926 5	0 06921	0 01093	0 12797	0 02021	0 16667	0 02632
	936 5	0 06902	0 01090	0 12759	0 02015	0 16611	0 02623

TABLE 3

SENSOR ATTITUDE ERROR (PER DEGREE)

LATITUDE	SATELLITE ALTITUDE (KM)	$\eta=0^\circ$		$\eta=10^\circ$		$\eta=20^\circ$		$\eta=30^\circ$	
		LATITUDE (N MI)	LONGITUDE (N.MI)	LATITUDE (N MI)	LONGITUDE (N MI)	LATITUDE (N MI)	LONGITUDE (N.MI)	LATITUDE (N.MI.)	LONGITUDE (N MI)
NORTHERN UNITED STATES ($\phi=70^\circ$)	916 5	8 159	1 288	8 470	1 337	9 523	1 504	11 770	1.858
	926 5	8.248	1 302	8 564	1 352	9 630	1.521	11 909	1 880
	936 5	8 337	1 316	8.657	1 367	9 738	1 538	12 050	1.903
SOUTHERN UNITED STATES ($\phi=30^\circ$)	916 5	8 141	1 285	8 453	1 335	9 503	1 500	11 743	1.854
	926 5	8 230	1 299	8 545	1 349	9 609	1 517	11 882	1 876
	936 5	8.319	1 313	8 638	1 364	9.717	1 534	12 021	1 898

factor by utilizing a two-dimensional table lookup feature for determining average height of the terrain above the spheroid

Because of storage requirements, a trade-off must be made between storage and accuracy which permits an accurate computation of the terrain altitude for "precise" picture imagery while minimizing the amount of storage required for the data processing Table 4 presents worst-case estimates of the uncertainty in terrain height averaged over the eastern and western portions of the United States and equivalent storage requirements for height information stored in n° x n° blocks The 1° x 1° square blocks represent an area equivalent to approximately 60 n mi x 60 n mi on the surface of the Earth

Using satellite tracking data, the altitude of ERTS above the spheroid can be determined to an accuracy of 50 meters This is far better than the accuracy to which the altitude above the terrain can be determined. To provide a similar type of accuracy for terrain altitude determination would overtax the storage requirements of the computer software package The intermediate area density grid of Table 4 provides a judicious choice for terrain maps for our purpose but it is uncertain whether the increased accuracy may exactly warrant the additional storage burden imposed on the system Therefore it is recommended that unless block storage requirements are extremely severe, the 0 5° x 0.5° blocks of terrain altitude information be considered for precise picture imagery . This would adequately supply the demand for an accurate correction factor in updating the latitude-longitude grids on the photograph

TABLE 4

HEIGHT ERRORS AND STORAGE REQUIREMENTS

BLOCK SIZE	EASTERN U S MAX HEIGHT UNCERTAINTY	WESTERN U S. MAX HEIGHT UNCERTAINTY	BLOCK STORAGE
1° x 1°	800 m	2000 m	1200
0 5°x0 5°	250 m	700 m	5000
0 25°x0.25°	100 m	300 m	20000

Recent maps from ESSA or USC and GS of the topological surface of the Earth provides altitude of the terrain above MSL (i.e., the geoid) These will need to be combined with geoid contour maps which provide altitude differences between the geoid (MSL) and the "best" reference spheroid to give the altitude of the terrain above the spheroid. The altitude data can most conveniently be stored in a two dimensional matrix $H(\phi,\lambda)$, indexed by ϕ and λ where ϕ is the latitude and λ the longitude

SECTION 2 0

GRIDDED APPROXIMATION SCHEMES

2.1 SATELLITE-EARTH PHOTOGRAPHIC TRANSFORMATIONS

2.1.1 CONSTRUCTION OF RECTANGULAR PLATE GRID COORDINATES

In this operation we wish to construct latitude and longitude lines that can be super-posed on a photograph That is, we start with latitude (ϕ) and longitude (λ) and wish to know the rectangular coordinates, x and y on the plate.

We make the following assumptions the sub-satellite latitude and longitude (ϕ_s, λ_s) is known, the point of intersection of the optical axis of the camera with the Earth is known (ϕ_o, λ_o), the direction of motion of the sub-satellite point - on the plate is known (angle α with respect to frame edge), height of satellite and orbit inclination are known

From Figure 2, triangle APB we obtain

$$\cos \delta_o = \sin \phi_s \sin \phi_o + \cos \phi_s \cos \phi_o \cos (\lambda_o - \lambda_s) \qquad (9)$$

From Figure 3 we obtain for the general case where the camera axis is inclined at an angle to the vertical,

$$d_o = \frac{Rf \sin \delta_o}{r - R\cos\delta_o} \qquad (10)$$

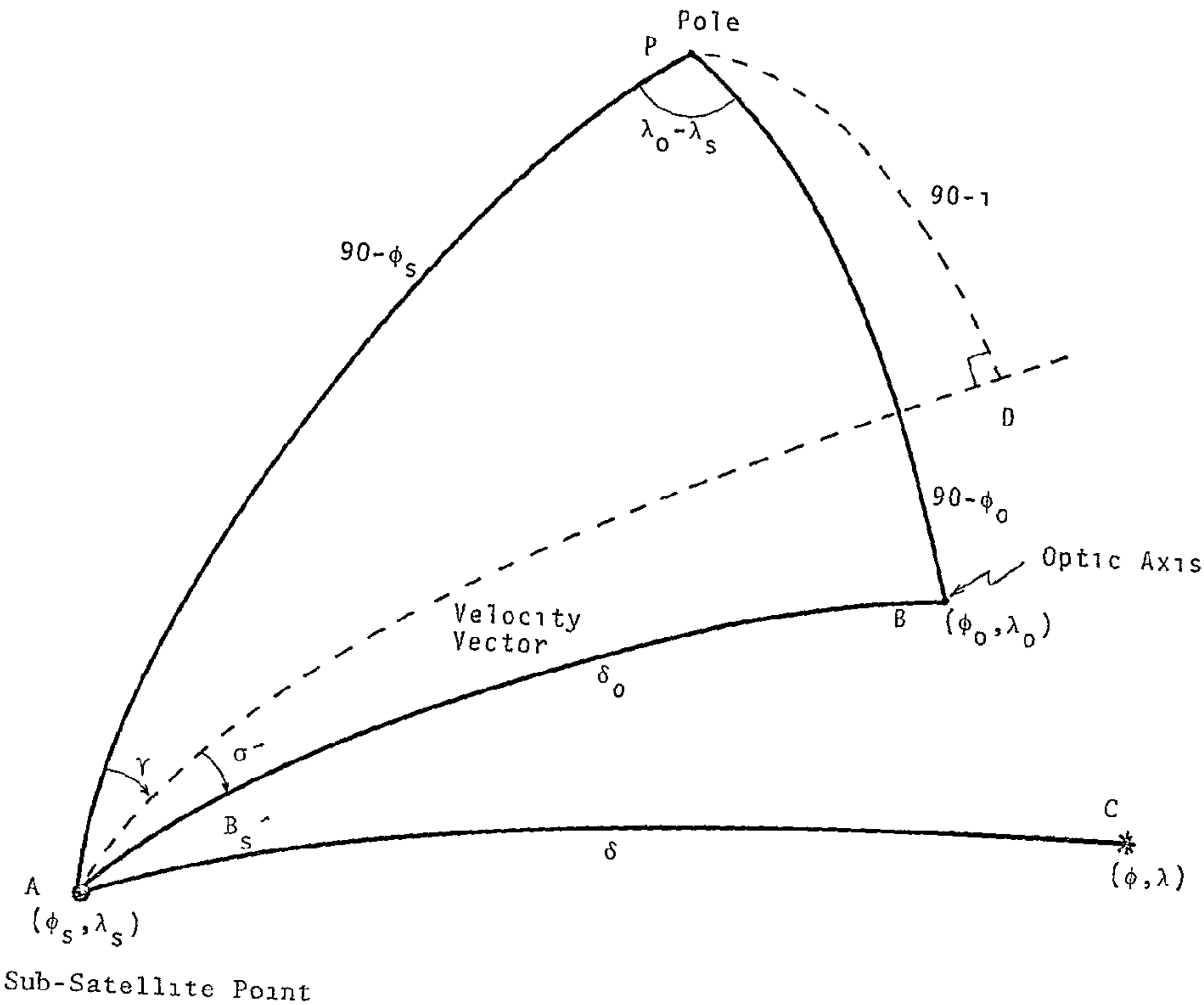

Figure 2. Spherical Triangles

and

$$\tan \varepsilon_o = d_o/_f \tag{11}$$

where f is the focal length of the camera and d_o is distance on the plate of the sub-satellite point - from the optic axis

Returning to Figure 2 and triangle APD we have

$$\sin \gamma = \frac{\cos i}{\cos \phi_s} \tag{12}$$

and from triangle APB

$$\sin (\gamma + \sigma') = \frac{\cos \phi_o \sin (\lambda_o - \lambda_s)}{\sin \delta_o} \tag{13}$$

If σ is the projection of the angle σ' onto the image plane (see Figure 4) then we can write

$$\tan \sigma = \cos \varepsilon_o \tan \sigma' \tag{14}$$

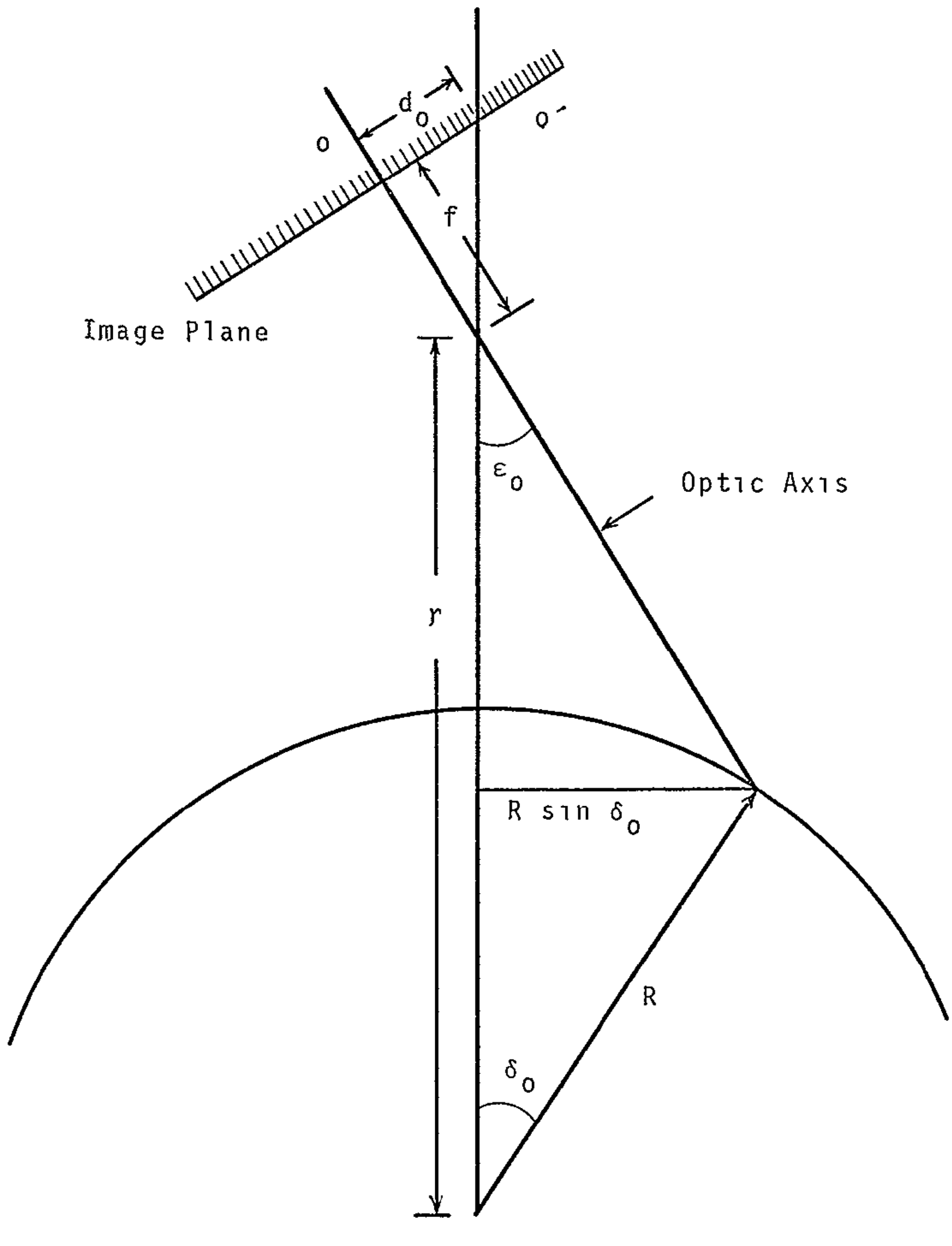

Figure 3. Optic Axis and Sub-Satellite Point

since ε is the angle between the line AB (Figure 2) and the projection of AB onto the image plane.

From Figure 2, triangle ABC, we have

$$\cos \theta = \sin \phi_o \approx \phi + \cos \phi_o \cos \phi \cos (\lambda-\lambda_o) \tag{15}$$

$$\cos \delta = \sin \phi_s \approx \phi + \cos \phi_s \cos \phi \cos (\lambda-\lambda_s) \tag{16}$$

and

$$\cos \beta_s' = \frac{\cos \theta - \cos \delta_o \cos \delta}{\sin \delta_o \sin \delta} \tag{17}$$

If β_s is the projection of angle β_s' onto the image plane then

$$\tan \beta_s = \cos \varepsilon_o \tan \beta_s' \tag{18}$$

The position (ϕ,λ) is angular distance δ from the sub-satellite point and its distance (d) in the image plane is (Equation 2)

$$d = \frac{Rf \sin \delta}{r-R \cos \delta_o} \tag{19}$$

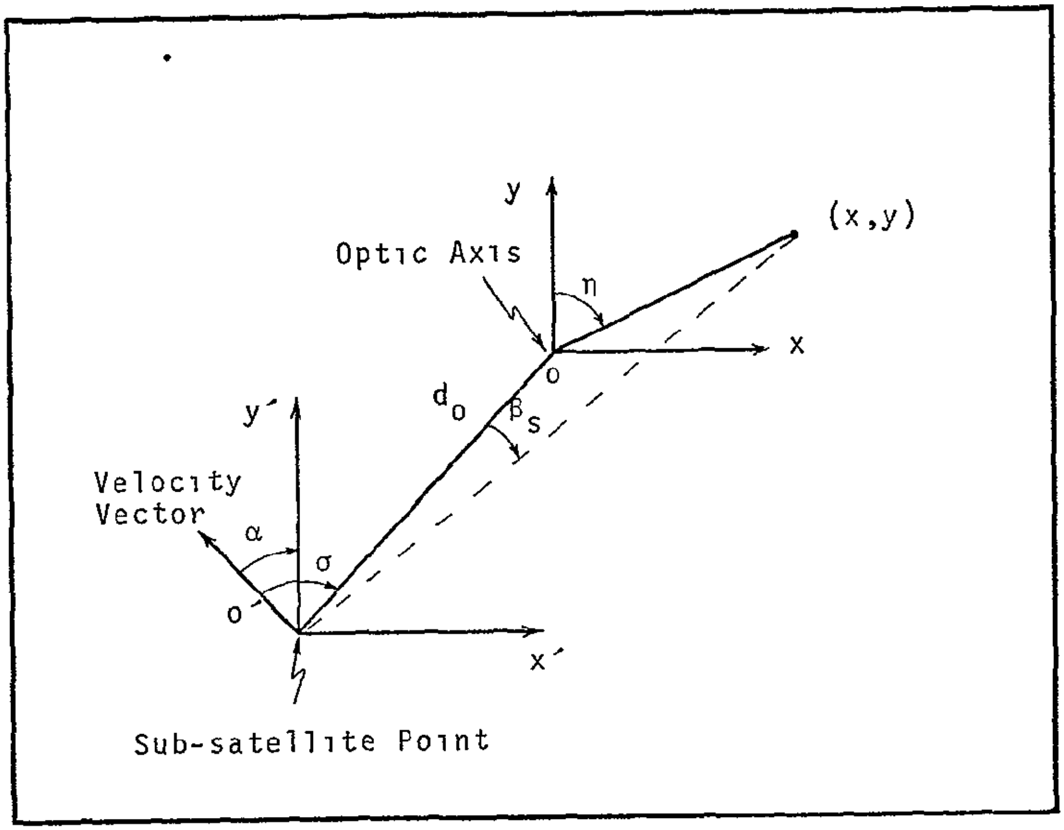

Figure 4 Image Plane

Thus if the position (ϕ,λ) transforms into the position (x',y') on the image plane with origin at the sub-satellite point, then

$$x' = d \sin(\sigma + \beta_s - \alpha) \tag{20}$$

$$y' = d \cos(\sigma + \beta_s - \alpha) \tag{21}$$

If the optic axis (picture centre) is the origin then

$$x = x' - d_o \sin(\sigma - \alpha) \tag{22}$$

$$y = y' - d_o \cos(\sigma - \alpha) \tag{23}$$

Contours of constant latitude (ϕ) and/or longitude (λ) can therefore be constructed from Equations 9 to 23 for use as an over-lay grid to any picture if the orientation of the satellite (camera) is known.

2 1.2 PRECISE RECTIFICATION OF A PICTURE ELEMENT

This process is essentially the reverse of the grid system just described Here we start with (x,y) coordinates on the image plane and transform to latitude and longitude and thence to some (η,ρ) on another projection This other projection is here assumed to be the Universal Transverse Mercator (UTM) Projection.

The same assumptions are made as for the rectangular grid.

From Equation 9 we can obtain δ_o and from Equation 10 d_o. Equations 12 and 13 provide σ' and Equation 14 gives σ

From Figure 4 we have

$$\frac{\dot{x}'}{y'} = \tan (\sigma + \beta_s - \alpha) \tag{24}$$

from which we can compute β_s, and Equation 18 gives

$$\tan \beta_s' = \tan \beta_s \Big/ \cos \varepsilon_o \tag{25}$$

from which we obtain β_s'.

If we let

$$r = (x^2 + y^2)^{1/2} \tag{26}$$

$$\tan \tau = \frac{r}{f} \tag{27}$$

$$\tan \eta = \frac{x}{y} \tag{28}$$

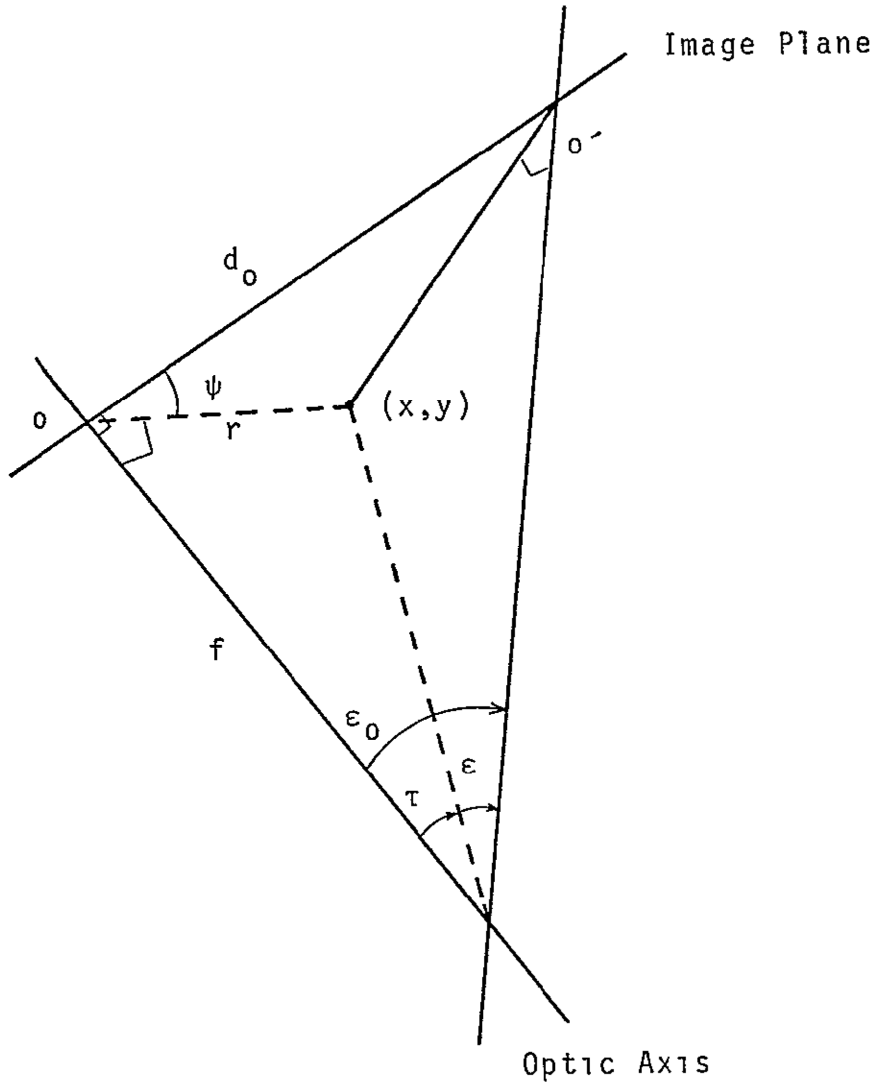

Figure 5. Angular Distance (ε) of the Point (x,y) from o´

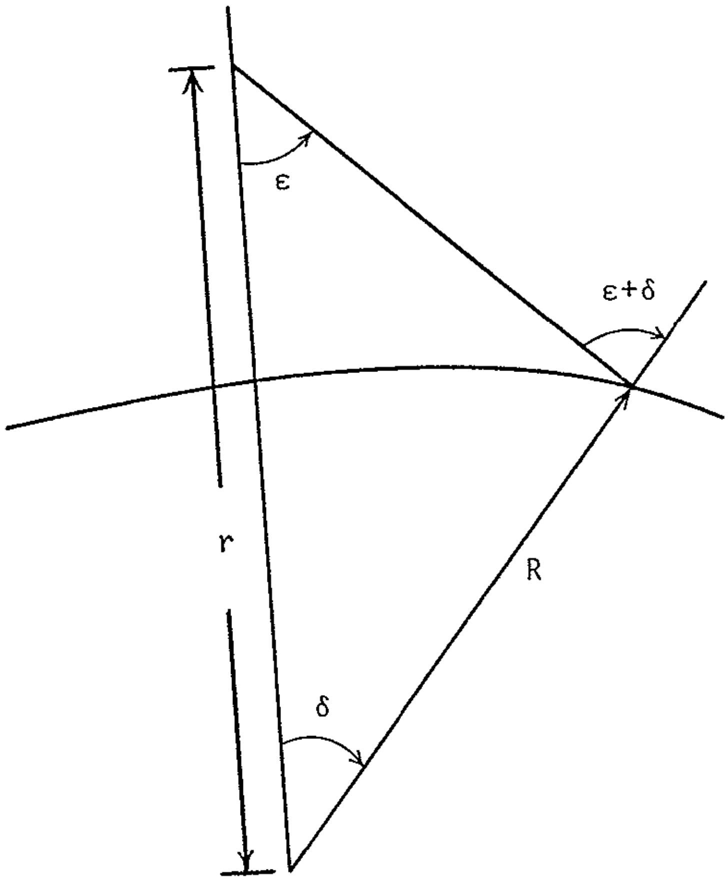

Figure 6   Angle Subtended at the Earth's Center

then from Figure 5 we can obtain

$$\cos \varepsilon = \cos \varepsilon_o \cos \tau - \sin \varepsilon_o \sin \tau \cos \psi \qquad (29)$$

where

$$\psi = (\sigma - \alpha - \eta)$$

and ε is the angular distance of (x,y) from the sub-satellite point on the image plane ($0'$). Note that $0'$ is the point $(-d_o \sin (\sigma-\alpha), -d_o \cos (\sigma-\alpha))$ with respect to the origin 0

Finally, from Figure 6 we can derive δ where

$$\sin (\delta+\varepsilon) = \frac{r}{R} \sin \varepsilon \qquad (30)$$

We now have all the required parameters to determine the latitude and longitude of the point (x,y) From Figure 2, triangle APC, we can obtain

$$\sin \phi = \sin \phi_s \cos \delta + \cos \phi_s \sin \delta \cos (\gamma+\phi'+\beta_s') \qquad (31)$$

$$\cos (\lambda-\lambda_s) = \frac{\cos \delta - \sin \phi_s \sin \phi}{\cos \phi_s \cos \phi} \qquad (32)$$

The latitude of all positions have been assumed to be geocentric and a correction to geographic will be required The geographic latitude (ϕ) of a point of geocentric latitude (ϕ) is given by

$$\phi' = \phi + 695.65 \sin 2\phi - 1\ 17 \sin 4\phi \quad \text{(arc seconds)} \tag{33}$$

We now have the point (x,y) on the plate transformed to geographical coordinates (ϕ',λ) which may, in turn, be transformed into the point ($\bar{x}$,$\bar{y}$) on the UTM projection by the equations

$$\cos \rho' = \cos \phi' \cos (\lambda-\lambda_1) \tag{34}$$

$$\sin \theta' = \cos \phi' \sin (\lambda-\lambda_1) \operatorname{cosec} \rho' \tag{35}$$

$$\bar{x} = -m_o R \theta' \tag{36}$$

$$\bar{y} = m_o R \tanh^{-1} (\cos \rho') \tag{37}$$

where R is the Earth's radius, m_o is the scaling factor of the max projection and λ_1 is the reference longitude of the projection

The above equations enable the point (x,y) on the image plane to be transformed into $(\overline{x},\overline{y})$, the coordinates on a Universal Transverse Mercator Projection.

2.2 APPROXIMATE METHODS OF GRID RECTIFICATION OF SATELLITE PHOTOGRAPHS

There are basically two methods that can be used for the rectification of satellite photographs, (a) computer methods and (b) graphical methods Although graphical methods require more analysis their primary advantage is the far greater accuracy achieved by them over conventional computer methods Generally the method selected depends upon the required accuracy of the gridded satellite pictures.

Computer methods have in the past achieved an average accuracy of 0.5 degrees whereas the most precise graphical method gives an accuracy of 0.1 degrees in geocentric angle (11 km) for nadir angles less than 15 degrees. However, the computer methods have generally utilized a grid system incorporating a large number of satellite height-tilt grids, over a range of several hundred kilometers in height and many tens of degrees in tilt angle Because errors in gridding or rectifying satellite pictures are caused mainly by the size of the discrete grid intervals, the minimization of storage requirements of a computer to process this information has generally led to the low order of accuracy of computer methods By reducing the size of the grids required for computation purposes to accommodate only relatively small variations in the parameters, the computer method can give an accuracy almost an order of magnitude better than approximate graphical techniques. It should be noted however, that although both methods can be utilized to rectify geographic grids, inherent distortions in the optics, TV-camera electronics, transmission and recording systems generally have limited the geometric accuracy to about 0.1 degree in geocentric angle It becomes very difficult to correct for these instrumental errors entirely, because of variations in the distortion from frame to frame.

We have shown in a previous section that by using a gridded approximation technique for determining altitude above the natural terrain of the Earth, errors in sub-satellite latitude and longitude should not exceed 0 20 n.mi. (0 003 degrees), excluding instrumentation errors Furthermore, if we consider attitude errors as well, the total ground error is only slightly above 1 n mi (0 015 degrees) If the attitude determination errors can be reduced to 0 05 degrees the maximum ground error on the photograph is only about 0 6 n mi., still well above any errors caused by the most severe variations in terrain altitude Assuming we can determine satellite altitude to $\pm$ 50 m from tracking data and orbit determination analysis, the maximum error in satellite height is certainly less than 1 km with a consequent ground error of less than 0 1 n mi Considering all reasonable sources of error, excluding the sensors, the maximum possible error expected from the proposed spacecraft system should not exceed 2.0 n mi Of course, for larger fields of view the ground errors will increase quite rapidly Thus, excluding non-nominal operating conditions we can expect satisfactory accuracy using approximate computer methods of grid rectification of the satellite photographs

SECTION 4.0
CONCLUSIONS

The investigation to evaluate terrain variations on the rectification of ERTS picture imagery has shown only a slight tendency to degrade image location accuracy Without correcting for terrain altitude variations that component of position error would amount to, at most, 0.20 n. mi on the picture image For very precise image location work, it might be desirable to include average terrain altitude as a correction factor by utilizing a table lookup feature in the software preprocessing Such a procedure, however, would be of marginal value except when ground-truth data is to be used to reduce total image location error to magnitudes more comparable to the error contributed by terrain altitude variations

It was shown that satellite attitude errors have a significant effect on imagery location For example, one degree errors in satellite or sensor orientation produces a 12 n mi error on the ground Current estimates of ERTS attitude determination errors amount to no more than 0 1 degrees in pitch and roll (1 2 n mi ground error) with the possibility of eventually reducing this error to 0 05 degrees (0.6 n mi ground error) when the system is operational It should be noted that contributions of error in yaw determination are an order of magnitude lower, even in the corners of the image, than those of pitch and roll

INFORMATION RETRIEVAL AT A SCIENTIFIC INSTALLATION

B I Blum
Wolf Research and Development Corp
and
R A Gunter
Applied Physics Laboratory

The computing center at a scientific installation is often equipped with a medium- or large-scale general purpose computer which runs under a tape-oriented batch-processed operating system The available programming languages may be an assembly language and one or two algebraic compilers, such as FORTRAN, ALGOL, or MAD

Such a configuration is adequate for scientific calculations, but poses some unique problems when the computing center is asked to design a specialized information retrieval system In this paper we shall outline the approach taken at the Applied Physics Laboratory when confronted by such a request We shall touch upon some of the problem areas that were encountered, the programming techniques used to overcome them and the input language employed by the users of the system

The Polaris division of the Applied Physics Laboratory is responsible for performing evaluation studies and analysis of the Polaris weapon system Much of this work involves the examination of the various subsystem logs after a patrol or special test For the purposes of APL analysis, there are four subsystems missile, launcher, navigation and fire-control Each subsystem is responsible for a different set of data and has its own set of requirements

Some four years ago the Polaris division recognized that they had a problem which might be helped by improved data management techniques A study was made and a coding system developed All subsystems began to code their analyzed events in a common format, one event per card with minimal free text An event would be a test, a piece of equipment down or repaired, a procedure, etc As the system developed it was found that the codes were not sufficient and each subsystem began to expand and revise them Within two years the only thing common to the various subsystems was the first 6 columns of the first card describing an event In some cases, a set of up to 8 different cards was used to document an event, for other subsystems a single card could be used to document up to 16 similar events

The computing center became involved with the problem when they were asked to write a program for the missile subsystem, which, at that time, had a fixed format card system with the capability of inserting free text comments Their initial goal was to be able to easily produce sorted listings of the file, generate analysis and tabulations of the data, and perform information retrieval based upon logical combinations of the descriptors

A first provisional system was operational by April of 1965 This used existing routines and required two machines and three operating systems While it gave results, it was cumbersome and difficult to work with At the same time, the card formats proved to be excessively time consuming and too restrictive for the Polaris personnel Taking advantage of a new generation of missile, the coding forms were revised, new kinds of outputs were defined, and a new set of specifications was tailored to the subsystem's needs

The computing center was then asked to develop a system which would utilize the coded data of the missile subsystem and perform the functions of the provisional system In addition, such a system would have to be general and flexible enough to incorporate the data of the other subsystems and perform parallel services for them Finally, there was the possibility that all the data would be coded onboard the submarine and delivered in a machine sensible form Hence, the independent programs would have to be able to communicate with each other

Thus, the Polaris Data Analysis and Retrieval System began after a provisional system was developed and its shortcomings noted. While the entire undertaking was to involve ten programming man years, it began by isolating a relatively small portion of the overall system In general, an evolutionary approach was followed throughout--routines were not provided until a use for them had been established As the system was developed and users gained confidence other subsystems defined programs and specialized output Today the system consists of over twenty coreload of instructions on an IBM 7094 It is still capable of expansion, and new projects suggest that this may be forthcoming soon

One might describe the Polaris Data Analysis and Retrieval system as a tape-oriented information-retrieval and report-generating system In general, its inputs are fixed-format, coded information This is complicated by the fact that many formats are acceptable, and in some cases free-format comment strings are allowed Moreover, one of the major routines reads in a specially formatted magnetic tape This is generated on board the submarine and, it is hoped, will become the basic input medium

While many of the reports generated involve only simple counting, classifying and elementary statistical techniques, some routines perform complicated mathematical and statistical analysis It follows that the system has many of the characteristics of standard management systems - file maintenance, report generation - and at the same time it also performs scientific and data reduction functions The programming environment, however, is oriented to scientific applications Thus the hardware and software available for the establishment of this system were somewhat limited At the time work began, APL had an IBM 7094 with FORTRAN II operating under FORTRAN Monitor System and SHARE Operating System No high level language was available to perform the string manipulation and data conversion functions * Moreover, since some routines had already been coded in FORTRAN and because some of the more complicated calculations could be easily coded in FORTRAN, compatibility with that language was desirable

It therefore followed that the system was to be developed using the tools at hand and supplementing them where required The problems of system development, however, were not limited only to the software requirements Because the system was relatively small in the overall laboratory operation, it had to be simple enough so that one could quickly learn how to use it At the same time, the user could not expect special treatment from the computing center Although large, it had to be set up so that it could be batched with standard runs, would require no special operator action, and at the same time run efficiently Finally, there was a logistics problem APL

*At that time, it should be added, APL was beginning the development of MANIPULATOR, a powerful string-manipulation language maintains two facilities The Polaris group is housed in one, the computing center is in the other This placed a premium on producing a small program deck that would allow the user his full range of options In the remainder of this paper we shall discuss what was done to overcome the software limitations and how the system was designed to facilitate the user's task

When programming began on the Polaris Data Analysis and Retrieval system, the standard operating system was SOS (called APLSOS) modified to contain the FORTRAN II compiler The functions which were required but could not be done using FORTRAN included scanning and converting data cards after they were read in, joining and isolating character strings, and establishing a subsystem to run under SOS control Because SOS is a multiphase system which allows many convenient output features not otherwise available, there was a tendency to do much of the printing by assembly language (SCAT) routines This reliance upon SCAT was reinforced by the fact that the powerful SOS debugging tools and I/O routines were not available to FORTRAN programs Moreover, the availability of SMASHT program decks together with the presence of a global dictionary made SCAT convenient to use

Thus, much of the programming would be done at the assembly level It therefore seemed reasonable to perform the conversion and string manipulation functions at this level Interpretive routines were written, and, to facilitate their utility, a system of macros was defined The following brief discussion outlines the use of the macro package

There are two types of macros in the package defining macros and execution macros The former are used to name records and identify substrings of a record The defining macros assign the names of the records and fields which are used in the parameter lists of the execution macros For example, to define a field consisting of columns 12 through 18 as alphanumeric information we might write

```
DEF A, FIELD, 12, 18, STORED
```

The data will be stored starting at STORED and all execution macros will refer to the name FIELD If FIELD were numeric, FORTRAN II decrement integer, octal or double precision, then A would be replaced by N, I, O, or D The store parameter is optional

A record is defined by a RECORD macro which supplies a name, tape unit (optional) and buffer to be associated with it (optional) It is then followed by all the DEF macros of the items belonging to it For example, the following might define the format of a data card

```
RECORD  CARD
DEF     A, TYPE, 1, 6, T
DEF     A, STRING, 7, 72
DEF     N, NUMBER, 7, 20, X
DEF     N, SEQ, 73, 80, N
```

Columns 1 to 6 define the type Once the type is known, then the body of the card contains either a string of characters (columns 7 to 72) or a single number (columns 7 to 20) In either case, columns 73 to 80 are used for a sequence number

Generally all items and records are defined in one segment of the program Because of the global nature of SOS, they need to be defined only once and may appear anywhere The execution macros always refer to defined names, in the above example - CARD, TYPE, STRING, NUMBER, SEQ The actual storage locations, e.g , T, X, and N, are used by SCAT instructions To see how this is used, we shall read in a card, convert the TYPE and test for "STRING " If it is "STRING, " we shall place the string in a record (OUTPUT) starting with character 20 If it is not, we shall convert NUMBER and place the six byte string X in the record starting at character 95 The record will then be written out and the next card read in Transfer is to EOF when the end of the card deck is sensed. The code might be

```
READ    RTAPE   CARD, EOF
        CONVRT  CARD, TYPE
        CAL     T
        ERA     =HSTRING
        TNZ     NUM
        PLACE   OUTPUT, =19, STRING, *
WRITE   WTAPE   OUTPUT
        TRA     READ
NUM     CONVRT  CARD, NUMBER
        PLACE   OUTPUT, =94, DUMNUM
        TRA     WRITE
```

In the case of the first PLACE macro, the data string STRING has never been converted and still resides in the input buffer. This fact is indicated by the asterisk following the parameter STRING In the second PLACE macro, we are assuming that

```
DEF  A, DUMNUM, 1, 6, X
```

was supplied which defines the location X to be a six character alphanumeric string The CONVRT took the character string in columns 7 through 20 and converted it to a binary number which was stored in X The PLACE moves the contents of X as a six character string In each of the PLACE calls, the characters skipped over are either left undisturbed or set to some predefined character upon option Up to 6 items may be used with a single PLACE expansion and a series of adjacent expansions can be joined by using "CONT" for the record in all but the first macro, for example

```
PLACE OUTPUT, =1, A, =O, B, =5, C, =O, D, *, =5, F
PLACE CONT,=O, G, *, =O, H, *, =5, I, *
PLACE CONT, =4, J, =O, K
```

There are many other macros available as well as additional options for those mentioned, but from this brief sketch one can recognize the flexibility afforded the user In general, the process of generating a record involves the use of several different kinds of cards By testing, converting the appropriate parts and then masking them into the record buffer, record generation is both simple and efficient To alter an item in an existing record, the record is read into its buffer, the control card is partially converted, and through a table lookup the item to be changed is identified Transfer is then made to a PLACE instruction which takes the required characters from the input card and corrects the record

By relying upon the Information Macro Package, we were able to create generalized routines which could be used by all the subsystem programs once the desired definitions were supplied The update routine for file maintenance and the select routine used in searching are examples of this By following the same general procedures for all subsystems, it was possible to adapt the data independent part of the system in a matter of days The writing of a new set of definitions was usually all that was required Unfortunately, the data dependent output listings and analysis routines took considerably longer to produce

As the number of programs in the system grew, procedures had to be established to allow convenient handling of the program decks A system was gradually devised which placed all the programs in absolute code on a magnetic tape. At execution time the requested program would be loaded into core with the required routines Where necessary, programs could automatically load subsequent routines into core Thus the only deck the user needed was a small deck of some fifty cards which could access any program in the system In addition to easing some of the tasks of programming and checkout, this also facilitated the mailing of job requests between the two APL installations

The maintenance of the system on tape was set up in a very simple manner The control program was loaded into a fixed portion of lower core leaving the remainder of core available to the using program The first portion of the using program's core is a table providing the names, core load numbers and entry points of the routines associated with the subsystem This table is always located at CORORG and the first executable instruction begins at SUBORG The main program reads in a control card, does the lookup in its own tables and in the tables located starting at CORORG The proper segment of the tape is loaded and control passes to that location given in the table

To generate a tape, one loads a tape to be updated on one unit and a blank tape on a second unit (The blank tape may be replaced by a segment of the disc) The input deck consists of the main program, all core loads that are to be inserted or which are to replace existing core loads, and a terminal segment Since all this will go through the assembly and compilation phase, they may be either source or object decks Each core load is assembled and ready to be loaded into core by SOS system The main program positions the tape to be updated by copying the desired section onto the new tape The next assembled segment is then loaded through SOS system routines and the desired portion of core is written out onto the new tape This process continues until the unique terminal segment is found The new tape is then closed and available for use A table indexing the tape is automatically generated

In this way the programmer generally works with only one core load of an overlay program Moreover, the assembly and load time is reduced, at execution time only the requested routines are loaded Finally, the program deck is a convenient size without loss of flexibility, and all of this is done under standard batch processing

To facilitate the use of the Polaris Data Analysis and Retrieval System, a standard set of input formats was defined Inputs were grouped into three categories request cards, qualifier cards and data cards The request cards always have an asterisk in column 1 and an operator starting in column 8 Their effect is to terminate the last request and initiate a new program For example, a LOAD request will cause a subsystem to be loaded into core A request of UPDATE will cause control to be sent to the UPDATE program of the last loaded subsystem The UPDATE request card would then be followed by a set of qualifier and data cards The UPDATE program branches to a termination section when the next request card or the end of the data deck is found

While some of the requests depend upon which program has been loaded, e g , UPDATE, there are several request programs that are always available Because most of the printout is classified, an option is provided to override the nominal classification This is done by a CLASS request which causes columns 16 to 36 of the card to be used wherever a security classification is to be printed In the same way, the LABEL operator allows the user to provide a label (columns 16 to 72) to be printed on each page of the output The user can print messages to the operator with the PAUSE and ONLINE requests. In each case the string given in columns 16 to 72 will be printed on-line

All tapes are labeled by the system to identify the subsystem and date generated When the user wishes to append an additional identifier, the TAPEID request is used If the tape is being written, the identification string is added, if it is being read, the tape is checked against the string

Six tapes are available to the user. They are numbered 1 through 6 Six logical tapes are used by the programs, first through sixth. By use of the TAPE request, the user may alter the logical assignments of the physical tapes at execution time, for example

```
*TAPE
 FIRST   2
 SECOND  3
 THIRD   1
```

will cause the program to reference unit 3 whenever an action is required of the SECOND tape

The LOAD request brings into core the table of routines available for a subsystem In general, each system has an UPDATE, TABLE, and SELECT routine which is called in by the appropriate request card If, during the execution of one of those routines, an error has caused the deletion of the program, then the remaining data cards will be scanned for errors but all execution will be deleted until a NEWJOB card is found In this way, jobs can be batched or sequenced with the user controlling the error response

Request cards are generally followed by qualifier cards which define how the file should be updated, what tables should be produced, which records selected, etc They follow a general format of blanks in columns 1 through 7, an operator name starting in column 8 and a variable field starting in column 16 This format was chosen because it was consistent with many of our coding forms The data cards are subsystem dependent and follow no general rule. They are used only in correcting or generating records by an UPDATE routine

To see how these cards are used, consider the following example

```
* LOAD      MIR
* LABEL     CORRECTED FOR ERRORS NOTED
* UPDATE    FULREC, CHECK
  NOLIST    00001
  LIST      00096
  PATROL    0009700176,11
  LOCATE    00187
XXXXXXXXXXXXXXXXXXXXXXXXXXX
XXXXXXXXXXXXXXXXXXXXXXXXXXX
  SHIP      00207,62
  DELETE    00208
* LABEL
* TABLE
  TBL2      3,6
* NEWJOB
* TAPE
  SECOND    3
  THIRD     2
* TABLE
  TBL2      1,2,3
  TBL3
```

The Missile Information Retrieval (MIR) program is loaded and a label is supplied The UPDATE program is then called in The variable field indicates that both the full record output listing and also the shorter error checking listing should be produced Because this is an update of a tape for which a listing exists, the first 95 records are not relisted Each record is identified by its position on the tape with a five character record number Each qualifier card defines its function in the operator field and then identifies the first record upon which it should operate in the variable field In this case, NOLIST suppresses all listings beginning with record 1 LIST resumes the listing starting with record 96

The PATROL operator will take the field following the comma, in this case "11," and use this to replace the PATROL field in the record For this example, the substitution is done for records 97 through 176 inclusive Each field within the record is given a mnemonic and changed by a qualifier card using this mnemonic In this way the user need not know anything of the actual record structure A table of qualifier operators and a listing of the tape are all that is needed to update a tape

THE LOCATE operator locates record 00187 Third card is followed by several data cards which are used to generate one or more records Depending upon the program, the tape may be updated in this way or by a special UPDATE subroutine In the present example, all data contained on the data card will be masked into a buffer which contains the last read record Thus, any fields not supplied by the data card will be identical to those of the previous record on the updated tape

The SHIP card gives an example of a field change made to a single record In the new tape, record 00209 will have a SHIP field containing "62 " Record 00208 will be deleted from the new tape by the DELETE card. Since the record numbers on the updated tape are sequential, the record numbers of events on the old and new tapes differ starting with record 00188

The LABEL request signals to the UPDATE program that no further qualifier cards are present Thus records 00209 to the end of the tape are copied onto the updated tape which is then terminated The UPDATE program returns control to the Polaris Data Analysis and Retrieval System which interprets the next request - in this case, set the label field to blanks

The TABLE request calls in the MIR TABLE routines The qualifier card indicates that tables 2 3, and 2 6 are to be printed using the tape that was just generated The NEWJOB request indicates that no more qualifier cards follow and so the TABLE routine reads in the tape and produces the requested tables

When the TABLE routine is completed, return is to the system which then identifies the NEWJOB request The NEWJOB was inserted so that if there were an error in the UPDATE input deck, that error would suppress the previous TABLE request but would not affect the one which follows If there is no input error, the NEWJOB card is ignored.

The UPDATE program updates the FIRST tape onto the SECOND tape The TABLE program uses the SECOND tape as input Thus, in general the output of the UPDATE is the input for the TABLE In this case, however, the tape mounted on unit 3 is altered by a TAPE request to become the SECOND tape The TABLE routine then produces tables 2 1, 2 2, 2 3 and all of the 3 series of tables The end of the data deck indicates that no more qualifier cards follow

If, in this last example, it were desirable to limit the last set of tables to only those events between January and March of 1967, this could be done with a call to the SELECT routine immediately before the TABLE request For example

```
* SELECT
  DATE      B,67101,67331
* TABLE
```

Only those records which satisfied the select conditions would be used in the requested tables

The SELECT routine was written to allow any logical combinations of the fields within a record The field mnemonics are identical to those used by the UPDATE qualifiers The following example will select all class 3, 4 or 5 submarine data after January 1, 1966 or all class 2 submarine data during 1965 excluding the ship 607 for the first half of that year

```
          SELECT
SHIP3     CLASS     3,4,5
          DATE      G,66101
607       SHIP      07
          DATE      B,65101,65630
SHIP2     CLASS     2
          DATE      B,65101,65C31
          607       NOT
          START
          OR
          SHIP3
          SHIP2
```

The few examples outlined above will indicate how the user approaches the system Every attempt was made to introduce consistency and ease of use without sacrificing flexibility or efficiency As an additional aid to the user, all input cards, error alarms and system actions are listed with each run In this way the user can usually tell at a glance how his job ran and where any errors may have been detected

Thus we have seen how one installation produced a flexible, easy-to-use information retrieval program while remaining within the bounds of a fixed operating system and utilizing a limited set of programming languages The individual techniques used, such as the usage of macros and interpretive routines and the interconnected modular structure, are not particularly revolutionary, however, the ways in which these techniques were brought together and the uses to which they were applied may prove useful to others who are faced with similar problems

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AN INFORMATION RETRIEVAL SYSTEM FOR PHOTOGRAPHIC DATA

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Introduction

For several years the National Space Science Data Center (NSSDC) has been engaged in the reproduction and distribution of high quality satellite photographs of the Lunar and Martian surfaces As the collection of such photographs has increased, both NSSDC and the user community have recognized the need for an effective system to identify and retrieve photographs As long as the number of photographs remained relatively small, investigators were able to identify the material they desired from maps, project-supplied support data, and personal contacts with other investigators Yet, as illustrated by Figure 1, the quantity of extra-terrestrial photographs expected to be available within a few years requires a more formal approach to the retrieval problem

Recently, NSSDC has been involved in the production of microfilmed and printed catalogs containing all the photographs of certain flights As the number of photographs increases, however, the size of such catalogs will make them difficult to use At the same time, the larger number of photographs limits the amount of identification which can be done by

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specifying a specific feature e g , "the Surveyor rock picture" or the "Lunar Orbiter photograph showing lunar pinnacles " In recognition of this need for an extended identification and retrieval system, the NSSDC has designed the Extra-terrestrial Photographic Information Center (EPIC) The NSSDC is able to provide the program and distribution support, the effective operation of the system will depend on the interest and participation of the user community

FIGURE 1 Completed and Planned Space Flight Projects Yielding Extra-terrestrial Photographs

Project	*Quantity of Photographs**
Ranger	10,000
Surveyor (individual frames)	100,000
Surveyor (mosaic photographs)	1,200
Lunar Orbiter	3,300
Mariner 4	200
Mariner '69	1,000
Mariner '71	10,000
Mariner '73	N/A
Apollo 8	1,200
Subsequent Apollo Flights	10,000**
Orbiting Astronomical Observatory	120,000

* Quantity of photographs for proposed missions are gross estimates
** Includes photographs of returned lunar samples

The EPIC System

The EPIC system is fundamentally an information retrieval program with a data base consisting of support information and keywords which describe the photographic data The program has a full logical search capability and can identify photographs which match any specific combination of descriptors For example, it is possible to perform a search and list out all photographs taken with a given camera lens and filter under certain conditions of illumination, with a range of altitudes, which had been found to contain sinuous rilles The program is also capable of providing periodic catalogs of photographs ordered by support identifiers and/or descriptive keywords

The operation of EPIC is illustrated in Figure 2 In this generalized model the responsible project office collects the exposed films, telemetry

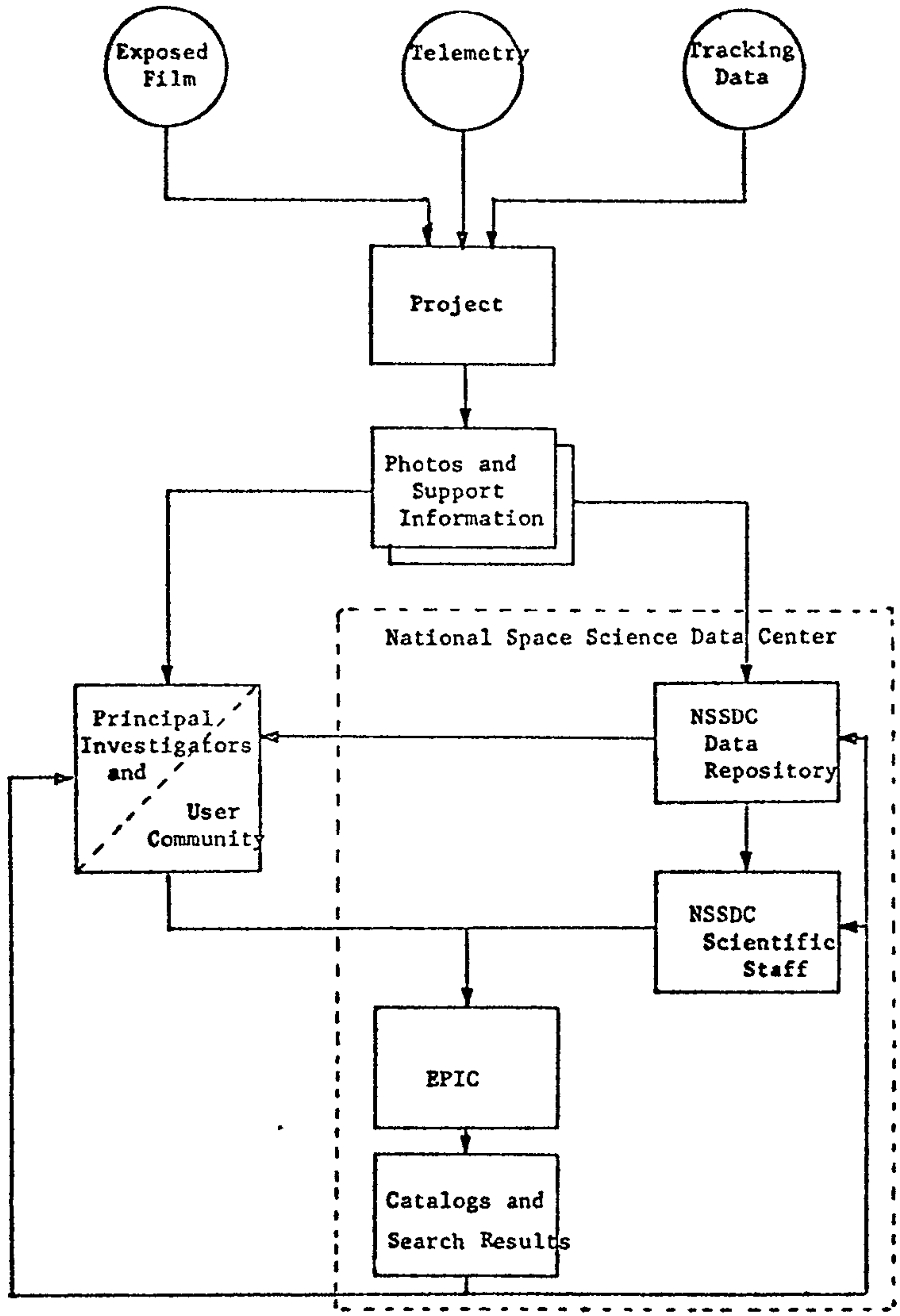

FIGURE 2 Operation of the Extra-terrestrial Photograph Information Clearinghouse.

and tracking data, produces the final photographs and support information, and distributes these to the principal investigators and the NSSDC In actual practice, there may be generations of distribution as the original processing is refined For the purpose of this illustration, the principal investigators and user community are merged together, their interaction with EPIC is identical

As shown in the figure, the NSSDC receives a set of photographs together with the related support data The photographs are filed by frame number and the support data is converted into a file accessible by the EPIC program Once this is done EPIC is capable of running searches based upon any logical combination of elements provided in the support data The real contribution of EPIC, however, lies in its ability to incorporate descriptive keywords not implicit in the support data. Since this information can only come from the investigator and user community, EPIC depends upon the data users to supply descriptors to the photographs In return it provides the same users with catalogs and searches using those keywords

The basic mechanism is quite simple Users of a data set are asked to supply descriptive keywords to the photographs they study The keywords are forwarded to NSSDC where they are entered into the EPIC file Once in the file, these keywords may be sorted and listed to produce catalogs ordered by keyword descriptors referencing frame numbers

Conceptually, the system is straightforward The major problem lies in defining a set of useful descriptive keywords This may be done in two ways· either by analyzing and defining the useful vocabulary before the system is implemented and then limiting the keywords to this vocabulary, or by using an unrestricted vocabulary and later establishing control over it The use of the first method, especially where a thesaurus of terms is available, has a definite advantage The user is provided with a list of valid terms We can also assume a consistent use of terms from one group of keywords to another Thus, the use of a catalog of photographs is easier and interchange between different user groups is simpler

The advantages of the controlled vocabulary approach diminishes when an appropriate vocabulary is not available For example, the proposed Mariner flights to photograph Mars will produce a body of photographs which may require a new and specialized vocabulary Moreover, certain studies of the lunar surface may also lead to highly specialized terminology In both these cases, much of the vocabulary can only be defined during the keywording process

Finally, one other point should be raised when considering the use of a controlled vocabulary, The persons supplying the keywords will be cientific investigators not professional indexers. They will be using terms convenient and meaningful to themselves; there will be no group reviewing their work in order to enforce uniformity. In this kind of environment, the insistence upon the use of a thesaurus may limit the contributions to the system.

Although the use of a controlled vocabulary has many advantages, the establishment of such a vocabulary is unrealistic in the present circumstances. For this reason EPIC has been designed to accept an open vocabulary with the ability of embedding and identifying special controlled vocabularies. In this way each user group may find the system responsive to its needs, while, at the same time working within a framework which may produce an acceptable thesaurus.

Keywording the EPIC File

The EPIC approach to keywording is to associate each keyword with its source. Each user or user group is given a unique identifier. Every keyword submitted has an identifier appended to it. This technique allows each user to embed his personal file in the total EPIC file. He may receive catalogs or perform searches based upon his personal file. He may also define a file which consists of his individual file and those of several other cooperating investigators or he may request results from the total EPIC file less the keywords of certain specialized groups.

By organizing the file in this way groups may cooperate in the use of a common vocabulary. At the same time other users may develop their own specialized set of keywords and individuals may tailor the system to their specific needs. The danger of this approach unfortunately is that the EPIC file may become so fragmented that the total system is of little use. To avoid this possibility, the NSSDC must coordinate the development of the vocabulary. The goal will be to produce a system which is of use to the scientific community. As the system grows the NSSDC will attempt to evaluate its utility and feed back suggestions to the contributors. Diversity and individual requirements will be respected to the degree they are economically feasible.

Figure 3 shows a sample EPIC input form. For each desired entry, a submitter will supply the frame number or other identification followed by the desired keyword. No limit is placed on the number of characters in the keyword, nor is there a limit to the number of keywords which may be used for a single photograph. In practice, users will find short keywords or even mnemonics desirable. These can be developed with the

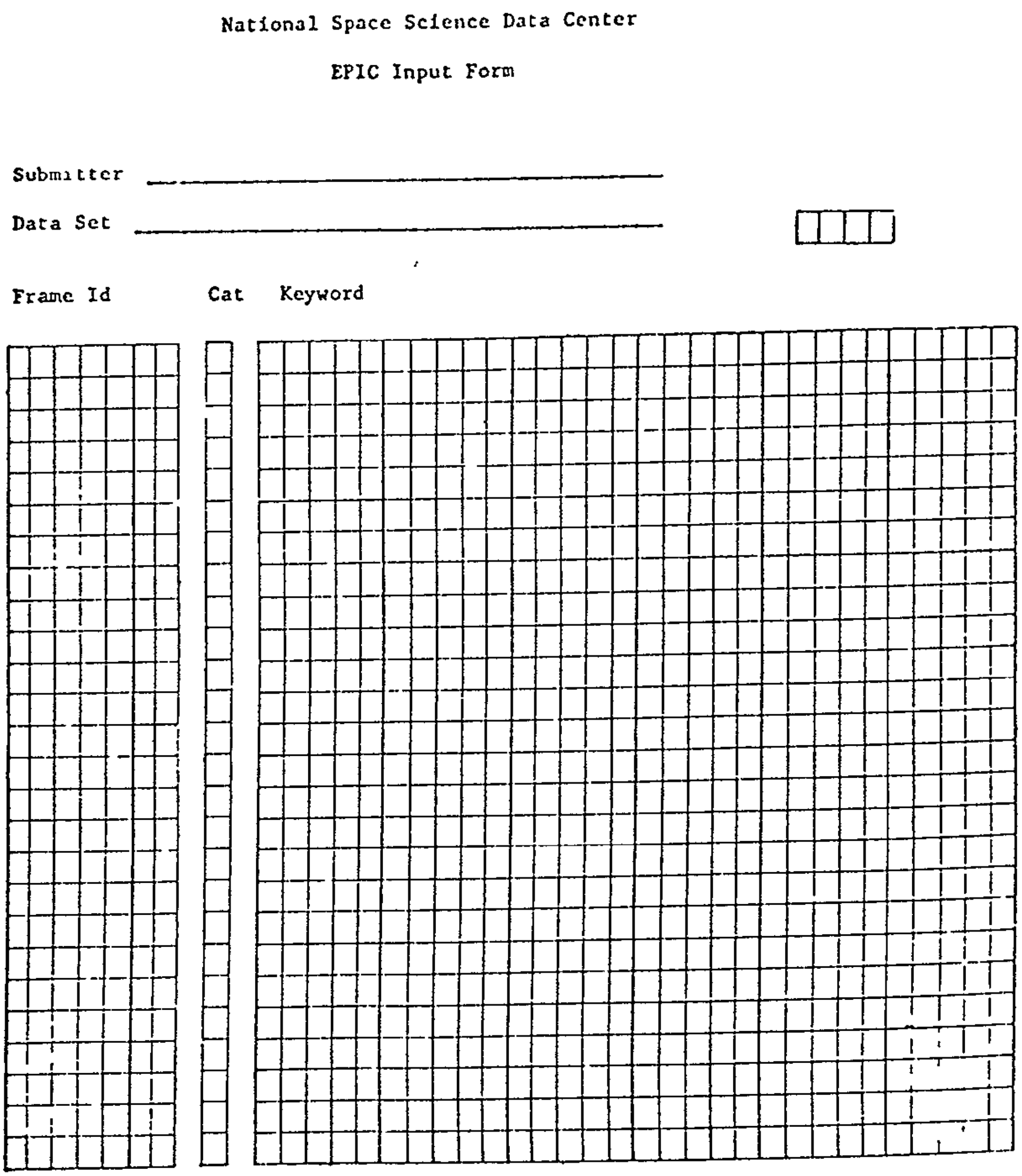

FIGURE 3 Sample Input Form

assistance of the NSSDC coordinator A sample group of keywords for lunar pictures is presented in Figure 4

As the system grows, it may be desirable to establish a fixed vocabulary and an open vocabulary The fixed vocabulary can be structured and narrow, the open vocabulary may be used for keywords which do not fall into one of the fixed vocabularies To facilitate this, a category column (CAT) has been included in the prepared form Through use of this column, one may classify a keyword as belonging to one of the fixed vocabularies For example, assume there was a vocabulary of accepted

FIGURE 4 Possible EPIC Keyword Descriptors

Category L, Location names

Names of craters and other general features shown, e g Copernicus, Tycho, etc Because location names may be converted to positional coordinates by an automated gazetteer, location names should be used only where the feature is especially well photographed The retrieval of all frames showing a given named crater or feature is best done on the basis of latitude and longitude

Category F, Feature types

Features shown in photograph of special interest for retrieval purposes

rayed mare	hummocky terrain	funnel crater
mare ridges	mudflow	pinnacles
dome structure		shatter cone
sinuous rille	drainage basin	volcanic cone
irregular depression	rockstrewn area	volcanic vent
chain craters	elongated pyroclastic cone	haloed crater
boulder tracks	bulbous dome	ejecta pattern
slope detail	rim detail	

Category Q, Quantitative qualities

Photographs well suited to special quantitative studies or examination

photoclinometry	photometric survey
albedo distributions	shadow progression study

skewness and kurtosis of slope frequency curves

Category E, Experiments and special events

Surveyor landing area	surface sampler instrument
Ranger input area	solar eclipse
Solar corona	star survey
Earthshine	infrared anomaly

nomenclature for certain features This might be fixed and identified with the category letter "F" In the same way, category "L" might be used for location names, with other categories developed as the need is identified

Thus, it can be seen that the keywording approach is very flexible and should be capable of accommodating the many requirements of the user community

Implementation of an EPIC File

Because the photographs which NSSDC distributes fall into natural groups or sets, several independent EPIC files will be created For example, there will be a separate file containing Surveyor photographs (ground-based, site-oriented lunar pictures), another containing Mariner (Martian) photographs and another with lunar pictures from the Lunar Orbiter and Apollo series Each file will have its own data structure and listing routines, each will share the same general program features and operating procedures

The first EPIC file to be created was designed to contain all high-altitude photographs of the moon such as the five Lunar Orbiter missions, Apollo 8, and any subsequent photo gathering flights or mapping efforts The accomplishment of this task has involved three major efforts. the creation of a file containing the support data, the compilation of a suitable list of keywords, and the programming of a system to operate on the file

The first of these tasks—creating a file containing support data—was somewhat simplified because most of the Lunar Orbiter support data was already available in a machine sensible form It was therefore decided to limit the initial file to Lunar Orbiter photographs with the capability of adding on Apollo 8 information as detailed data became available

While the file was being generated, we contacted several prominent scientists working in lunar studies to find out what they thought of the system All persons contacted were interested and willing to participate We began to collect several lists of potential identifiers, and NSSDC now has a geologist combining them into an initial vocabulary The purpose of this set of terms will be to serve as a guide and a first step in the development of a fully responsive vocabulary

At the same time, we have been modifying the NSSDC information system to operate upon the Lunar Orbiter EPIC File The specifications and capabilities of this system are detailed in the Appendix We expect to have the file fully implemented and all listing features operational by the time the initial set of keywords has been compiled When this work is complete, we will have both an operational program capable of providing a useful service and a meaningful set of guidelines for appending keywords to the file entries We shall then be in a position to actively invite participation in the keywording effort

Participation with EPIC

All scientists using the data for which an EPIC file has been established will be invited to participate in the development of the keyword file Each user or group of users will be assigned an identifier and will be provided with coding forms As investigators examine the photographs and identify useful keywords, they will place each keyword and frame number on the coding form At convenient intervals, the forms will be forwarded to NSSDC for entry into the EPIC file

At NSSDC cards will be punched for the forms and the file will be updated and verified On a regular basis—perhaps monthly—a listing of the updated file will be returned to the submitter, this will allow each participant to edit his contributions At the same time, the NSSDC coordinator will make suggestions leading to a more consistent use of the system The number of inputs and the frequency of submission will be optional The coordinator will not alter any inputs without the advance understanding and permission of the submitter The NSSDC will, however, reserve the right to exclude individuals from contributing to the EPIC file if their keywords become inconsistent with the effective use of the system

Requests for searches will be accepted from contributors to the EPIC file and other users of NSSDC services They will be collected and processed when the file is updated Because NSSDC has only a limited number of people who can devote time to the maintenance of the EPIC file, response time may initially be measured in weeks

Special catalogs will be produced periodically or whenever the EPIC file has grown significantly beyond the last published catalog Groups of investigators who cooperate may request catalogs containing only their keywords Others may request catalogs in special orderings NSSDC will attempt to honor such requests insofar as its resources allow

As the system develops, it may become incorporated into the other aspects of the NSSDC system For example, NSSDC maintains a Technical Reference File of documents which relates to the data available Once a vocabulary has been established, it could be incorporated into this file All analysis and theoretical papers could be forwarded to NSSDC for entry into the Technical Reference File Searches could then be made for both photographs and documentation that satisfied certain specialized criteria

Another possible extension to the system would be to satisfy search requests with high quality microfilm images of the photographs This would allow the user to identify—and hence, when necessary, pay for—only those photographs he wished to examine in detail Many other outgrowths of the system are possible Nevertheless, the utility of the basic systems is obvious

The development of the EPIC file will provide the NSSDC with a powerful tool in serving requests for photographic data At the same time, the system should prove very helpful to all the participating investigators Its success will depend upon the interest and cooperation of these investigators

APPENDIX

EPIC SYSTEM FOR LUNAR ORBITER PHOTOGRAPHS

A computer program is currently being developed at NSSDC to implement the EPIC system This program is currently limited to photographic data obtained from Lunar Orbiter spacecraft To describe the capabilities of the system, we are including in this appendix some of the preliminary system specifications

Contents of the File

The Lunar Orbiter EPIC File consists of a set of entries maintained in two levels The first level entry contains photographic supporting data for a related pair of high- and medium-resolution frames Included are the time of exposure, the spacecraft position, the spacecraft orientation, elements defining the photography illumination, and the principal point of the frame To these are added the corner coordinates and distances between corners for both the high- and medium-resolution photographs Finally, each entry contains a site number, some subjective quality measures defined by NSSDC, and other information of general interest

Associated with each level-1 entry are four level-2 entries—one for the medium-resolution frame and one for each of the three high-resolution component frames The level-2 entries contain information which relates to a single picture One may supply alternate frame identifiers, a textual description of the photograph, and a set of descriptive keywords Since the level-2 entries are unrelated, each medium-resolution frame or high-resolution component frame can be treated as an independent photograph for keyword retrieval This is displayed in Figures A-1 and A-2

It will be noted from Figure A-2 that the entries are broken down into categories The program will process an open ended number of categories, Thus, if new data elements are identified they may be inserted at a later date Because the program does not require all entries to have the same number of categories, new categories may be defined which relate to only a portion of the file

Search Capability in the System

Any element in any level entry may be used as a search term The allowable search terms to be used in the initial system are given in Figure A-3 Each of the terms may be combined in any logical relationship with any other term For numeric fields, the relationships of "greater than," "less than," or "between" are valid In the case of keywords, provisions are being made to perform searches based upon keyword source, composite keyword, and word or root within the keyword field

For example, one might wish to perform the following search We are interested in all high resolution photographs containing the point 5 3° latitude, −10 2° longitude which have been keyworded with either of the terms "volcanic cones" or 'volcanic vents" In addition, we require that the incidence angle be between 15° and 45° and the emission angle be less than 10° This could be coded as shown in figure A-4 The results of this search could be listed in any of the 14 types of output described below

Outputs of the System

The entire file and/or the results of a search request can be listed in one of 14 standard output forms The information can be sorted in one of three basic categories Individual entries can be listed in one of five standard formats The generalized form for these listings, together with the kinds of outputs available, are shown in Figure A-5

The standard file order is by mission and frame number In addition to this ordering, entries may be listed by keyword Because keywords may be broken into categories which may have logical orderings that are not alphabetical, more than one kind of keyword ordering may be required In general, however, this ordering will consist of the keyword name followed by all entries which are flagged by that keyword If an entry contains five keywords, then it will be listed five times—once under each keyword

The third kind of ordering is by area The surface of the moon can be divided into sectors with all frames containing some part of a given sector listed under it There are already several standard ways of subdividing the Moon's surface Listings of the file can conform to any existing subdivision or to any other useful positional criteria.

Each of these orderings may be listed in one of five basic formats. In the first, only the frame numbers are given, for example

3-073M, 5-023M, 5-127H2

A second format displays the frame identification together with the corner coordinates and other positional information This format is most useful when ordered by keyword The third class of output is similar to the second in that it is limited to a single line per frame In this case, the altitude, nadir, principal point, sun azimuth, incident angle, emission angle, phase angle and alpha are presented

The remaining two formats list all the support information In one form, only level-1 information is provided, in the other form, the keywords and additional commentary are included Because this kind of

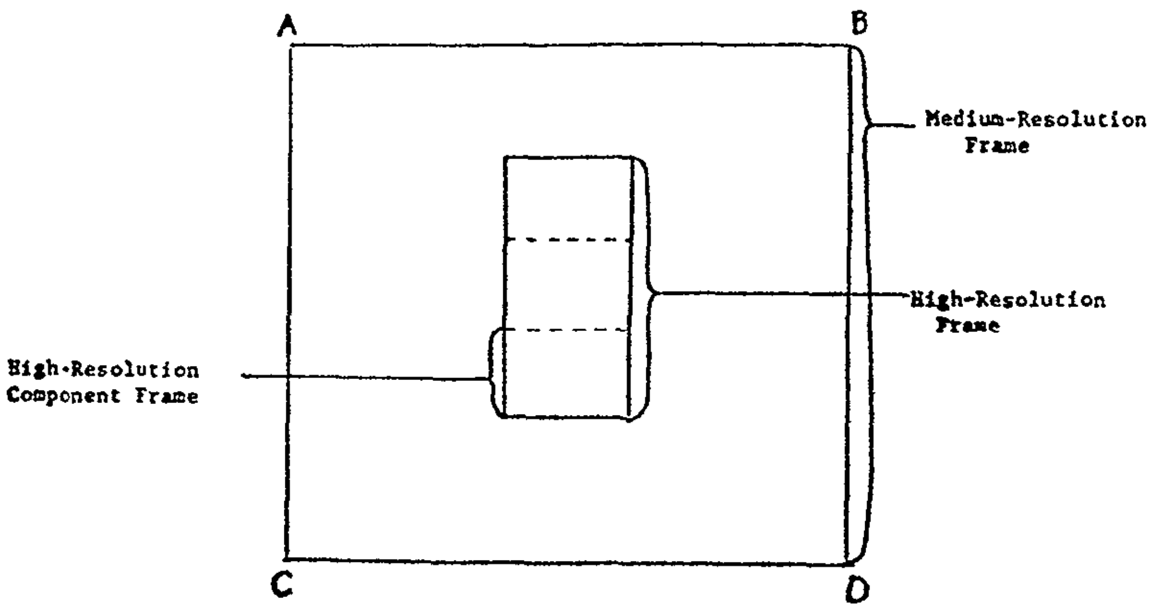

FIGURE A-1 Generalized Lunar Orbiter Photograph Set

Frame Identification MFFFRC with M= 1, 2, 3, 4, 5, (mission)
FFF = 001 (frame number)
R = H, M (resolution)
C = 1,2,3,4 (1,2,3, for high resolution components, 4 for medium resolution frame)

Level 1 *Support Information* for High- and Medium-Resolution Frames

Category 1 General Postmission Support Data

Time	Year, month, day	YYMMDD	
	Hour, min, sec	HHMMSS SS	
S/C Position	Altitude	XXXX XX	KM
	Altitude rate	±X XXXX	KM/Sec
	Latitude	±XX XX	DEG
	Longitude	±XXX XX	DEG
S/C Orientation	Tilt angle	XXX XX	DEG
	Tilt azimuth	XXX XX	DEG
	Swing angle	XXX XX	DEG
	North deviation	XXX XX	DEG
Photography/Illum	Sun azimuth	XXX XX	DEG
	Incident angle	XXX XX	DEG
	Emission angle	XXX XX	DEG
	Phase angle	XXX XX	DEG
	Alpha	XXX XX	DEG
	Albedo*	X XXX	——
	Shutter speed*	X XX	SEC
Principal Point	Latitude	±XX XX	DEG
	Longitude	±XXX XX	DEG
	Slant distance*	XXXX	KM

*Not in support data for L O I, II

FIGURE A-2 EPIC File for Lunar Orbiter Data

Category 2 Medium Resolution

Corner coordinate	A Lat	±XX XX	DEG
	A Long	±XXX XX	DEG
	B Lat	±XX XX	DEG
	B Long	±XXX XX	DEG
	C Lat	±XX XX	DEG
	C Long	±XXX XX	DEG
	D Lat	±XX XX	DEG
	D Long	±XXX XX	DEG
Side length	AB	XXX X	KM
	BC	XXX X	KM
	CD	XXX X	KM
	DA	XXX X	KM
Scale factor		X XX	x10^{6*}
Tilt distance		XX XX	MM

Category 3 High Resolution

Corner coordinate	A Lat	±XX XX	DEG
	A Long	±XXX XX	DEG
	B Lat	±XX XX	DEG
	B Long	±XXX XX	DEG
	C Lat	±XX XX	DEG
	C Long	±XXX XX	DEG
	D Lat	±XX XX	DEG
	D Long	±XXX XX	DEG
Side length	AB	XXX X	KM
	BC	XXX X	KM
	CD	XXX X	KM
	DA	XXX.X	KM
Scale factor		X XX	x10^{6*}
Tilt distance		XX XX	MM

* 10^3 for L O I, II, III

Category 4 Supplementary Support Data

Site number	XXXXXXXX
Quality flag	X=G, F, P
Pct readout	XXX
Photo mode	XXYZZZ
Forms available	XXXX XXXX

Level 2 *Photograph Information* for each Medium-Resolution Frame or High-Resolution Component Frame

Category 1 Alternate frame identification (optional)

Category 2 Free text description of photograph (optional)

Category 3 Keywords and source of keyword (to be defined in greater detail)

FIGURE A-2 Continued

Search Terms

Mnemonic	*Definition*
ALT	Spacecraft altitude
SCLAT	Spacecraft latitude
SCLONG	Spacecraft longitude
TILTAN	Spacecraft tilt angle
TILTAZ	Spacecraft tilt azimuth
SUNAZ	Sun azimuth
INCDAN	Incident angle
EMISAN	Emission angle
PHASAN	Phase angle
ALPHA	Alpha
ALBEDO	Albedo
SHUTR	Shutter speed
PPLAT	Principal point latitude
PPLONG	Principal point longitude
PPSLNT	Principal point slant distance
RES	Resolution (H, M)
POINT	Latitude and longitude of a point which must be included in a photograph
QUAL	Quality G F P
KEY	Keyword (this could be expanded into more than one term)

FIGURE A-3 Search Terms Included in Preliminary Lunar Orbiter EPIC System

```
x   SEARCH
    RES         H
    POINT       5 3, -10 2
    KEY         VOLCANIC CONES, VOLCANIC VENTS
    INCDAN      $B, 15, 45
    EMISAN      $L, 10
```

FIGURE A-4 Sample Search Definition.

Format type	Sorted by		
	Frame number	Keyword	Location
Frame number	—	X	X
Position (1 line)	X	X	X
Illumination (1 line)	X	X	X
Full level 1	X	X	X
Full levels 1 and 2	X	X	X

Fourteen Standard Listing Types

```
sort Key item i
    frame 1
    frame 2
      •
      •
      •
    frame n
sort Key item i + 1
    frame 1
      •
      •
      •
```

FIGURE A-5 General Form of Standard Outputs

output tends to be bulky, it will usually be reserved for search listings

While these represent the basic system outputs, the program design is flexible enough to allow the generation of special listings For example, a report has been defined to cross reference the various photograph identifiers with the standard mission frame numbers As new categories of information are defined and inserted into the file, additional classes of output can also be generated

Conclusion

The Lunar Oribter EPIC program is general enough to adapt to changing requirements. The capability exists to provide indexing to any level within a photograph, to correlate photographs and documents, and to add new classes of information or measurements. The limitations of the EPIC system will be determined by its utility and the interest of the scientific community.

FREE-TEXT INPUTS TO UTILITY ROUTINES

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Through the use of some rather simple techniques, it is frequently possible to produce a program which will accept free-text inputs. The techniques are discussed and related to a general tape manipulation routine.

The use of free-text inputs to utility routines has several obvious advantages. Such routines simplify the user's task and at the same time provide readable documentation of the functions performed. By adopting some techniques currently in use, a reasonably unsophisticated syntax scanner can produce quite reliable results. A general tape manipulation routine accepting natural language inputs has been successfully used at this installation for the past six months. In what follows, a slightly generalized version of this program is presented. *

Consider a general tape routine to copy or list tapes in either binary or BCD mode, blocked or unblocked format, at densities of 200, 556 or 800 bpi on a set of units U1, U2,•••. In addition, the routine must be able to skip or backspace files or records, rewind tapes, write end-of-file marks, print messages to the operator and pause.

To allow the user maximum flexibility, the following conventions are adopted. Inputs are in the form of statements. Each statement defines a single executable request and ends with a terminator. Where convenient, qualifiers are given nominal values, e.g., blocked binary 556 bpi tapes are assumed unless otherwise specified. Once a qualifier is set, it remains fixed until altered by a subsequent statement. The program treats each statement independently. A statement is scanned and if a well-defined request results the operation is performed. Upon successful execution of the request the next statement is read in, listed and then analyzed. The program terminates when the last statement has been processed.

THE SCAN TECHNIQUE

Because the scope of the program is limited, the number of words which could define or qualify a request is small. In some cases several words may have the same meaning (e g., BLOCKED and BUFFERED) but it is highly unlikely that the same word will have more than one possible meaning. Thus it is not difficult to map from the words in a state ment onto a set of keywords The method of selecting keywords is in principle similar to that which Weizenbaum uses in his ELIZA program [Reference 2] However, since each

* In the program in use, only two tape densities (HI and LOW) are used, unit names reflect the manufacturers hardware designation, and each request is limited to a single card The differences between what is in use and what is described are only superficial. The coded program was written in SCAT for the IBM 7094.

keyword suggests an independent function, there is no need to rank the keywords or decompose the text string Words in the statement which are not keywords are considered "noise" and ignored. This concept of noise is very much like that used in XPOP [Reference 1] In XPOP the set of possible noise words is supplied. In the present offline program it was felt that the dangers inherent in a broader definition of noise were compensated by the simplicity it brought. If man/machine interaction were available, it is doubtful that one would want to use this notion of noise.

The keywords fall into three categories those which define the request (e.g., LIST, COPY, BACKSPACE, etc.), those which qualify the request (e.g., BCD, BINARY, BLOCKED, etc.) and those which quantify the request (e.g., the number of records, the number of bpi). Viewed another way, the keywords might be classified as either words or numbers.

Since the number of keywords is small it was found that each could be uniquely associated with its first three letters. This made the lookup easier in a fixed-word machine and had the additional advantage of ignoring word endings and allowing abbreviations. Thus, RECORD, RECORDS and REC are all evaluated in the same way. Were a possibility of ambiguity to exist, an additional check might be made once the initial match was found.

With this in mind, a text-scanner was written which would (a) isolate the first three characters of a word if the first character was alphabetic, (b) convert to a binary number any contiguous string of digits and store the result in a pushdown list and (c) take a special return when a terminating character is identified. When a scan returns with a set of characters a search of the keyword table is made. If a match is found, control is sent to a keyword routine. If there is no match, the word is considered noise and the scan routine is called again

If the scanned word is a request keyword a check is made to see if a conflicting request has been made. If so, an alarm is given, otherwise, a switch is set. It is possible for example to both LIST and COPY, but impossible to COPY and BACKSPACE.

Return with a request qualifier is sometimes more complicated. Words such as ALPHANUMERIC or OCTAL are obvious qualifiers to a LIST request, but BINARY is an ambiguous qualifier for a COPY request. Does it refer to the input tape, the output tape or both? To eliminate this problem the following convention was established. If more than one tape qualifier is given the first refers to the input tape and the second refers to the output tape If two tapes are being used and only one qualifier is supplied, then that is used for both tapes. This is simply programmed by having the first qualifier of a class set both tapes while the second, if present, affects only the output tape. The treatment of tape units is handled in a similar way. The first unit named is considered to be the input unit, the second is the output unit. If two units are expected and only one supplied, an alarm is given

By establishing an order on certain keywords one is able to maintain an independence between keywords As presently described,

COPY 5 FILES FROM U1 ONTO U2.

and

COPY 5 FILES ONTO U2 FROM U1.

would product different results. This might easily be overcome by including ONTO and FROM in the keyword list Each would set a switch and where a unit name was identified the switch would be tested. If neither ONTO nor FROM were found, the conventional order would be assumed. Otherwise the order would be established by the keyword. This limited interdependence of keywords is used for request quantifiers and their associated qualifiers.

As stated earlier, when a number is scanned it is converted to binary and placed into a pushdown list. When a qualifier keyword is encountered which requires a quantifier, the last entered number is removed from the stack and associated with the qualifier. One qualifier is assumed to be implicit (generally record or file count). If at the end of the scan a number remains in the stack and none has been associated with the implicit qualifier, the association is then made. Thus, the following would all produce the same request

COPY 4 FILES BINARY 556 BPI.
COPY 4 BINARY 556 BPI FILES

and (where FILE is the implicit qualifier)

COPY 4 BINARY 556 BPI.

When a statement terminator is found the program tests to see if a well-defined request exists If it does, the request is performed and the result is printed out In a system allowing man/machine interaction it would be more reasonable to display the request and offer the user an opportunity of confirming it. In the present offline program, however, it was considered better to document the result rather than the request.

EXAMPLE

Using a period as a statement terminator and the blank and comma as word delimiters, the following would be a natural way to merge two tapes (U1 and U2 onto U3) and list the result

COPY 1 FILE FROM U1 ONTO U3 IN BINARY, 556 BPI COPY 3 FILES FROM U2. REWIND U1 REWIND U2. REWIND U3. RESET LIST 4 FILES FROM U3 IN OCTAL

Since the output unit is set to U3 by the first copy statement, it is assumed to be the same unit in the second statement. The mode and density are also assumed to be unchanged. The last statement requests a listing. Because COPY and LIST are not mutually exclusive the RESET statement is required to turn off the implicit COPY request. If no RESET statement was supplied the implicit output tape would be the same as the given input tape. This would generate an alarm.

The above request could be altered by eliminating the last two statements and changing the first to

LIST AND COPY 1 FILE FROM U1 ONTO U3 IN BINARY, 556 BPI.

To block a binary tape, one might write

COPY 1 FILE FROM U1 BINARY ONTO U2 BLOCKED, 556 BPI

The intent of the following request is obvious.

COPY 3 RECORDS FROM U1 ONTO U2, BINARY.
SKIP 1 FILE ON U1.
COPY 1 FILE FROM U1. REWIND U1. SKIP 3 RECORDS ON U1
COPY 1 FILE FROM U1. REWIND U1. REWIND U2

If the routine is used often it may be desirable to supply requests in a more abbreviated form The following are equivalent to the first statement of the above request

COPY, 3, REC, U1, U2, BIN.
COPY, 3, BIN, REC, U1, U2.
3, REC, COPY, U1, BIN, U2.

Indeed, to the program these are the only inputs. Word endings and noise words are allowed only for documentation and ease in setting up a request Thus, if one has a program which will accept inputs in the above form he may find that with little additional programming he may also have a routine which will accept input in free text.

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USE OF MICROFORM TECHNIQUES IN THE ERTS PROGRAM

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SECTION I
PURPOSE OF STUDY

Any given user, or ERTS data, will want only images related to his particular interests   It has been determined that some sort of browsing capability must be made available, by the NDPF, to users, in order that they may identify the images which suit their particular needs This study was undertaken to assess the feasibility of employing microform techniques in the operation of the NDPF   The utilization of these techniques in providing a browse capability was of particular interest   In addition, other potential areas of application to the NDPF functions such as micropublication of imagery, organization of data by various parameters, and the implementation of satellite files, were identified

There is a wide variety of microform information storage and retrieval systems available today   Their number has increased significantly during the last two years and is expected to continue at a rapid pace through the next decade   This report provides a survey of the current state-of-the-art in this field Recommendations are made for the most effective system which will enable the NDPF to accomplish its functions

SECTION II

GENERAL REVIEW

In general, a microform information storage and retrieval system consists of the following components

1. Film Materials

This refers to the microform itself The following comprise the available materials

- Roll film is available in a variety of sizes It may be wound on a spool or housed in a cassette or a cartridge Standard sizes are 16 and 35 millimeter.
- Microform Jackets are thin plastic folders separated into chambers which accept strips of roll film A human readable title may be placed along its upper edge
- Aperture cards are tab cards in which a slot is provided for a film chip or strip
- A microfiche is a small sheet of film which normally contains from 60 to 98 images in a grid pattern It usually contains a human readable title along its upper edge

- Ultrafiche and Ultrafilm are high density storage forms of microfiche and microfilm The fiche or film strip in these cases may contain thousands of images

- A microcard is somewhat analagous to a microfiche The difference is that the microcard itself is composed of an opaque material The microimages are therefore positive prints

The material and its size are two important variables in determining both the degree of mechanization which can be applied to the system and the effectiveness and convenience of the system to the user, for his particular application

2 Camera

This device makes the microphotographic image Cameras used in microfilming are of 3 types rotary, planetary, and step and repeat Selection of one or the other depends on the degree of precision required in placing the image on the film, and the desired format Another device, an optical printer, not commonly used in microform systems will also be considered

3 Reduction Ratio

In microphotography, the film image is reduced to the extent that the image is no longer legible to the naked eye The size of the micro image, as compared with the size of the original image, is expressed in terms of the reduction ratio For example, when an image 19 inches long is reduced to 1 inch of film, the reduction ratio is 19 to 1 This is commonly expressed as 19 1 or 19 x The reduction ratio is an extremely important variable in the design of a reliable document storage and retrieval system It can have a significant impact on the cost of the system as well as the legibility of the final product Frequently the reduction ratio is a function of the particular camera selected

4 Film and Film Chemistry

This is the basic data storage medium. It is a photographic image-recording material of high resolution, available in a variety of sizes A number of emulsions, such as silver halide, diazo, and kalvar are available, and are used at different functional locations in various systems, where their respective properties are of advantage
A silver based film is used as the master record file in most systems, due to its high resolution and image retention qualities.

5 Processor

This is the means for developing the film and fixing the image permanently on the storage medium Processors vary widely in cost They may be completely manual, semiautomatic, or fully automatic

6 Reader/Reader-Printer

The reader is a device used to enlarge and display the image from the microform on a viewing screen for the user's inspection There is a wide variety available with an equally wide range of costs The hard-copy printer is a reproduction device that makes a facsimile of an image, enlarged from the microform, and printed on paper The printer is housed in the same cabinet as a reader, the combination being called a reader-printer.

7 Storage and Retrieval

This provides the storage unit for housing the file of reduced documents on microforms Storage units range in complexity from simple cabinets with drawers designed to hold formats of a given size and shape, to variously mechanized units The more sophisticated of the latter present specially selected microforms at a retrieval station, or projected on a reader In designing a system with a central storage area and remote retrieval stations the problems of display and transmission must be considered

A DISCUSSION OF SYSTEM COMPONENTS

1. Film Materials

Several materials are available These include roll film, cartridges, jackets, microfiche, aperture cards, and microcards Aperture cards, microcards, and certain microfiche are commonly referred to as unitized microforms

a Roll Film

Roll film is still the most common microform found today It comes in a variety of sizes although the 16mm and 35mm widths are the most popular Length is commonly on the order of 100 feet

At standard reduction ratios, it is common to find from 2,000 to 3,000 images on a roll of film The actual number of images is of course dependent upon the image size and the reduction ratio used

Roll film may be used as a source for any other microform, as a dissemination medium, and as a retrieval vehicle Although roll film preparation is relatively simple, the retrieval of specific information from roll film sometimes is not Various coding schemes have been employed to alleviate this problem

1) Advantages

- Most economical to produce
- Easy to label
- Easy to duplicate
- Easy to file
- Can be used to produce any other microform
- Wide selection of related equipment easily available
- File Integrity
- By simple editing and splicing revissions or additions can easily be made to a sequence

2) Disadvantages

- Slow retrieval speed

b Cartridges

A cartridge film system is superior to a roll film system An advantage of this system over the roll film approach is that retrieval speed is significantly increased since the operator merely inserts the cartridge into a reader instead of having to manually thread the film through a transport mechanism and onto an empty spool

Several of the cartridge readers on the market are equipped with odometers This provides an excellent indexing system, by noting at what portion of the film a given data set is located The user can retrieve the data in a matter of a few seconds The indices can be placed directly on the cartridges. Cartridges are available in a variety of colors, thereby providing a further indexing capability In addition to the standard cartridge reader are image control devices A device of this nature consists of a keyboard interfacing with a standard cartridge reader By pushing a few buttons, the desired piece of data is displayed on the viewing screen The main drawback to a cartridge system is the fact that once the cartridge or the reader of a particular vendor is selected, any future purchases of cartridges or readers must be from that same vender This is due to the lack of standardization in the dimensions of the cartridges manufactured by the various vendors

1) Advantages

- File Integrity
- Economical to produce
- Easy to label
- Easy to duplicate
- Easy to file
- Can be used to produce any other microform
- Wide selection of related equipment easily available
- Relatively easy to index
- Can provide rapid retrieval speed
- By simple editing and splicing revisions or additions can easily be made to a sequence

2) Disadvantages

- Bound to a system once it has been selected c Jackets

Jackets are merely thin plastic folders separated into several chambers that accept strips of roll film They can be obtained in a multitude of sizes although the most popular size is the 4 x 6 inch jacket.

Because of the high speed in which these microforms can be created, they cost only a fraction of their unitized counterparts One pays for this cost reduction, however, since it is almost impossible to prepare microthin jackets that meet the existing standards

If meeting these standards is not essential, consideration should be given to the use of these microforms since it is a cheap alternative to preparing unitized microforms

1) Advantages

- Ease of making additions or revisions to jacket file
- Easy to group jackets by subject matter or other parameter
- Good dissemination medium
- Easy to file and index

2) Disadvantages

- Difficult to set up duplicate decentralized files

- No standardization of size

- Difficult to locate one item of the multiple items stored with the jacket

- Jacket can easily be misplaced

- Resolution not of highest quality

d Aperture Cards

An aperture card is an EAM card, modified to contain a frame of film (usually 35mm) permanently mounted in a die-cut window The card may be duplicated positively or negatively and may be processed through EAM equipment Each aperture card contains from one to eight 8 1/2 x 11 inch pages

Aperture cards have become one of the more widely used microforms due to the fact that they truly are a unitized record This factor is extremely important when a high-volume automated retrieval system is being considered

Due to the fact that in most cases, each aperture card will contain only one document, the image to unit cost is the highest of any microform

1) Advantages

- Card size is standard and meets Government regulations

- Readily applicable to duplicate decentralized files

- Easily integrated into automatic data processing systems

- Fast retrieval speed

- Easiest to update of any microform

- Reliable dissemination medium

- Excellent indexing medium

- Wide selection of related equipment available

2) Disadvantages

- Cards can be misplaced in a manual file, making sequencing difficult

- Most expensive of all microform systems in overall cost of equipment and supplies

- Normally only one or two images recorded on a single card, requiring many cards to maintain a large file e Microfiche

Microfiche is a sheet of film (negative or positive), having a standard size of 4 x 6 inches which holds anywhere from 60 to 100 frames on a single sheet (fiche) Microfiche may be made from roll film by cut-and-paste methods, or may be made with a step-and-repeat camera that automatically positions the individual image in the appropriate column on 105mm film. The cost per image is not as great as with aperture cards but is greater than roll film The use of microfiche has grown very rapidly over the past 5 years The storage is more convenient than roll film as well as retrieval in some cases, which are automated. Until recently indexing and retrieval of individual items was difficult, however, several companies have developed carrousel type systems which can store and retrieve the items or interact with a computer to retrieve them

1) Advantages

- Storage is convenient and economical

- Filing and indexing is easy if an automated retrieval system is used

- With step-and-repeat camera the negative can be developed quickly and economically

- Excellent dissemination medium.

- High quality inexpensive readers are readily available

- This is envisioned as the medium of the future

2) Disadvantages

- Automated retrieval systems introduce additional expenses

- Fiche can be easily lost or misfiled

- Loss of 1 sheet equivalent to losing from 60 to 100 pages of text

- Special equipment or modifications required to use microfiche and roll film or aperture card on same reader.

- Positioning for viewing or printing is a critical factor

- Indexing and retrieval of individual items is difficult in some systems

f. Ultrafiche and Ultrafilm

PCMI Ultrafiche is a format developed by National Cash Register which utilizes a reduction ratio of 150 to 1 The letters PCMI stand for Photo-Chromic Micro Image This is a relatively new development and at the present time production is being done in a clean room environment

Ultrafilm is a product of Microform Data Systems A reduction ratio of 210 to 1 is obtained. Instead of being in a fiche format a film strip is utilized Again, this is a relatively new technique and a clean room environment is needed

Both of the above systems are quite expensive

1) Advantages

- An extremely large data base can be stored in a minimum of area

2) Disadvantages

- Special equipment and conditions are required
- Expense
- Bound to the particular system that is chosen

g Microcard

This is a positive photographic print 3 x 5 inches in size The cards are more durable and less expensive than microfiche However, they are not widely used and the only readers available are the small portable type

2 Cameras

The camera is one of the major items of equipment in a microfilm document storage and retrieval system There are two major factors relating to cameras which must be evaluated in designing a system (1) the basic camera type (rotary, planetary, step and repeat, or an optical printer), and (2) cost

a Rotary Camera

The rotary camera derives its name from the rotating drum over which input documents are fed to be photographed It differs from the planetary camera in that the document is in motion while it is being filmed When a document is inserted into the machine, its leading edge actuates a tripping mechanism that turns on the camera lights and starts advancing the film The rotation of the document and the film advance are synchronized The image is automatically exposed on the moving film through a slit as the document passes directly in front of the camera aperture The amount of film exposed varies according to the length of the document being filmed The reduction ratio of the lens is also geared to the film-advance mechanism Thus, more film is exposed for a document being photographed at 17x than the same document being photographed at 30x

The reduction ratios of most rotary camera range from 16x through 40x This ratio is changed by replacing the lens-block assembly with another assembly of a different ratio Approximately 40 to 60 letter-size documents can be filmed per minute With an automatic device, this rate would naturally be higher Rotary cameras accept only a loose, single sheet at a time

Normally, rotary cameras are not used for precision microfilming work. The advantages of a rotary camera are in the ease of operation and in the speed with which the image can be recorded. Most of the factors dealing with the basic rules of photography (light-value reading, aperture opening, exposure time, focusing distance, and shutter speed or film advance speed) can be taken for granted, since they usually all function automatically in the rotary camera Thus, little training is needed to become an operator The lack of manual controls to override some of the automatic features, however, sometimes results in uneven film resolution, background density, and frame size

b Planetary Camera

This type of equipment is used for microfilming when very high-quality reproduction is necessary These are often referred to as flat-bed or overhead cameras because of their mechanical design The document to be filmed is placed on a flat copy table The camera is mounted on a column or arm extending over the document The reduction ratio is altered by either raising or lowering the camera If the size of the document image on the film is to be increased, the camera is lowered, if the image size is to be reduced, the camera is raised This is in contrast to the rotary camera, in which lenses must be changed and thus can only change reduction ratio in several discrete steps

Most planetary cameras use a fixed shutter speed and control exposure by varying the light intensity on the image to be copied

The primary disadvantage of the planteary camera is the relative slowness with which documents are filmed The fixed shutter speed, of course, imposes an absolute maximum on the throughput rate. In addition, unlike the rotary camera, many variables must be contended with before a high-quality microimage is achieved. The ability of the camera oeprator to evaluate every document to be photographed and to determine the proper settings and adjustments is essential in obtaining good image resolution, proper density, correct reduction ratio, and perfect positioning on the negative Thus, a good operator must have basic training in photography and experience in microphotography This means a significant investment in training

c The Step-And-Repeat Camera

The usefulness of procuring a camera with this capability should be evaluated, when considering the implementation of a microfiche document storage and retrieval system Each image is precisely positioned on the sheet of film with frame centers a specified distance from each other in both height and width. This positioning can be obtained in one of two ways First, the documents can be photographed on a narrow film, such as 35mm width, and then cut into strips of 12 images each and pasted up on clear acetate to form the master fiche Or the documents can be photographed on 105mm film (4 1 inches wide) by means of a camera that will transport the film magazine in a step-and-repeat fashion until it has sequenced through 5 rows of 12 frames before advancing the film another 6 inches

Microfiche masters made by the method of compositing and pasting up narrower strips of film are called microfolio microfiche. Additional equipment is required to trim the strips to size and to coat the edges of the film with adhesive An additional set of steps is required to paste up the original master fiche The throughput time for materials prepared in this manner is longer The step-and-repeat camera, which does the job of composition and placement as it exposes the master fiche, however, is significantly more expensive than a camera without this capability The microfiche master produced by a step-and-repeat camera is called a unitized microfiche

There is considerable difference between the costs of rotary and planetary cameras, and cameras of either type which have the step and repeat capability The following table summarizes the ranges of these costs

	Low	Average	High
Rotary Camera	$1,000	$ 3,000	$ 4,500
Planetary Cameras	$1,000	$ 8,000	$14,000
Step-and-Repeat Cameras	N A	$25,000	$35,000

As was mentioned eariler, an optical printer is not normally utilized in a microform system However, it may be applicable to the ERTS program This device has been widely used in the motion picture industry for producing 16mm copies of 70mm film The copy produced is identical in resolution quality to the 70mm original This is due to the fact that the optical printer operates on a light projection principle, and utilizes extremely high quality optics Therefore, its product is of higher resolution than can be obtained with any of the cameras. The reason for this is that the cameras are taking a picture of a picture The optical printer however, projects light through a 70mm transparency to an optical system which reduces the size of the image and focuses it onto the 16mm film The main characteristics of a device of this type are given below

- It provides a completely automated system
- The resolution is of the highest possible quality
- A processor is incuded as a component of the device
- It can copy directly from film to film
- It can act as a duplicating device
- Its cost is comparable to a step and repeat camera

3 Reduction Ratio

In microphotography, the film image of the original document is reduced in size to the point that it cannot be read by the naked eye Just how great this reduction may be depends on the size, detail, and contrast of the material printed on the original documents and the legibility desired in the film copies The relationship between the size of the microimages, and the size of the original document, is expressed in terms of a reduction ratio. For example, when a reduction ratio of 20 to 1 (commonly expressed as 20 1 or 20x) is used, it is possible to reduce a document measuring 20 inches in length to 1 inch of film More images can be recorded on the same amount of film by using a higher reduction ratio, thus resulting in film economy and a lower cost per item photographed The reduction ratio, therefore, is the most significant measure of the storage capacity of a microfilm system.

At least three factors must be considered when determining the reduction ratio to be used in a system

- The resolving power of the human eye

  For error free reading of print it has been found that the resolving power of the eye is 7 to 12 lines per millimeter

- The resolving power of the film.

  Government specifications state that a resolution of 100 to 120 lines per millimeter is acceptable for microfilm recording at reduction ratios of 16x to 30x The average Kodak film emulsion has a resolution of 250 lines per millimeter. However, films are available that measure in excess of 2,240 lines per millimeter.

  If a film has a resolution of 100 lines per millimeter, a character one mm. in height reduced 25x, would be 04 mm in height on the film   This would mean that the character would be comprised of 4 lines on the film   As mentioned previously, the resolving power of the eye is 7 resolution lines   Therefore, the character would appear illegible when enlarged

- The number of regenerations

  It has been shown that in successive regeneration of diazo film only 80 percent of the resolution in the original is obtained in the copy

Generally, documents are microfilmed at the lowest reduction necessary to record the images on the film being used   Technically, present day cameras and some films can microphotograph records at reduction ratios considerably greater than 44 1, but the practical use of higher reduction ratios is limited by the current design of reader-printer machines now on the market

The reduction ratio normally used for recording ordinary letter-size documents (8 1/2 x 11) is either 17 1, 19 1, or 24 1. The approximate number of documents that can be recorded on a 100-foot roll of film is 1,800 images at 17 1, 2,400 images at 19 1, and 3,000 images at 24 1   The number of images per 100 feet of film varies with the size of the record and the degree of reduction. For estimating purposes, the following formula is generally used

$$\frac{\text{Reduction Ratio} \times 1{,}200 \text{ Inches}}{\text{Longest Dimension of Document (in inches)} + \text{1/2 inch for each Document}} = \text{Number of Images Per 100 Feet of Film}$$

4 Film and Film Chemistry

Microfilm is available in both positive and negative formats. Positive microfilm is defined as consisting of dark lines on a white background Negative microfilm consists of white lines on a dark background. Negative microfilm is generally regarded as being of higher resolution and easier to read

There are 3 types of film used in microreproduction silver, diazo, and kalvar

Silver film is composed of a silver halide base It is a fast film and has high resolution qualities It is an excellent medium for archival storage since it retains the image over a long period of time. However, since the image is actually recorded on the emulsion, it is very susceptible to tearing, scratching, and other physical defects Therefore, it should be handled as little as possible Master record copies of images should be made on silver halide film but duplicate negatives should be made for use in a working file

Diazo is a slow film and takes longer to expose than silver halide Development however can take place in a lighted room The duplication cycle for diazo is significantly faster than for silver halide Because the emulsion of diazo is incorporated into the base material the diazo image is much less susceptible to damage during handling. After a period of time, however, the diazo image fades Therefore, diazo is recommended only for use as a working file copy

Kalvar film is not widespread in use as a storage medium It works on an entirely different principle than either silver halide or diazo Rather than containing a silver emulsion, it is composed of a material which, when exposed to ultraviolet radiation, forms the nucleus of a tiny bubble at each point where the radiation impinges These nuclei form the latent image. When simple heat is applied to the exposed material, the microscopic bubbles expand in proportion to the amount of radiation received during exposure

The bubbles scatter light differentially, depending on their size This is in contrast to the principle behind silver-based films, in which the darkened silver particles absorb light Its image-retention capabilities are excellent, as long as the film is kept in a temperature-controlled environment Exposure and processing are extremely simple. Its primary application is similar to that of diazo, for information storage and retrieval applications It has the disadvantage that it lacks the well understood supporting technology built up around the use of silver halide and diazo film

Along with resolution, as discussed previously, the background density also governs the quality of the processed microfilm Density is a measure of the opacity of the image

Density is expressed in a logarithmic scale ranging from 0 00 to 3 00 The lower value represents the perfect transmission of light and the upper value represents virtually total opacity A measurement of 1 0 to 1 2 for negative microfilms, obtained with a densitometer, is acceptable by Government specifications The image density obtainable from virtually all films is widely controllable by varying exposure time and by varying development time during processing. Most commercial microfilm manufacturers provide exposure and processing instructions for obtaining proper density

Most commercial microfilm is currently manufactured and distributed in rolls of four common widths 16mm (0 6 inches), 35mm (1 3 inches), 70mm (2 8 inches), and 105mm (4 1 inches) The standard raw film normally comes in unperforated 100-foot rolls, however, other lengths (50-foot rolls and 200-foot rolls) are available Most commercially available microfilm storage cabinets are designed to receive the 100-foot lengths

Costs of the duplicating equipment are quite variable In general, the silver film duplicators are the lowest cost followed by the diazo and kalvar, in that order In the cost of the film the diazo is the lowest cost followed by silver and kalvar

5 Processor

Once the film has been exposed, it must be processed so that the latent image on the raw negative film becomes visible. There are two stages in silver film processing, often referred to as the wet and the dry stages. In the wet stage, the exposed film is placed in a developing solution that converts the exposed silver halide in the emulsion to metalic silver and creates the image. The film is then rinsed to remove any traces of the developer and placed in a fixing bath The fixing solution, often referred to as hypo, removes the unexposed silver halide. The film is then placed in a final wash bath to remove any traces of hypo carried over from the fixing bath

After the film is developed and fixed, it enters the drying stage. The timing and the temperature of the drying stage are important, if an infrared lamp or warm air blower is improperly used for drying, the surface of the film can become excessively dry while the body of the film is left with excessive moisture content Improperly dried film does not retain archival permanence and cannot be used without being easily scratched and damaged

Diazo and kalvar film printers have a developer section which processes the film directly following exposure The diazo processing utilizes liquid ammonium hydroxide The odors from this chamical can cause considerable problems when allowed to escape into the surrounding atmosphere Kalvar film is processed by passing the film through heated rollers The temperatures used in this process are 240°

Microfilm is processed the same way as conventional black and white film, except that the time intervals in the various developing stages, solution strengths and temperatures, and general handling techniques are far more critical than with conventional films For large production systems, completely automated film processing equipment is required, as is test equipment for quality control. Spectrometers, densitometers and temperature gauges, are required for positive quality assurance Costs for fully automated processing equipment range from $2,000 to $50,000 or more For smaller systems, semiautomatic equipment is available, however, skilled operators are required

6 Reader/Reader-Printer

Once the original records are microfilmed, a reading device is required to complete a basic system A reader consists essentially of a microfilm holder, a lens system for enlargement of the image, a screen for viewing the enlarged image, and controls for focusing the image or for selecting a portion of the image and focusing

Readers may be equipped to handle roll film only, cartridges only, aperture cards only, microfiche only, or any and all combinations of microforms

In terms of controls, readers may have fixed magnification ratios or variable magnification, variable illumination, and multiple focusing jontrols The number of control features largely determines the cost of a reader The least expensive readers cost about $2 and work like a hand slide viewer, using ambient light. These, of course, are impractical for any purpose other than the most cursory inspection. An average cost for a good, flexible, self-contained microfiche or aperture card viewer is about $340 Roll film or cartridge viewers cost approximately $1,200 for a quality machine.

The function of the printer is to provide enlarged hard copies of microimages for immediate use By far the large majority of such devices are combined with readers, and are called reader-prints The reader allows the user to inspect the microform before it is printed to be sure that he is getting what he desires The printer records the image from the microform on paper stock and ejects the printed material Paper stock may be in sheets or on rolls Printers may be of the wet-process type, electrostatic, electrochemical, or dry-photo process.

To obtain an enlarged reference copy of the microimage, the image is sharply focused on the viewing screen, exposure time is set, and a button is pushed

The print material may be paper suitable only for reference copies Normal writing materials may be used on the paper Or the paper may be suitable for printing techniques, including offset lithography In general, the output from reader-printers is not itself reproducible

Reader-printers range in cost from $500 to about $5,000

7. Storage and Retrieval

This is the storage unit for housing the working master file of reduced documents on microforms Depending on the needs of the user, the unit can vary widely in both cost and sophistication At the very least, the unit need be no more than a filing cabinet It must, however, be designed to receive the microforms established as the storage medium for the system This means that the filing trays must be of the correct size, and designed to protect the film materials on which the documents are recorded For larger files, motorized files are available These are usually rotary files, which have the filing trays mounted on a ferris-wheel arrangement inside the cabinet By pressing a button, the operator brings the correct tray to the retrieval station By storing microforms in trays of optimum size, the retrieval time is considerably lessened

The most sophisticated of current available film storage devices stores unit records in units containing 200,000 unit records each Retrieval is fully automatic By inserting an accession number into a keyboard, the correct microfiche or aperture card is retrieved in 6 to 10 seconds and positioned in a reader-printer, ready for immediate viewing and printing. This device is also available with a digital computer interface, such that retrieval instructions can be output directly from the computer to the film store without human intervention The retrieved microforms can then be viewed either through the reader or remotely, through closed-circuit television The cost of the film store ranges from about $100 for the simple file cabinet to about $250,000 for the fully automatic store with computer interface

B. REMOTE DISPLAY AND TRANSMISSION

The fact that to date no one can transmit large amounts of documents economically or quickly, if at all, from one area to another is difficult to comprehend in this day and age, yet it is true

The following is a brief discussion of the state of the art, various means of transmission, the advantages and disadvantages of most

Transmission of images may be divided into two distinct groups One group involves local interrogating stations, arbitrarily restricted to a radial distance of less than 5,000 feet from the file These systems are known as "in-house" systems The second group includes all interrogating stations beyond this range The operational area of the first group eliminates the problems associated with wide band video transmissions since the majority of the available 5 MC Closed Circuit TV systems exhibit sufficient signal to noise ratios to provide good signal definition at distances up to 5,000 feet when transmitted over a RG 11/U Polyfoam cable

The following are technical approaches to this application

- Closed Circuit TV-CCTV
- Slow Scan Video
- Scan Conversion Techniques

1. CCTV Systems

Closed Circuit TV provides the most convenient and economically feasible system for remote display It offers wide band system capability at an extremely low cost TV is a wide band system because of its motion capturing capability or frame rate However, in the remote display of stationary graphics and alphanumerics it would be better to have increased resolution capability.

These camera and monitor systems employ standard TV components and are compatible with commercial TV Since the transmission of wide band video is a difficult and expensive proposition, TV systems have tended to standardize and emphasize the economics of production rather than improved performance As a result, the standard 5 MC TV systems available represent the most economically attractive application when their performance parameters suffice

Additional complications are encountered in the transmission of video information to remotely located output stations CCTV information may be distributed by one of the following communication links The table also indicates the probable maximum bandwidth of the channel

Type of Channel	Bandwidth
Microwave	20 MC
Video	20-30 MC
R F	5 MC

The FCC has imposed stringent conditions upon the allocation and operation of micro-wave radio links The significant technical requirements that apply to such a link are (1) it is very directional (line-of-sight) thereby essentially requiring a transmitter for each receiver and (2) the available bandwidths coincide with the 5 MC standard TV channel with a 20 MC band-width (4 adjacent 5 MC channel) representing a maximum The price of such a 2 way microwave transmitting link is conservatively estimated at $30,000

The CCTV information may also be distributed as wide band video via coaxial cable This scheme would require line amplifiers about every 3,000 feet to maintain the signal to noise ratio Only one channel of video could be transmitted over each link The cost of coaxial cable is about $0 12/foot Line amplifiers are available in the 5 MC range for approximately $250/ amplifier.

The third method relies extensively on standard TV to be transmitted over the link simultaneously This system can be transmitted over air sheath Bell supplied lines at a cost of approximately $120/mile/ month A disadvantage to this transmission mode is that it is limited to a 5 MC bandwidth and consequently features limited resolution

The state-of-the-art of conventional CCTV systems is not sufficient to meet stringent performance requirements because (1) contemporary transmission links with a 30-50 MC capacity do not exist and (2) the potential resolution of both the camera and monitor system falls short of the 1500 TV lines required in most cases for good image transmission

2. Slow Scan and Scan Conversion Systems

Slow scan high resolution camera tubes, in addition to conventional vidicons are

1. The image dissector tube

2. The flying spot scanner

3. The slow vidicon

The limits of resolutions established by the inherent characteristics of these devices are tabulated below

Resolution limitations of slow scan and scan conversion systems

Tube Designation	Limiting Resolution (TV Lines)
Image Dissector Tube	3000
Flying Spot Scanner	4000
Slow Scan Vidicon	700
Direct View Storage Tube	800/diameter
Recording Storage Tube	2500/diameter
High Resolution CRT (5 inch)	5000/diameter
Fiber Optic CRT	3000/diameter
Laser Scanner	40,000

From this inventory of components, one may, in theory, hypothesize slow scan vidicon systems capable of meeting all the performance objective However, Slow Scan TV systems employ the lowest resolution components available and consequently are severely limited in their potential resolution capability (560 TV lines per frame). Components and subsystems do exist to provide higher resolutions. Their incorporation into any of the system concepts considered in this section would require considerable development effort.

C. COMPUTER OUTPUT ON MICROFILM

COM is an expression that variously means Computer Output Microfilm, Computer Output Microfilming, or Computer Output Microfilmer In any case, a COM device is any unit of hardware which produces some form of microfilm record from a signal which has been created in a computer, regardless of whether the signal comes directly from the computer or from an auxiliary memory unit

There are two major types of COM devices Alphanumeric COM's basically produce characters, numerals, and symbols Graphic COM's produce varied images, including characters as well as all types of drawings Alphanumeric COM devices are primarily used as substitutes for impact printers Whereas an impact printer can produce 2400 characters per second, COM devices can write characters at rates up to 500,000 characters per second

Graphic COM devices are used in the marking of bar charts, graphs, and drawings Typesetting characters, company logos, and half-tone pictures are further examples of graphical output The basic components of a COM device are 1) the input, 2) the logic section, 3) the conversion section, 4) the deflection controls, 5) the display section, and 6) the film-handling section. The input section sends an electrical signal to the logic section where a logical conversion of the input is accomplished. The logic section then routes this information to the conversion section, where characters, lines, or symbols are graphically created The conversion section, in turn, regulates deflection controls to determine information location, controls the display section, and adjusts the devices in the film-handling section. Some COM devices combine functions, but all perform basically the same operations to convert computer-encoded digital information to man-readable information on film.

Input can come from an on-line computer or from an off-line memory unit Appropriate software interfaces are needed between these units and the COM logic section Most COM machines handle or will soon be able to handle the full range of tape densities up to 1600 bpi, and at tape speeds up to 75 ips Standard 1/2", 7- or 9-track magnetic tape is currently handled in most all cases on tape drives supplied by the COM manufacturer

The function of the logic section is to coordinate and direct the action of all system elements to achieve the end product of exposed microfilm. The logic section serves as the interface between the tape drive and the display and photographic units It determines, from the tape input, what is to be recorded (data records), and in what size and position on the "page" it is to be located, with what "form overlay" (if any) it is to be recorded, and when the film is to be advanced to the next frame It also controls the handling of coding tape read error conditions, and reread, and it controls frame marking to indicate unreadable characters

The conversion section consists of a character generator, vector generator, point-plotting system, or a combination of the three. All these modes of plotting can be accomplished by electronic circuitry

The deflection controls adjust the location of the image on the film. They may be regulated by commands from either the logic section or the generators in the conversion section.

The display section handles the image area to be photographed and, possibly, an optical forms-overlay system With most units, the display section is represented by the face of a cathode ray tube

The film-handling section is generally a camera which accommodates 16mm, 35mm, 105mm, or a combination of these film sizes Roll films up to 1000 feet in length can be sprocketed or non-sprocketed and can be advanced in steps of varying size. When a camera is using 105mm film to record multi-image microfiche, the camera will step and repeat either in rows or columns, as well as advance from image area to image area Some units process the film on-line and provide a finished product directly

Microfilm systems which require several generations of duplication place the most stringent requirements on COM output. All reproduction processes introduce degradation of the image. Unless the original image is of very high quality, the third-or fourth-generation copy will be unreadable COM units vary widely in this respect

Most COM units are conventional silver microfilm that requires "chemical bath" processing to develop the latent images Although this off-line processing requires additional work, several film processors are available to develop the film in what might be considered a very convenient, fast, and relatively inexpensive manner. The additional cost, for chemicals, amounts to about 35¢ per 100 feet of 16mm film

One exception to the above uses a "dry silver" microfilm that is developed by heat in a film processor unit that can be operated on-line with the COM unit As a result of the on-line developing of film the user is able to monitor the finished output after about 10 feet of film has passed through the display and record unit

The costs of COM Devices vary from 50 to 650 thousand dollars with an average of about 200 thousand dollars

SECTION III
APPLICATIONS TO THE ERTS PROGRAM

The ERTS program is especially suited for the application of microfilm techniques Due to the voluminous quantities of data which will be acquired, a microfilm system would prove advantageous in the DSL Browse Facility. The technology is also very effective in the areas of data dissemination and catalog publishing.

A small section of the NDPF will be available to users for the purpose of inspecting ERTS data products. Sample of RBV and MSS images, precision processed precision images, and color composites will be available These items will be presented in 9 1/2 inch positive transparencies and prints

The utilization of microfilm however, will enable the browse facility to contain images of the entire data base A 100 ft roll of 16mm microfilm can hold approximately 2500 high quality ERTS images Therefore, there is no reason why the entire ERTS data base, including color composites, could not be available for browsing

An ideal microform system would consist of

- A COM device to record the ERTS imagery on microform

- An automated central file in which to store the microforms

- o Remote display of the data contained in the central file, at various user sites throughout the country

- o The remote sites and the central repository would be interfaced with a computer to facilitate the handling of requests and the retrieval of the information.

However, there are two significant disadvantages to this type of approach First, the remote display and transmission of high resolution imagery over great distances is not feasible Secondly, assuming it were feasible, the cost of such a system would be prohibitive

A viewing station in the browse facility would require little space. Two readers on a table would be ideal A single table top file could provide storage for an entire years's data. The readers would require no special alterations to the facility, and could be operated under normal lighting conditions. Inexpensive microfilm readers are available which will allow the user to identify any image to within 10 images in a 100 ft microfilm roll. Average retrieval time is a few seconds. Such viewers may be used under normal light conditions. It would thus appear that microfilm is the most economical and efficient way of making high quality sample images of the total ERTS data base available to visitors to the DSL.

Images on the microfilm are normally stored in a time order However, by editing and splicing, a geographic ordered format could easily be prepared. It is possible to group swaths of the same geographic area taken at different times of the year, swaths covering a particular country can also be arranged in sequence from West to East It would not be difficult to order images by cloud cover. All of these formats can be easily indexed and cross-referenced by the NDPF Information Retrieval System.

In addition to the above data organizations, an 18 day micropublication of all images of the United States could be recorded on two rolls of microfilm If data were ordered by cloud cover, all cloud free U.S. images can be included on a single roll This could be utilized as a supplement to the standard montage catalog

In any of these applications, microfilm provides an excellent dissemination medium It is inexpensive to prepare and viewing equipment is widely available In fact, most user agencies probably already have viewers capable of viewing 16mm roll microfilm

Because microfilm is so inexpensive to reproduce, it would be possible to generate 100 rolls of microfilm each day with each roll containing all images processed during the previous 24 hours, These could be distributed to user agencies within 1 day of the initial image processing The microfilm could be distributed to satellite reviewing stations in the user agency where they would provide an inexpensive and up-to-date user maintained browse capability The cost of such an operation to the NDPF and the user agency would be more than offset by the savings in materials, processing, and analysis, due to reduced throughput

Since all the images will be produced as 70mm positive transparencies these will be the original input to the microform system A reduction ratio of 4-5X is required to provide a 16mm microfilm record of the images Rotary or step and repeat cameras would require an extensive modification to existing lens systems to accommodate such a small reduction ratio Then backlighting would be necessary which would be quite difficult with a rotary camera A planetary camera or an optical printer can accomplish such a reduction ratio

Since the images contained in the browse file must be of the highest resolution as is possible, a silver base film is needed The expense is not a great deal more than for diazo film, and the resolution is superior

SECTION IV
STATE-OF-THE-ART OF INFORMATION STORAGE AND RETRIEVAL SYSTEMS

A. LARGE AUTOMATED RETRIEVAL SYSTEMS

1 Mosler

The Mosler 410 system is capable of storing micro-images on aperture cards or microfiche.

It can be controlled by local or remote terminals or a computer The system is capable of producing three types of output (1) video display, (2) duplicate microform, and (3) hard copy

Up to 200,000 cards may be stored and retrieved from a single module. As many as five storage modules may be operated in a single system Microfiche and aperture cards can be intermixed in the system

The microfiche used in the system is a tab-card-size all-film diazo copy of a different size microfiche or jacket The fiche normally contain 56 page size images A single aperture card can contain as many as eight pages.

After the desired images are transferred to the card or fiche they are processed through a notcher A pattern of notches and round holes are made by the notcher in the bottom 2/10 inches of the card This serves as the identification for the card It is used to retrieve the card from storage

The storage area consists of two parallel honeycombed walls each containing 1,000 cartridges Each cartridge can hold 100 cards. Each cartridge has its own unique address The combination of cartridge location and card identification creates a unique retrieval order of as many as eleven digits

After a retrieval command has been entered into the system, it is decoded, and then a high speed retrieval mechanism located between the walls retrieves the proper cartridge and delivers it to the output station. A group of pins is inserted through the cartridge at the output station A jet of air causes the proper card to pop up out of the cartridge. The identification number of the card and the cartridge are maintained in the system so that when a return command is entered, the return station files the card in the cartridge and makes the cartridge available to the retrieval mechanism which returns the cartridge to its assigned station

Mosler control terminals may be adjacent to the file or thousands of feet from it A terminal has 20 data keys for the input of numerics, alphabetics, and special characters Other keys specify and control functions Status indicator lights signal system readiness and document availability. Typical functions include notch, select, infile, display, copy, print, and refile

The system equipped with the appropriate interfaces can be controlled by third generation computers. In this type of arrangement the Mosler system is treated as one of the computer's output devices. All inputs or requests are made through computer inquiry terminals and requests are fulfilled by Mosler output devices. All communications control, priority assignment, indexing and search is provided by the computer

A single storage module can serve several output stations. One station is reserved for file maintenance In addition to the video terminal other local output stations include an on-line printer, card to card, fiche to fiche, and card to roll film duplicators All duplicates are diazo in nature.

Remote terminals are linked to the central control area by means of coaxial cable The terminals have zoom lens and print capabilities

Cost of the system ranges from 30 to several hundred thousand dollars

2 <u>Sanders Diebold</u>

The SD 500 information system stores microforms of differing formats in a central repository and provides remote viewing capability.

The system accommodates aperture cards, microfiche, jackets, and film strips. The microforms are placed in film retainers which are stored in a power file. One of the files measures approximately 8' high 10' wide and 6 1/2' deep There are 20 rotating shelves within the file Each shelf contains seven storage modules Each module contains seven bins each holding 50 micro-image retainers Therefore, one file will house 49,000 micro-image retainers.

Up to 10 display terminals can be located as far as 6,000 ft. from the central repository They are connected by closed circuit TV to the central repository

When a request is entered into the system by means of the keyboard at the terminal - the closed circuit TV camera moves within the repository to the particular shelf and a mechanism extracts the proper module The camera then moves to the designated bin and the appropriate microimage retainer is pulled and displayed The entire process takes approximately 8 seconds

The cost of this system ranges upwards from 200 thousand dollars

3 Ampex Videofile System

Although this is not a microform system, it was felt that it should be included in the survey because of its future potential. The Videofile system is composed of six basic units File Section, Buffer Section, Display Section, Printer, and System Control Center This system converts a paper document into a television-type electronic image The electronic image with its identifying address are automatically filed and stored in compressed form on magnetic video tape

The function of the filing section is to convert documents into electronic video images This section contains a high resolution TV camera, optics for focusing the image on the tube, a lighting system, an address keyboard, a platen system, and indicator lights. After the operator places the document on the platen, and enters the address, the image is electronically filed. No further processing or development is needed Two keyboard types are available One consists of 26 alpha and 10 numeric characters plus the control keys The other is comprised of 10 numeric characters plus the control keys The filing section accommodates either 8 1/2" x 11" or 8 1/2" x 14" size documents.

After the image has been entered by the filing section it is stored in the tape section. It converts the video image and its address into a magnetic tape recording. It also retrieves recorded images in response to requests The video image is frequency modulated and occupies 1 3/4" of the 2" wide tape Each 8 1/2" x 11" document occupies about 1/3" of tape length. The digital address is recorded in a longitudinal track on one edge of the tape The packing density is approximately 620 bits per inch. The control track is written on the opposite edge of the tape from the address track It consists of a series of short pulses written at a rate of 240 per second at a tape speed of 5 ips. This track synchronizes the passage of the tape with system timing and aligns the video tracks with the passage of the video heads The tape can be transported at two speeds 380 ips in the search mode in either the forward or reverse directions, and 5 ips while reading, writing or erasing video or address information but in the forward direction only

When a request for an image or series of images is entered into the system the tape section seeks out the appropriate images and they are copied into the buffer section. The original remains in the master file and is available for use at other terminals. The duplicate images can be held in the buffer for reference as long as is needed Buffer sections are available in one, two, or four divisions which are capable of storing 50, 25, or 12 frames respectively Reading or writing operations are performed as 1/15 second per frame Input to a output from the buffer can be continuous

The display section consists of a high resolution CRT, and an address keyboard. This keyboard is similar to the filing keyboard The user can browse at his own pace through all documents held in the buffer The keyboard is used to call up the images desired The display unit can be used in offices with normal illumination levels. An electrostatic printer is also available for producing hard-copy

The system control section directs the interaction of the other sections in a pre-determined manner This section uses a set of operating instructions which are entered from a paper tape or card reader. It contains a logic distribution system which interconnects all the sections, and a small general purpose computer A teletype unit provides the communication channel between the controller and the system librarian

The cost of this system is on the order of $500,000 to $1,000,000

4 Univac

The basic storage device in this system is a cassette. One cassette is capable of storing 1024 microfiche Assuming a 98 page format is used, a cassette would hold approximately 100,000 images Modular addition of cassettes is possible to expand the storage capacity Each microfiche is suspended in the cassette by means of binary pins. Each fiche is coded by means of slots in the upper edge Therefore, each fiche has a particular address

When an address is entered into the system the alignment of the pins allow the proper fiche to drop from the cassette and be transported to the viewing station by means of air currents

The desired image is projected on a screen by means of manipulating a carrier in the X-Y directions. After viewing, air jets return the fiche back to the cassette. When it is refiled, the fiche is placed in the front of the cassette

This fluidic handling device can be interfaced with any desired computer The system can be computer indexed, the microfiche can be computer generated, and the data can be transmitted to remote locations

5. Foto-Mem

TISAR is an acronym for total information storage and retrieval system It is manufactured by Foto-Mem Inc. It consists of a memory bank, a master controller, a buffer, and a viewer

The data is stored on Photo-Data-Cards. The Photo-Data-Cards are stored in Photo-Data-Cells. Up to 100 Photo-Data-Cards can be randomly filed in a Foto-Data-Cell. Up to 250 Foto-Data-Cells can be contained in the selecting mechanism housing of a standard unit. A Foto-Data-Cell measures approximately 6" x 4" x 1 1/2" and is capable of storing approximately 8,000 micro images of letter size documents.

The master controller directs inquiries from the various inquiry stations to the appropriate section of the system. The desired information is then located and it is sent to the inquiry station.

A buffer memory stores the retrieved data, thereby freeing the main file to service other requests. Up to 800 images can be stored in the buffer at any given time.

The display terminal consists of a TV receiver and a keyboard. The keyboard can be used with the TV receiver to request, modify, or enter data into the system.

6 Microform Data Systems

Ultrafilm is a product of Microform Data Systems. It is similar to ultrafiche in reduction ratio but the medium is 35 mm film strips. A typical 6 inch strip contains 2,000 8 1/2" x 11" pages.

Ultrafilm is produced with special cameras and processing equipment operated in a controlled environment. A primary 35mm film is produced by either a planetary camera or a COM device The primary microfilm is then processed and loaded into an Ultrafilm-Compositor-Recorder (UCR) for final reduction. The UCR operates automatically at a rate of 5,400 frames per hour Its operation is controlled by punched paper tape which contains the merging, updating and compositing programs to create the Ultrafilm masters Duplicate copies are produced by contact printing The final reduction ratio obtained is 210 1 The image on the film is a positive

Three models of Ultrafilm readers are available one manual and two automatic models Magnification ratios available range from 150-230X Storage capabilities range from 2,000 pages (one Ultrastrip) for the manual model to a maximum of 120,000 pages (60 Ultrastrips) in an automatic model Access time is less than six seconds. The automatic models have the capability of interfacing with a computer Keyboards allow the viewer to call upon a particular address to view an image

The costs of a system of this nature are prohibitive for any but the largest data bases

7 NCR - PCMI Ultrafiche

The films used in this system are completely grain free and capable of high resolution (1,000 lines/mm) Each 4 x 6 inch fiche can hold up to 3,200 letter size documents reduced to a ratio of 150 1

The images may be erased or corrected An NCR class 455 viewer is required to view the fiche. The viewer enlarges the image 115 or 150X. The photography must be done in a clean room environment. The cost of this type of system is approximately a million dollars

8 Applications to ERTS Program

The NCR and Microform Data Systems products are really not feasible for the ERTS program. The ERTS data base will not be large enough to justify the expense of either of these systems. In addition, the quality of resolution which could be maintained with these systems is an unknown They are feasible for printed matter but this may not be the case for photographic data

Any of the other systems although feasible are rather expensive and, since the viewing stations are only going to be at the NDPF, are really over-qualified for the task. **In addition, the resolution quality of some of the** systems may not be sufficient for the ERTS imagery **Therefore, none of the large automated retrieval systems are recommended for the ERTS Program.**

B MEDIUM SIZED SEMI-AUTOMATED RETRIEVAL SYSTEMS

1 The Recordak Miracode System

The format utilized in this system is 16mm microfilm Two types of images appear on the microfilm, a reproducible image of the document and an image of its associated code

Every document on the film is assigned an identifying code field comprised of one or more binary coded columns. This is accomplished by an arrangement of clear and opaque rectangles. Fourteen bits, including a parity bit, are contained in each column. Fixed and open code fields can be employed

There are three modes of input available a manual system, a data card system, and a CRT system.

The manual system is composed of a microfilmer, and an input control keyboard With the document in place on the screen portion of the keyboard an operator sets the code by positioning a group of switches Then by pushing a button the code is exposed on the film by a series of lights in the film unit of the microfilmer. After the code exposure the film advances automatically and the document image is exposed by push button control These operations are repeated for each document

With the data card system the desired code is punched onto cards The cards are then passed through a card reader, which is connected to the film unit of the microfilmer After a card has been read the document is photographed The punched cards thereby automatically control the exposure of the code image as well as the cycling of the system

With the CRT system the image of the document is displayed on a Cathode Ray Tube and this display along with a code image is photographically recorded on microfilm

A 100 foot roll of film is housed in a 4 x 4 x 1 inch magazine. The magazines are housed in access files adjacent to the viewing station Magazines can be color coded to denote different subject areas

Each retrieval station is composed of a control console, a reader-printer, and a filing cabinet The control console is comprised of a keyboard control unit and a set of retrieval keyboards After the cartridge is inserted into the reader and the appropriate code is punched on the retrieval keyboard, the system will find the requested document, no matter where that document appears on the film, in less than 10 seconds.

This system provides good browse capability and due to its modular concept can be expanded or interfaced with a computer. The cost of the basic system is approximately $36,000

2 <u>Sanders-Diebold and Mosler</u>

For remote viewing the SD 550 and the Mosler 20/20 systems provide a more economical approach to the problem than their larger counterparts The micro-images can be stored in any type of file. A clerk must be contacted by the user to retrieve a particular microform Upon retrieving the desired data, the clerk places it in a transmitting station which displays the desired image on a remote viewing terminal

The SD 550 is capable of handling microfiche, jackets, or aperture cards. The Mosler 20/20 handles only aperture cards The remote viewing stations consist of a high resolution TV monitor and a keyboard to provide focus, scan, and zoom capabilities. As many as 6 terminals may be serviced at any one time by one transmitter. However, only one image may be transmitted at any one time by a transmitter. If two remote terminals desired different images at the same time there would have to be a separate transmitter for each or one of the viewers would have to wait

After the user is finished viewing the image a "return" button is pushed and the clerk returns the image to the file and goes on to service the next request

The costs of these systems vary from approximately 15 to 25 thousand dollars for a transmitting station, a remote viewer, and a power file

3 Applications to ERTS Program

The Sanders-Diebold and Mosler systems, although applicable to the ERTS program, are somewhat extravagent in terms of an on-site facility The need for remote viewing terminals within the NDPF is not necessary.

The Kodak Miracode system offers an excellent browse capability and is well suited for use in the ERTS program However, the $36,000 cost of this system is the main drawback

C. SEMI-AUTOMATED RETRIEVAL UNITS

1 Houston-Fearless

The HF Image Compact Automatic Retrieval-Display system (CARD) is a high speed microfiche data storage and retrieval system. It may operate independently or be tied in with a computer. The basic hardware in the system is the CARD reader.

The reader's pushbutton retrieval provides rapid access to 73,500 letter size pages of information filed on 750 microfiche which are randomly located on a carrousel Each microfiche can contain up to 98 pages of information, any one of which can be displayed on the screen in 4 seconds or less Selection of the information to be displayed is made by pressing a maximum of 4 keys on the control panel. Any information can be stored in black and white or in color It will interface with any third generation computer or computer peripheral equipment. Updating is accomplished by replacing microfiche. Any storage requirement in excess of 73,500 images can be filed outside the reader for quick exchange with data stored in the unit

The machine is a desk top unit. The enlargement capability in 24X A binary coded clip is attached to each to provide a unique address Once it is found, the fiche is withdrawn from the file into a projection gate

Ten category buttons corresponding to a section of information select the appropriate section. A second set of keys select the sub-section. The sub-section index is automatically displayed so that the actual page may be selected Two buttons are pushed and the desired page appears on the screen

2 Image Control Devices

Another method of semi-automatic retrieval is that of image control. The film is annotated with magnetic "blips" at the base of each frame The film is then placed in a cartridge The cartridge reader contains or has a keyboard attached The identification of the desired image is punched on the keyboard The reader then goes through the roll of film until the appropriate number of "blips" have been counted and projects that image on the screen. Systems of this nature range in price from $1300 - $5600.

3 Applications to ERTS Program

Both of the aforementioned alternatives could be applied to the ERTS program The Houston-Fearless system would require additional carrousels as time progressed It would be best if this could be avoided Image control devices are merely cartridge readers with a keyboard added One can locate the image desired by use of the keyboard It is not believed that this ability is necessary since a standard cartridge reader is almost as efficient. Also, the top quality image control systems cost about four times as much as a top quality cartridge reader.

D. INDIVIDUAL READERS

There are a wide variety of readers on the market today Microfiche, jacket, and aperture card readers are available for approximately $300, for a good quality reader Roll film and cartridge readers of good quality are available for approximately $1200

A cartridge reader provides the fastest retrieval speed of the above readers with the exception of an aperture card reader A roll film or cartridge system though requiring a more expensive viewer than other microforms would more than compensate for the differential in other areas of the operation

A cartridge reader equipped with an odometer would be virtually as good as an image control device and not as expensive Therefore, it is concluded that a cartridge reader is the best method of providing the browse capability in the NDPF.

E. CAMERAS

There are only two types that are feasible in the ERTS program A planetary camera and an optical printer While the optical printer is more expensive, it provides for a completely automated operation and can also be used as a duplicating device The need for a processor is also eliminated The planetary camera on the other hand offers an inexpensive approach to the problem at the cost of automation and resolution A planetary camera operation would involve the mounting of a roll of 70 mm film on a winding apparatus, positioning of the frame over the proper location on a light table, placing a celluloid mask over the frame to keep it flat, adjusting light levels as necessary, snapping the shutter, and moving on to the next frame to repeat the same process.

SECTION V

DESIGN OF SYSTEM

A. CONCLUSIONS AND RECOMMENDATIONS

The use of microfilm in the NDPF will provide a capability for a DSL Browse Facility which will have available to visiting users high quality representative images for all ERTS data.

It will also provide the capability to distribute these images as supplements to or in lieu of montage catalogs

Because images may be distributed at less than one tenth of a cent per image, microfilm represents an ideal quick reaction, rough screening mechanism.

The general availability of microfilm readers and the production inexpensive, convenient, and rapid-retrieval viewers make microfilm an ideal medium for use in user agency browse facilities

The use of microfilm will become increasingly popular in the next few years Its numerous applications as related to the ERTS mission strongly command its utilization

Since the original inputs to the microfilm process will be 70mm positive transparencies a reduction ratio of approximately 5X must be employed to obtain a 16mm microfilm record Other inputs could be utilized such as 9½ x 9½ inch or 70 mm positive prints. Table 1 details the additional cost in photographic materials in order to accommodate these other formats The costs are on yearly basis

Table 1
Additional Cost Per Year in Photographic Materials to Produce Positive Prints

	Loading	
Size	U S Only	Case B
9 x 9 inch	$1330	$54,600
70mm	$ 140	$ 5,750

Based on the data in Table 1 it has been concluded that the cost of producing everything in a 9 x 9 positive print format for microfilming is prohibitive. Two alternatives remain 70mm positive transparencies and prints With either of these the reduction ratio will be approximately 5X Rotary and step and repeat cameras cannot accommodate such a small reduction ratio without considerable modification. Therefore, the planetary camera and the optical printer are the two feasible alternatives for the production of the microfilm Both of these devices can produce 16mm microfilm from the 70mm positive transpariences. Therefore, the prospect of producing 70mm positive prints can be disregarded.

The planetary camera offers the most economical approach to the problem in terms of the initial investment The camera would be equipped with a winding assembly, a light table, a masking device, and an acetate covering to keep the image flat The operator would position each image over the aperture and then photograph it It is estimated that, assuming that the operator is a competent individual, approximately 90 images per hour could be recorded This would amount to approximately 700 images per day For the loading for the U.S only this would be more than adequate For Case B or any greater volume of data this would be inadequate This would result in a lag between the time when the 70 mm positives were received and their microfilming

The optical printer on the other hand is considerably more expensive However, it would easily handle all loading conditions In addition, it would eliminate the need for a microfilm processor since it contains one as an integral component. The optical printer could also be used for duplicating purposes

It is concluded that the best method of generating the 16 mm microfilm from the 70 mm positive transparencies is an optical printer The main reason for this conclusion are the higher resolution capability of the optical printer and the rapid turnaround time If satellite files at user agencies are developed, this device could easily provide high quality microfilm distribution copies of data within 24 hours of its receipt at the NDPF

Table 2 presents an evaluation of the various microform formats which have potential application to the ERTS program From this table it has been concluded that the optimal and most cost effective system for the NDPF browse file, is either a cartridge or roll film system Since cartridges are easier to index and retrieve information, it is concluded that a cartridge system will best suit the needs of the NDPF The following advantages are noted:

Table 2

Rating of Microforms

Factor	Roll	Cartridge	Aperature Card	Jacket	Microfiche
			Material		
Initial Cost	1	1	4	2	3
Storage Density	1	1	4	3	3
Ease of Distribution	2	2	2	1	1
Retrieval Speed	3	2	1	2	2
Preparation Cost Per Image	1	1	3	2	4
Duplication Cost Per Image	1	1	3	2	2
Preparation Time	1	1	4	3	4
Storage Space	2	2	2	1	1
Future Potential	2	2	2	4	1
Ease of Indexing	3	2	1	2	2

1 = Excellent

2 = Good

3 = Fair

4 = Poor

- Maintains File Integrity
- Economical to produce
- Easy to index
- Easy to label
- Can provide rapid retrieval speed
- Easy to duplicate
- Easy to file
- Can be used to produce any other microform
- Wide selection of related equipment readily available

Other microforms can be produced from the cartridge system should the need arise This is shown in Table 3. The roll film can also be utilized as a distribution media to satellite files

In order to maintain the highest resolution possible, a silver base microfilm must be used. This is a widely recognized fact which has been born out by experience

The viewing device will be a standard cartridge viewer with an odometer index. The image control capability is not believed to be necessary Chances are that the users would not in most cases have a particular image in mind that must be found in a time frame of 5 or 6 seconds

The information system will easily provide the retrieval parameters denoting the cartridge and the location on the film where the data could be found Within seconds, the film can be positioned to within 10 images of the desired image In addition, the cartridges eliminate handling of the film and provide rapid and automatic threading of the viewer.

Table 3

Can be Produced From

Microform	Roll Film	Jacket	Microfiche	Aperture Card
Roll Film	X			
Jacket	X	X		
Microfiche	X	X	X	
Aperture Card	X	X	X	X

It is recommeded that the microfilm system of the NDPF will consist of the following equipment

- Optical Printer - This unit will be used to optically reduce the 70mm positive transparency roll film to the 16mm microfilm.

- Roll Contact Printer - This unit will be utilized to duplicate the 16mm microfilm, from the optical printer, for distribution to users This unit provides a more economical mode of duplication than the optical printer.

- Microfilm Processor - This unit will be utilized to process the 16mm roll film output from the contact printer. It will automatically develop, fix, wash and dry a 100 ft roll of microfilm in minutes

- Microfilm Editor - This unit will be used to edit microfilm to provide rolls organized by parameters other than time.

- Cartridge Loader - This unit will be used to load 16mm roll film into cartridges for use in the NDPF browse facility

- Splicer - This unit will be used in conjunction with the editing function to generate rolls of microfilm organized by parameters other than time

- Microfilm Readers - These units will provide the browse capability in the User Services function They will utilize 16mm microfilm cartridges to provide rapid retrieval of data

- Carrousel File - This will provide storage for a year's data in microfilm cartridges It will be located on the same table as the readers

APPENDIX 11 F

LINE SCAN SYSTEMS FREQUENCY SPACE ANALYSIS

11 F.1 ASSUMPTIONS

The following analysis encompasses a wide range of system elements, therefore, some limitations must be placed on the system to be studied. There are two important assumptions

1. The analysis is confined to linear systems

2 Only repetitive, transverse scanning systems are considered

These assumptions naturally limit the generality of the results, but the results do provide a convenient procedure for estimating system performance

11 F 2 INTRODUCTION

The goal of this analysis is to determine the spatial frequency response requirements of the final imaging system as a function of the sensing system The information is initially represented as a two-dimensional power distribution in the spatial domain (the object scene) This information is transformed to a time-varying analog voltage by the sensing system (e g , multispectral scanner or RBV). The analog voltage follows one of two paths in the ERTS system, depending upon the sensor, and can be summarized by the following table (assuming direct transmission)

Sensor	Data Handling
RBV	Direct transmission - storage on magnetic tape
MSS	Analog/digital conversion - direct transmission,
	storage on magnetic tape

Now the information can be formatted for either computer processing of recording onto film or both Figure 11 F-1 summarizes the above process and identifies the associated symbols and coordinate systems that will be used in the following analysis

The analysis is directed toward describing these transformations, and frequency space analysis is a convenient procedure to account for all operations on the information Fourier Transform techniques are used to transform the information from the spatial or temporal domain to the frequency domain. The spatial frequencies differ only by a scale factor-- the scanning spot's linear velocity -- from their equivalent temporal frequencies

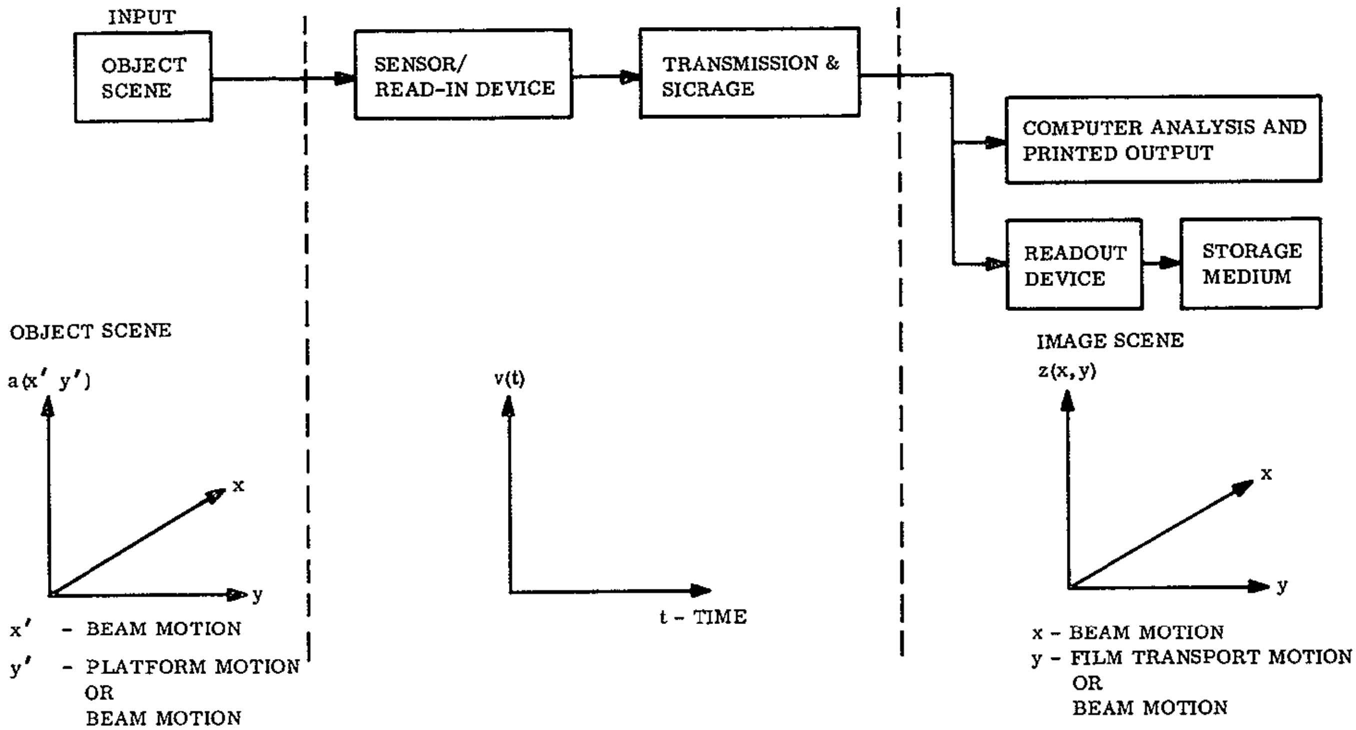


Figure 11.F-1. Coordinate Systems

11.F.3 ANALYSIS

Referring again to Figure 11.F-1 and assuming the final product is an image on film the integral equation relating the output (image on film) to the input (object scene) is

$$i(x,y) = \iint_{-\infty}^{\infty} a' \left[(x - x'),\ (y - y') \right] o\,(x',\ y')\, dx'dy' \qquad (11\ F\text{-}1)$$

where

$o(x', y')$ = two-dimensional energy distribution of the object scene

$i(x, y)$ = two-dimensional density distribution of the image scene on film

The term $a'(x, y)$ is the system spatial impulse response function, and the Fourier Transform of $a'(x, y)$ is the system spatial frequency response function In optical systems $a'(x, y)$ is referred to as the point spread function (i e , a spatial impulse function will spread out as a function of a' (x, y) and acts as a low pass filter on the input signal $o(x'y')$ Thus, the output signal $i(x, y)$ is just the input signal with the high frequencies attenuated.

Equation 11.F-1 expresses the total transformation, but line scanning systems introduce an intermediate step: the transformation to a time-varying electrical signal. Within limitations, the system is symmetrical about this electrical signal, i.e., the process of generating the electrical signal is just the reverse of using this signal to generate the final image. The analysis, therefore, need only consider the generation of the electrical signal and the results extended to the remainder of the system.

Equation 11.F-1 can now be re-written as Equation 11.F-2 to show the intermediate step: the generation of the time-varying electrical signal.

$$v(t) = \iint_{-\infty}^{\infty} a'(x' - vt,\ y')\ o\ (x',\ y')\ dx'dy' \qquad (11.F\text{-}2)$$

where $v(t)$ = time-varying electrical signal

$a'(x', y')$ = aperture response function - detector projected onto the object (scanning) plane

$o(x', y')$ = two-dimensional power distribution of the object scene

The scanning direction has been arbitrarily designated as the x-axis. The y-axis represents the direction of the discrete lines or samples which are generated by the aircraft of film motion. The scanning aperture response function, $a'(x', y')$, is actually composed of two identifiable response functions (spatial and temporal), and, in conjunction, act as a low-pass filter on $o(x',y')$ to generate the time-varying signal, $v(t)$.

The relationship between the scanning aperture response and the input-output signals can be determined by looking at the Fourier Transform (Equation 11.F-3) of Equation 11.F-2.

$$\left|V(f)\right| = \frac{1}{v} \left|A'(k)\right| \quad \left|O(k)\right| \qquad (11.F\text{-}3)$$

Equation 11.F-3 says that the magnitude of the electrical signal's frequency spectrum is equal to the product of the aperture's frequency response function, $A'(k)$, and the input signal's frequency spectrum, $\left|O(k)\right|$. The term $(1/v)$ is a constant of proportionality and is the reciprocal of the scanning aperture's linear velocity on the object plane. Thus by analyzing the system parameters that determine the aperture's frequency response function, the output signal spectrum, assuming a general input signal, can be described.

The aperture frequency response function can now be represented as the product of two terms.

$$\left|A'(k)\right| = \left|A(k)\right| \quad \left|H(kv)\right| \qquad (11.F\text{-}4)$$

or with $f = vk$

$$\left| A'(f/v) \right| = \left| A(f/v) \right| \cdot \left| H(f) \right| \qquad (11.F\text{-}5)$$

where

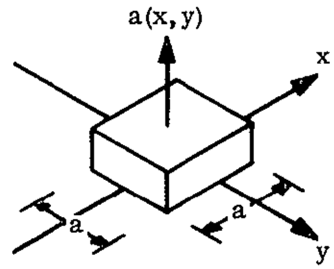
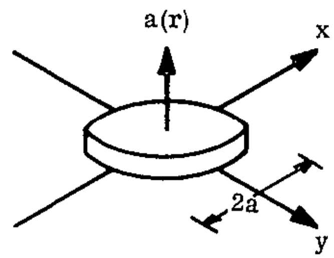
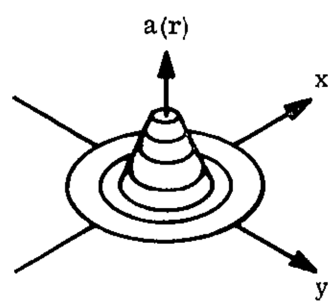
$\left\| A(k) \right\|$	=	absolute value of the aperture's spatial frequency response function
$\left\| H(f) \right\|$	=	absolute value of the aperture's temporal frequency response function
f	=	temporal frequency (Hz)
k	=	spatial frequency (cycles per linear dimension, e g , mm)
v	=	aperture's linear scanning velocity (mm/second).

Equation 11.F-4 presents the terms as functions of the spatial frequency, k, and Equation 11 F-5 is the same equation translated to the temporal frequency space The first term, $\left| A(k) \right|$, is a function only of the aperture's projected area onto the scanning plane The second term, $\left| H(f) \right|$, is a function only of the aperture's electrical characteristics The spatial frequency response function $\left| A(k) \right|$, is generally referred to as the modulation transfer function (MTF). Figure 11 F-2 summarizes the point spread functions and MTF's for three important apertures

As can be seen, the MTF for each aperture is a function of only one physical parameter of the aperture

1. Square aperture - the length of one side (a)
2. Circular aperture - the radius of the circle (a)
3. Gaussian aperture - the equivalent width ($2.51\,\sigma = \sqrt{2\pi}\,\sigma$)

The expressions given in Figure 11 F-2 are shown as absolute values because the frequency spectrum eventually goes negative for the first two apertures The phenomenon of the spectrum going negative is called "spurious resolution " In realizable systems the frequency at which this occurs represents the system's limiting resolution The limiting resolution is actually less because of system noise and errors. Finally, the equations for each aperture's MTF are normalized to their value at zero frequency, which facilitates the frequency space analysis

POINT SPREAD FUNCTION $a(x,y)$		MODULATION TRANSFER FUNCTION $A(k)$
$a(x,y) = \pi\left(\frac{x}{a}, \frac{y}{a}\right)$ $\pi\left(\frac{x}{a}, \frac{y}{a}\right) = A_s \quad \left\lvert\frac{x}{a}\right\rvert \le \frac{1}{2}, \left\lvert\frac{y}{a}\right\rvert \le \frac{1}{2}$ $= 0 \quad \left\lvert\frac{x}{a}\right\rvert > \frac{1}{2}, \left\lvert\frac{y}{a}\right\rvert > \frac{1}{2}$		$\lvert A(k)\rvert = (A_s a) \left\lvert\frac{\text{SIN}(\pi ka)}{(\pi ka)}\right\rvert$ $A(c) = A_s a$
$a(x,y) = a(r) = \pi\left(\frac{r}{2a}\right)$ $\pi\left(\frac{r}{2a}\right) = A_c \quad \left\lvert\frac{r}{2a}\right\rvert \le \frac{1}{2}$ $= 0 \quad \left\lvert\frac{r}{2a}\right\rvert > \frac{1}{2}$		$\lvert A(k)\rvert = (A_c \pi a^2) - 2 \left\lvert\frac{J_1(2\pi ka)}{(2\pi ka)}\right\rvert$ $A(a) = A_c \pi a^2$
$a(x,y) = o(r)$ $a(r) = A_c \cdot \epsilon^{-\frac{1}{2}\left(\frac{r}{J}\right)^2}$		$A(k) = \lvert A(k)\rvert$ $A(k) = (A_c 2\pi\sigma^2) \cdot \epsilon^{-2(\pi K\sigma)^2}$ $A(0) = A_c 2\pi\sigma 2$

*TRANSFORMED TO LINE DIMENSION

Figure 11.F-2 Point Spread Functions and MTF's for Three Apertures

Figures 11 F-3, 4, and 5 are normalized frequency (ν) plots for each aperture listed in Figure 11 F-2. The note on each figure explains the procedure for converting the frequency axis to either spatial or electrical frequencies. Figure 11 F-6 compares the three apertures under the following conditions

1 Normalized frequency ($\nu = k \cdot a$)

2 The square aperture length ($a = 2\ 51\sigma$)

3. The circular aperture diameter ($2a = 2\ 51\sigma$)

4 The value $2\ 51\sigma$ is the equivalent width of the Gaussian aperture (the width of a rectangular pulse of the same maximum amplitude as the Gaussian function with the same area as the Gaussian function)

This comparison is very important because each aperture has the same equivalent width, thus, differences in the frequency attenuation become obvious

The second part of the aperture frequency response function, the temporal response, cannot be summarized as neatly as the aperture response. The electrical frequency response of each scanning aperture (infrared detector, electron beam, laser beam, etc.) must be determined independently. For purposes of demonstration, however, the assumption will be made that the electrical response can be modeled by an ordinary, linear first - order differential equation This assumption is very close to experimental results for a broad class of scanning apertures

An ordinary, linear first-order differential equation can be characterized by a single parameter T In electrical systems, T is known as the time constant of the system, and this terminology is generally used in specifying an aperture's temporal response. Figure 11. F-7 is a representative temporal frequency response ($|H(f)|$) for a first-order system The curve is normalized for both amplitude and frequency The absolute electrical frequency scale can be determined by dividing the normalized frequency by T

When the curves shown in Figures 11 F-3, 4, and 5 are converted to the electrical frequency from spatial frequencies, they represent the electrical frequencies that the detector (or aperture) must be capable of transmitting without attenuation. Thus, the aperture "time constant", T, must be compatible with the signals being generated. Naturall all the electronics following (or preceding) the aperture must also have bandwidths capable of transmitting the information If the aperture time constant is exceeded, then the information will be degraded, and the final imagery will exhibit a loss of spatial resolution This effect can be corrected only by reducing the bandwidth of the input signal derived from the aperture by reducing the scan rate A reduction of the scan rate implies a direct reduction of the system throughput capability

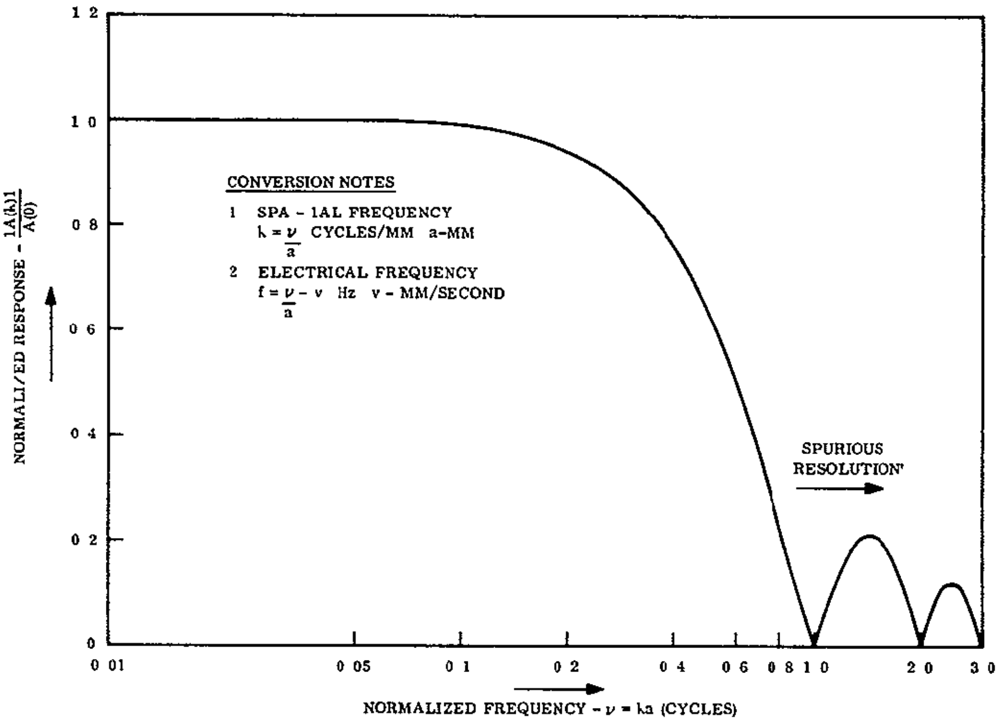


Figure 11 F-3. Square Aperture

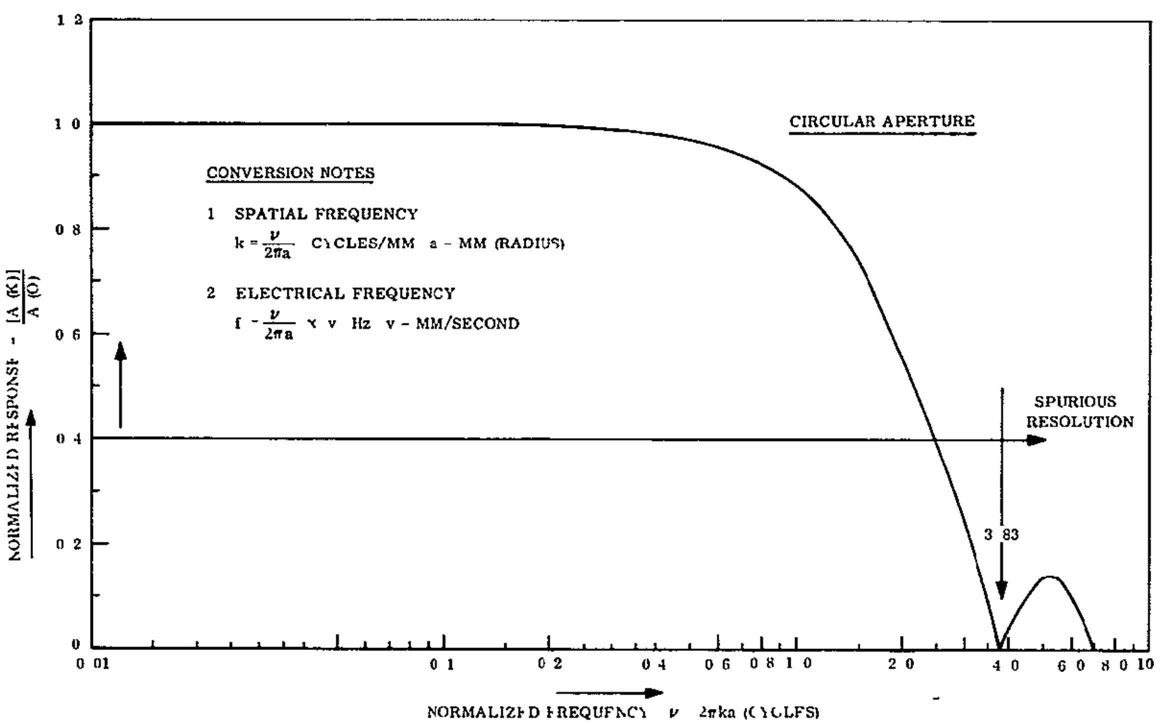


Figure 11. F-4 Circular Aperture

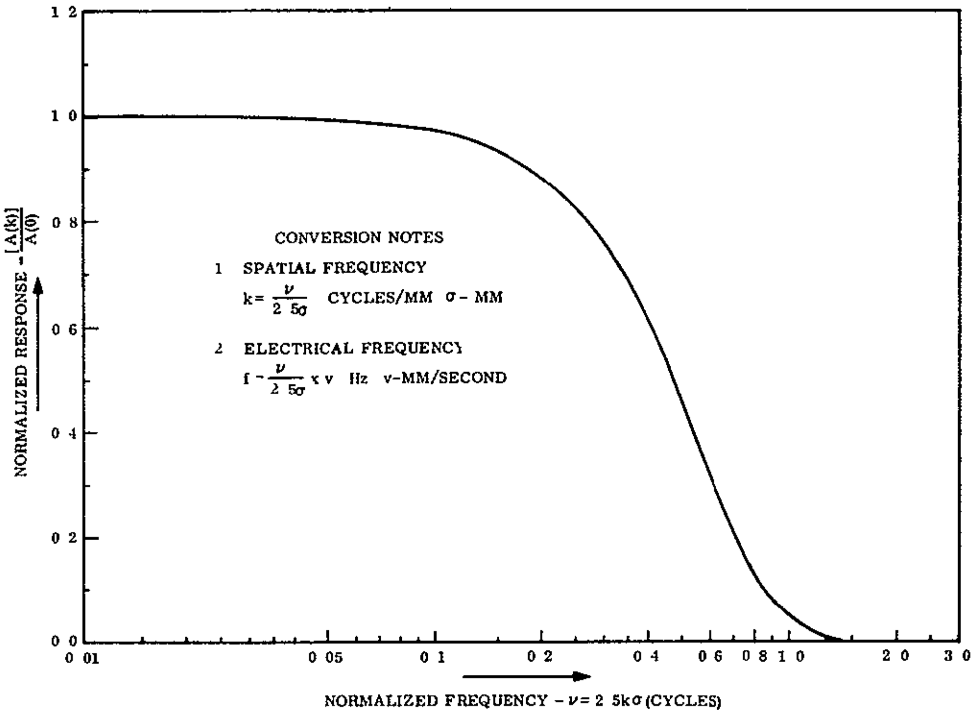


Figure 11 F-5. Gaussian Aperture

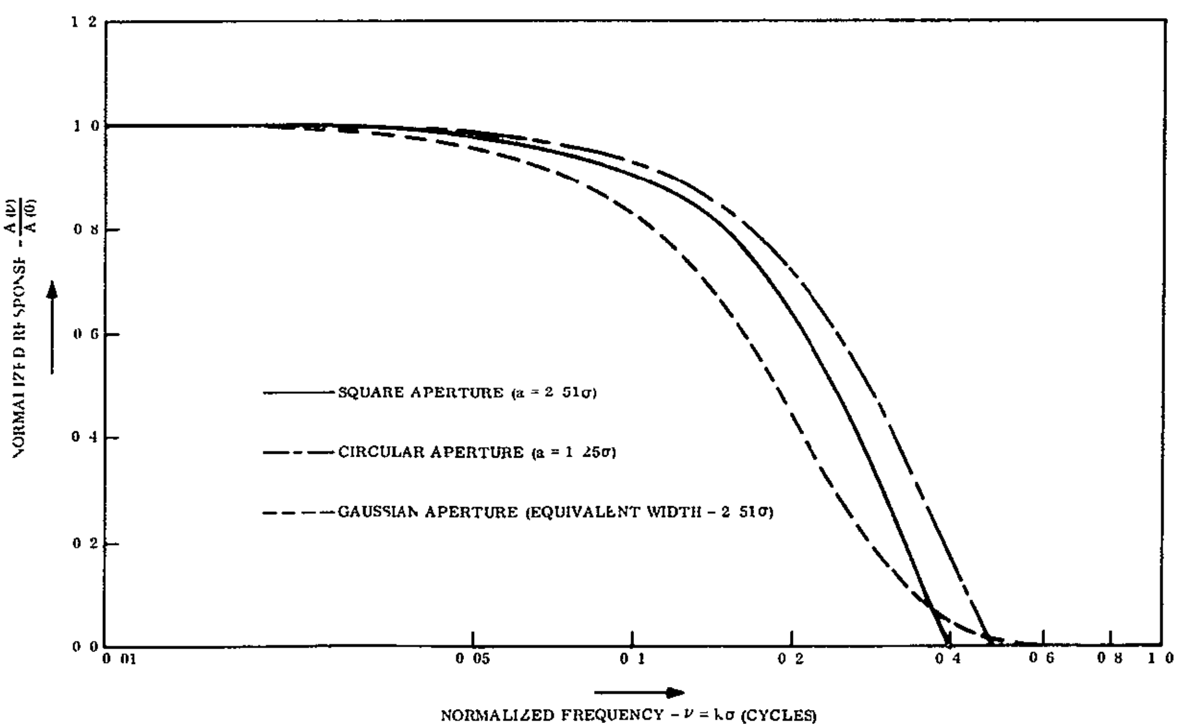


Figure 11 F-6 Aperture Comparison

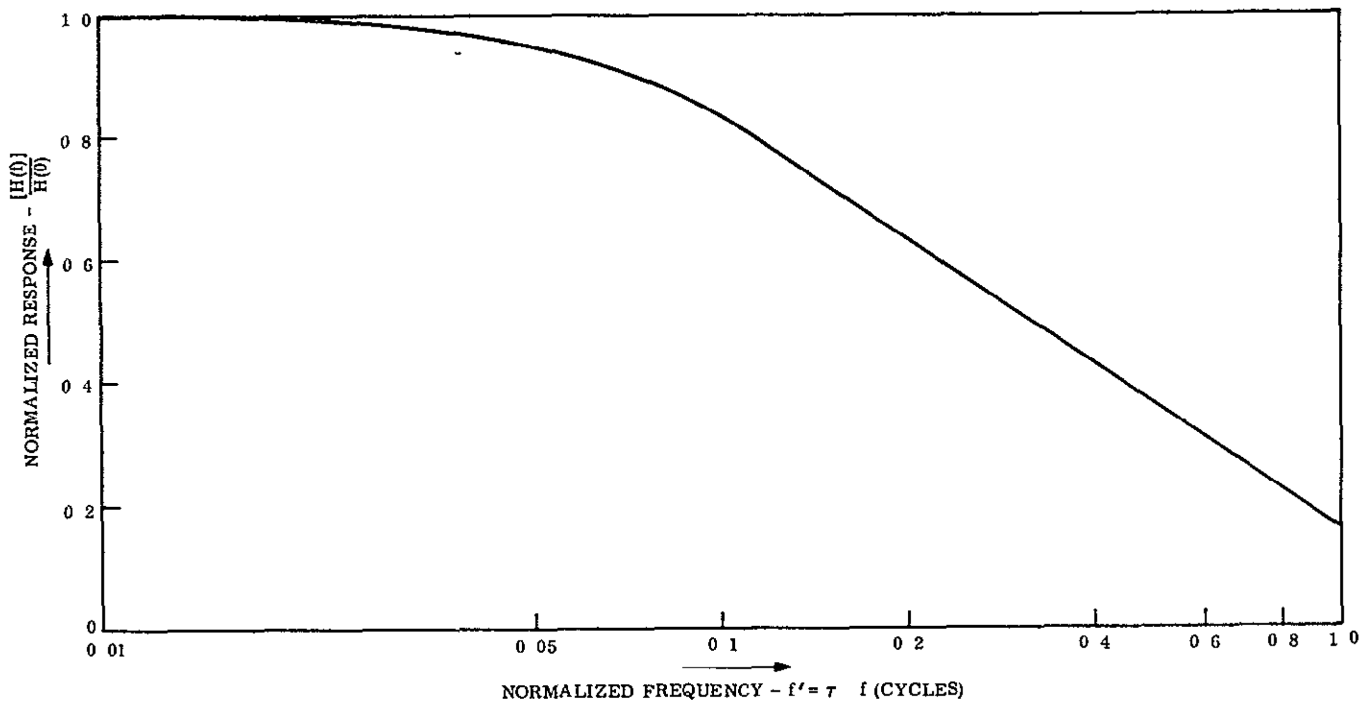


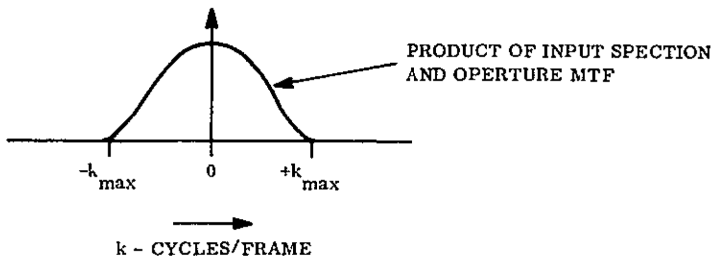
Figure 11.F-7 Temporal Frequency Response

In order to reproduce the signal generated by scanning, the recording scanning aperture must minimize the attenuation of the signal This required that the aperture's response be essentially flat (i e., greater than 90 percent) over the bandwidth of the input signal Because the general geometry of the aperture is known, its required equivalent width can be determined The reproduction of the signal in the vertical direction is not as straightforward and is discussed in the following paragraphs.

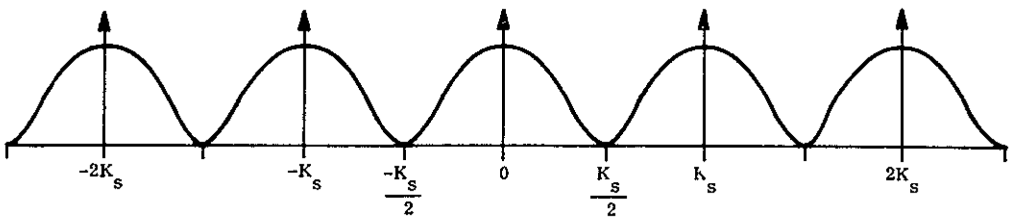
The scanning operation is equivalent to sampling in the vertical direction with the aperture representing a pre-sampling filter. If the aperture does not sufficiently low-pass filter the input signal, then there is the possibility of aliasing in the vertical direction The following analysis assumes that (1) the signal is properly conditioned before sampling and (2) the possibility of aliasing is eliminated Figure 11 F-8 summarizes the input signal, the sampled input signal to the film recorder, and the critical parameters.

The reconstruction of the data into imagery conventionally involves the modulation of a periodic raster with the data signal, this process must take into consideration the spatial bandwidth of the input information and the undesirable raster effects Because of the periodic nature of the raster, it is possible to reproduce the entire sampled spectrum Obviously, only the original spectrum need be reproduced. The higher-order components can be minimized or greatly attenuated by the proper selection of the aperture superimposed on the raster. The following paragraphs discuss the tradeoffs involved with the raster technique

(a) INPUT SPECTRUM TO BE SAMPLED



(b) SAMPLED SPECTRUM



(c) DEFINITIONS

(i) K_s - SAMPLING FREQUENCY $K_s = n_v \frac{\text{CYCLES}}{\text{FRAME}}$

(ii) n_y - NUMBER OF SCAN LINES (i e SAMPLES) PER FRAME

(iii) k_{max} - LIMITING INPUT SPATIAL FREQUENCY

$k_{max} \leq \frac{K_s}{2}$ (FOR NO ALIASING ERRORS)

(iv) IF L IS THE VERTICAL FRAME DIMENSION (e g mm), THEN $K_s - n_v \frac{\text{CYCLES}}{\text{FRAME}} \cdot \frac{1}{L}$

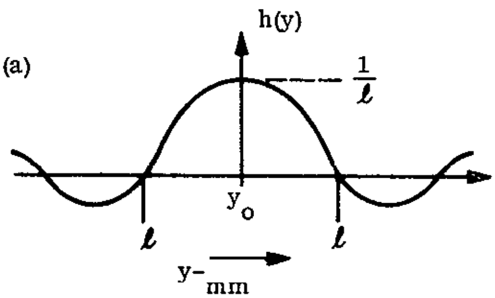
$\frac{\text{FRAME}}{\text{MM}} = \frac{n_v}{L} \frac{\text{CYCLES}}{\text{MM}}$ LET $\frac{L}{n_v} = \ell$ mm (THE DISTANCE BETWEEN SAMPLES)

Figure 11 F-8. Summary of Vertical Input Signal

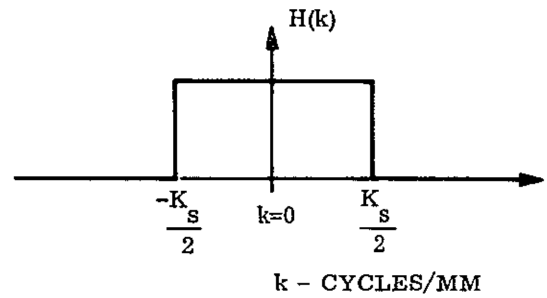
It is instructive to first examine ideal reconstruction The aperture impulse response and MTF are summarized in Figure 11 F-9(a) This raster will pass all information up to $\frac{K_S}{2}$ $\left(= \frac{1}{2} \frac{A_V}{L} = \frac{\ell}{2}\right.$ cycles/mm) with attenuation, and then attenuate all other signals. Any presence of the raster will also disappear, leaving only the signal The raster consists of a series of $\frac{\sin (\pi y/\ell)}{(\pi y/\ell)}$ pulses placed ℓ mm apart (i e, the point at which the previous pulse is zero If each pulse has the same peak amplitude (i e , dc signal), then the sum of all the $\frac{\sin (\pi y/\ell)}{(\pi y/\ell)}$ pulses will be constant Thus the dc signal has been perfectly reconstructed with no raster effects This intuitive example can be extended to spatially varying signals, up to a frequency of $K_S/2$, and it will be seen that the same results hold This technique is impractical, however, because the required pulse, $\frac{\sin (\pi y/\ell)}{(\pi y/\ell)}$, can only be obtained with an infinite time delay, thus, an alternate approach must be sought

APERTURE IMPULSE RESPONSE	APERTURE MTF

(a)

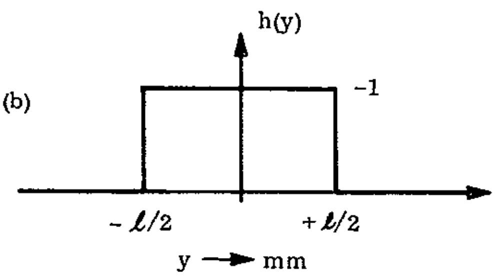


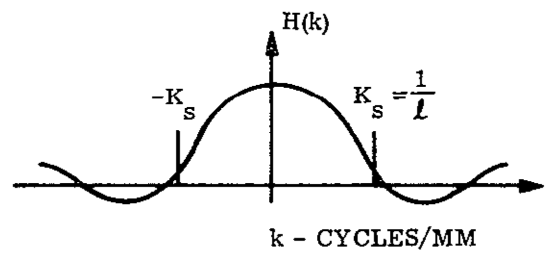
$$h(y) = \left(\frac{1}{\ell}\right) \frac{\sin\ (\pi y/\ell)}{(\pi y/\ell)}$$



$$K_s = \frac{1}{\ell}$$

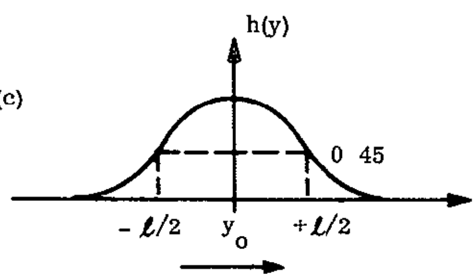
(b)





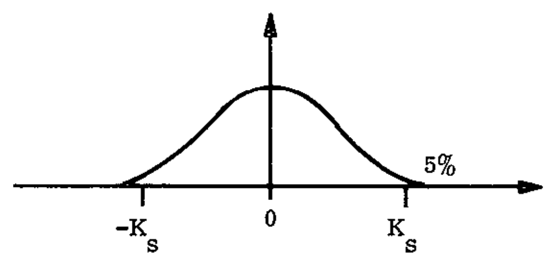
$$H(k) = \left(\frac{1}{K_s}\right) \frac{\mathrm{Sin}\ (\pi k/ks)}{(\pi k/Ks)}$$

(c)



$\ell = 2\ 5\sigma \quad \ell/2 = 1\ 25\sigma$

$$h(y) = e^{-\frac{1}{2}\left(y/\sigma\right)^2}$$



2.5τ k - CYCLES/MM

$$H(k) = \sigma\sqrt{2\pi}\ \ \epsilon^{-2\,(\pi k \tau)^2}$$

If $H(k) = 0\ 05$ at K_s, then

$2\ 5\,\sigma\, K_s = 1$ Thus, $\sigma = \frac{0\ 4}{K_s} = 0\ 4\,\ell$,

or $\ell = 2\ 5\,\sigma$, where $\ell = \frac{L}{n_v}$

Figure 11. F-9. Summary of Raster Apertures

The simpliest reconstruction technique is zero-order interpolation. See Figure 11. F-9(b) for the summary of the aperture characteristics It is obvious that no raster errors will be present for constant signals with the square pulses placed 1 mm apart Notice, however, that the aperture does not have a uniform response over a bandwidth of $K_S/2$, and that the bandpass of the aperture theoretically extends out to infinity If the input bandwidth is limited to $K_S/2$, then the only error is from attenuation to the signal out to a frequency of $K_S/2$ If the input bandwidth exceeds $K_S/2$, (i e., under sampled) then an additional error from aliasing will appear. This error can only be minimized (i e., in the mean-squared sense) by attenuating the signal more rapidly beyond a frequency of $K_S/2$ This is one serious limitation of this approach, the following are two others

1. Any gaps between raster lines caused by scanning serrors will be very noticeable

2. A square aperture is difficult to make in most applications

The best compromise appears to be with the next approach

Most recording systems, when taken in total (i e., writing beam, film, development, etc) exhibit a Gaussian aperture characteristic. The Gaussian aperture, although it never results in perfect reconstruction*, represents a good compromise between ideal reconstruction and ease of implementation Figure 11 F-9(c) summarizes the Gaussian aperture characteristics The problem is to determine the value of the Gaussian aperture parameter, $\bar{\sigma}$. The best compromise appears to be the following The spatial frequency response of the Gaussian aperture must be approximately zero (i.e , about 50 percent) at K_S This will result in attenuating the input signal out to $K_S/2$, but will minimize the presence of the raster The value for σ is worked out in Figure 11 F-9(c), and it is equal to 0 4 times the distance between scan line centers, $\ell = \frac{L}{N_V}$ mm Again, aliasing will not occur only if the signal is limited to a maximum frequency of $K_S/2$

It is interesting to compare these results with those of other investigators Otto Schade[1] converted all MTF's to equivalent passbands (N_e), and his results indicated that a good compromise was for $N_e = \frac{0\ 7N_V}{L} = \frac{0\ 7}{\ell}$. The equivalent passband for a Gaussian aperture is

$$N_e = \frac{1}{2\sqrt{\pi}\,\sigma}.$$

Substituting our value for σ ($\sigma = \ 4\ell = \frac{0\ 4L}{N_v}$ into the equation for N_e

* meaning flat frequency response out to $K_S/2$, and no raster effects

1 "Image Gradation, Graininess and Sharpness in Television and Motion Picture Systems, Part 3 - Train Structure of Television Images," Journal of the SMPTE, August 1953, Vol 61.

which is

$$N_e = \frac{1}{2\sqrt{\pi\sigma}} = \frac{1}{2\sqrt{\pi \frac{L\,4}{N_v}}} = \frac{2\ 5\ N_v}{2\sqrt{\pi\ L}}$$

$$= 0.71\ \frac{N_v}{L} = 71\ell^{-1}$$

a value of 0 71 $\frac{N_v}{L}$ is obtained for N_e, a very good correlation with Schade's value By definition of N_e, the effective area of the aperture can be obtained By definition

$$A_e = \frac{1}{N_e^{\,2}} \quad \text{or } N_e = \frac{1}{\sqrt{A_e}} = \frac{1}{d_e}$$

where d_e is the equivalent aperture width in mm Substituting our above value for N_e

$$N_e = \frac{71}{\ell} = \frac{1}{d_e} \text{ or } \frac{\ell}{d_e} = 0.71$$

This last ratio, ℓ/d_e, of the scan line spacing (ℓ) to the equivalent aperture width (d_e) is generally referred to as the Kell Factor [2] The value of 0 64 is one that has been empirically obtained (by Kell and others) as being a limiting value before raster effects become too pronounced and destroy information

Thus, a good compromise between minimizing raster effects and optimizing the spatial bandwidth of the raster has been derived

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2 R D Kell, "A Determination of Optimum Number of Lines in a television System," RCA Review, Vol 5, pp 8-30, 1940

APPENDIX 11 G

PRECISION POSITIONING EXPERIMENT

11 G 1 GENERAL

This experiment was performed to furnish confirming data on the capabilities of precision positioning of space images using ground control points selected from maps

The space images used were 70 mm Hasselblad multispectral photographs taken during the Apollo 9 flight for the S065 experiment The characteristics of these images have been exhaustively described in recent literature, they are considered by most users to be the closest approximations presently available to ERTS images, both in spectral band and in ground resolution

The maps used in the experiment were standard 1/24, 000, 1/62, 500, and 1/250, 000 topographic maps published by the U S Geological Survey These maps comply with National Map Accuracy Standards

The experiment answered several questions of concern for precision processing of ERTS images

1 Can map suitable for positioning be consistently identified on ERTS images?

2 Will the positional accuracy match that predicted by analysis?

3 What kinds of map features are easiest to identify on space images?

4 Does the 1/250, 000 topographic map have enough detail to permit its use as the standard source for ground control points?

The answers to these questions will be developed in the course of this appendix

11 G 2 MATERIALS

Four S065 exposures were selected for the experiment Nimbus 3741, 3799, 3803, and 3810, corresponding to the areas near Vicksburg, Mississippi, Salton Sea, California, Arizona-New Mexico border and Phoenix, Arizona The red spectral band was chosen for general sharpness in these areas Later experience confirmed this choice, the red band appears to be the most suitable for most areas, the infrared band is second, and the green least valuable If the ground resolution were somewhat higher, the utility of the green band would be greatly increased, however

The maps used to select control points were ordered from open stock at the Geological Survey Compilation dates ranged from the 1890's to 1967 All maps were printed on standard map paper Geographic reference marks were printed at intervals of 2'30" on the 1/24, 000 scale, 5'00" on the 1/62, 500 scale, and 15'00" on the 1/250, 000 scale Except for a few of the oldest maps, all were in color, brown for relief (contours), green for vegetation blue for drainage, black and red for culture, and purple for interim revision overprint

The photographs and selected images are shown in Figures 11 G-1 through 11 G-4 Figure 11 G-5 shows the appearance of sample control points on the source maps

11 G 3 CONTROL
Table 11 G-1 shows the number of control points selected for the four photographs, the map scales from which the points were selected, and the number of points later rejected because of high residuals A total of 8 percent of the points initially chosen were rejected This is a larger percentage than would occur in a production system, some marginal points were chosen intentionally to get a better estimate of the identification errors to expect, some points showed the effects of blunders in the manual process used to record image and map coordinates Rejection rate in a production system with automatic coordinate recording and better-experienced point selection is expected to be one to two percent

Table 11 G-1 Control Points and Map Source

Photograph	Total Number of Control Points	Map Scale User			Control Points Rejected		
		1/250 000	1/62,500	1/24,000	1/2500 000	1/62,500	1/24 000
Arizona - New Mexico	21	21	0	0	0	--	--
Phoenix	41	12	28	1	0	1	1
Salton Sea	16	0	16	0	--	2	--
Vicksburg	63	8	55	0	2	4	--

Table 11 G-2 shows the types of features selected as control points A somewhat greater number of cultural features was used for the Vicksburg photo than would normally be the case, mostly in an effort to test the ease in identifying the intersections of gravel roads on the image

11.G 4 EXPERIMENTAL PROCEDURE
The first spatial resections were performed for the four images using an assumed focal length of 80 mm, the nominal focal length of the Hasselblad camera for the S065 experiment An additional assumption was that the principal point of the image (the point where the optical axis pierces the image plane and the origin of the x, y image coordinate system) was in the geometric center of the frame, as defined by the three visible corners A different picture corner is obscured for each of the four S065 cameras, this is the lower left or southwest corner for the red spectral band No other assumptions were made concerning the internal geometry of the photographs

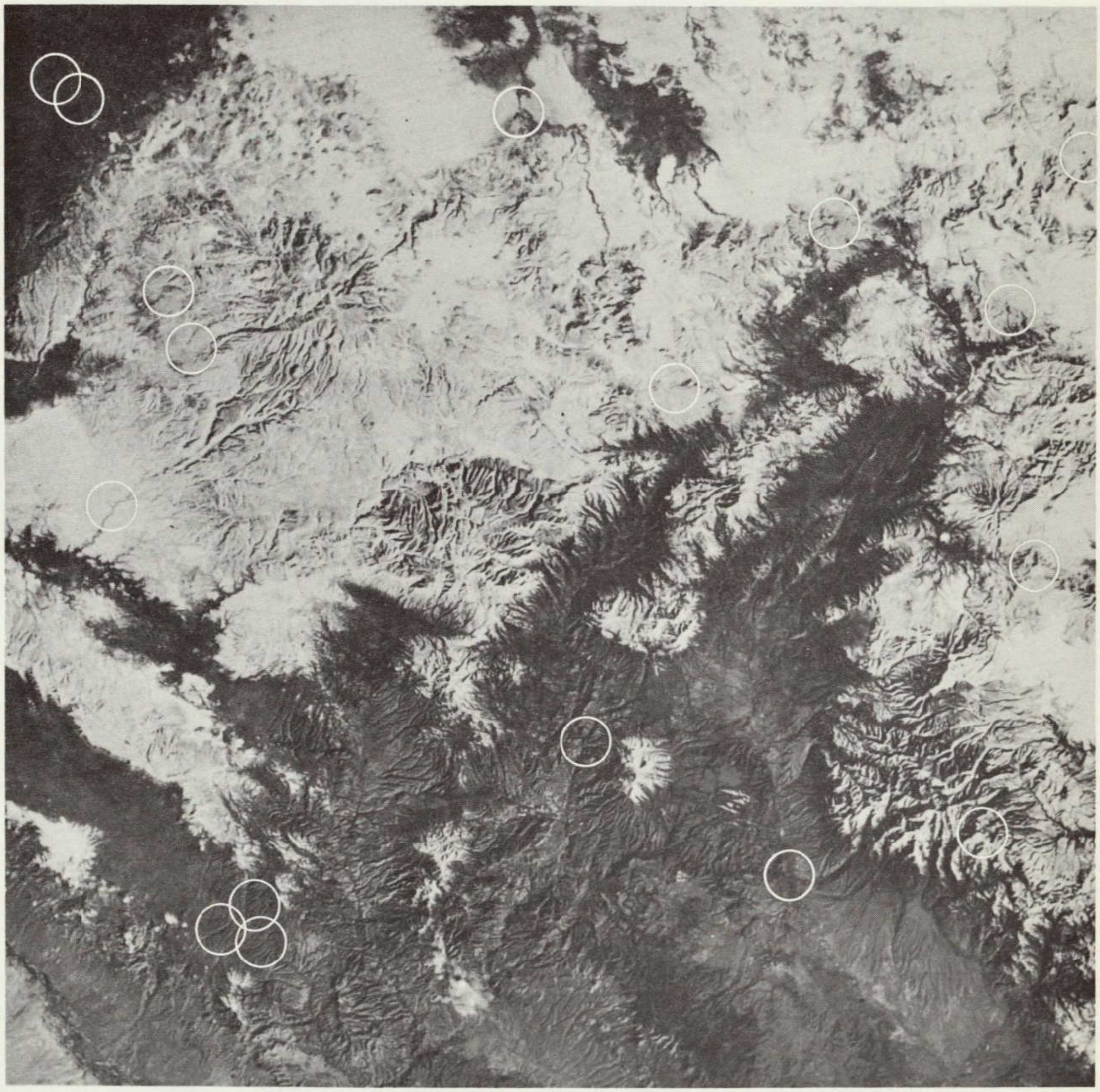


Figure 11. G-1. Arizona-New Mexico Photo with Control Points

Figure 11. G-2. Phoenix Photo with Control Points

Figure 11.G-3. Salton Sea Photo with Control Points

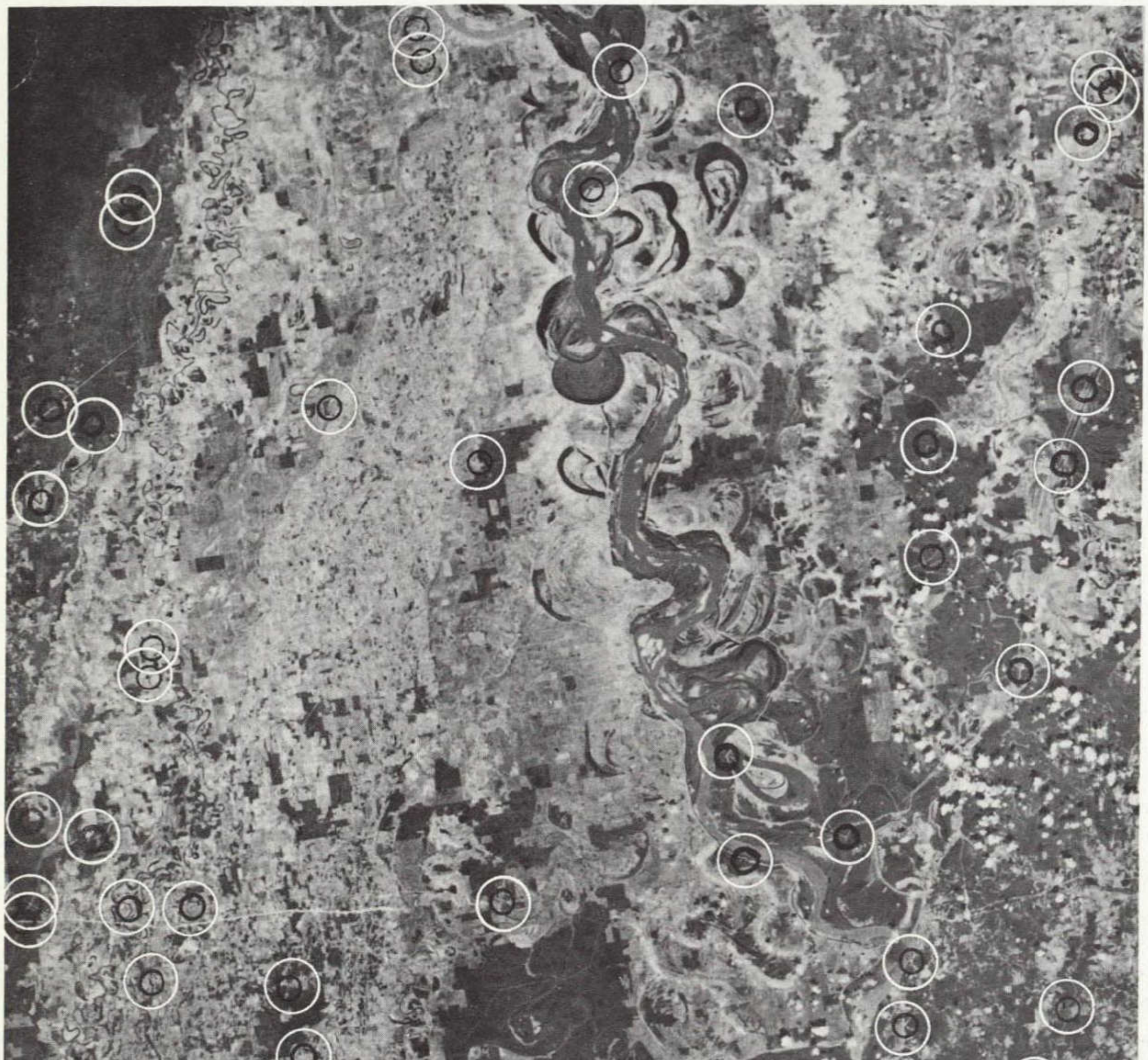
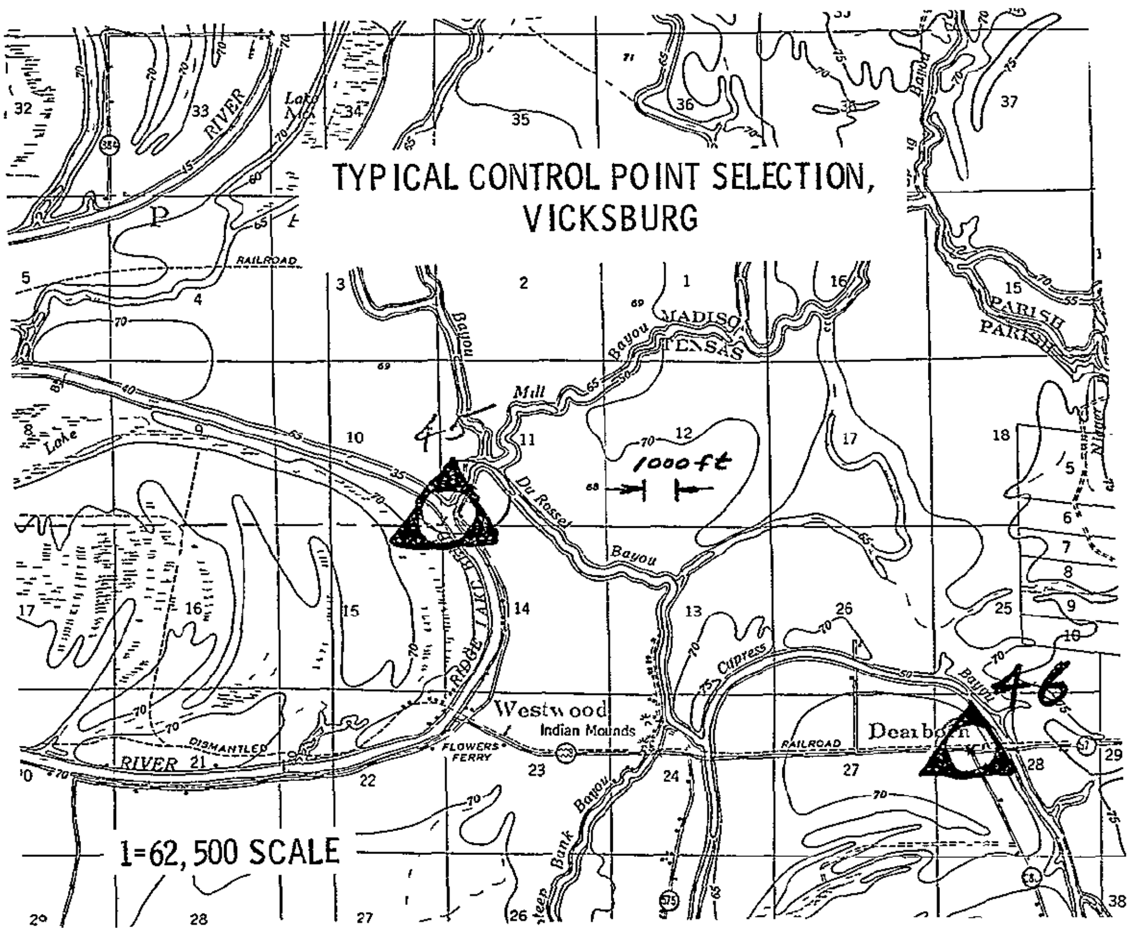


Figure 11. G-4. Vicksburg Photo with Control Points



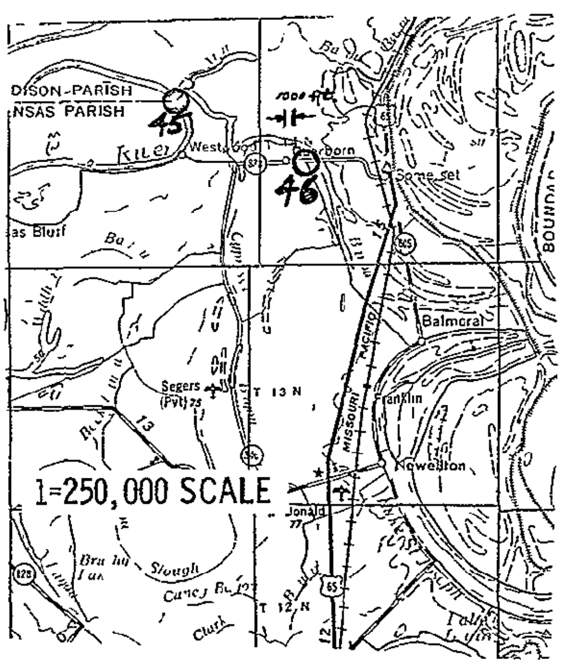


Figure 11 G-5 Typical Control Point Selection, Vicksburg

After the initial least-squares spatial resections, the control points showed residual standard errors for the four images of 885, 695, 640, and 690 feet in the same order used in Table A-1 At the scale of the photographs these errors would be considered unacceptably large Analysis of the residuals showed a systematic differential scale error indicating the effects of systematic film shrinkage difference in the x and y directions

The spatial resections were repeated, this time permitting film shrinkage in the y direction as an additional unknown in the resection This meant that instead of six unknowns (pitch, roll, yaw, X, Y, and Z) for a photograph, there were seven unknowns With the incorporation of a y-shrinkage factor, the residuals standard errors decreased to 780, 695, 610, and 665 feet At the scale of photographs, these errors correspond to 0 084, 0 073, 0 064, and 0 084 mm The results were not much improved numerically However, the use of the y scale factor made much more evident the main error cause Figure 11 G-6 shows a composite plot of the control-point residuals for the four exposures The radial character of the residuals is striking, and formed the basis for the next step in the experiment

From Figure 11 G-6 the radial component of each control-point residual was scaled off and plotted against the radial distance of the control-point image from the photo center This plot is shown in Figure 11 G-7 The systematic character of the radial components is striking From the residuals plotted in Figure 11 G-7, an empirical radial distortion curve was calculated that best fit the residuals in a least-squares sense This curve is shown superimposed on the residuals in Figure 11 G-7 Readers familiar with lens distortion patterns will recognize the similarity of this curve - allowing for the tipping of the curve caused by the least squares spatial resection - to that of the Zeiss Planar lens used in the S065 Hasselblad camera

This part of the experiment illustrates the power of control-point positioning In addition to positioning the images, control points permit additional unknown systematic errors in the image geometry to be detected

The spatial resections then were performed a third time, this time adjusting the image coordinates with the empirical radial distortion curve derived in Figure 11 G-7 Determination of a y-shrinkage factor again was made as a part of the spatial resection This time the residual standard errors decreased to 420, 400, 315, and 318 feet on the earth At the scale of the photographs these errors correspond to 0 045, 0 042, 0 033, and 0 040 mm These values are more nearly in line with those expected for the positioning accuracy

Figure 11 G-8 shows a plot of the composite residuals for the four photographs No systematic radial trend of the errors is apparent, and when a radial-component plot was prepared (Figure 11 G-9) no radial systematism was seen However, there appear to be some other systematic local effects These are not surprising As stressed earlier, the Hasselblad camera is not of metric quality It has no mechanism for flattening the film in the image plane, mandatory for photogrammetric work As a result, the film when exposed, has a wavy uneven surface instead of being truly a plane Some of this waviness is repeatable from one frame to the next, largely as a result of camera defects However, a large part of the film behavior is random from one exposure to the next These uncertainties will not be a problem for the precision processing of the ERTS images, nor indeed for any imaging device that is properly designed for metric use However, they may make the results achieved from the spatial resection appear too large to those familiar with photogrammetric analysis When the internal geometric errors of the camera are considered, standard errors of 300 to 400 feet must be considered as quite adequate to verify the concept of using ground control points to position ERTS images

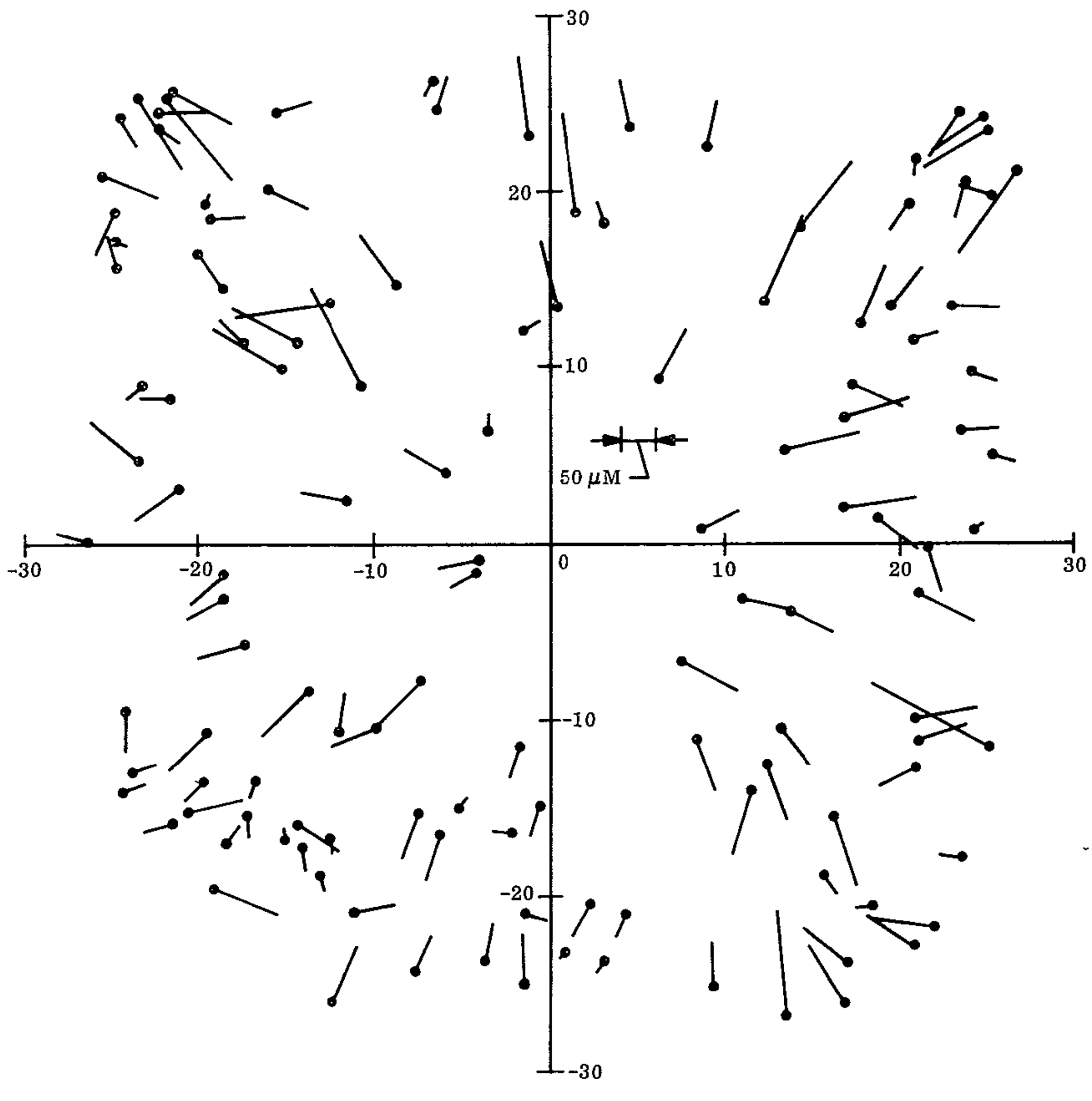


Figure 11 G-6 Composite Control Point Residuals after Spatial Resection with Y-Scale Factor Only

Table 11 G-2 Types of Features Selected as Control Points

Type of Feature	Number Selected In Each Photo				
	Arizona-New Mexico	Phoenix	Salton Sea	Vicksburg	Total
Natural					78
Intersection of drainage features	2	0	1	6	9
Bends or loops in drainage features	5	3	0	12	20
Terrain relief features	8	27	10	1	46
Vegetation features	0	0	0	3	3
Man-Made					36
Intersections or corners of roads, power lines, pipelines and other linears	1	2	2	25	30
Structures (dams, runways, etc)	0	4	2	0	6
Mixed					27
Intersections of man-made linears with drainage features	5	5	1	14	25
Intersections of man-made linears with relief of vegetation features	0	0	0	2	2

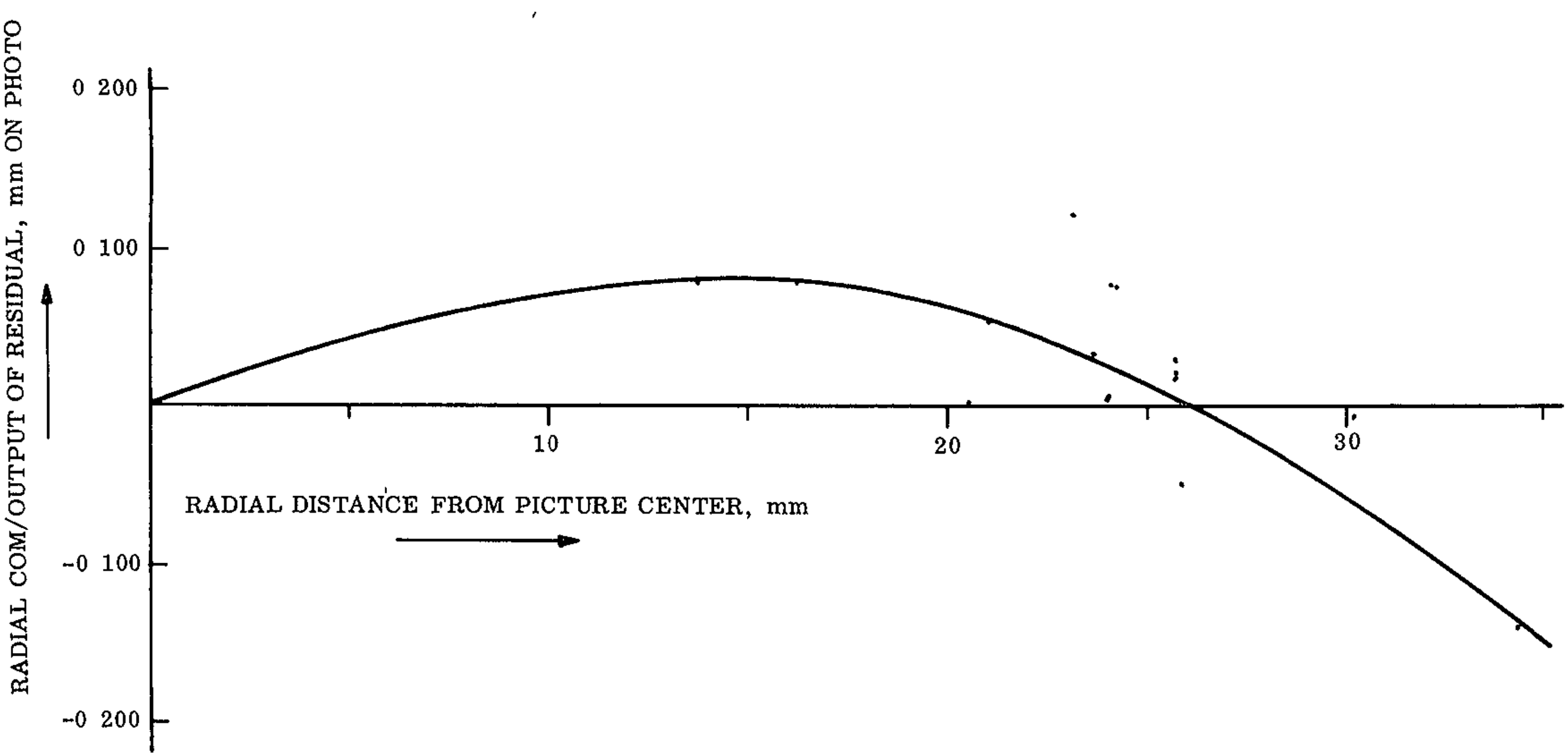


Figure 11 G-7 Radial Distortion Curve Derived Empirically from Control Point Image-Coordinate Residuals

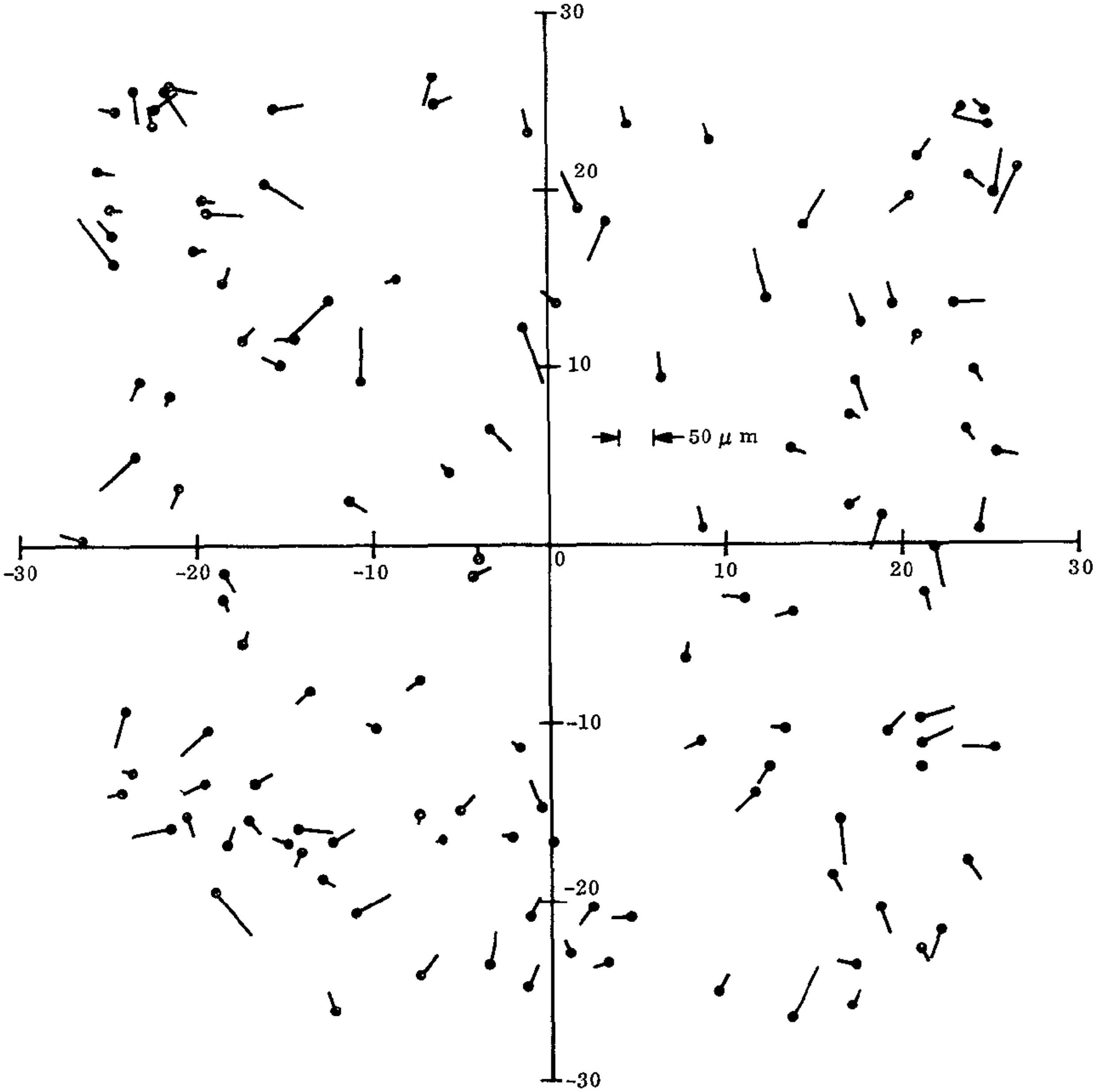


Figure 11 G-8 Composite Control Point Residuals After Spatial Resection with Y-Scale Factor, Plus Lens Distortion Factor

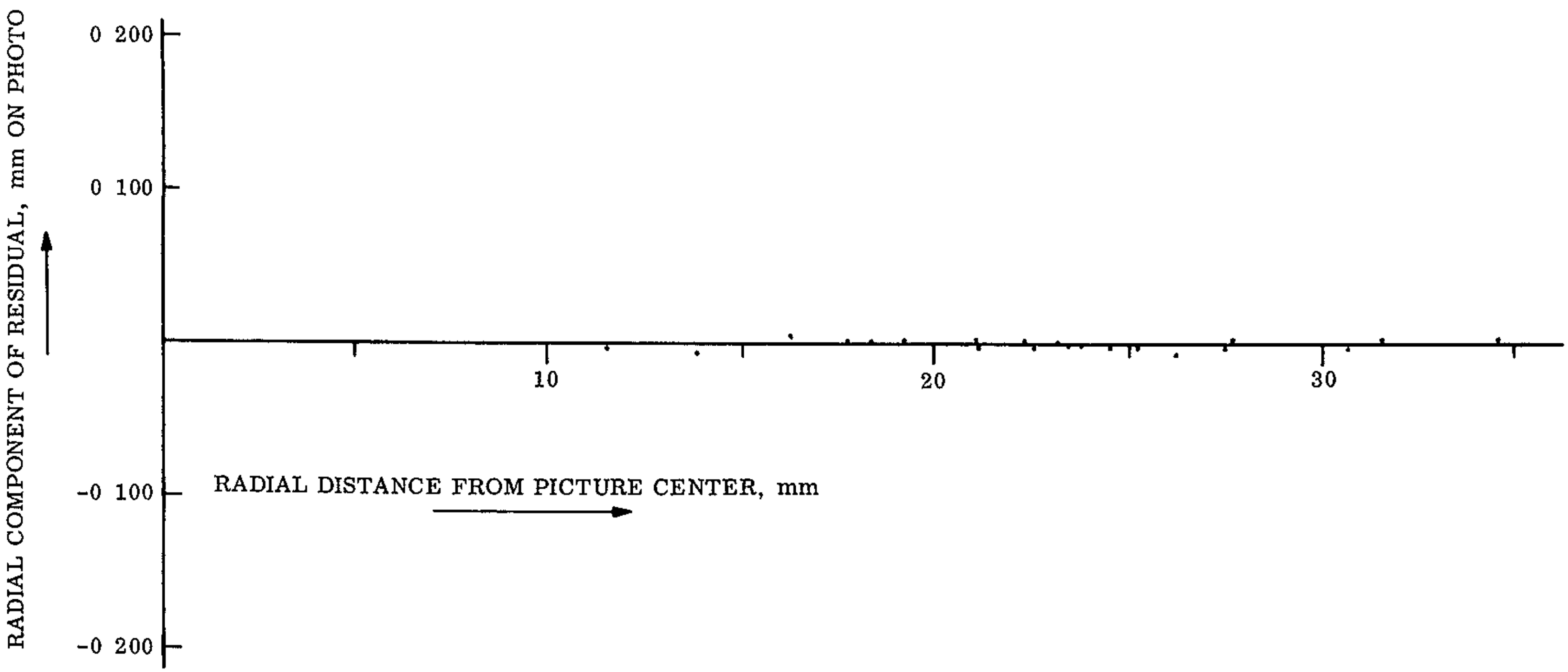


Figure 11 G-9 Radial Residual Components after Application of Radial Distortion Curve

HYBRID TECHNIQUES FOR ANALOG FUNCTION GENERATION

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INTRODUCTION

In computing systems involving real-time simulation, data processing, or control, it is often possible to combine digital and analog computing techniques to improve the over-all system capability or performance Effective combinations of analog and digital techniques have been made at several levels At the systems level, general-purpose digital and analog machines have been linked through conversion equipment, enabling more effective solution of classes of problems which involve both precision arithmetic operations and rapid solution of differential equations At the component level the capabilities of digital equipment for information storage, logical decisions, and sequence generation can be used in a variety of ways to augment the capabilities of analog equipment for wideband computation Finally, at the information representation level, hybrid codes have been utilized[1 2] to represent variables to obtain high-accuracy computing structures from an assembly of less accurate components

This paper discusses techniques for employing hybrid concepts at the component and information representation levels to generate arbitrary functions Particular emphasis is placed on the generation of multivariant functions in analog systems One reason for this emphasis is that while currently available diode function generators are adequate for univariant function generation, they generally result in a prohibitive amount of circuitry in multivariant applications Approaches involving servos have been used to reduce the equipment requirements, but these techniques are limited in the areas of speed and programming flexibility A multivariant function generation capability can, of course, be obtained by incorporating a digital computer in the system The present approach, however, obtains this capability at a considerably lower level of complexity, is generally capable of higher speeds, and does not contain the limitations of sampled data systems

In general terms, generation of an arbitrary function requires two basic operations

(1) *Storage*—Values of the output function are stored, the number of values depending on the required functional accuracy In analog systems, the function values are normally stored on potentiometers, often implicitly in the form of slope values If the function is not defined at predetermined points (i e , fixed breakpoints), it is also necessary to store the values of the input variables at which the breakpoints occur

(2) *Interpolation*—After the function is defined in terms of stored values, the output is formed by interpolating among these values as a function of the input variables In most analog systems, first order interpolation is used

The capabilities of digital techniques for information storage are well known These techniques, of course, are most advantageous where the amount of stored data becomes large This condition tends to occur in multivariant function generation For example, airframe simulations often involve the generation of ten or more bivariant functions, each of which may require storage of several hundred function values and breakpoint locations Thus, the total storage requirements are in the order of several thousand quantities Similar requirements occur in the generation of just one function of three variables

The major objective of the following paragraphs is to show how the interpolation process can be effectively implemented by employing hybrid data representation codes and utilizing a combination of digital and analog circuits It will be shown that these techniques are useful even in cases where storage requirements more modest than those cited above imply that potentiometer storage will be more economical than digital storage techniques

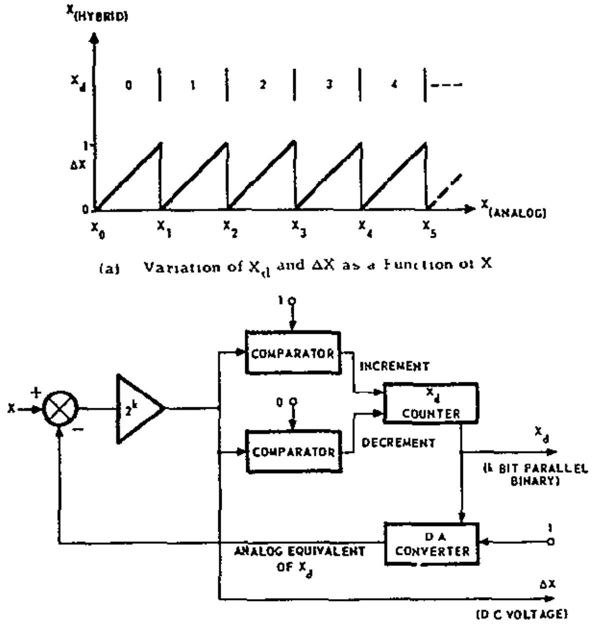
As noted above, the major emphasis herein will be on techniques for multivariant function generation However, many of the concepts involved apply equally well to the single-variable case, and are more readily visualized at this level Hence, the procedure in the following paragraphs will be to show first how hybrid techniques can be applied in the univariant case, and then to extend these techniques to functions of more than one variable

BASIC CONCEPTS

In a conventional hybrid code, a variable, X, is represented by the sum of two quantities a digital number, X_d, and a d-c analog voltage, ΔX For the present discussion, X_d can be visualized as a short binary number, say 3 or 4 bits, which would be the most significant bits of X in a normal binary representation As indicated in Figure 1a, each value of X_d corresponds to a particular segment within the range of X

$$X_d = j \text{ for } X_j < X < X_{j+1}$$

Within each segment, the analog quantity, ΔX, varies from zero to a maximum value which represents one bit of X_d In practice, ΔX is scaled to vary over the full range of the machine variable, which is assumed here to be zero to unity, in order to utilize the full dynamic range of the equipment This scaling leads to



(b) Analog To Hybrid Converter

Figure 1 Conventional Hybrid Code

a definition for ΔX in a normalized form, which is convenient for the following discussion

$$\Delta X = \frac{X - X_j}{X_{j+1} - X_j} \tag{1}$$

Equation 1 defines ΔX as varying linearly from 0 to 1 within each segment, independent of the width of the segment in X

The conversion of X from a d-c analog voltage to the hybrid code is obtained with a circuit similar to the familiar closed-loop analog-to-digital converter, as shown in Figure 1b The term X_d is generated as a k-bit parallel binary number, which is converted to analog and differenced with X This difference is scaled to form ΔX in a precision gain section The amplifier gain of 2^k is based on 0 to 1 full scale ranges for X, ΔX, and the analog equivalent of X_d Comparators increment the X_d counter when ΔX exceeds unity and decrement X_d when ΔX becomes smaller than zero

Schmid[3] describes a linear-segment analog function generator which utilizes a hybrid code generated in the above manner This circuit, shown in Figure 2, provides a good starting point for the present discussion The output function, $f_o(X)$, is defined at fixed evenly-spaced breakpoints located at each of the transition points of X_d Each segment of $f_o(X)$, then, is permanently associated with a particular

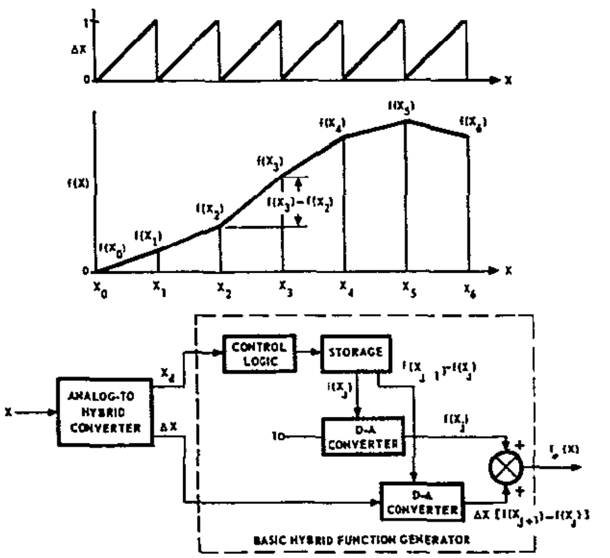


Figure 2 Basic Univariant Analog Function Generator

value of X_d For each segment, the storage section is programmed with two quantities

(1) $f(X_j)$, the value of the function at the j^{th} breakpoint
(2) $[f(X_{j+1}) - f(X_j)]$, the first difference of the function values for the interval $X_j < X < X_{j+1}$

The value of X_d is used to control the readout of the stored function and first difference values into two parallel D-A converters which, respectively, have unity and ΔX as analog inputs (The D-A converters can be visualized as the standard resistor-matrix parallel decoder, with the analog input replacing the normal reference voltage) The D-A converter outputs, which are the products of their analog and digital inputs, are summed to form

$$f_0(X) = f(X_j) + \Delta X[f(X_{j+1}) - f(X_j)], \quad (2)$$

which is a linear segment approximation of the desired function

In Schmid's function generator, the control logic consists of a decoder with 2^k output lines, one of which is energized for each segment The storage section is a diode matrix, driven by the decoder, which can generate an independent parallel number for each function value and first difference The program is stored by the presence or absence of a diode at each bit location Figure 2 has been drawn in the more general form to emphasize that any form of digital memory can be utilized, provided that the access time is sufficiently short It is also possible to modify Figure 2 for potentiometer storage, however, this concept, for convenience, is introduced in a later section

The configuration shown in Figure 2 has two characteristics which are disadvantageous, particularly when the approach is expanded to the multivariant case

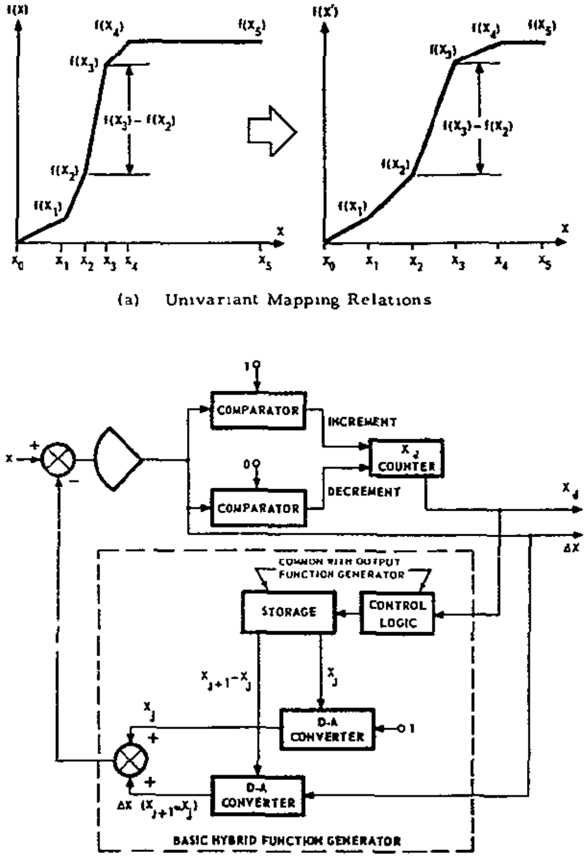
(1) The fixed, evenly spaced breakpoint locations limit the programming flexibility A movable breakpoint capability is desirable for functions which change slope rapidly in some places and are straight in others It is almost essential when data are given in tabular form
(2) The requirement for storing first differences, in addition to the function values, represents a redundancy which increases both the programming effort and the storage requirements

The following paragraphs develop techniques for overcoming these disadvantages

MOVABLE BREAKPOINTS

Consider a function $f(X)$ which is defined at non-uniform intervals in X as shown in Figure 3a Now suppose this function is re-plotted on a new axis, X', on which the breakpoints are evenly spaced Note that the function values and their first differences remain unchanged in this process Hence, if a function generator of the type shown in Figure 2 is programmed with $f(X_j)$ and $[f(X_{j+1} - f(X_j)]$ and excited with the new variable X' the correct function will be generated

It remains, then, to implement the mapping of the independent variable from X to X' This can be done with another function generator, however, a much more efficient method is to modify the analog-to-hybrid (A-H) conversion circuit already present in Figure 2 to a function generator which forms X' (Hybrid) from X (Analog) In Figure 3b, the required non-linear conversion is obtained by placing the basic hybrid function generator, developed in Figure 2, in the feedback path of a closed-loop system and replacing the programmed function values and first differences with the X-breakpoint locations and their first differences The output of this function generator is differenced with X at the input of a high-gain amplifier, the



(a) Univariant Mapping Relations

(b) Mapping Configuration for Generation of Conventional Code

Figure 3 Univariant Movable-Breakpoint Conversion

output of which is $\Delta X'$ Thus, within each segment, the closed loop system continuously solves the equation

$$X = X_j + \Delta X'(X_{j+1} - X_j) \qquad (3)$$

where $\Delta X'$ is the dependent variable If Equation 3 is rewritten as

$$\Delta X' = \frac{X - X_j}{X_{j+1} - X_j}$$

it is clear that $\Delta X'$ varies linearly from 0 to 1 within each segment The generation of X'_d, the digital part of X', is carried out in the same manner as before Since X' is generated using a feedback loop, there must be no slope reversals or points of zero slope in the nonlinear conversion from X' to X This is equivalent to requiring that the X breakpoints be assigned in order, $X_1 < X_2 < X_3$

Comparing Equations 1 and 3 it is seen that $\Delta X = \Delta X'$ This is true because both quantities are normalized to vary linearly from 0 to 1 within the segment The reader may argue, then, that the introduction of the mapping concept is entirely academic—that Figure 3b is simply a circuit which generates the ΔX quantity required to implement Equation 2 in the presence of non-uniformly spaced breakpoints This is true, of course, but the mapping concept aids in the visualization of a process which can become quite involved in the multivariant case

Note that the X-breakpoint locations and their first differences are inserted in numerical form in the same manner as the function values and first differences This is an important feature from the standpoint of programming ease

DIRECT PROGRAMMING

In considering methods for eliminating the requirement for storing first differences, it is helpful to re-write Equation 2 in the form

$$f_0(X) = (1 - \Delta X)f(X_j) + \Delta X f(X_{j+1}) \qquad (4)$$

Equation 4 expresses the output function within a given segment as a weighted mean of two stored breakpoint values, with the weighting determined by the instantaneous value of the independent variable, X, via the coefficients $(1 - \Delta X)$ and ΔX

The implementation of Equation 4 involves the generation of a new hybrid code, which is plotted versus X in Figure 4 In the analog portion of the code, ΔX is replaced by two quantities, A_1 and A_2, which are defined as

$$\left.\begin{aligned} A_1 &= 1 - \Delta X \\ A_2 &= \Delta X \end{aligned}\right\} \text{ For } X_d \text{ Odd}$$

and

$$\left.\begin{aligned} A_1 &= \Delta X \\ A_2 &= 1 - \Delta X \end{aligned}\right\} \text{ For } X_d \text{ Even}$$

Note that A_1 and A_2 are complementary, i e, $A_2 = 1 - A_1$ and $A_1 = 1 - A_2$

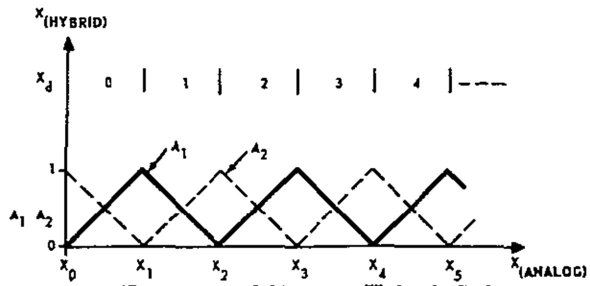


Figure 4 Odd-Even Hybrid Code

The quantities A_1 and A_2 excite the D-A converter configuration, shown in Figure 5, in which all the function values stored for odd numbered breakpoints ($X_1, X_3, X_5,$) are permanently associated with one D-A converter and those for even numbered breakpoints are permanently associated with the other D-A converter (For convenience, in Figure 5 and future diagrams, D-A converters are shown as boxes marked with their digital inputs which are assumed to be generated by appropriate storage and control logic equipment) Then, if the D-A converters are programmed according to the following schedule it can be seen that Equation 4 is obtained in each interval

X_d	A_1	A_2	f_{odd}	f_{even}
0	ΔX	$1 - \Delta X$	$f(X_1)$	$f(X_0)$
1	$1 - \Delta X$	ΔX	$f(X_1)$	$f(X_2)$
2	ΔX	$1 - \Delta X$	$f(X_3)$	$f(X_2)$
3	$1 - \Delta X$	ΔX	$f(X_3)$	$f(X_4)$

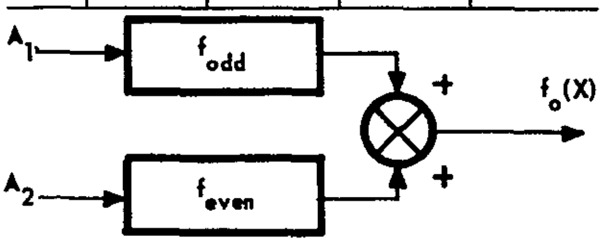


Figure 5 D–A Converter Configuration for Odd-Even Code

Figure 6 provides a graphical explanation of the synthesis of an arbitrary function using the odd-even code which makes the process easier to visualize Within the first two segments, A_1 is multiplied by $f(X_1)$ to form a triangular function having height $f(X_1)$ as shown on line b At $X_2, f(X_1)$ is replaced in the f_{odd} D-A converter by $f(X_3)$, so that the next triangle has a height of $f(X_3)$, etc A_2 is multiplied by the even numbered function values to form the function shown on line c The sum of the odd and even contributions (line d) is the desired function

The configuration shown in Figure 5 is not a unique method for implementing Equation 4 However, the odd-even approach has several virtues which would not be present if the conventional code were utilized

(1) The permanent association of each function value with one of the D-A converters eliminates switching of the stored values between D-A converters This type of switching would be particularly difficult in the simpler forms of storage such as the diode matrix

(2) All switching of function values in D-A converters occurs when the associated coefficient, A_1 or A_2, is equal to zero This feature greatly reduces switching noise seen at the output of the function generator

(3) The odd-even code, while more difficult to generate than the conventional code, contains no step changes and can therefore be used by analog equipment with less distortion due to limited amplifier high frequency response

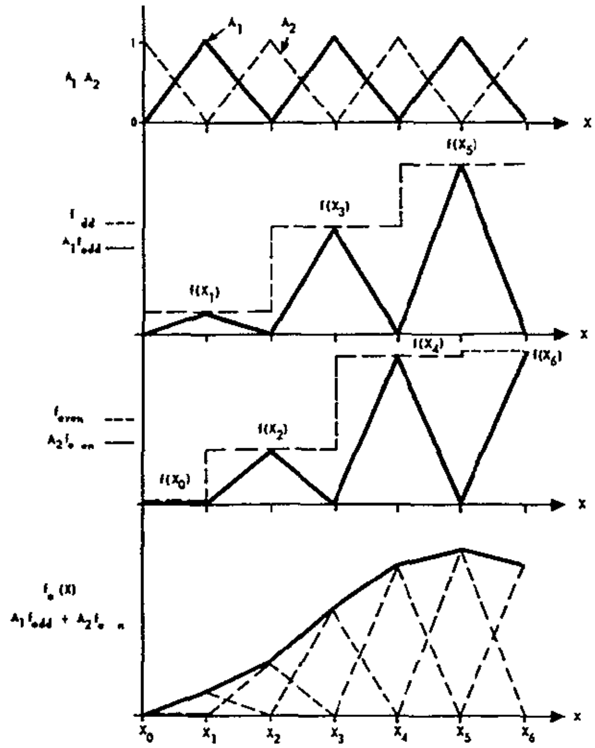


Figure 6 Synthesis of a Univariant Function

It remains to be shown how the odd-even hybrid code can be generated from a continuous analog input This explanation will be carried out in terms of the previously discussed need for movable breakpoints, so that the result will be a movable-breakpoint univariant function generator which can be programmed directly with the function values and their locations in X As shown in Figure 7, two odd-even D-A

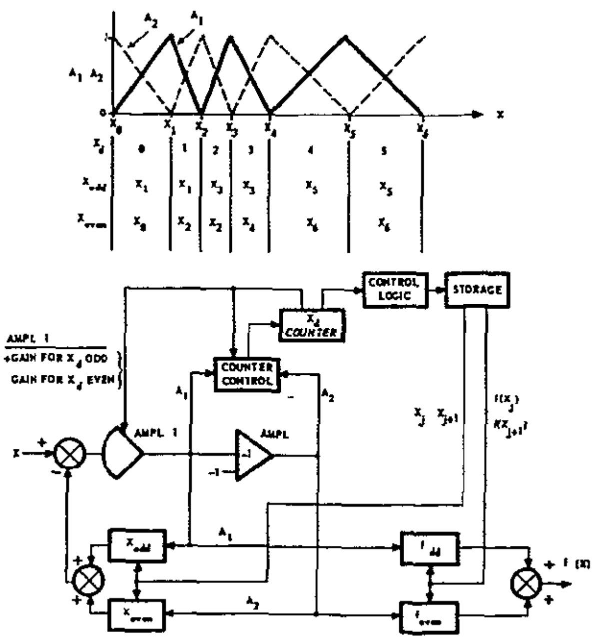


Figure 7 Movable-Breakpoint Odd-Even Univariant Function Generator

converter configurations are connected back-to-back and driven from A_1 and A_2 which are, respectively, the outputs of Amplifier 1 which has high gain and Amplifier 2 which is connected to generate $A_2 = 1 - A_1$ Figure 7 also indicates the programming schedule for the D-A converters in the feedback path The feedback loop solves the equation

$$X = A_1 X_{odd} + A_2 X_{even}$$

where A_1 is the dependent variable and $A_2 = 1 - A_1$

In the first segment where X'_d is even

$$X = A_1X_1 + (1 - A_1)X_0$$

or

$$A_1 = \frac{X - X_0}{X_1 - X_0} = \Delta X \text{ and } A_2 = 1 - \Delta X$$

In the next segment where X'_d is odd

$$X = A_1X_1 + (1 - A_1)X_2$$

or

$$A_1 = \frac{X_2 - X}{X_2 - X_1} = 1 - \Delta X, \text{ and } A_2 = \Delta X$$

Note that the feedback path of the A-H conversion loop contains a gain term $X_{odd} - X_{even}$ Remembering that $X_0 < X_1 < X_2$ it is seen that this term is positive during even numbered intervals and negative during odd numbered intervals Thus, it is necessary to invert the sign of the gain of Amplifier 1 at each breakpoint The information for this switching is contained in the least bit of X'_d

The logic requirements presented in Figure 7 differ from those in Figure 2, in two ways First, signals to increment or decrement X'_d, which are generated when either A_1 or A_2 become less than zero, must also be based on whether X'_d is odd or even

	$A_1 < 0$	$A_2 < 0$
X'_d odd	Inc	Dec
X'_d even	Dec	Inc

The second control logic modification occurs in the generation of the control signals for read-out of the stored quantities, where the following selection process is required

f_{odd}, X_{odd}	X'_d	f_{even}, X_{even}	X'_d
$f(X_1), X_1$	0 or 1	$f(X_0), X_0$	0
$f(X_3), X_3$	2 or 3	$f(X_2), X_2$	1 or 2
$f(X_5), X_5$	4 or 5	$f(X_4), X_4$	3 or 4
• • • • •	• • • •	• • • • •	• • • •

This selection can be implemented with a decoder for X'_d and one OR gate for each segment

POTENTIOMETER STORAGE

The configuration shown in Figure 7 provides a convenient place to introduce the method, promised earlier, of using potentiometers to store the function values and breakpoint locations Figure 8 shows a potentiometer-storage univariant function generator having the same capability as the Figure 7 configuration Each function value and breakpoint location is stored as the shaft position of a separate potentiometer Each potentiometer pair, X_j and $f(X_j)$, is connected to A_1 or A_2 by a switch during the $(j - 1)^{th}$ and j^{th} segments, using exactly the same logic as for Figure 7 The potentiometer outputs, then, represent the products required, to implement Equation 4 and are summed to form the output function

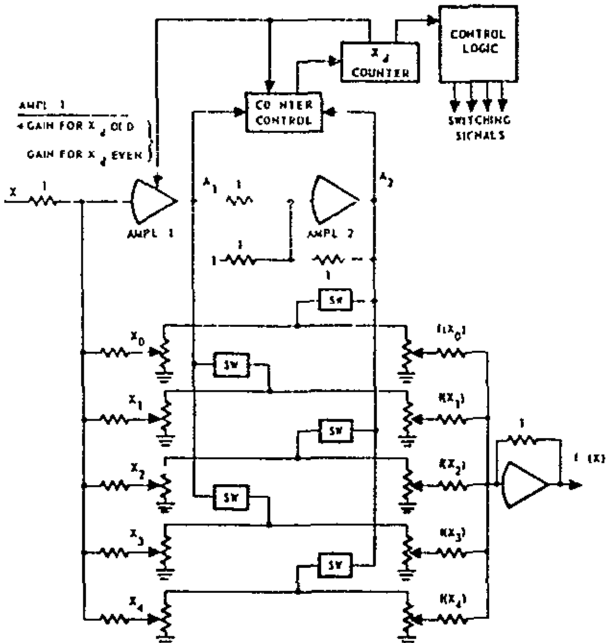


Figure 8 Potentiometer Storage Univariant Function Generator

Any of the function generator block diagrams discussed in this paper can be converted to potentiometer storage by replacing the digital storage and the D-A converters with potentiometers and electronic switches The required number of potentiometers is equal to the sum of the number of function values and breakpoint locations to be stored The number of switches is equal to the number of function values

BIVARIANT FUNCTION GENERATION

In considering the extension of the above concepts to the generation of functions of more than one variable, the first problem encountered is that the linear segment approximation for one variable has no unique counterpart in the multivariant case Restricting the discussion to two variables for the present, Equation 2 (and its alternate form, Equation 4) can be expanded into at least three essentially different approximations to a surface $f(X, Y)$ which is defined by stored values at various points in the X-Y plane

In the following paragraphs, these three approximations are briefly described, and their relative advantages are evaluated Initially, it will be assumed that the function is defined in the X-Y plane at all the intersections of evenly spaced values of X and Y (This does not provide a movable breakpoint capability, but this feature can be added as was done in the univariant case) Thus, each approximation must define the function inside a square sector using stored values at the four corners In general terms, the discussion should be carried out for the n^{th} sector in which the function is defined by the corner values $f(X_i, Y_j)$, $f(X_{i+1}, Y_j)$, $f(X_i, Y_{j+1})$, and $f(X_{i+1}, Y_{j+1})$ However, this notation is much too complicated for the present requirements It will suffice to denote the four values $f(11)$, $f(21)$, $f(12)$, and $f(22)$ as shown in Figure 9, and let it be understood that the square under discussion could be any sector in the X-Y plane

The first approximation method, which might be called *summation of partial derivatives*, results from noting that Equation 2 gives $f(X)$ as the sum of a stored function value and a difference term which is proportional to the slope in the X-direction A two-variable approximation, then, is obtained by adding a term which includes the effect of the slope in the Y-direction

$$f(X, Y) = f(11) + \Delta X[f(21) - f(11)] + \Delta Y[f(12) - f(11)] \qquad (5)$$

Equation 5 generates a plane surface which passes through $f(11)$, $f(21)$ and $f(12)$ as shown in Figure 9a In general, the surface does not pass through $f(22)$—a plane defined by three points will not pass through an arbitrarily located fourth point Thus, if the approximation is repeated in adjacent sectors, a discontinuity

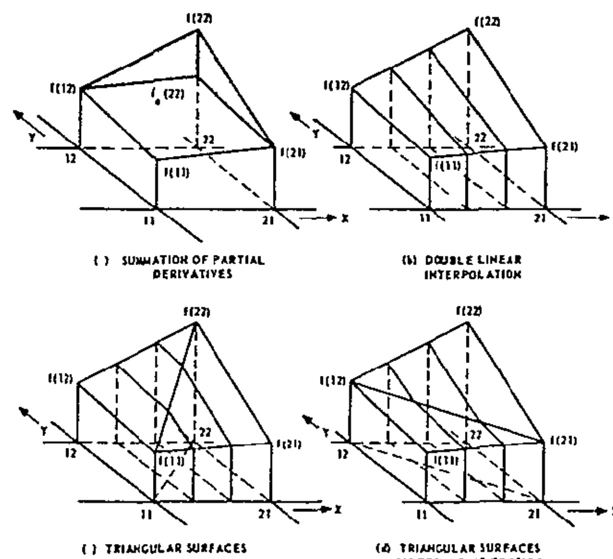


Figure 9 Approximation Methods for Bivariant Function Generator

will occur at each sector boundary as indicated by the shaded vertical areas in Figure 9a For many applications these discontinuities present a severe disadvantage

The implementation of Equation 5 is a direct extension of Figure 2 A third channel, in which the Y-first difference term is multiplied by ΔY, is added to the basic hybrid function generator However, although an analogy to the odd-even method can be applied, the configuration cannot be rearranged to eliminate switching of non-zero quantities Since the other approximations to be discussed present neither this disadvantage nor the discontinuous output surface, it is concluded that the summation of partial derivatives method is the least suitable of the three methods for wideband analog function generation

DOUBLE LINEAR INTERPOLATION

The second approximation, which will be called *double linear interpolation,* can be thought of as being formed by a linear interpolation in (say) the Y-direction between two functions of X which, in turn, are formed by linear interpolation between the corner values Expanding the form of Equation 4 gives the following equation

$$f_0(X, Y) = (1 - \Delta Y)[(1 - \Delta X)f(11) + \Delta X f(21)] + \Delta Y[(1 - \Delta X)f(12) + \Delta X f(22)] \quad (6)$$

Reversal of the order of the ΔX and ΔY interpolations will result in the same equation The surface generated by Equation 6 is shown in Figure 9b This is a curved surface which has the property of being straight along any line of constant X or constant Y

Most approaches to bivariant function generation make use of this approximation by utilizing a linear interpolation device to interpolate between outputs of univariant function generators[4, 5] This can be implemented in hybrid form, using two univariant circuits operating from a common control logic and storage section In this approach, the linear interpolator requires the formation of two products of analog variables, and each multiplication must be performed with an accuracy equivalent to the desired output accuracy

An alternate implementation which requires only one multiplication, and this of less ac-

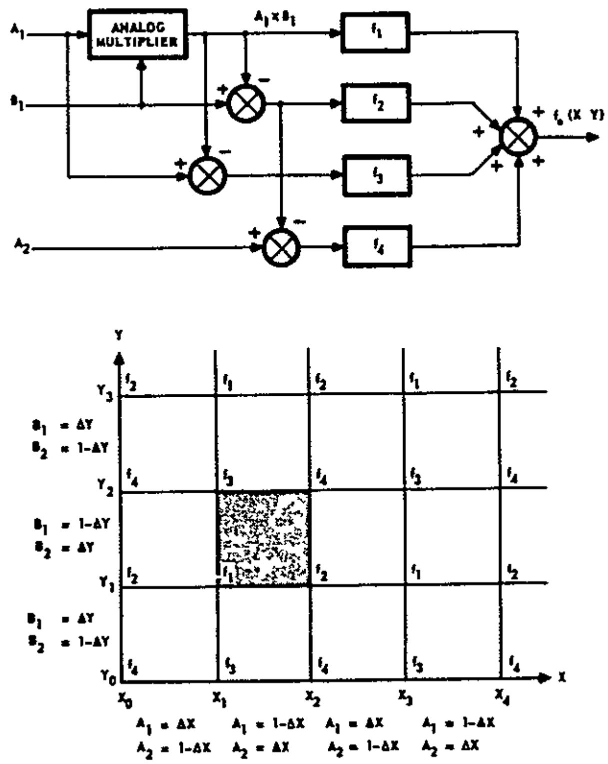


Figure 10 Double Linear Interpolation D–A Converter Configuration

curacy, is shown in Figure 10 Figure 10 also extends the odd-even concept to the bivariant case Each stored function value is permanently associated with one of four D-A converters according to the indicated schedule Auxiliary signals are generated as follows

$$\left.\begin{array}{l} A_1 = 1 - \Delta X \\ A_2 = \Delta X \end{array}\right\} \text{For } X_d \text{ odd}$$

$$\left.\begin{array}{l} A_1 = \Delta X \\ A_2 = 1 - \Delta X \end{array}\right\} \text{For } X_d \text{ even}$$

$$\left.\begin{array}{l} B_1 = 1 - \Delta Y \\ B_2 = \Delta Y \end{array}\right\} \text{For } Y_d \text{ odd}$$

$$\left.\begin{array}{l} B_1 = \Delta Y \\ B_2 = 1 - \Delta Y \end{array}\right\} \text{For } Y_d \text{ even}$$

The 1, 1 sector ($X_d = Y_d = 1$, shown shaded in Figure 10) is considered first Here, Equation 6 becomes

$$f_0(X, Y) = (1 - \Delta Y)[(1 - \Delta X)f_1 + \Delta X f_2] + \Delta Y[(1 - \Delta X)f_3 + \Delta X f_4]$$

or

$$f_0(X, Y) = B_1(A_1 f_1 + A_2 f_2) + B_2(A_1 f_3 + A_2 f_4) \quad (7)$$

Moving up to the 1, 2 sector, Equation 6 becomes

$$f_0(X, Y) = (1 - \Delta Y)[(1 - \Delta X)f_3 + \Delta X f_4)] + \Delta Y[(1 - \Delta X)f_1 + \Delta X f_2],$$

and making the inverted substitutions, $1 - \Delta Y = B_2$ and $\Delta Y = B_1$, Equation 7 is again obtained This equation also holds in the 2, 1 and 2, 2 sectors, and since all other sectors are repetitions of one of these four cases, Equation 7 is valid for the entire X-Y plane

In Figure 10 the coefficients for all four function values are obtained with one analog multiplier by using the relations

$$A_2 = 1 - A_1 \text{ and } B_2 = 1 - B_1$$

to rearrange Equation 7 as follows

$$f_0(X, Y) = A_1B_1f_1 + (B_1 - A_1B_1)f_2 + (A_1 - A_1B_1)f_3 + (A_2 - B_1 + A_1B_1)f_4 \quad (8)$$

In addition to the multiplier, four summing amplifiers are required to invert the multiplier output and obtain the required summations Note that multiplier accuracy is generally not as important as it would be in an output interpolator because errors in the term A_1B_1 in Equation 8 tend to cancel The error cancellation is greatest where the four stored values are nearly equal, i e, where the slope of the function is small

In a function generator having the configuration shown in Figure 10, the control logic section must perform the following type of selection for each of the four D-A converters

f_1	X_d	Y_d
$f(X_1, Y_1)$	X_0 or X_1	Y_0 or Y_1
$f(X_3, Y_1)$	X_2 or X_3	Y_0 or Y_1
$f(X_1, Y_3)$	X_0 or X_1	Y_2 or Y_3
$f(Y_3, Y_3)$	X_2 or X_3	Y_2 or Y_3

For a function being approximated by N segments in the X-direction and M segments in the Y-direction, the selection for all four D-A converters can be implemented with approximately $N + M$ OR gates and NM AND gates in addition to the X_i and Y_i decoders

TRIANGULAR SURFACES

The third bivariant approximation, which will be called the *triangular surfaces approximation*, is based on passing plane surfaces through values of the function taken three at a time For a unit square sector in the X-Y plane, the approximation consists of two triangular surfaces, as shown in Figure 9c The equation of the line dividing the two triangles is $\Delta X = \Delta Y$ An equation for the right hand surface, where $\Delta X > \Delta Y$, is formed by adding two terms to $f(11)$ which account for the change in the function as the sector boundary is traversed from point (11) to (21) and then to (22)

$$f_0(X, Y) = f(11) + \Delta X[f(21) - f(11)] + \Delta Y[f(22) - f(21)] \text{ for } \Delta X > \Delta Y$$

Similarly, for the left hand surface

$$f_0(X, Y) = f(11) + \Delta Y[(f(12) - f(11)] + \Delta X[f(22) - f(12)] \text{ for } \Delta Y > \Delta X$$

Rearranging,

$$f_0(X, Y) = (1 - \Delta X)f(11) + (\Delta X - \Delta Y)f(21) + \Delta Y f(22) \text{ for } \Delta X > \Delta Y$$

and (9a)

$$f_0(X, Y) = (1 - \Delta Y)f(11) + (\Delta Y - \Delta X)f(12) + \Delta X f(22) \text{ for } \Delta Y > \Delta X \quad (9b)$$

An alternate method for subdividing the unit square is shown in Figure 9d In this case, the equation of the diagonal is $1 - \Delta X = \Delta Y$ Conceptually, these two methods are the same Mathematically, one can be obtained from the other by complementing one of the input variables However, it is interesting to note that the two methods do not, in general, yield the same functional error within a particular sector Comparing these surfaces with Figure 9b, it is seen that the double linear interpolation method produces a surface which is, at all points, intermediate to the two possibilities available with triangular surfaces Hence, it is deduced that the triangular surfaces method will generally produce a greater functional error, especially if the diagonal is located indiscriminately On the other hand, it will be shown that the triangular surfaces approximation is considerably simpler from an equipment standpoint

Figure 11 shows an implementation of Equation 9 which continues the concept of permanently associating each stored value with a particular D-A converter The accompanying schedule indicates the assignment of function values to the three D-A converters and also

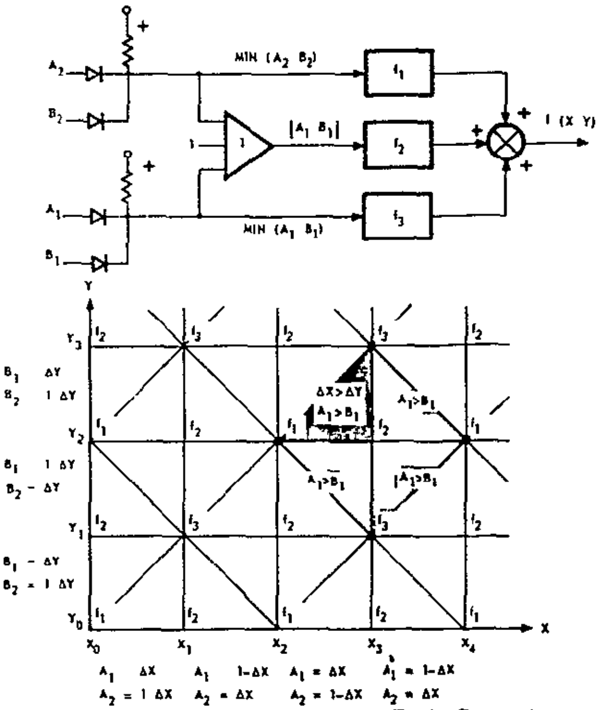


Figure 11 Triangular Surfaces D–A Converter Configuration

shows the diagonal locations, which have been selected to be compatible with the same set of auxiliary signals—A_1, A_2, B_1, B_2—that were obtained from ΔX and ΔY as in the previous example

In showing how Figure 11 implements Equations 9a and 9b, the right hand portion of the 2, 2 sector (shown crosshatched) is investigated first Here, $\Delta X > \Delta Y$, and by Equation 9a,

$$f(X, Y) = (1 - \Delta X)f_1 + (\Delta X - \Delta Y)f_2 + \Delta Y f_3$$

or

$$f_o(X, Y) = A_2 f_1 + (A_1 - B_1)f_2 + B_1 f_3 \quad \text{for } A_1 > B_1 \qquad \text{(10a)}$$

In the triangle directly to the right of this, Equation 9a can again be utilized by complementing ΔX

$$f(X, Y) = \Delta X f_1 + (1 - \Delta X - \Delta Y)f_2 + \Delta Y f_3$$

But, since moving across X_3 has reversed the definitions of A_1 and A_2,

$$f(X, Y) = A_2 f_1 + (A_1 - B_1)f_2 + B_1 f_3,$$

which is Equation 10a again In a similar manner, or by applying Equation 9a, it can be shown that Equation 10a applies throughout the shaded region and in all other regions where $A_1 > B_1$

In the rest of the regions, where $B_1 > A_1$, a similar development results in

$$f_o(X, Y) = B_2 f_1 + (B_1 - A_1)f_2 + A_1 f_3 \quad \text{for } B_1 > A_1 \qquad \text{(10b)}$$

Equations 10a and 10b taken together, define $f_o(X, Y)$ over the entire X-Y plane However, for the purpose of discussing their implementation in Figure 11, it is desirable to combine Equations 10a and 10b into a common equation This can be done by noting that $A_2 = 1 - A_1$ and $B_2 = 1 - B_1$, and observing the following

(1) In Equation 10a, where $A_1 > B_1$, $B_2 > A_2$ and $A_1 - B_1 > 0$
(2) In Equation 10b, where $B_1 > A_1$, $A_2 > B_2$ and $B_1 - A_1 > 0$

Clearly, the coefficient of f_2 can be written $|A_1 - B_1|$ in both equations The coefficient for f_1 can be written MIN (A_2, B_2), if MIN (A_2, B_2) is defined as being equal to A_2 or B_2 whichever is smaller (This quantity could be called the analog AND of A_2 or B_2) The coefficient of f_3 can be treated in the same manner Thus,

$$f_o(X, Y) = [MIN(A_2, B_2)]f_1 + |A_1 - B_1|f_2 + [MIN(A_1, B_1)]f_3 \qquad (11)$$

Figure 11 shows the implementation of Equation 11 using diode AND gates to form MIN (A_1, B_1) and MIN (A_2, B_2) The coefficient for f_2 is formed from

$$\begin{aligned} &1 - MIN(A_1, B_1) - MIN(A_2, B_2) \\ &= 1 - B_1 - 1 + A_1 = A_1 - B_1 \text{ for } A_1 > B_1 \\ &= 1 - A_1 - 1 + B_1 = B_1 - A_1 \text{ for } B_1 > A_1 \\ &= |A_1 - B_1| \end{aligned}$$

Thus, the required coefficients are obtained from A and B quantities with two AND gates and one amplifier Diode AND gates can probably be utilized in most applications, inserting compensating diodes to cancel the first order effects of diode forward conduction offsets, and following the gate with a buffer amplifier If higher accuracy is needed, each AND gate can be implemented with two D-C amplifiers Either of these configurations compare favorably with the double linear interpolation approach from an equipment standpoint, since both eliminate the analog multiplier and one D-A converter

The control logic required for selection of the f_1 and f_3 D-A converter inputs is the same as that for the double linear interpolation method However, the selection for f_2 must also include the $A_1 > B_1$ or $B_1 > A_1$ condition

f_2	A_1, B_1	X_d	Y_d
$f(X_1, Y_0)$	$A_1 > B_1$	X_0 or X_1	Y_0
$f(X_3, Y_0)$	$A_1 > B_1$	X_2 or X_3	Y_0
$f(X_0, Y_1)$	$B_1 > A_1$	X_0	Y_0 or Y_1
$f(X_2, Y_1)$	$B_1 > A_1$	X_1 or X_2	Y_0 or Y_1

Thus, the control logic differs from that for the double linear interpolation method only in that a third input must be added to ½ NM AND gates

In comparing the triangular surfaces approximation to the double linear interpolation approximation, the modest equipment savings available with triangular surfaces must be balanced against its generally higher functional error No general conclusion can be reached on this point However, it can be argued that stability and repeatability—which both methods provide in an approximately equal degree—are much more important than true functional accuracy in most analog applications On this basis, it is concluded that the triangular surfaces approximation will generally be the optimum approach

BIVARIANT MOVABLE BREAKPOINT SYSTEMS

If the approach for obtaining movable breakpoints that was developed for the univariant case is used separately for each input variable in a bivariant system, a mapping of the type shown in Figure 12a is obtained Breakpoints located on arbitrarily spaced lines of constant X are translated to a uniform spacing in X', the only restriction being that order $X_1 < X_2 < X_3$ be retained The same type of translation is carried out for the Y breakpoints The feedback paths of the X and Y analog-to-hybrid (A-H) converters employ the odd-even configuration, of course, so that the A_1, A_2, B_1, B_2 quantities required, in Figures 10 or 11, are generated

In Figure 12b, the flexibility of the mapping has been increased by making the X breakpoints movable as a function of Y This requires insertion of a bivariant function generator in the feedback path of the X-input A-H converter Either of the bivariant configurations shown in Figures 10 or 11 can be utilized The feedback path is programmed directly with

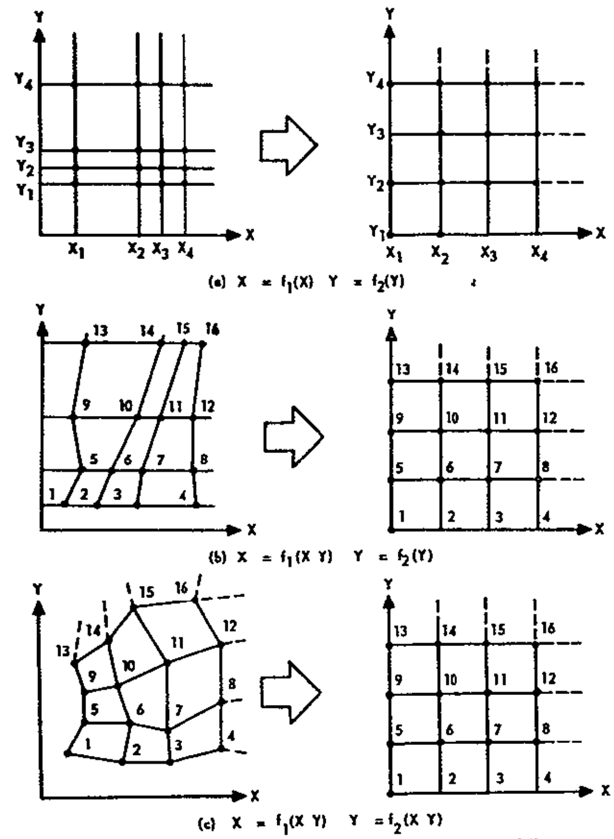


Figure 12 Bivariant Movable-Breakpoint Mapping Configuration

the breakpoint locations in X The generation of the coefficients for the bivariant approximation can be common for both the output and X-feedback path

Figure 12c indicates a completely general bivariant mapping Randomly located breakpoints in the X-Y plane are converted into a uniform grid in the X'-Y' plane To obtain this mapping, a bivariant function generator is required in the feedback path of both the X- and Y-input A-H converters

The three movable breakpoint systems then provide increasing programming flexibility along with increasing equipment complexity and, in particular, increasing storage requirements For example, if a 10 x 10 segment approximation is implemented by each of the three methods, the storage requirements are

Mapping	Number of Stored Quantities			
	X	Y	$f(X, Y)$	Total
12a	11	11	121	143
12b	121	11	121	253
12c	121	121	121	363

It may be argued that the intermediate mapping configuration, Figure 12b, is sufficient for most applications because raw data for bivariant functions is almost always presented as a set of functions of one variable with the other variable as the parameter of the set However, since the configuration shown in Figure 12c is the most general case, it will be used in the following description of a complete bivariant function generator

Figure 13 shows the implementation of a bivariant random-breakpoint analog function generator utilizing the triangular surfaces approximation The output section (right half) of Figure 13 is essentially a repetition of Figure 11 The operation and logic requirements of the digital storage equipment are also as indicated in conjunction with Figure 11 except that three quantities—the value of the function, the X-coordinate, and the Y-coordinate—must be stored for each breakpoint The assignment procedure for placing the X-coordinates in the X-input A-H converter and the Y-coordinates in the Y-input A-H converter is identical to that for placing the function in the output D-A converters

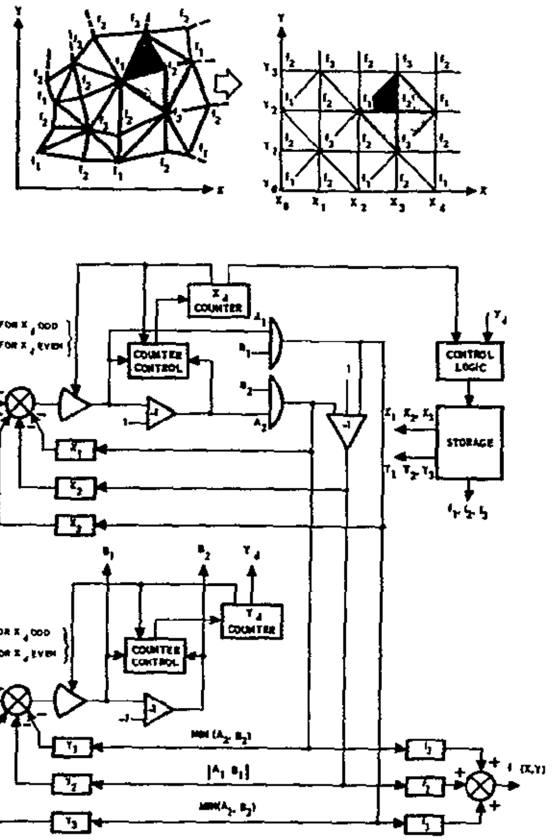


Figure 13 Random-Breakpoint Triangular Surfaces Bivariant Function Generator

The X- and Y-input A-H converters, then, simultaneously solve the equations

$$\left.\begin{aligned} X &= [MIN\ (A_2, B_2)]\, X_1 + |A_1 - B_1|\, X_2 + [MIN\ (A_1, B_1)]\, X_3 \\ Y &= [MIN\ (A_2, B_2)]\, Y_1 + |A_1 - B_1|\, Y_2 + [MIN\ (A_1, B_1)]\, Y_3 \end{aligned}\right\} \quad (12)$$

in which $\Delta X'$ and $\Delta Y'$, as contained in the A's and B's, are dependent variables

A step-by-step proof that Equations 12 perform the required mapping is a lengthy procedure, consequently, only a summary is presented

The first step is to show that each of the oblique triangles formed by joining breakpoints in the X-Y plane is mapped into a corresponding isosceles right triangle in the X'-Y' plane This is done by showing that for any particular triangle Equation 12 is satisfied along all three boundaries, and that points in the interior of the triangle in X-Y remain in the interior in X'-Y'

The second step is to show that the closed loop system formed by the X- and Y-analog-to-hybrid converters provides a stable solution of Equations 12 Classical stability criteria for implicit solution of simultaneous equations[6] can be applied to this problem to show that the following conditions, taken together, are sufficient for stability

(1) An increase in X always corresponds with an increase in X'
(2) An increase in Y always corresponds with an increase in Y'
(3) The transformation does not invert the triangle, i e , if the corners are numbered 1, 2, 3 clockwise in the X-Y plane, this order is not reversed in the X'-Y' plane
(4) The phase shift in each amplifier is less than 90 degrees at all frequencies where gain exceeds unity

The first three conditions restrict the choice of breakpoint locations in a manner analogous to the $X_1 > X_2 > X_3$ requirement in the single variable case Generally, they imply that two lines of constant X' (or Y') cannot cross in the X-Y plane and that no sector in X-Y can contain an interior angle of greater than 180 degrees

FUNCTIONS OF MORE THAN TWO VARIABLES

Of the three approximations discussed for bivariant interpolation, the first two have direct extensions for functions of three or more variables. For the summation partial derivatives method, a new first difference term is added to the basic equation, and another channel is added to the block diagram for each new variable. As in the bivariant case, the major disadvantage of this method is the discontinuous output.

A trivariant linear interpolation is formed by interpolating between the output of two bivariant function generators. Also, a trivariant extension of the configuration shown in Figure 10 is available. However, in either approach, a minimum of four analog multipliers are required.

The extension of the triangular surfaces approximation to functions of three or more variables is less direct. Generalizing, it can be argued that the virtue of the triangular surfaces approximation lies in the fact that the interpolation is carried out among the least number of points that can define a surface. Therefore, the trivariant analogy should implement an interpolation among the least number of points that can define a volume—four points in the form of a tetrahedron.

Figure 14 indicates a subdivision of unit cube into six tetrahedrons each of which is defined by a unique inequality among ΔX, ΔY, and ΔZ. Assuming the function is defined at the eight corners of the cube, and following the same procedure used in the bivariant case,

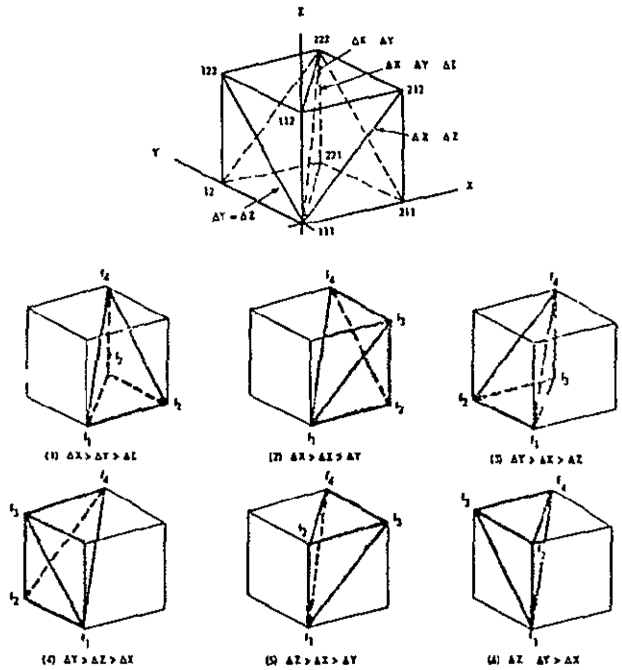


Figure 14 Generalized Triangular Surfaces — Subdivision of the Unit Cube

$$\begin{aligned} f_o(X, Y, Z) &= f(111) + \Delta X[f(211) - f(111)] \\ &\quad + \Delta Y[f(221) - f(211)] \\ &\quad + \Delta Z[f(222) - f(221)] \\ &\quad \text{for } \Delta X > \Delta Y > \Delta Z \end{aligned}$$

Each of the four function values involved can be assigned to one of four D-A converters as indicated in the sketch of the $\Delta X > \Delta Y > \Delta Z$ tetrahedron in Figure 14. Thus,

$$\begin{aligned} f_o(X, Y, Z) &= (1 - \Delta X)f_1 + (\Delta X - \Delta Y)f_2 \\ &\quad + (\Delta Y - \Delta Z)f_3 + \Delta Z f_4 \\ &\quad \text{for } \Delta X > \Delta Y > \Delta Z \end{aligned}$$

Continuing, a set of six equations is obtained which defines the output function throughout the cube. Adopting the odd-even notation for the variables, the set becomes

$$\left.\begin{aligned} f_o(X, Y, Z) &= A_2 f_1 + (A_1 - B_1)f_2 + (B_1 - C_1)f_3 + C_1 f_4 \text{ for } A_1 > B_1 > C_1 \\ &= A_2 f_1 + (A_1 - C_1)f_2 + (C_1 - B_1)f_3 + B_1 f_4 \text{ for } A_1 > C_1 > B_1 \\ &= B_2 f_1 + (B_1 - A_1)f_2 + (A_1 - C_1)f_3 + C_1 f_4 \text{ for } B_1 > A_1 > C_1 \\ &= B_2 f_1 + (B_1 - C_1)f_2 + (C_1 - A_1)f_3 + A_1 f_4 \text{ for } B_1 > C_1 > A_1 \\ &= C_2 f_1 + (C_1 - A_1)f_2 + (A_1 - B_1)f_3 + B_1 f_4 \text{ for } C_1 > A_1 > B_1 \\ &= C_2 f_1 + (C_1 - B_1)f_2 + (B_1 - A_1)f_3 + A_1 f_4 \text{ for } C_1 > B_1 > A_1 \end{aligned}\right\} \quad (13)$$

The first and last term of Equations 13 can be generated as before with analog AND gates The center terms, however, involve the intermediate quantity in the inequality and cannot be generated passively They can, of course, be generated with active switching, employing the same logical process that must be implemented in the selection of the correct set of stored function values The configuration retains the triangular surfaces' property of switching function values only when the coefficients are zero

Since the tetrahedral volume approximation requires only four D-A converters and no analog multiplier, it possesses a considerable equipment advantage over the triple linear interpolation process As more variables are added this advantage becomes greater In a n-variable function generator, generalized interpolation requires $2^n - 2^{n\,2} - 2$ multipliers and 2^nD-A converters, whereas, the generalized triangular surfaces approximation requires no multipliers and $n + 1$ D-A converters

HARDWARE CONSIDERATIONS

In general, the equipment configurations that have been developed in the foregoing discussion can be implemented with an assemblage of standard components The D-A converters, switches, and control logic circuits fall into this category The amplifiers can be of the standard operational type with the one exception of the switched amplifier which is utilized in the generation of the odd-even hybrid code

The switched amplifier, Amplifier 1 in Figure 7, provides the forward gain for a feedback loop whose feedback transfer function reverses sign at each segment boundary To compensate for this reversal, the gain of the forward path must be inverted within Amplifier 1 The design should emphasize accomplishing this switching without generating a switching transient at the amplifier output, which is the signal voltage A_1 One rather conservative approach to this problem is to design Amplifier 1 as a short time-constant integrator with differential inputs, one for each feedback polarity, and then utilize the following switching sequence

(1) When A_1 or A_- less than zero is sensed, open the forward path placing Amplifier 1 on hold

(2) Switch the feedback path by inserting the new value in the proper D-A converter

(3) Close the forward path through the opposite input

STORAGE METHODS

It has been noted that hybrid interpolation techniques are applicable with a variety of storage media Each of these media, of course, has a characteristic set of advantages and limitations The following paragraphs summarize some of these characteristics, for the major types of storage media

Potentiometers

For requirements of less than about 1000 quantities, potentiometers probably are the most economical form of memory, assuming that manual setup procedures are employed The disadvantage is that considerable labor is required in programming the equipment to generate a new function Automatic potentiometer setting systems are in general more expensive than an equivalent digital memory

Static Card Readers

The diode matrix memory proposed by Schmid can be increased in flexibility by making the connection at each bit location through the contacts of a static card reader Readers are available which will handle about 1000 bits or (say) 100, 10-bit quantities The disadvantages are a relatively high first cost and no reduction in cost per bit with increasing storage requirements

Magnetic Cores

The fast random access capabilities of the core memory, together with the reducing cost per bit for large capacities, are ideal for large function generation capabilities The only disadvantage is that, in order to justify the basic cost, the storage requirement must be in the order of 1000, 10-bit quantities, e g , generation of several functions of two variables or one function of three variables

Delay Lines, Drums

These storage media suffer generally from access time problems If the full bandwidth capabilities of the hybrid function generation approach are to be realized, access times of a few microseconds are required Some improvement is available by inserting a buffer store to rapidly make available the values required in adjacent sectors

The above discussion has emphasized storage methods which, by their programming flexibility, are best suited to general purpose computing applications For special-purpose equipment, where a fixed or plug-in card program is suitable, the diode matrix storage is probably more economical than digital bulk storage methods up to a level of several thousand quantities

CONCLUSIONS

Hybrid equipment and information representation techniques can be effectively applied to a wide class of analog function generation problems The simpler configurations, such as shown in Figure 8, are comparable with the conventional diode function generators in the bandwidth and equipment complexity areas They are advantageous in that the function values and breakpoint locations can be inserted directly from numerical data Also, each function value and location is independent of all the others

The major advantage of hybrid techniques, however, is that the above advantages can be extended to include generation of arbitrary functions of two or more variables with no great increase in the required equipment An exception to this statement occurs in considering the storage requirements, where an equipment increase is inevitable However, the hybrid approach makes efficient use of digital bulk storage techniques to handle the large amounts of data required to define multivariant functions

In the discussion of bivariant approximation methods, it is concluded that the triangular surfaces approximation is optimum for wideband analog applications since it generates a continuous surface with the least amount of equipment This argument is strengthened when the approximations are extended to functions of three or more variables Differing system requirements may modify this conclusion, of course For example, in systems which involve multiplexing of the variables, the continuous output has no great advantage, and therefore the summation of partial derivatives approximation may be adequate In other cases, the fact that generalized linear interpolation is a more conventional approach mathematically or that it generally produces a lower functional error may justify the added equipment Perhaps an additional advantage of hybrid function generation techniques is that they present a unified approach for implementing any of the three methods

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17 April 1970

APPENDIX 11.I
DETAILED FUNCTIONAL REQUIREMENTS OF TRAINING SET ANALYSIS COMPUTER PROGRAMS

11 I 1 FACTOR ANALYSIS

Principal component analysis serves as the first step in signature data processing The role of the principal component transformation is to express the raw data in a new coordinate system in which the new variables - principal components - are more nearly independent than originally Factor analysis, as performed by computer, often begins with a principal component or principal factor analysis of the data The reader is referred to the literature of factor analysis (see Harmon)* for further discussion of the terms and techniques of that important subject A principal component transformation is obtained as follows

1 Prepare the data sample for analysis Express this as a matrix with m rows, corresponding to multivariate observations with m channels, and n columns, corresponding to n observations of the target described by the data sample Require that $n > m$ Call this matrix X

2 The data may or may not be put in standard form It has been found desirable to do so Compute the mean and standard deviation of each row of the data matrix From each element, subtract the mean value of its own row and divide by the standard deviation Define this as

$$Y = \frac{1}{\sqrt{n}} S^{-1} (X - \overline{X})$$

which is the matrix of the data sample in standard form S is the diagonal matrix of standard deviations for each row and S^{-1} is the diagonal matrix with non-zero elements of S_{ij}^{-1} and $\overline{X}$ is a matrix of n identical columns, each row is the mean value of a row of X repeated n times

3 Form the correlation matrix of the data sample This is

$$R = YY^T$$

4 Diagonalize the correlation matrix using standard procedures The result is

$$D = URU^T$$

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* Harmon, Harry H , Modern Factor Analysis, The University of Chicago Press, 1968

The real symmetric matrix, R, is diagonalized to a form of eigenvalues, $\lambda_1, \ldots, \lambda_m$, by the unitary matrix U, formed from the m eigenvectors of R U^T = U transposed

5 Multiply both sides of the above by the inverse of D expressed in the form

$$D^{-1} = D^{-1/2} \, D^{-1/2}$$

$$D^{-1/2} = \lambda_1^{-1/2} \quad \lambda_2^{-1/2} \quad . \quad \lambda_3^{-1/2}$$

The result is

$$I = D^{-1/2} \, D^{-1/2} \, URU^T$$

$$= D^{-1/2} \, UYY^TU^TD^{-1/2}$$

6 Define

$$F = D^{-1/2}UY$$

$$= \frac{1}{\sqrt{n}} S^{-1} D^{-1/2} U(X - \overline{X})$$

This is the matrix of principal components in standard form It is m x n just as is the data sample matrix In non-standard form the principal component matrix is

$$G = F + \frac{1}{\sqrt{n}} S^{-1} D^{-1/2} U\overline{X}$$

$$= \frac{1}{\sqrt{n}} S^{-1} D^{-1/2} UX$$

Note that the principal components are uncorrelated because the correlation matrix of the principal components is equal to the identity matrix

$$FF^T = (D^{-1/2} UY) (D^{-1/2} UY)^T$$

$$= (D^{-1/2} UY) (Y^TU^TD^{-1/2})$$

$$= L$$

7 The principal component transformation is thus identified as the m x m matrix

$$T = \frac{1}{\sqrt{n}} S^{-1} D^{-1/2} U$$

and $G = TX$

or $F = T(X - \overline{X})$.

The output products of the factor analysis program are the coefficients necessary to perform the principal component transformation

11 I 2 DIVERGENCE

Divergence is a measure of the amount of information that the differences between two distributions contribute to the classification of a spectral signature The divergence is defined as the sum of two information measures

Suppose a signature $\tilde{x}$ arises from one of two object classes, j or k. The likelihood ratio method of classification is to evaluate the likelihood function

$$L(\tilde{x}) = \frac{f_j(\tilde{x})}{f_k(\tilde{x})}$$

and assign the signature to object class j if L exceeds some criterion value, and to class k otherwise The amount of information in the likelihood ratio for making the decision is log L (The base of the logarithm does not matter since the results vary only by a multiplicative constant, however $\log_2 L$ gives the information in bits)

To obtain the average information per observation for evaluating the hypothesis that the signature belongs to object class j against the alternative class k, it is necessary to take the expected value over distribution j

$$L(j,k) = \int (\log \frac{f_j(\tilde{x})}{f_k(\tilde{x})}) f_j(\tilde{x}) d\tilde{x}$$

$$= \int \log L(\tilde{x}) f_j(\tilde{x}) d\tilde{x}$$

Similarly, the average information for evaluating the hypothesis that the signature belongs to object class k against the alternative class j is

$$L(k,j) = \int (\log \frac{f_k(\tilde{x})}{f_j(\tilde{x})}) f_k(x) dx$$

$$= -\int \log L(\tilde{x}) f_k(x) dx$$

The divergence between the two populations is

$$J(j, k) = L(j,k) + L(k,j)$$

Note that $J(j, k)$ applies to differences between distributions and not to the sample of signatures to be classified Note also that $L(j,k)$ and $L(k,j)$ are integrals, but the integration takes place over different distributions, namely the distributions of the two object classes Finally, note that the information measures, while integrated over only one of the two object class distributions, are not defined unless the alternative class is specified, i.e , each is defined for the distribution, but only against a well-defined alternative

To evaluate the divergence between distributions of object classes, average the log likelihood functions over the reference data sets. The distributions, which are unknown, are assumed to be characterized by the reference data sets and the algorithms for evaluating the density functions

Let N_j and N_k be the two reference samples The required computations are

$$L(j,k) = \frac{1}{N_j} \sum_{i=1}^{N_j} \log \frac{f_j(\tilde{x}_i)}{f_k(\tilde{x}_i)}$$

$$L(k,j) = \frac{1}{N_K} \sum_{i=1}^{N_k} \log \frac{f_k(\tilde{x}_i)}{f_j(\tilde{x}_i)}$$

$$J(j, k) = L(j,k) + L(k,j)$$

The computation of the density functions $f_j(x)$ and $f_k(x)$ is performed by subroutines which are also incorporated in the Bayesian decision scheme (likelihood ratio processing)

The output of this program will be the divergence, expressed in bits of information, between pairs of distribution functions

11 I 3 <u>BAYES DECISION PROGRAM</u>

The criterion is minimum cost The expected cost of an experiment is

$$E(w) = \sum_{k=1}^{K} \sum_{j=1}^{K} w(j, k)P(j, k)$$

where

$$w = \text{cost of the experiment}$$

$$w(j,k) = \text{cost of assigning an object of class } j \text{ to class } k$$

$$P(j,k) = \text{probability of assigning an object of class } j \text{ to class } k$$

The probability $P(j,k)$ can be expressed as the product of an <u>a priori</u> and a conditional probability

$$P(j,k) = P(j)P(k|j)$$

where

$$P(j) = \underline{\text{a priori}} \text{ probability of occurrence for objects of class } j$$

$$P(k|j) = \text{probability of assigning an object to class } k \text{ provided it belongs to class } j$$

The problem is to define values of the observed signature which cause it to be attributed to a class k Let Γ_k be the set of signatures (i e., a region in the space of signatures) which is attributed to class k Then, by definition

$$P(k|j) = \int_{\Gamma_k} f_j(\tilde{x})d\tilde{x}$$

where

$$\tilde{x} = \text{an observed signature}$$

$$f_j(\tilde{x}) = \text{the probability density function of signatures for objects of class } j$$

$$\Gamma_k = \text{acceptance region for assignment to class } k$$

or

$$P(k|j) = \int_{\Omega} \Gamma_k(\tilde{x})f_j(\tilde{x})d\tilde{x}$$

where

$$\Omega = \text{the entire signature space}$$

$$\Gamma_k(x) = 1 \text{ for } \tilde{x} \in \Gamma_k$$

$$= 0 \text{ for } \tilde{x} \in \Omega - \Gamma_k$$

The expected cost is then

$$E(w) = \sum_{k=1}^{K} \sum_{j=1}^{K} w(j, k) P(j) \int_{\Omega} \Gamma_k(\tilde{x}) f_j(\tilde{x}) d\tilde{x}$$

$$= \int_{\Omega} \sum_{k=1}^{K} \Gamma_k(\tilde{x}) \left[\sum_{j=1}^{K} w(j, k) P(j) f_j(\tilde{x}) \, d\tilde{x} \right]$$

To minimize the expected cost, evaluate the cost function in square brackets for each k and set $\Gamma_k(\tilde{x}) = 1$ for the k associated with the minimum cost

Example 1

2 object classes

Evaluate

$$w(1, 1)P(1)f_1(\tilde{x}) + w(2, 1)P(2)f_2(\tilde{x})$$

$$w(1, 2)P(1)f_1(\tilde{x}) + w(2, 2)P(2)f_2(\tilde{x})$$

Choose k = 1 if

$$w(1, 1)P(1)f_1(\tilde{x}) + w(2, 1)P(2)f_2(\tilde{x})$$

$$\leq w(1, 2)P(1)f_1(\tilde{x}) + w(2, 2)P(2)f_2(\tilde{x})$$

or

$$\frac{f_1(\tilde{x})}{f_2(\tilde{x})} \geq \frac{[w(2, 1) - w(2, 2)]P(2)}{[w(1, 2) - w(1, 1)]P(1)}$$

The quality $f_1(\tilde{x})/f_2(\tilde{x})$ is called the likelihood ratio

It is usual to attribute costs of 0 to correct classifications and consider only penalties for errors The rule is then to choose k=1 if the likelihood ratio

$$\frac{f_1(\tilde{x})}{f_2(\tilde{x})} > \frac{w(2,1)P(2)}{w(1,2)P(1)}$$

The likelihood ratio is a function of the observed signature, the criterion value is a constant which depends on the <u>a priori</u> probabilities and the costs of errors.

<u>Example 2</u>

For 3 object classes compute

$$w(1,1)P(1)f_1(\tilde{x}) + w(2,1)P(2)f_2(\tilde{x}) + w(3,1)P(3)f_3(x)$$

$$w(1,2)P(1)f_1(x) + w(2,2)P(2)f_2(\tilde{x}) + w(3,2)P(3)f_3(x)$$

$$w(1,3)P(1)f_1(x) + w(2,3)P(2)f_2(\tilde{x}) + w(3,3)P(3)f_3(x)$$

and attribute the signature to class 1, 2 or 3 according as line 1, 2 or 3 is a minimum

When $w(1,1) = w(2,2) = w(3,3) = 0$, compute

$$w(2,1)P(2)f_2(\tilde{x}) + w(3,1)P(3)f_3(\tilde{x})$$

$$w(1,2)P(1)f_1(\tilde{x}) + w(3,2)P(3)f_3(\tilde{x})$$

$$w(1,3)P(1)f_1(\tilde{x}) + w(2,3)P(2)f_2(\tilde{x})$$

Choose object class 1 if

$$f_1(\tilde{x}) \geq \frac{w(2,1)P(2)}{w(1,2)P(1)} f_2(\tilde{x}) + \frac{[w(3,1) - w(3,2)]P(3)}{w(1,2)P(1)} f_3(\tilde{x})$$

$$f_1(\tilde{x}) \geq \frac{[w(2,1) - w(2,3)]P(2)}{w(1,3)P(1)} f_2(\tilde{x}) + \frac{w(3,1)P(3)}{w(1,3)P(1)} f_3(\tilde{x})$$

There are 4 more such inequalities, two for each of the other object classes. Note that each inequality is a function of two likelihood ratios

If the costs of all errors are equal, say

$$w(2,1) = w(3,1) = w(1,2) = w(3,2) = w(1,3) = w(2,3) = 1$$

The inequalities (L) are equivalent to two likelihood ratio tests

$$\frac{f_1(\tilde{x})}{f_2(\tilde{x})} \geq \frac{P(2)}{P(1)}$$

and

$$\frac{f_1(\tilde{x})}{f_3(\tilde{x})} \geq \frac{P(3)}{P(1)}$$

with 2 other such tests for the other two object classes

The Bayes Decision Program is capable of forming the appropriate likelihood ratios from the input signature distributions It also computes, on the basis of input cost and a priori estimates, the appropriate thresholds Its output will be a classification of the input signatures into one of the classes of allowed features.

The Bayes Decision Program computes estimates of probability density functions The estimation of probability density functions for sample data is based on the actual distribution of a reference sample The assumption is that the reference sample represents the population, and that the true distribution can be approximated with any desired accuracy with a random sample which is sufficiently large. A method for estimating the probability density of an arbitrary observation is needed which is independent of assumptions as to distributional form The method described here is based on a function proposed by Specht For purposes of computation, the reference sample may be expressed in the form of a histogram, or the computations can be made directly from the individual observations

The method consists of attributing a normal probability density function to each point of concentration in the reference sample with an amplitude proportional to the number of points represented The density function at a point is obtained by adding up the contributions from all points in the reference data set.

The density function for a normally distributed variable in a space of m dimensions (channels) is

$$f(x_1, x_2, \quad , x_m) = \frac{1}{(2\pi)^{m/2} \sigma_1 \sigma_2 \quad \sigma_m} \exp\left(-\frac{1}{2}\sum_{i=1}^{m}\frac{(x_i - a_i)^2}{\sigma_i^2}\right)$$

provided the variables are uncorrelated Here a_i is the mean and σ_i the standard deviation in the i^{th} channel. By substituting the points of the reference sample and summing, the density function of an arbitrary point is obtained For the k^{th} target class.

$$f_k(x_1, x_2, \quad , x_m) = \frac{1}{(2\pi s)^{m/2} N_k \sigma_1 \sigma_2 \quad \sigma_m} \sum_{j=1}^{N_k} \exp\left(- \frac{1}{2} \sum_{i=1}^{m} \frac{(x_i - y_{ijk})^2}{s\sigma_i^2} \right)$$

$$= \frac{1}{(2\pi)^{m/2} N \sqrt{s_{1k} s_{2k} \quad s_{mk}}} \sum_{j=1}^{N_k} \exp\left(- \frac{1}{2} \sum_{i=1}^{m} \frac{(x_i - y_{ik})^2}{s_{ik}} \right)$$

where the y_{ij}'s are the observation vectors of the reference sample The parameter s_{ik} is a smoothing parameter for the i^{th} channel, k^{th} group which determines the extent to which the density is concentrated about the observation vectors of the reference sample, and replaces the variance in the equation for the multivariate normal density function

For large values of s the density function is quite smooth As $s \rightarrow o$, the density function approaches the reference sample with an impulse function which integrates to 1/N at each observed point By choosing some suitably small value of s, the reference sample distribution can be smoothed without sacrificing the underlying characteristics of the population distribution

The output of the Bayes Decision Program shall be a class designation for each input spectral signature This designation will be one of the four numbers representing the allowed class of features It shall output, as an option, the likelihood ratios and thresholds used in the decision process These outputs shall be on computer compatible tapes

11 I 4 SCATTER DIAGRAM PLOTTER PROGRAM

This program shall output coordinate pairs formed from the four variables produced by the principal component transformation. These pairs shall be recorded on HDDT so that they can be recorded on film as a scatter diagram in the Bulk Processing EBR

SECTION 12

NDPF INSTALLATION, INTEGRATION AND TEST

SECTION 12

NDPF INSTALLATION, INTEGRATION, AND TEST

As compared with OCC installation, integration, and test (Section 7 0), the NDPF activation activities allow for more parallel or independent scheduling of work The NDPF activation schedule recommended by General Electric is shown in Figure 12-1. Note that except for image data processing, equipment is expected to be available on 1 April 1971 These availability dates, plus the relative independence of equipment installations, will make possible considerable flexibility in installation and test sequences

In arriving at the recommended approach, careful consideration was given to work and cost effectiveness in all areas, including

1 Facility modification

2 Installation workload

3 Test efficiency (in-plant versus on-site)

4. Avoidance of interfering activities

5. Activation staffing

Separate discussions of NDPF installation, integration, and test are given in the following paragraphs

12 1 NDPF INSTALLATION

The sequence of NDPF equipment installation is

1 NDPF computer equipment

2 Photo processing equipment

3 Image generation equipment

The computer equipment is scheduled first so that the maximum time is available for software debugging and system compatibility tests. The image generation equipment is scheduled last to provide maximum procurement time. The photo processing equipment sequence is most flexible and will be phased for the most efficient overall sequence of NDPF activation. The installation requirements for the NDPF are conventional, and no significant problems are anticipated

The approved installation sequence must of course be established in a form which is compatible with the phasing of facility modifications Some of the considerations in this area are

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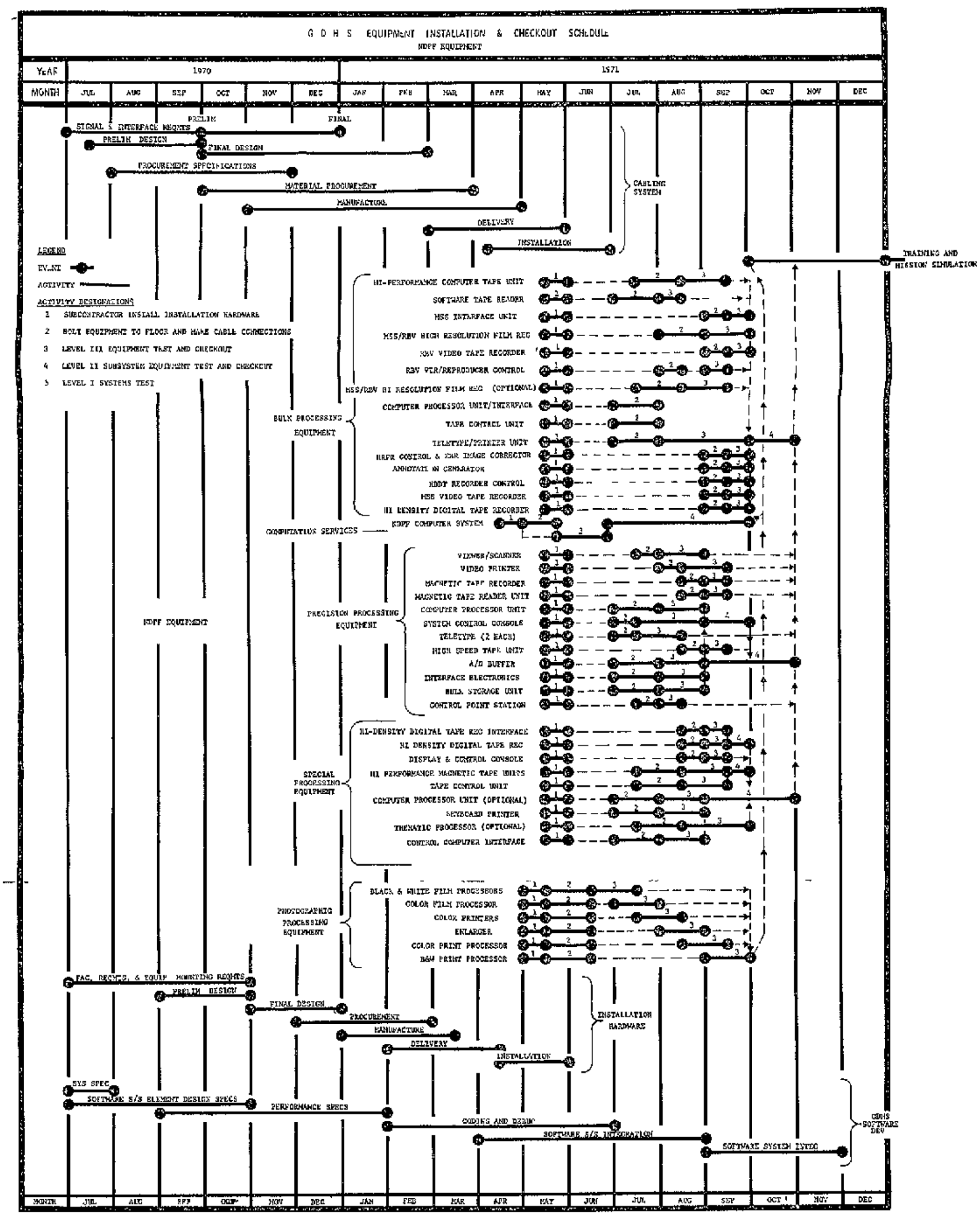

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Figure 12-1 NDPF Installation, Integration, and Test Schedule

17 April 1970

1 Subfloor, floor, and ceiling work should be completed in the area before equipment is placed for mounting

2. Air conditioning and a clean environment (relative to paint, dust, etc) must be available before computer equipment is installed

3. Some partition installation can be done after equipment is in place (and may even be preferable)

4. Facility work must be avoided after precision equipment is in place

These considerations suggest that a Facility Beneficial Occupancy Date of 1 April 1971 would be most desirable This would provide a fully modified facility at the scheduled start of equipment installation.

However, an intermeshed facility modification/equipment installation schedule can certainly be established, should it be necessary

A listing of NDPF equipment, with installation sequences by area and amplifying comments, is given in Tables 12.1-1 through 12.1-7

The viewer-scanner and video printer are items of special interest, in the NDPF installation process These items will be dismantled into subassemblies after testing at the manufacturer's facility. Reassembly at the GDHS precision image processing area will be done by special technicians who will perform precision alignments and checkouts during the reassembly process. It is desirable that these activities occur as late in the activation cycle as possible, after a semi-clean room and controlled temperature environment have been established The present schedule also calls for the installation, integration, and test to occur after the heavy construction work associated with the addition of a new top floor on Building 23 is completed.

12 2 NDPF ACCEPTANCE TEST

12.2 1 COMPONENT TEST CRITERIA

Components comprising the various subsystems of the NDPF will undergo performance evaluation by their manufacturer's prior to integration into the next higher functional subsystem This performance evaluation will consist of a final visual inspection of the article to determine compliance to the quality standards regulating its fabrication and a functional performance test to determine compliance to the operational requirements of the design specification This performance evaluation will be performed at and by the responsible manufacturer and will be, in selected cases, witnessed by a Quality Assurance representative of the subcontractor processing the component

Formal Acceptance Test, per se, will not be performed at the component level, but will be deferred to factory acceptance testing of subsystems in order to reduce redundant effort

Table 12.1-1. Precision Processing Installation Requirements

Hardware Item	Quantity	Installation Sequence	Rationale	Comments
PRECISION PROCESSING				
1 Legs and Isolation Pads for Viewer Scanner Table	1 Set	1 or 3	Must precede viewer scanner table - bulky item	
2 Viewer Scanner Granite Table	1	2 or 4	May require wall removal-heavy bulky may need heavy equipment to handle	Possible removal of false floor required movement into area
3 Legs and Isolation Pads for Video Printer Granite Table	1 Set	3 or 1	Must precede video printer	
4 Video Printer Granite Table	1	4 or 2	Heavy bulky May need heavy equipment to handle May need wall removal	Possible removal of false floor required movement into area
5 System Control and Interface Console (Plus Cabling)	1	5	Bulky back (4 bay rack) as a single assembly - may require wall removal for movement into area	Cable installation will require access to subfloor area
6 High Speed Recorder	1	6	Next in line from system control console	
7 A/D Converters/Buffers (4 each)	2 Racks	7	Next in line from recorder	
8 Magnetic Tape Reader	1	8	Next in line from A/D converter racks	
9 Magentic Tape Recorder	1	9	Next in line from tape reader	
10 Control Computer	1	10	Dual rack	
11 Standard Peripheral Interface	1	11	Next in line from computer	
12 Bulk Storage	1	12	Next in line from interface	
13 Viewer Scanner Assembly	1	13 or 14	Delicate equipment - may require wall removal for movement into area	To be assembled by BRLD technicians only (Assy' on table)
14 Video Printer Assembly	1	14 or 13	Delicate equipment - may require wall removal for movement into area	To be assembled by BRLD technicians only (Assy on table)
15 Laminar Airflow and Filter Assembly	1	15 or 16	Follows installation of viewer scanner	
16 Laminar Airflow and Filter	1	16 or 15	Follows installation of video printer	
17 Teleprinter	1	17	Mobile printer - install after cabling	Fits into niche in viewer scanner
CONTROL POINT STATION				
18 Film Files	2 racks	18	Corner installation - may require wall mounting	8 shelves each rack - 2 cans deep 3 cans high
19 Status map display board	2	19	Requires wall mounting	
20 Map files	6	20	Bulky Items	
21 Chip Plate File	1	21		
22 Light Table with Encloser	1	22		Seq 22 through 28 are totally arbitrary - any sequence is acceptable except as noted
23 Overhead Reflecting Projector	1	23		
24 Screen for Projector	1	24	Install after light table	
25 X-Y Digitizer	1	25		
26 Teleprinter with Paper Tape Output	1	26		
27 Chip Plate Status Chart Table	1	27		
28 Maps	1 Set	28		

Table 12.1-2. Special Processing Installation Requirements

Hardware Item	Quantity	Installation Sequence	Rationale	Comments
SPECIAL PROCESSING				
1 CRT Display Interface and Control Console	1 Option	1	Bulky item – fits farthest into work area may require wall removal	
2 Control Computer	Option	-		
3 Hi Performance and Magnetic Tape Unit	4	2, 3, 4 and 5	In-line installation	
4 Magnetic Tape Unit/Tape Control	1	6	Fits next to tape units	
5 Process Control Computer	1 Option	7	Fits next to magnetic tape control	
6 Computer Interface	1	8	Fits next to computer	
7 Keyboard Printer and Paper	1	9	Fits next to interface	
8 Tape Reader and Punch	1			
9 Thematic Processor	1 Option	10	Fits farthest into corner area	
10 Hi Density Digital Tape Recorder Control	1 Option	11 and 12	Fits next to Thematic Processor	
11 Hi Density Digital Tape	1 Option	13 and 14	Fits next to tape recorder control	
12 Cable Set	1 Set	15	Requires access to plenum chamber for installation of subfloor cabling	

Table 12.1-3 Bulk Processing Installation Requirements

Hardware Item	Quantity	Installation Sequence	Rationale	Comments
BULK PROCESSING				
1 Hi Resolution Film Recorder	1	16 and 17	Bulky Items – May require wall removal for movement into area	
2 RBV Video Tape Recorder	1	20	Fits next to HRFR Control	
3 RBV Video Tape Recorder/Reproducer Control	1	21	Fits next to RBV recorder	
4 MSS Video Tape Recorder/Reproducer Control	1	22	Fits next to RBV control	
5 MSS Video Tape Recorder	1	23	Fits next to MSS video tape control	
6 HRFR Control		18 and 19	Fits next to film recorders	Not previously shown on layout drawings (Contains EBR Imag Corrector)
Teletypewriter	1	24	First item of last row of equipment	
8 Control Computer	1	25	Fits next to TTY	
9 Control Computer Interface	1	26	Fits next to computer	
10 Hi Density Digital Tape Recorder Control	1	-	Fits next to computer interface	
11 Annotation Generator	1	8	Fits next to HDDT recorder control	
12 Tape Units (Computer)	-	29 and 30	In-line installation fit next to annotation generator	
13 Hi Density Digital Tape Recorder	1	31		
14 Electron Beam Recorder Image Corrector	1	-		Installed in rack with HRFR control [illegible]
15 Cable Set	1 Set	3	Requires access to plenum chamber for installation of subfloor cabling	

Table 12 1-4 Photo Processing Installation Requirements

Hardware Item	Quantity	Installation Sequence	Rationale	Comments
PHOTO PROCESSING				
1 Fixed Focus Enlarger 70 mm-9-1/2 x 9-1/2	1	5		
2 Color Composite Printer and Punch	1	1	Requires wall removal for installation - Bulky item	
3 Contact Printer - B&W	2	With items 5 7 6 10		
4 Contact Printer - Color	1	With items 8 and 10		
5 Continuous Strip Printer B&W	1	With items 3 6 7 10		
6 Film Processor - B&W	5	With items 3 5 7 10		
7 Paper Processor and Dryer-B&W	2	With items 3 5 6 7 10		
8 Paper Processor and Dryer-Color	1	With items 4 and 10		
9 Film Processor - Color	1			
10 Paper Print Cutter - Auto	2	With items 3 4 5 6 7 8		
11 Photo Chem Mixers and Storage Units	TBD/AR			
12 Egg Sensitometer	1			
13 Reflection Densitometer	2	-	Items 13 and 14 should be available for items 4 8 and 10 checkout	
14 Transmission Densitometer	3	-		
15 Color Transmission Densitometer	1			
16 Light Tables	5			

*TBD/AR = To be determined as required

Table 12 1-5. Microfilm Processing Installation Requirements

Hardware Item	Quantity	Installation Sequence	Rationale	Comments
MICROFILM PROCESSING AND REPRO			No specified installation sequence is required	
1 Microfilm Reader	2	N/P		
2 Cartridge File	1	N/P		
3 Optical Printer	1		- Priority item for Checkout	
4 Microfilm Processor	1		- Priority item for Checkout	
5 Roll Contact Printer	1		- Priority item for Checkout	
6 Microfilm Editor	1			
7 Cartridge Loader	1	N/P		
8 Microfilm Splicer	1	N/P		
9 Microfilm Winder	1	N/P		
10 Aperture Card Mounter	1			

*N/P - No priority

Table 12.1-6. Utility Darkroom Installation Requirements

Equipment	Quantity	Installation Sequence
1. Contact Printer, Studio Type	1	Utility photo processing function is not priority item. No installation sequence is required.
2. Enlarger 4 x 5 Format	1	
3 Color Enlarger 10 x 10 Format	1	
4. Print Processing Sink/Washer	1	
5. Color Print Processor, Rapid	1	
6 Print Dryer	1	
7. Copy Camera	1	
8 Chemical Mixers	A/R	
9. Chemical Storage Units	A/R	
10. Trays	A/R	
11. Light Tables	A/R	

Table 12 1-7 Storage Equipment Installation Requirements

Hardware Item	Quantity	Installation Sequence	Rationale	Comments
STORAGE			No specified installation sequence is required	
1 Tape Storage	A/R*	N/P*		9000 tapes
2 Film Storage	A/R	N/P		Tub File Shelves Bucket files
3 Punch Card Storage	A/R	N/P		50 000 cards
4 Materials Storage	A/R	N/P		

*N/P = No priority
A/R = As required

Each component performance test will be conducted in accordance with a previously prepared test procedure and inspection planning as prepared by the manufacturer

Software provided as part of the NDPF system will undergo performance testing by the developing agency on hardware similar or identical to the hardware for which it is to be prepared Final acceptance of software modules and programs will be deferred to final subsystems or systems acceptance test to be performed at GSFC

Government Furnished Equipment (GFE) supplied to NDPF contractors for use during performance or acceptance testing will be considered as having successfully completed formal acceptance test prior to receipt

A make/buy breakdown has been assumed in the following discussions to show the difference in flow

12 2 1 1 Component Test Plan

Figure 12 2-1 shows in block diagram form all components comprising the NDPF system and the planned flow from fabrication to integration into the next higher subsystem

In an effort to reduce redundant testing and associated costs, those components which are not dependent on or for operation of components in a subsystem will be shipped directly from the manufacturer's plant to GSFC for installation and integration. Other components, where required, will be shipped from the manufacturer's plant to the subsystems manufacturing facility for integration and test of the total subsystem

12 2 2 SUBSYSTEM TEST CRITERIA

Functional subsystem tests will be conducted to obtain a confidence level in the equipment design and fabrication prior to higher level testing at GSFC Tests will be performed with static test signals and will be conducted to verify that the NDPF subsystems will meet the performance characteristics and requirements of all discrete functions, utilizing special test equipment and software where needed to simulate and/or record input/output data All logic circuitry will be checked for proper performance relative to requirements with static input signals

Upon satisfactory completion of these tests, a final factory subsystem acceptance test will be performed on each subsystem and between subsystems where applicable The test data will be recorded to provide documented evidence of the successful completion of the test This data will be shipped with the equipment These tests will utilize the same approach for verification of the discrete and analog functions as noted in the preceding paragraph

12.2.2.1 Subsystem Test Plan

Factory acceptance test of the NDPF subsystems will follow the plan and sequence shown in Figure 12 2-2 and as defined in the preceding paragraphs This test program will be controlled through test plans and procedures developed to assure compliance to the requirements of the subsystem specifications Functional testing or demonstration of performance characteristics will be reserved primarily for higher level testing at GSFC to minimize cost of redundant simulation. Before any equipment is shipped from the factory, all operable components will be exercised and all interfaces monitored and evaluated for acceptability in accordance with the test plan requirements

12 2.3 NDP SYSTEM ACCEPTANCE

12 2 3 1 Criteria

Final acceptance and buyoff of the NASA Data Processing Facility will be based on the successful demonstration that all performance criteria specified in the NDPF System Requirements Specification are fulfilled. The final acceptance test will be conducted at GSFC by Contractor personnel and will be performed only upon successful completion of component and subsystem integration and test.

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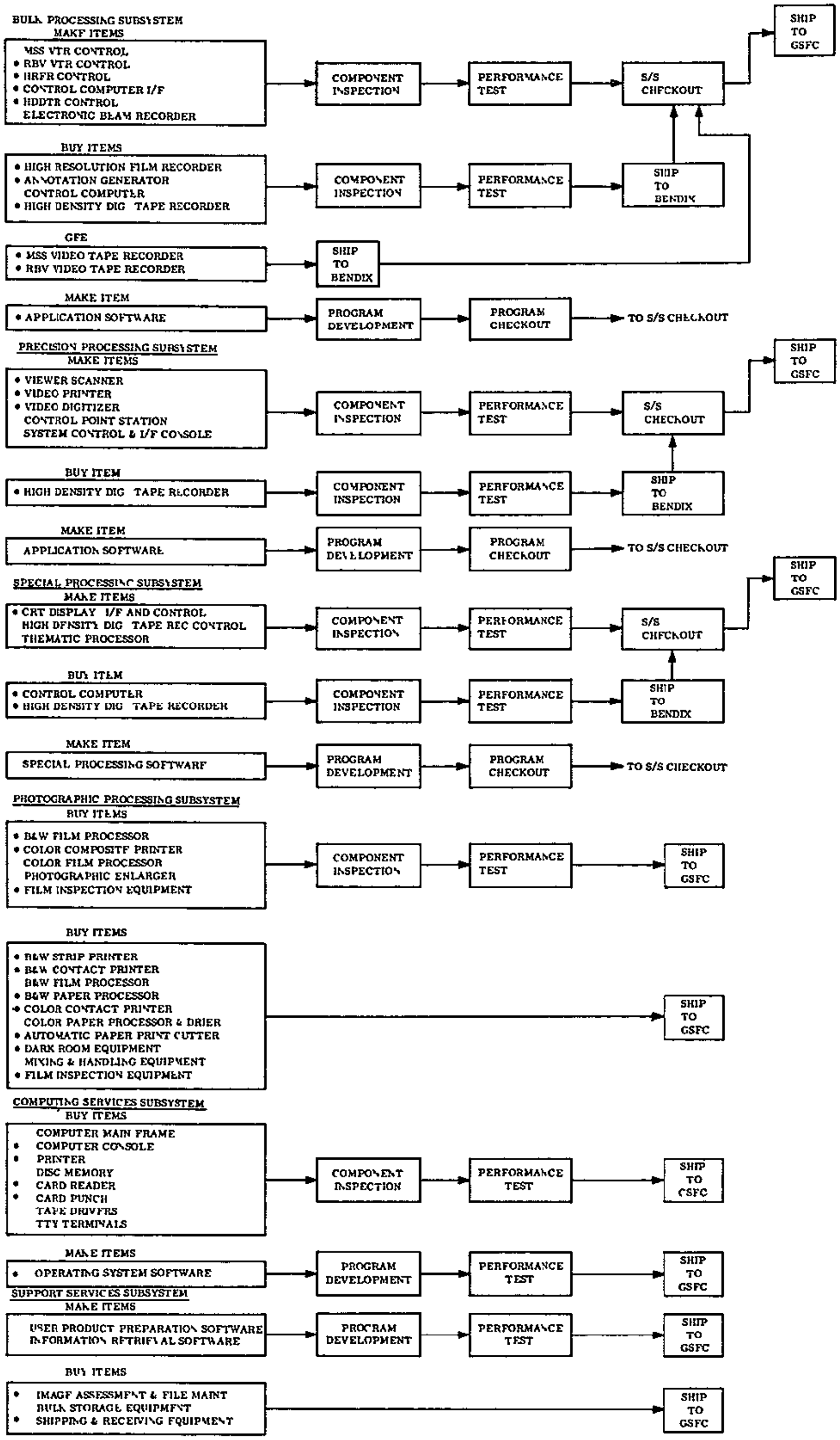


Figure 12 2-1. Component Test Plan

Test procedures governing the system configuration, test stimulus (live or simulated), output data and supporting test equipment will have been generated and approved by the Contractor and NASA/GSFC prior to test conduct and will be used, in addition to the test team, by the Contractor and NASA/GSFC Quality Assurance personnel to verify adequacy and accuracy of the test and resultant data

Upon successful completion of the NDPF acceptance test, all data will be submitted to NASA/GSFC for approval and system buyoff.

12 2 3 2 Test Plan

Prior to any equipment interconnection and/or operation at GSFC, all interfaces will be verified mechanically and electrically. The following requirements of the NDPF shall be verified by demonstration and will utilize an acceptable spacecraft simulator system as stimulus

1 Conversion of RBV and MSS video data to film

2 DCS data processing

3 Precision and special processing techniques

4 Data storage and access

5 Production and distribution of all data products

6. Satisfactory demonstration of total system readiness

Figure 12 2-3 shows in block diagram form all subsystems comprising the NDPF system and the present plan for system acceptance flow

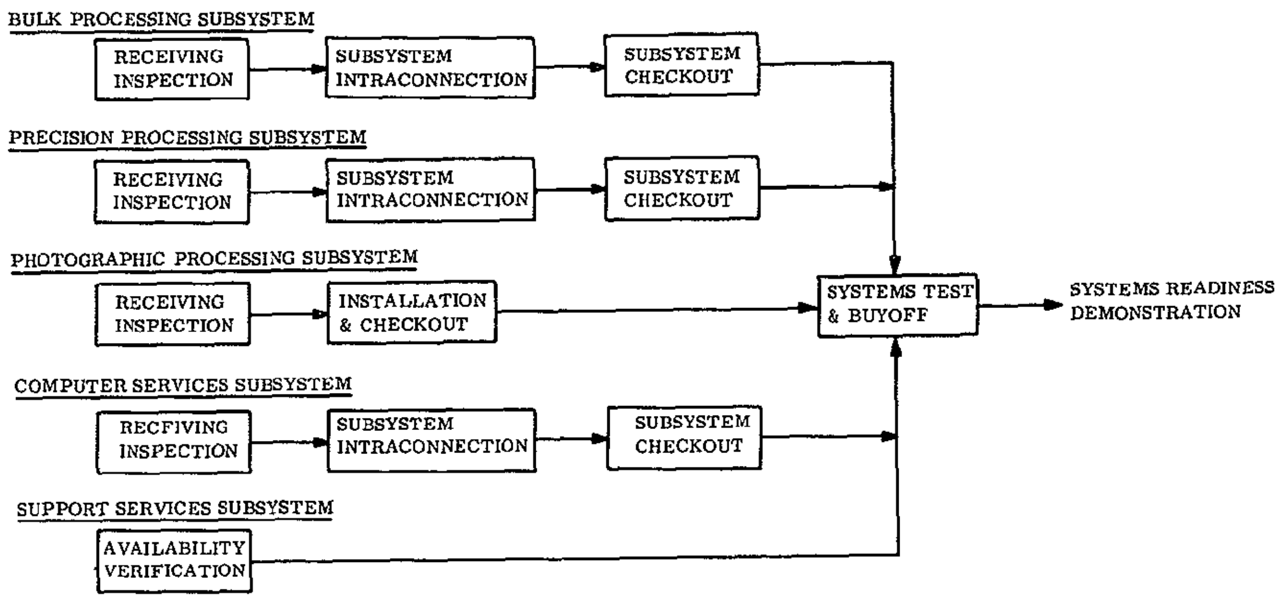


Figure 12.2-3. NDPF System Acceptance Test

SECTION 13

NDPF SUPPORT FUNCTIONS

13 NDPF SUPPORT FUNCTIONS

SECTION 13
NDPF SUPPORT FUNCTIONS

The basic operating objective of the NDPF is the efficient throughput of quality imagery at a rate easily adjusted to the observatory output

Previous sections have discussed the trade studies performed to arrive at the optimal system design configuration The selected approach combines equipment production rates and shift manpower in a highly efficient, flexible system

This section defines the operations support aspect of the NDPF in terms of its

Operational Requirements (13 1)

Data Flows (13.2)

Operating Timelines (13 3)

Organization and Staffing (13 4)

Maintenance and Logistics (13 5)

13.1 NDPF OPERATIONAL REQUIREMENTS

13 1.1 PHOTOGRAPHIC MATERIAL LOADING

Table 13 1-1 shows the requirements for production of photographic materials in the NDPF Numbers are based on Case B loading, and where not specified, numbers are weekly (7 days) figures Ability to meet Case B production requirements in 120 hours automatically implys the ability to satisfy Case A in a 40 hour week These requirements and throughput levels are summarized in Table 13 1-2 for Case A, Case B, and Recorder Limit loading cases The data production for shipment to users totals as follows

9,672 Black-and-white masters

96,720 Black-and-white negatives

96,720 Black-and-white positive transparencies

96,720 Black-and-white positive prints

986 Color composite negatives

9,864 Color prints

Detailed analysis of the system throughput appears in Section 4 5 2 The photographic processing is discussed in Section 11 4

Table 13.1-1 NDPF Production Requirements

B-W	Black and White
C	Color
+	Positive transparency
-	Negative transparency
+ Prints	Positive paper prints
C Prints	Color Positive Paper prints

RBV Input

188 Scenes/Day — 1316 Scenes/Week
564 Images/Day — 3948 Images/Week

Product	Scenes Per Week	For Each Scene	Items Per Week
100% Bulk	1316	3 B-W masters	3,948
		30 +	39,480
		30 -	39,480
		30 + prints	39,480
20% Bulk Color	263	1 C-	263
		10 C prints	2,360
5% Precision	66	3 B-W masters	198
		30 -	1,980
		30 +	1,980
		30 + prints	1,980
		1 C-	66
		10 C prints	660
		Computer Readable	≈ 238 Tapes
1% Digitized	13 2	3 copies Computer readable	≈ 158 tapes

MSS Input

188 Scenes/day — 1316 Scenes/week
752 images/day — 5264 Images/week

Product	Scenes Per Week	For Each Scene	Items Per Week
100% Bulk	1316	4 B-W masters	5,264
		40 +	52,640
		40 -	52,640
		40 + prints	52,640
20% Bulk Color	263	2 C-	526
		20 C prints	5,260
5% Precision	66	4 B-W masters	264
		40+	2,640
		40 -	2,640
		40 + prints	2,640
		2 C-	132
		20 C prints	1,320
		Computer Readable	≈ 238 Tapes
5% Comp Readable	66	3 copies Computer Readable	≈ 713 tapes

Table 13 1-2. Case A, Case B, and Recorder Limit Cases

	Case A	Case B	Recorder Limit
1. Images/day (4/7 MSS + 3/7 RBV)	315	1,316	2,268
2 Images/week (4/7 MSS + 3/7 RBV)	2,205	9,212	15,876
3 Color neg, RBV/week (20% of line 2 — 3 x 3/7)	63	263	453
4 Color neg, MSS/week (line 3 x 2)	126	526	906
5 Total, line 3 + line 4	189	789	1,359
6 Precision B&W neg/week (5% of line 2)	110.3	460 6	793 8
7 Precision color neg/week (3/7 of line 6)	47 4	197.4	340 2
Bulk B&W images/hr - 40 hr week	55 1	230 3	396 9
- 80 hr week	27.6	115 2	198 5
- 160 hr week	13 4	56.1	96 8
Production Processing			
8 B&W bulk/week (10 x line 2)	22,050	92,120	158,760
9 Color bulk/week (10 x line 5)	1,890	7,890	13,590
10 Precision B&W/week (10 x line 6)	1,103	4,606	7,938
11 Precision color/week (10 x line 7)	473	1,974	3,402

13 2 NDPF OPERATIONAL FLOW

13 2.1 INTRODUCTION AND OVERVIEW

The fundamental NDPF generation depends upon the following inputs

1. Spacecraft Performance Data Tape (SPDT) - From the OCC
2. Best Fit Ephemeris Tape (BFET) - From NASA
3. Wideband Video Tapes - From receiving stations
4. Requests for data - From the user community

From these inputs, the NDPF

1. Generates master images
2. Performs precision processing
3. Reproduces data for users
4. Processes and distributes DCS data
5. Ships data to the users

Each of these functions is subject to flow timeline analysis Other functions, such as user services, information systems maintenance, and computer generated data production have short and frequently executed time sequences and, hence, are not suitable to flow analysis

Timeline analysis for the NDPF may be broken into two basic cycles the 18-day coverage cycle and the 10-day production cycle The 18-day coverage cycle represents a period in which all points of the earth's surface have been available for observation by the spacecraft The 18-day coverage cycle is significant from an assessment point of view only All catalogs, cumulative microfilms, and coverage documents will be geared to that 18-day cycle

All catalog materials will be prepared or maintained in the Information Retrieval Data Bank on a daily cycle Montage paste-ups will be performed upon a daily cycle. Thus, if we assume that all information is available for assessment 5 days after the observation, then the preparation of catalog materials for 18-day coverage catalogs may begin 5 days after the 18th day of the cycle.

Because all catalog materials will be maintained in an up-to-date form, no more than one day will be required by the Catalog Preparation group to get the materials proofed, indexed, and forwarded to NASA/GSFC graphic arts facility for production Assuming a one week production cycle for catalog printing, and one day for packaging and labeling, the total lapsed time between the end of an 18-day cycle and the mailing of catalogs to users will be as follows

Day	
0	Last day of 18-day coverage cycle
5	All data ready for assessment
6	Materials sent out for printing
13	Materials returned from printing
14	Materials mailed to users

It should be noted that the two major delays in catalog production are the result of processes outside the control of the NDPF The 5-day delay to have data ready for assessment is a function of delays in the forwarding of wideband video tape and best fit ephemeris tape The week publication delay is based upon a quick reaction publication requirement and is considered a minimum production cycle for a 1,000 catalog job

It should be pointed out, however, that the catalog production period is a fixed processing schedule Thus, if a 6-month catalog were desired, it could be produced and printed in the same nominal 14-day preparation cycle

The 10-day production cycle is based upon the requirement to deliver data to the user within 10 days of the observation The following processes are involved

1 Receive the PCM data stream (Spacecraft Performance Data Tape, SPDT)

2 Receive the ephemeris data (Best Fit Ephemeris Tape, BFET)

3 Receive the video tape

4 Process the PCM data and ephemeris data to produce an Image Annotation Tape

5 Process the Image Annotation Tape and the video tape to produce the master image (IAT)

6 Process and quality check the master image

7 Assess the master image for cloud cover and quality

8 Generate work orders which define the required photographic processing

9 Perform the photographic processing

10 Collate and ship the data to the user

As ıllustrated ın Fıgure 13.2-1, Steps 4 and 5 are dependent upon prevıous steps and may ınvolve delays Step 4, generate the IAT, cannot be done untıl the BFET whıch correspond to the SPDT are avaılable Step 5, generate the master ımages, cannot be started untıl the IAT whıch corresponds wıth the vıdeo tape ıs avaılable After these steps, however, all processıng ıs lınear

Not shown ın Fıgure 13 2-1 are the DCS flow and the flow ın the Photographıc Productıon facılıty The DCS flow ıs gıven ın Sectıon 13.2 2 and the photographıc flow ıs presented ın Sectıon 13 2 3

Tımelıne analysıs for the 10-day cycle ıs dıscussed ın Sectıon 13 3

13 2 2 DCS DATA FLOW IN THE NDPF

DCS data are receıved ın the NDPF wıthın 30 mınutes of theır receıpt and preprocessıng by the OCC. Data tapes are processed on the NDPF control computer as they are made avaılable, the output from thıs processıng ıs valıdated and sorted DCS data stored ın the Actıve DCS Fıle mounted ın random access storage At the end of 24 hours, the Actıve DCS Fıle ıs copıed onto magnetıc tape for off-lıne storage

Requests for recent data are satısfıed by accessıng the Actıve DCS Fıle Thus, requests for recent data may be processed wıthın 40 mınutes of data receıpt at the OCC Request for data older than 24 hours requıres ıdentıfyıng the data tape, gettıng the tape from storage, settıng up the computer run, and performıng the processıng Because these data wıll no longer be consıdered perıshable, a processıng perıod of 48 hours ıs acceptable.

13 2 3 PHOTOGRAPHIC MATERIAL FLOW IN THE NDPF

The summary of the flows by functıon ıs shown ın Fıgures 13.2-2 through 13 2-5 These flows show functıons beıng performed to the data flow (solıd lınes) and the control ınterfaces for qualıty maıntenance (dashed lınes) Common equıpment to perform these functıons has been ıdentıfıed ın Sectıon 11 5

13 2 3 1 Generatıon and Inıtıal Processıng of Imagery

The Master Image Generatıon portıon of the Bulk Image Processıng Subsystem converts vıdeo data to 70-mm fılm When suffıcıent fılm ıs exposed, the roll ıs removed from the fılm recorder and processed Nomınally, thıs wıll be done on a 4-hour basıs to allow suffıcıently frequent qualıty assessment As ıs done wıth fılm throughout the NDPF, suffıcıent tıme (30 mınutes) ıs allowed for latent ımage formatıon between exposure and development The development of these ımages must be closely controlled and evaluated to ensure the productıon of the desıred qualıty ımages

One spectral band wıll be used, as descrıbed ın Sectıon 11 6, for cloud cover and gross usefulness evaluatıon Thıs evaluatıon and any evaluatıon provıded from Master Image Generatıon (such as the ıdentıfıcatıon of test frames) wıll be used, along wıth productıon requırements stored ın the NDPF Informatıon System, to produce a Work Order Thıs Work Order wıll ıdentıfy those frames to be further processed

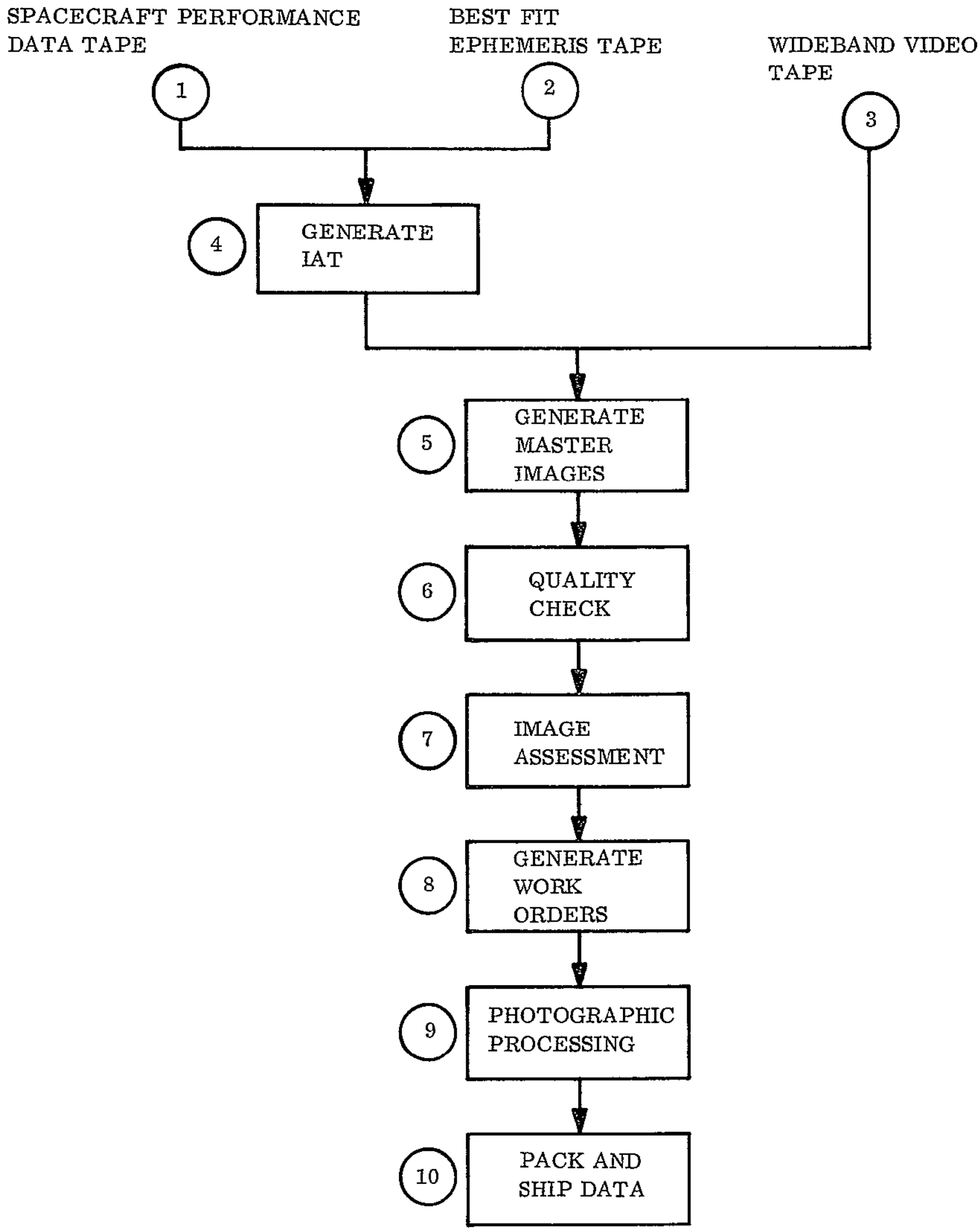


Figure 13 2-1 Ten Day Bulk Processing Cycle Flow

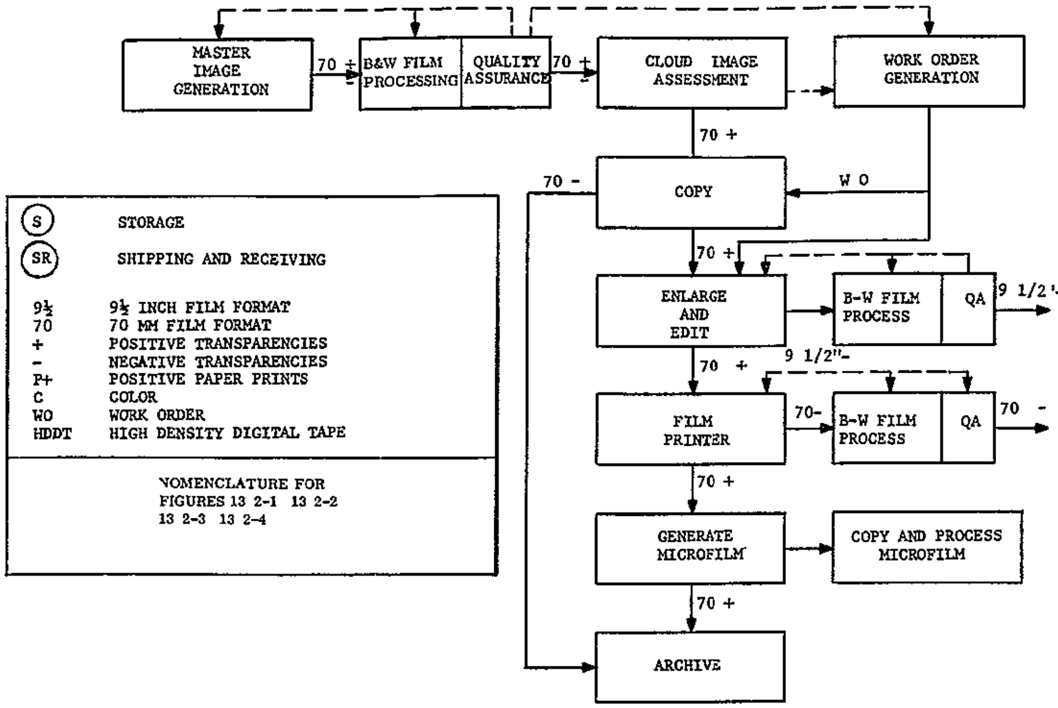


Figure 13 2-2 Flow for Generation and Initial Processing of Imagery

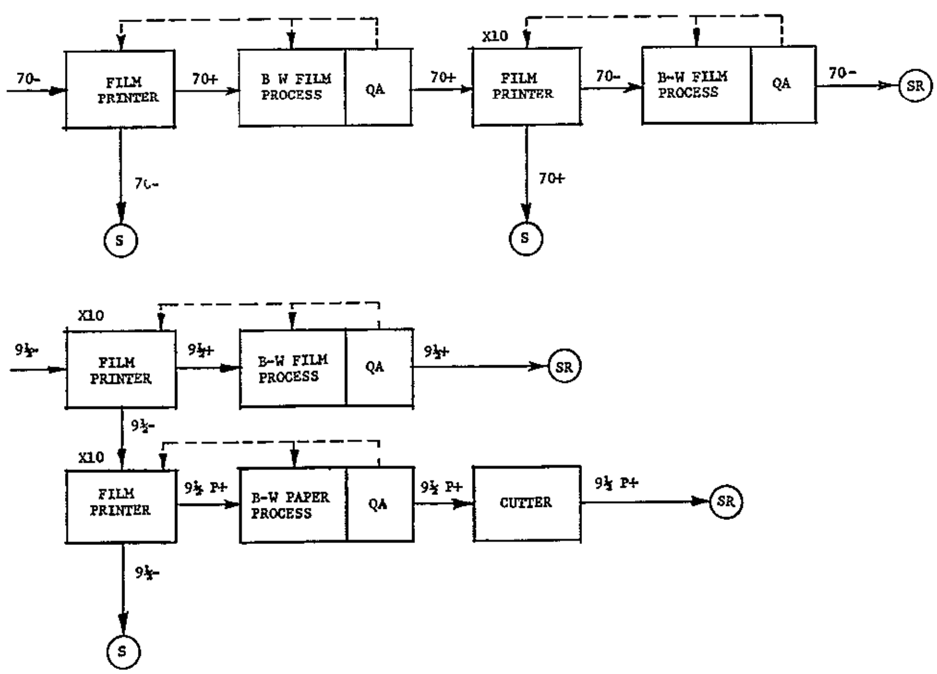


Figure 13.2-3. Flow for Production Processing

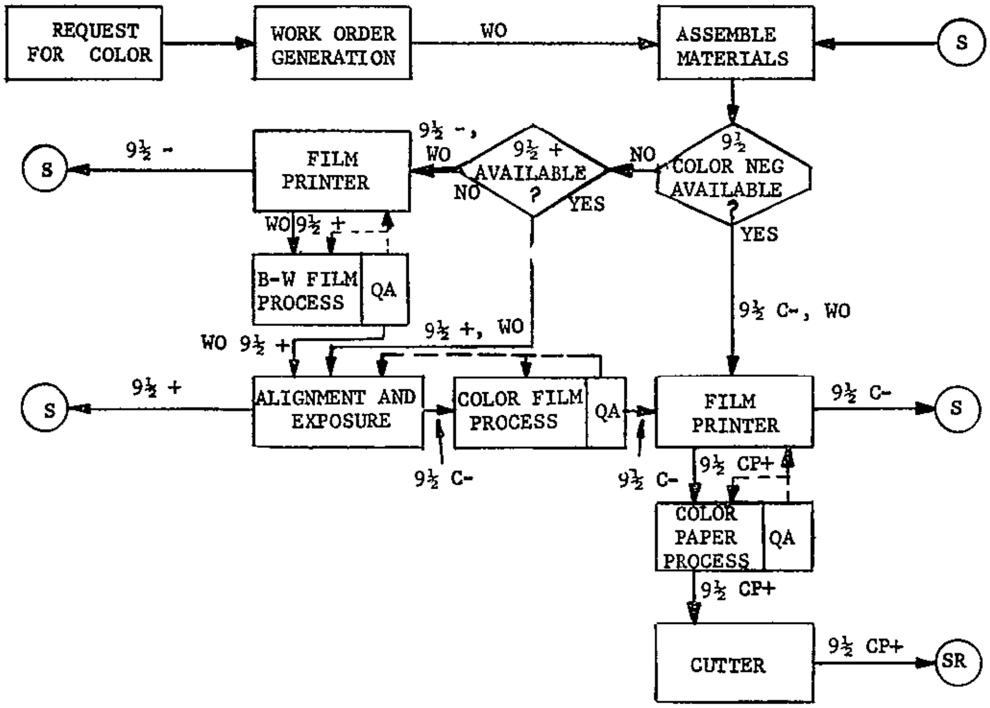


Figure 13 2-4 Flow for Color Production

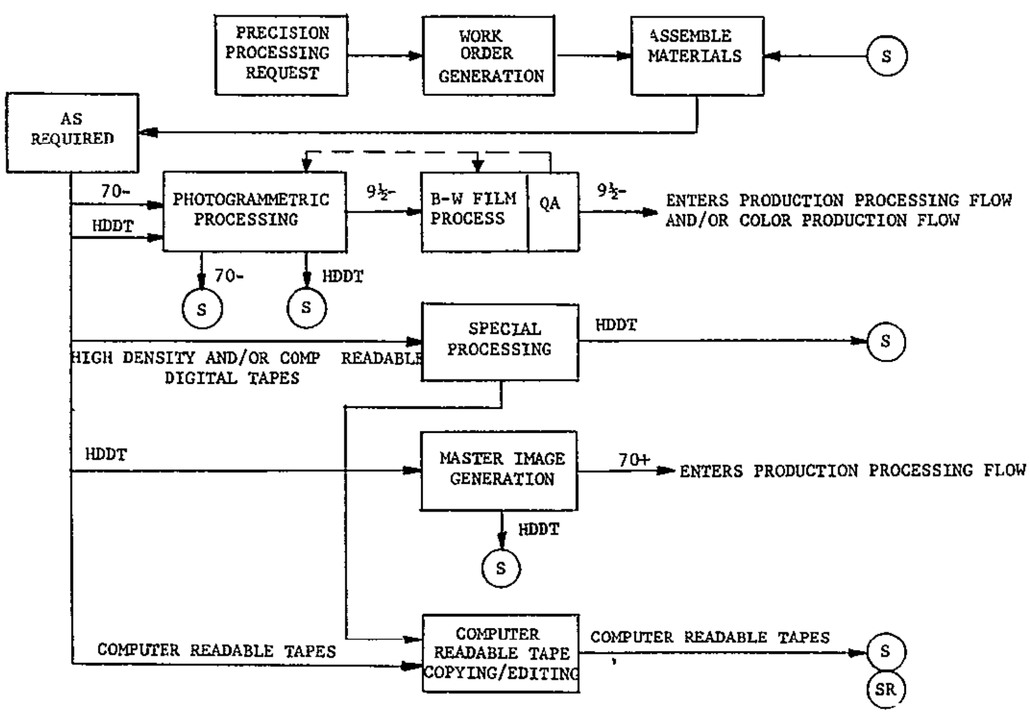


Figure 13 2-5 Flow for Precision Processing

As shown in Figure 13 2-2, the function of selecting those frames to be processed is done on the enlarger, and is a "yes-no" decision, frame by frame The original 70-mm roll of positives is copied (perhaps with editing again) to produce a 70-mm roll of negatives, and to produce negative microfilm imagery It is then placed in archive storage The output from the enlarger is 9-1/2-inch rolls of negative imagery, processed to produce quality working negatives The 70-mm negative roll is processed, copied to produce working 70-mm positives, and saved for possible input to the Photogrammetric Processing section of the Precision Processing Subsystem The load up to this point is 9,212 images per week through each of the functions identified Section 11 4 shows that this is a small part of the total load

13 2 3 2 Production Processing

As shown in Figure 13 2-3, the 9-1/2 inch roll of working negatives is used to make 10 rolls of 9-1/2 inch positive transparencies, 10 rolls of 9-1/2 inch positive prints (which are cut), and the 70-mm working positives are used to make 10 copies of 70-mm negative transparencies for shipment to the users

13 2 3 3 Color Processing

Color processing (Figure 13 2-4) is done on request, and, as necessary, 9-1/2 inch positive transparencies are made (to required density range) on cut film These positives are aligned and exposed as explained in Section 11 5 1 to produce a color negative This negative is processed and used to produce 10 color prints for the users

13 2 3 4 Precision Processing

Precision processing (Figure 13 2-5) includes producing precision-corrected 9-1/2 inch negatives or computer readable tapes with appropriately edited and processed digitized imagery Use of high-density digital tape allows use of the EBR and the 9-1/2 inch film printer in Photogrammetric Processing for converting digitized data to film It allows input and output of digitized imagery with the computer for editing, processing, or conversion to standard computer-readable tapes Also, both raw and precision-corrected imagery can be placed on high-density digital tape, with no slowdown to the respective processes

13.3 NDPF OPERATING TIMELINES

The timelines for accomplishing the NDPF functions just described are presented in the following sections.

13.3.1 BASIC 10-DAY NDPF TIMELINE

The following processes must be performed serially before bulk image data can be sent to the user. While many of these processes may be performed in a relatively short period of time, total unit production may delay their availability for as much as a day. For this reason, one must consider processing which will speed system timelines without adversely affecting throughput. In this discussion, loading estimates are given for Case B normalized to a five-day week.

Receipt of PCM Data (2-shift operation) This will be done in real time, and the spacecraft performance data tape (SPDT or engineering units tape) will be ready for the generation of the Image Annotation Tape (IAT) and the Master Digital Data Tape (MDDT) within 1 hour

Receipt of Video Tapes (1-shift operation)
Tapes will be received either at the OCC or forward to the NDPF In either case, they will be logged and available for processing within one hour of their receipt in the NDPF.

Receipt of Ephemeris Data (1-shift operation)
Ephemeris data will be received by the OCC and available to the NDPF within minutes

Generation of IAT (2-shift operation).
The IAT is produced when the SPDT and Ephemeris data are available If the SPDT contains one day's processing, the outputs would be one IAT for each reel of video tape recorded and a single summary MDDT. For Case B, a maximum of two MDDT tapes would be produced per day, for Case A, the number would be one tape per day, with additional computing possible Processing time may be taken as four hours for the production of all IAT data.

Generation of 70-mm Master Images (2-shift operation).
The 70-mm master images are produced when a video tape and associated IAT are available The MSS throughput rate is approximately 4 times slower than RBV processing The setup time is five minutes per tape (or pass) Thus, the processing for an average pass would be 15 minutes for RBV and 45 minutes for MSS data In both Case A and Case B the number of images produced in a single day of processing will be less than the proposed film storage of the recording equipment Thus, data will be made available for processing only once per day To even out the processing which will follow, RBV and MSS data should be unloaded and forwarded to processing at different times of the day

Processing and Inspection of 70-mm Master Images (2-shift operation)
The exposed film will be removed from the recorder and sent to a film processor Counting setup time and routing of materials, two hours will be required before the images can be quality control inspected Assuming 10 percent inspection at three minutes per image

	Case A	Case B
Inspection time, RBV (minutes)	57	237
Inspection time, MSS (minutes)	75	315

for approximately 1 hour for Case A and 4.5 hours for Case B.

Image Assessment (3-shift operation)
Image assessment requires the estimation of cloud cover for a sample image and the recording of quality expections Assuming that cloud cover assessment may be prepared at two minutes per image

	Case A	Case B
Observations made per day	63	263
Minimum total assessment, time per day (minutes)	123	526
Entering of quality data (minutes)	30	60

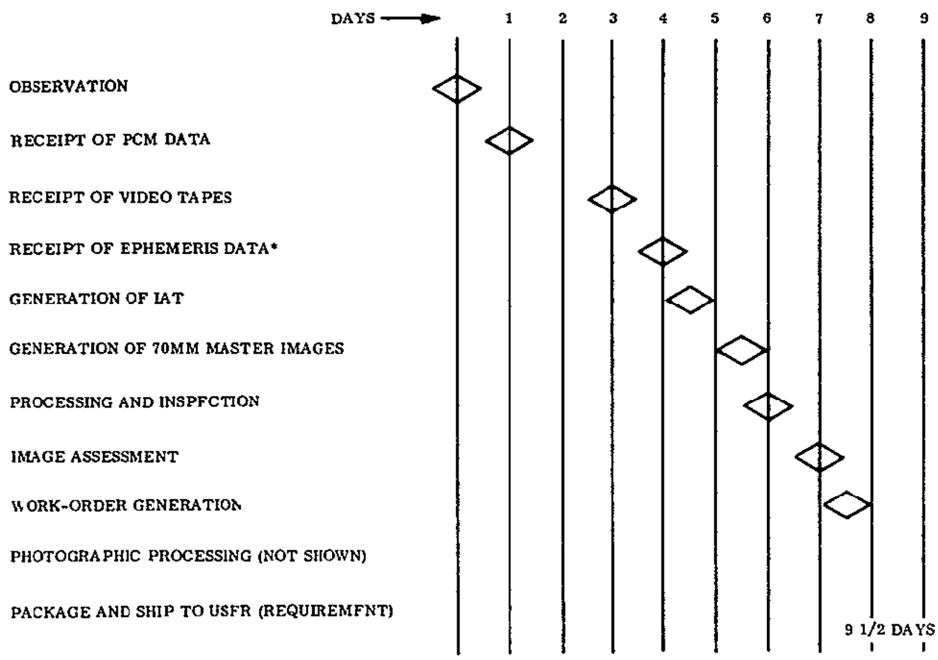
For Case A, there is no throughput problem. For Case B, two inspection stations are recommended for equipment redundancy Two stations will also allow for relaxed equipment utilization to assure accurate image assessment

The output of this step is computer-sensible data Assuming a direct entry device is available, data are entered as generated In a backup mode, an off-line device is used, and work will be batched in hour processing loads This would result in a total two-hour hold before the next step can begin.

Work-Order Generation (3-shift operation)
Once the above data are available to the information system, work orders are generated Assuming normal priorities, one hour's image assessment data requires one hour of processing before work orders are generated

Photographic Processing (3-shift operation)
The photographic processing facility has been designed to process many independent small jobs concurrently The processing timeline of each production form is a function of the data form produced. A discussion of each processing timeline is given in the section below. Based on that analysis, all data should be received, processed, collated and packed for shipment within 2 working days (6 shifts)

The cumulative result of these timelines, presented in Figure 13 3-1, is the worst case timeline for NDPF Bulk Processing.



*WORST-CASE DELAY OF 4 DAYS FOR EPHEMERIS DATA ALLOWS FOR SHIPMENT TO USER WITHIN 9 1/2 DAYS SINCE OBSERVATION

Figure 13.3-1 Worst-Case Time Line for Bulk Processing

13 3 2 PHOTOGRAPHIC PROCESSING TIMELINES

As mentioned in the previous section, photographic processing timelines are a function of the materials used There are three basic production lines in the photographic facility

1 Black-and-white film

2 Black-and-white paper

3 Color paper

The processing time is a function of material size and quantity throughput figures for equipments are given in Section 11 4 Assuming one hundred 9 1/2 by 9 1/2 inch images, the following timelines apply These timelines reflect the equipment throughput rates used in the analysis reported in Section 4 5.2 With the NDPF running on a 5 days per week, three-shift basis, these timelines will satisfy the photographic processing production requirements The facility will have much of this processing going on concurrently Delays between production processes will normally be the result of the existence of a queue, representing one hour's processing

Black-and-white Time Processing	
Time (minutes)	Operation
0	Materials assembled and ready for exposure
8	Materials exposed (contract prints, no editing)
30	Latent image stabilization delay
38	Materials ready for development
20	Materials processed
4	Quality control inspection
62	Materials ready for assembly for shipment

Black-and-white Paper Processing	
Time (minutes)	Operation
0	Materials assembled and ready for exposure
8	Materials exposed (contact prints, no editing)
8	Materials ready for development
10	Materials processed and dried
4	Quality control
22	Materials ready for cutting
6	Materials cut
28	Materials ready for assembly for shipment

Color Paper Processing	
Time (minutes)	Operation
0	Materials assembled and ready for exposure
8	Materials exposed (contract prints, no editing)
8	Materials ready for development
32	Materials processed and dried
4	Quality control
44	Materials ready for cutting
6	Materials cut
50	Materials ready for assembly for shipment

13 4 NDPF ORGANIZATION, STAFFING, TRAINING AND MANUALS

Efficient execution of the flow described in the preceding section is implemented by the staff described below The organization of this staff is shown in Figure 13 4-1

13 4 1 NDPF CONTROL MANPOWER REQUIREMENTS

A NDPF Director Responsible for the overall operation of the NDPF Coordinates activities in the NDPF and serves as the principal point of contact for all GSFC contractor interfaces

B NDPF Assistant Director Provides assistance to the NDPF Assistant Director shall also serve as the Director, Production Control

C Administrative Assistant Responsible for accounting and budgeting procedures and management reports, as well as secretarial services

D Secretaries Act as receptionists and do typing for NDPF Director and NDPF elements

E Supervisor, User Services Responsible for all NDPF activities associated with user requirements, including request services, publications preparation, and special programming

F User Services Clerical Assistants Performs all clerical tasks associated with serving requests for data and information Prepares and monitors inputs to the information system which relate to user services

G Publications Chief Senior technical writer responsible for the preparation of NDPF publications and the efficient operation of the publications unit

H Publications Technician Responsible for the layout of charts, graphs, photos, and text for the preparation of publications Also maintains liaison with GSFC publication facilities

I Quality Control Coordination Responsible for the collection, evaluation, verification, and reporting of all quality control standards and procedures throughout the NDPF

J Programmer/Analyst Provides programming support and maintenance as required

13 4 2 IMAGE GENERATION MANPOWER REQUIREMENTS

A Supervisor, Image Generation Responsible to the NDPF Director for coordinating the activities of the Bulk Image Generation, and the Precision Processing Also responsible for materials and data flow in Image Generation, and supervision and training of equipment operators assigned Background should include a business administration or technical degree with five years experience in automatic data processing equipment

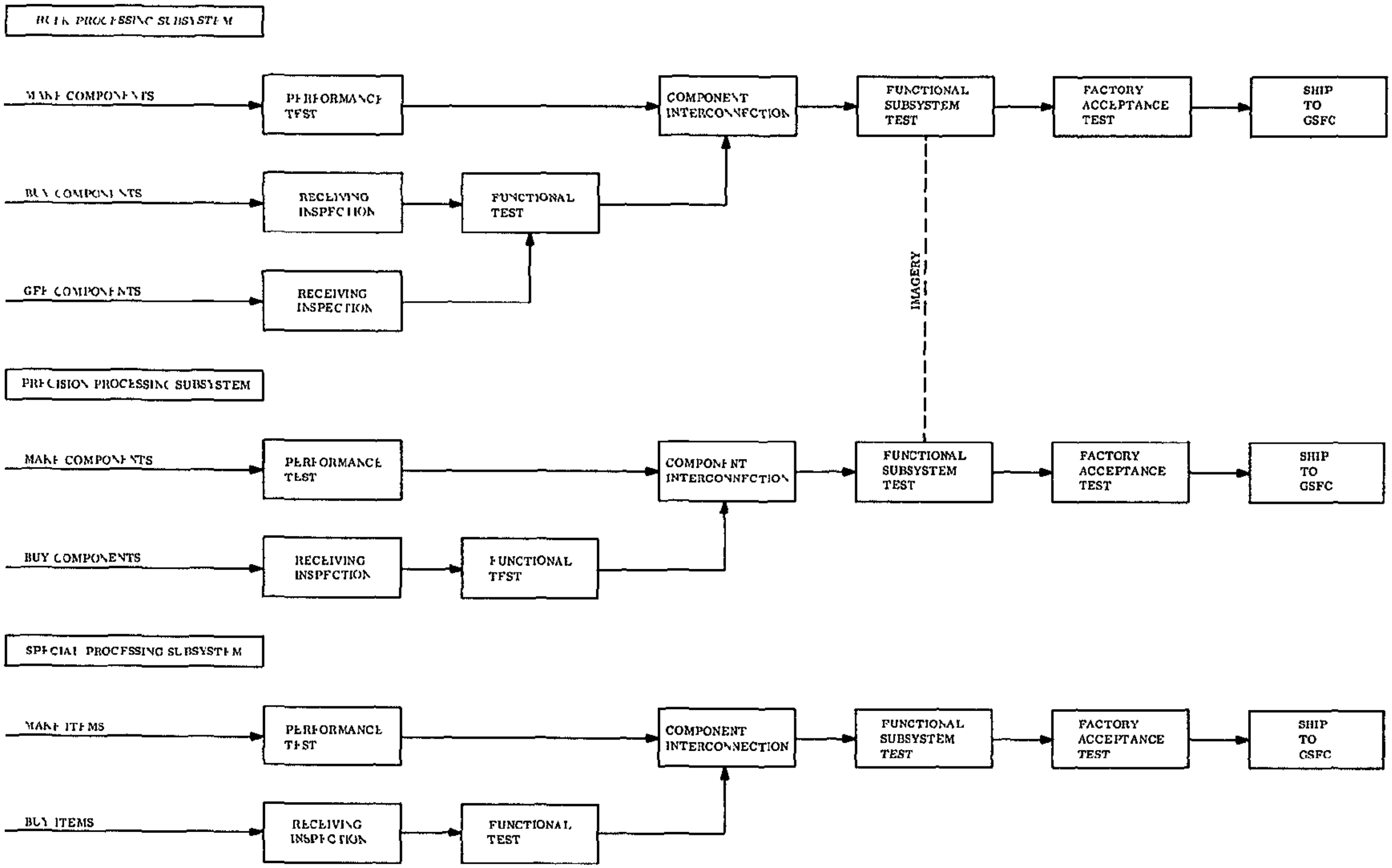


Figure 12.2-2. Factory Subsystem Test Plan

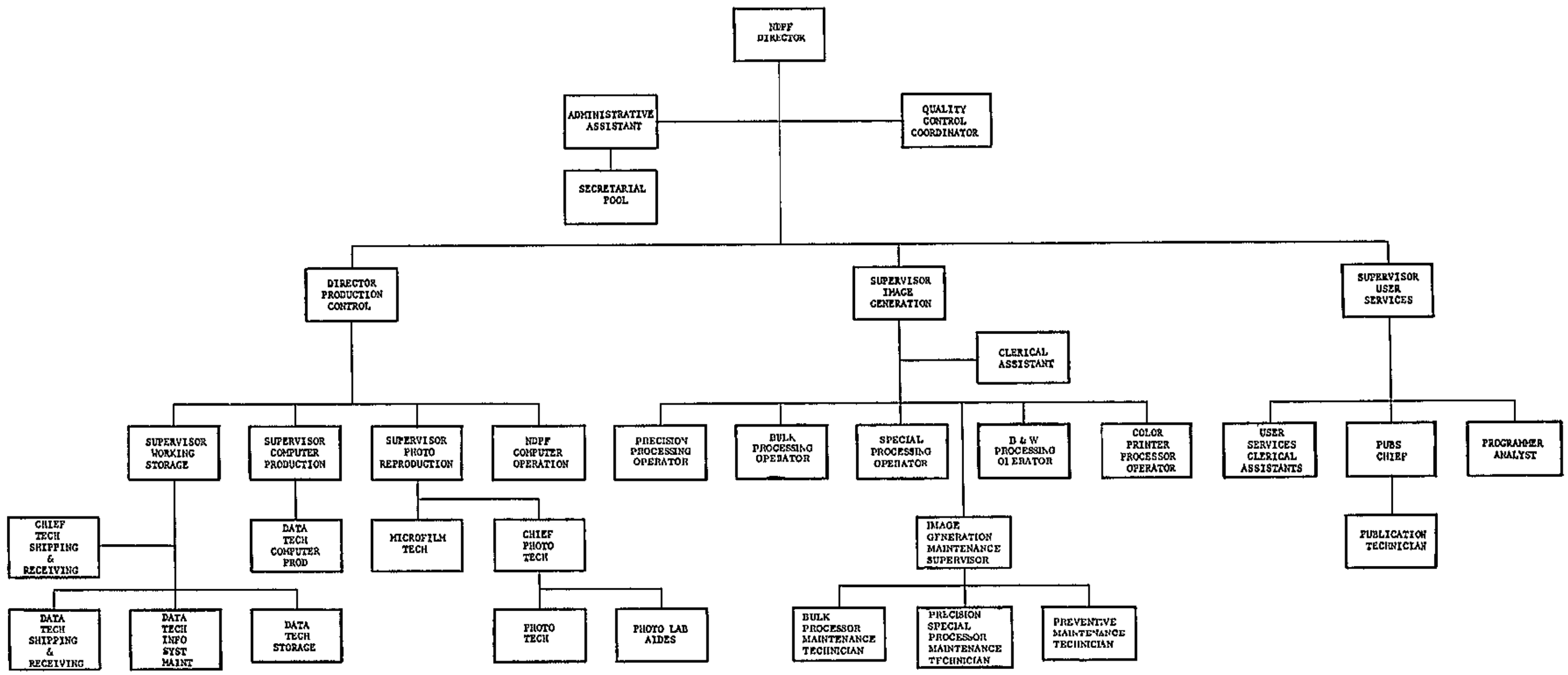


Figure 13.4-1. NDPF Organization and Staffing

B   Bulk-Processing Operator   Responsible for the operation of the High Resolution Film Recorders in producing the RBV and MSS imagery from the original video tape. Also, serves as backup operator for the Precision Processing Operator   Background should include a minimum of two years technical school and five years experience with electronic film recording, with analog and digital equipment

C   Precision Processing Chief Operator   Responsible for the operation of the Precision Processing Equipment in correcting the selected imagery   Background should include a degree in Photogrammetry, Geography, Cartography or related field, Mathematics through Calculus, and three to five years experience in photogrammetry, or seven to ten years practical experience in all phases of photogrammetric mapping

D   Precision Processing Operator   Responsible for operation of the Precision Processing Equipment   Also, serve as backup operator for the Bulk Processing Operator   Background should include a degree in Photogrammetry, Geography, Cartography, or related field, Mathematics through College Algebra, five to six years experience photogrammetric mapping, and knowledge or experience in computer programming or photographic technology

E   Special Processing Operator   Responsible for the operation of the Special Processing Equipment   Also, serves as backup operator for the Bulk Processing Operator   Background should include a minimum of two years technical school and three years experience with electronic film recording, thematic processing, and production of digitized image data tapes

F   Black and White Processing Operator   Responsible for the processing operations of the master black and white film from bulk and precision operations   He properly interprets the production travelers, draws the unexposed film from supply and passes on the exposed material to the processors   Also, serves as back-up operator for the Color Printer and Processor Operators   Background should include a knowledge of photographic principles and mechanical aptitude

G   Color Printer and Processor Operator   Responsible for producing color composites, and operating the color film processor   He properly interprets the production travelers, draws the unexposed film from supply, and produces color composites on negative film Also serves as back-up operator for the Black and White Processing Operator   Background should include education in photography or photochemicals, and three years experience in color photo processing

H   Image Generation Maintenance Supervisor   Responsible to the Supervisor, Image Generation for coordinating the preventive and corrective maintenance schedules, equipment replacement, recommendations for improvement of equipment, training and supervision of the maintenance technicians assigned   Background should include a minimum of two years technical schooling, seven years experience as a technician of which three years must have been in supervisory capacity

I Bulk Processor Maintenance Technician Responsible for the preventive and corrective maintenance of the Bulk-Processing Equipment including coordination with service contract personnel for the off-the-shelf equipment Requires a full understanding of the electronic equipment as well as the related photo processing and ADP equipment Also serves as back-up for the Precision Processing Maintenance Technician Background should include electronic schooling and three years experience in maintenance of electronic equipment

J Precision/Special Processor Maintenance Technician Responsible for the preventive and corrective maintenance of the Precision and Special Processing Equipment Requires an understanding of electronics, viewing optics, video scanning, video film, vacuum systems, and tape recording equipment Also serves as back-up for the Bulk Processing Maintenance technician Background should include two years electronic schooling and five years experience in maintenance of video electronic, vacuum, computer and/or electromechanical equipment

K Preventive Maintenance Technician Responsible for preventive maintenance of the computers and photoprocessing equipment used in conjunction with the Bulk Processing and Precision Processing Equipment The position will require an understanding of computer hardware and software, the interface with film scanners and recorders, and the photo developers and printers used in the photo-optical processing Also, provides assistance in preventive maintenance of Bulk Processing and Precision Processing Equipment Background should include electronic schooling and two years experience in preventive maintenance of electronic, ADP, or photo processing equipment

L Clerk Typist Provides clerical and typing support for all image generation functions

13 4 3 NDPF PRODUCTION MANPOWER REQUIREMENTS

A Director, Production Control Responsible for the scheduling and performance of all operational functions including photographic production, computer production, storage, information system maintenance, storage maintenance, and computer operations

B Supervisor, Photo Reproduction As the administrator of the Photographic Laboratory, he is responsible for overall supervision of operational personnel as well as planning and modification effort relating to facility set-up

C Chief Photo Technician Responsible for individual shift operation of photo lab, issues assignments, maintains work flow, and quality control policing

D Photo Technicians These are production line personnel, engaged in black and white or color film and print processing and duplication

E Photo Lab Aides Associated production line personnel duties will include chemical mixing and equipment maintenance

F Microfilm Technician Responsible for all production operations associated with microfilm, including generation, editing, and reproduction

G Supervisor, Computer Production Responsible for the scheduling and performance of all applications involving the NDPF computer This includes production processing, data production generation, production of catalogs, and special reports, etc

H Data Technician, Computer Production Provides support in setting up, verifying, and distributing computer generated outputs

I Supervisor, Working Storage Responsible for the scheduling and performance of all operational functions associated with the storage and cataloging of materials, shipping and receiving, and maintenance of the information system

J Chief Technician, Shipping and Receiving Responsible for the scheduling and performance of all functions which involve the collation, packaging, and shipment of materials to users and the receipt of data and supplies Also, assists the Supervisor, Working Storage, and substitutes for him in his absence

K Data Technician, Shipping and Receiving Supports the shipping and receiving function as directed

L Data Technician, Information Systems Maintenance Enters and verifies data maintained in the information retrieval data bank Also, provides keypunch services as required

M Data Technician, Storage Provides assistance in the cataloging, storage, and retrieval of data maintained in storage

N NDPF Computer Operations Supports the operation of the NDPF computer, including the operations and dispatching functions

13 4 4 MANPOWER REQUIREMENTS SUMMARY

The total NDPF manloading required is summarized in Tables 13 4-1 through 13 4-3 Positions that could be manned by M&O personnel are indicated by (M&O)

13 4 5 NDPF TRAINING

To develop the staffing and organization just described a two-phase training program is required These phases, an NDPF Orientation and selected M&O Courses, are described below The schedule for conducting this training appears in Figure 13 4-2

13 4 5 1 Image Processing Training Courses

13 4 5 1 1 Orientation Course -- Image Processing

The orientation course will present an overview of the Image Processing Subsystem, its functions, the interface with other NDPF equipment, the inputs required, and the outputs obtained The equipments covered will be the Bulk Processing Element, Precision

Processing Element, Special Processing Equipment, and although not part of the subsystem, the Photo Processing Equipment. The course will be a three-hour classroom course with the element project engineers as the instructors. The Image Processing Subsystem Familiarization Manuals will be used as the text, along with slides and a course handout.

13 4 5 1 2 Image Processing -- Operator Training Course

The operator training course includes each element of the Image Processing Subsystem The course will cover all aspects of the equipment including a complete understanding of the functions, the data flow inputs and outputs, along with the detailed operation of the equipment Following the classroom courses, the participants will receive on-the-job training with the installed equipment prior to participation in mission simulations

Table 13 4-1 NDPF Control Manpower Requirements

Position Titles	Number Persons Per Shift		Number Shifts	Total
	Case A	Case B	Case A or B	Case B
NDPF Director	1	1	1	1
NDPF Assistant Director*	1	1	1	1
Administration Assistant	1	1	1	1
Secretaries	2	3	1	3
Manager, User Services	1	1	1	1
User Services Clerical Assistants	2	4	1	4
Supervisor, Publications	1	1	1	1
Publications Technician	1	1	1	1
Quality Control Coordinator	1	1	1	1
Programmer/Analyst	1	1	1	1
Totals	12	15	1 shift 5 days/week	15

*NDPF Assistant Director is also double listed as Director, Production Control

Table 13 4-2 Image Generation Manpower Requirements

Position Titles	Number Persons Per Shift		Number Shifts Case B	Total Case B
	Case A	Case B		
Supervisor, Image Generation	1	1	1	1
Clerk-Typist	1	1	1	1
Bulk Processing Operator (M&O)	2	2	2	4
Precision Processing Operators (M&O)	3	2	2	4
Special Processing Operator (M&O)	2	2	2	4
B&W Processing Operator (M&O)	1	1	2	2
Color Printer and Processor Operators (M&O)	1	1	1	1
Image Generation Maintenance Supervisor (M&O)	1	1	1	1
Bulk Processing Maintenance Technician (M&O)	1	1	1	1
Precision/Special Processing Maint Technician (M&O)	1	1	1	1
Preventive Maint Tech (M&O)	1	1	2	2
Totals	15	14	Case A 1 Shift 5 days/week Case B 2 Shifts 5 days/week	22

Table 13 4-3 NDPF Production Operation Manpower Requirements

Position Titles	Number Persons Per Shift		Number Shifts Case B	Total Case B
	Case A	Case B		
Director, Production Control*	-	-	-	-
Supervisor, Photo Reproduction	1	1	1	1
Chief Photo Technician	0	1	3	3
Photo Technicians (M&O)	10	10	3	30
Photo Lab Aides (M&O)	2	2	3	6
Microfilm Technician	1	1	1	1
Supervisor, Computer Production	1	1	1	1
Data Technician, Computer Production (M&O)	2	2	2	4
Manager, Working Storage	1	1	1	1
Supervisor, Shipping and Receiving	1	1	1	1
Lead Data Technician, Shipping and Receiving	0	1	2	2
Data Technicians, Shipping and Receiving (M&O)	3	3	2	6
Data Technician, Information Systems Maintenance (M&O)	2	2	2	4
Lead Data Technician, Storage	1	1	3	3
Data Technician, Storage (M&O)	1	2	3	6
NDPF Computer Operations (M&O)	4	3	3	10**
Totals	30	32	Case B 3 shifts 5 days/week	79
			Case A 1 shift 5 days/week	

*Director, Production Control, is double listed and accounted for as the NDPF Assistant Director

**Shift operation is seven days a week, four persons prime shift, three persons each other shift

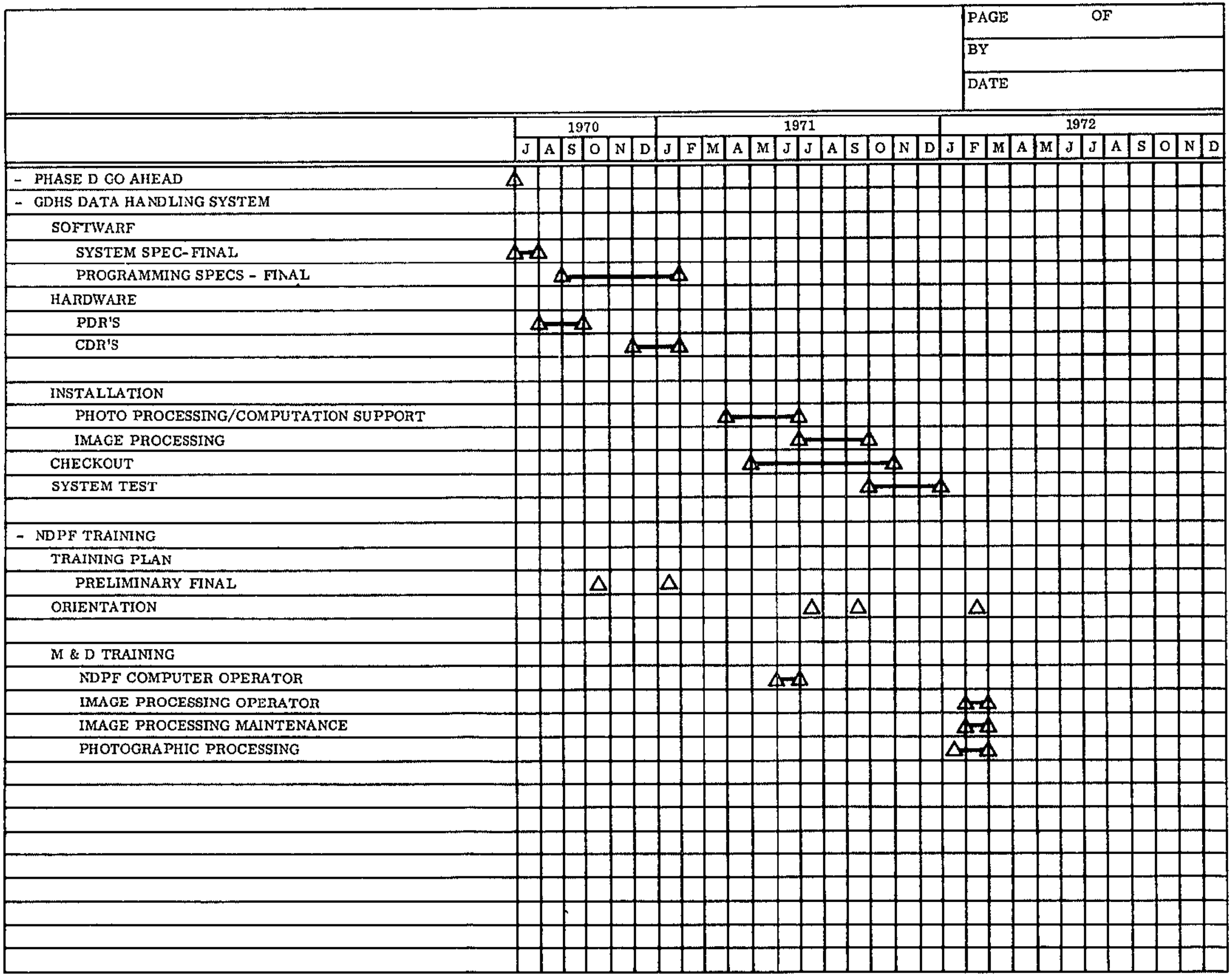


Figure 13 4-2 NDPF Training Schedule

The classroom course will be divided into sections to permit the various types of operators to participate in the section or sections pertinent to their job description, and to permit use of project engineers as instructors. The Maintenance Technicians and Quality Control Inspectors will participate in all Operator Training Course sections

The course will be a 40-hour classroom course with the element Project Engineers as the instructors The Subsystem and Element Operation and Training Manuals will be used as the text, along with slides and a course handout

A Bulk Processing Operator Course Section This section presents the equipment used to convert the original video tapes received from the OCC and provide annotated imagery on black and white film Of importance in this section is the operation of the High Resolution Film Recorders. The Precision Processing, and Special Processing Operators are participants of this section since they serve as backup to the Bulk Processing Operators.

B Precision Processing Operator Course Section This section presents the Precision Processing Equipment for geometrically and radiometrically correcting the selected imagery The Bulk Processing Operators are participants in this section since they serve as backup to the Precision Processing Operators The Bulk Processing Operator Course Section and the Precision Processing Course Section will be in sequence to permit participation of the backup operators

C Special Processing Operator Course Section This section permits the Special Processing Equipment used in the production of digitized image data, correction to precision processed images, and thematic processing for analysis of target signatures

D Black and White Processing Operator Course Section This section presents the equipment used in the processing of master black and white film from bulk and precision operators The Color Printer and Processor Operators are participants in this section since they serve as backup operators for Black and White Processing

E Color Printer and Processor Operator Course Section. This section presents the equipment used in the processing of color composites on negative film The Black and White Processor operators are participants in this section, to serve as backup to the Color Processor Operator

13 4 5 1 3 Image Processing -- Maintenance Training Course

The maintenance technician training course includes preventive and corrective maintenance of all equipment in the Image Processing Subsystems The exception being corrective maintenance of off-the-shelf equipment maintained under a service contract The participants in the Maintenance Course pertinent to the maintenance course Following the classroom courses, the participants will receive on-the-job training through assisting in the maintenance of the equipment during operator training and Mission Simulations

The 60-hour classroom courses will be divided into sections to permit use of project engineers as instructors These are

1 Bulk-Processing Maintenance Course Section

2. Precision Processing Maintenance Course Section

3 Special Processing Maintenance Course Section

4 Photographic Processing Maintenance Course Section

13 4.5.2 Photographic Processing, Computation and Support Services Training
There are several basic approaches which may be taken in training for and staffing of an operation such as the NDPF. A turnkey operation may be established In this approach an M&O staff is assigned, all personnel are trained, and at the end of the training period, the facility is turned over to the new staff for operation In an alternate approach, the operational personnel are phased into the program in such a manner so that full staffing is achieved just prior to operational status. Finally, a combination of these two methods may be used whereby certain operations are identified for turnkey (or M&O) support while others are staffed through phasing in Each of these methods has advantages and disadvantages In general, the turnkey concept is used either for total staffing or for training those groups of individuals who perform well defined tasks which are manual or repetitive in operation In the latter case it is important that there be a distinct interface between all other functions.

In the NDPF operation, several factors are essential for the facility to fulfill its mission Foremost among these is the ability to produce high quality photographic outputs in very large quantities in a small turnaround time Experience at the National Space Science Data Center and with users of photographic data at other NASA facilities, indicates that a close interrelationship between the photographic processing group and the other operational branches is essential In the same way, the technical support in the areas of storage, information systems maintenance and packaging can be most effectively provided only when integrated into the total NDPF operation Because the efficiency of operation for each of these tasks has a major impact on the total effectiveness of the NDPF, it is strongly recommended that these functions be phased in as part of an integrated staff.

Finally, one other factor in favor of phased-in staffing should be considered Because Wolf, the Photographic Processing and Support Services Contractor, operates a high quality photographic facility, it will be possible to use this facility to train photographic technicians prior to their assignment on the ERTS contract. This has two major advantages. First, a team of proficient technicians can be formed with experience in working together, and, second, some of the staffing and training costs are not transferred to the ERTS operation Inasmuch as Wolf also employs many responsible data technicians, these same advantages hold true for the storage technician staffing

Thus, it is recommended that the following functions be supplied by the contractor during the Phase D operational period

1 NDPF Control

2 Photographic Production

3 Working Storage

Because of its well defined interface and general indepence of action, it is recommended that the function of operating the NDPF computer be supported by a separate M&O contract.

If it should be decided to procure a separate M&O staff for the Photographic Production and Working Storage elements, then senior personnel in each of these areas should be integrated into the NDPF Control element Positions which could be staffed by M&O personnel were indicated by (M&O) in Table 13.4-3

The training of the NDPF computer operators will be performed by the computer vendor It is recommended that the NDPF computer software-related positions by filled by the contractor personnel who designed and developed the NDPF application programs Thus, no additional training is required in these areas

The rest of this section will discuss two training course -- one for the recommended phase in and the second for the training of M&O support staffs.

The staffing required for the operation of the NDPF has a sharp buildup in only two areas photo technicians and data technicians All key personnel positions will be filled by the staff which has been involved in the development, integration and testing the NDPF operation This includes

1 NDPF Director

2 NDPF Assistant Director

3 Administrative Assistant

4 Manager, User Services

5 Supervisor, Publications

6 Quality Control Coordinator

7 Programmer/Analyst

8 Supervisor, Photo Reproduction

9 Chief Photo Technician

10 Microfilm Technician

11 Supervisor, Computer Production

12 Manager, Working Storage

13. Supervisor, Shipping and Receiving

Thus, the developmental stages will produce a team which has participated in the design and fully understands the operation of the NDPF As a result of staff meetings, design reviews, and normal exchange of information, no training for this staff will be required

To staff up the Photographic Production and Working Storage elements, approximately 53 technicians of varying skills will be required With the proper supervision, many positions can be filled with personnel with little previous related experience For this reason, the Photographic Processing and Support Services Contractor proposes to identify 25% of these positions to be filled by persons from disadvantaged or high unemployment areas Initial orientation and training may be funded by an OEO grant or a JOBS contract If no grants or contracts are available in 1971, then Wolf will provide any necessary orientation and training All training will be located at the Wolf facility

The Photographic Processing Contractor has had experience in the upgrading of underutilized labor at the National Space Science Data Center (NSSDC) During the operation of that contract, a limited number of positions were identified and filled by selective hiring through the Critical Employment Program and the Urban League All necessary training was provided by Wolf, in no case did the operation of the NSSDC suffer as a result of this selective hiring When viewed from the point of view of the personnel hired, the program produced impressive long range beneficial effects Wolf is confident that an extension of this program in the operation of the NDPF will lead to effective work performance, economical operation, high morale, and a significant social service

Independent of whether the initial buildup is through a phase in or the availability of an M&O staff, some training at the NDPF will be required Two courses are recommended One for photographic processing, the second for general technical support, part of which can also serve as an ERTS orientation course Descriptions of each course follow.

<u>Course Title</u> Operation of the NDPF (Orientation) This course will be of short duration and will be given to new M&O contract support personnel to explain how their responsibilities and actions interrelate to the total ERTS

<u>Objective</u> Show how the staff contributes to the NDPF operation and how the various activities interrelate.

<u>Content</u> Overview of the system followed by detailed description of interfaces and functional responsibilities as related to the operations Separate courses will be given for photographic and data support technicians

<u>Duration.</u> Three half-day classroom sessions with On Job Training (OJT) follow-up in areas which will be supported by the M&O personnel. Total training with classroom and OJT will last one week.

Instructor Director, Production Control and NDPF Manager for process in question

Supporting Documentation Standard Operating Procedure for operation in question and vendor supplied M&O Manuals

Course Title Photographic Processing This course is intended to acquaint all photographic personnel with the equipment and procedures used at the NDPF

Content Description of the photographic equipment used, its operation and maintenance Quality control standards, techniques, and procedures will be emphasized

Duration	Classroom	1 week, half time
	On Job Training	1 week, half time, 1 week full time

Instructor Supervisor, Photographic Production and Staff

Supporting Documentation Vendor M&O Manuals, Photographic Processing SOP, Quality Control Standard SOP

NOTE

Since three operational shifts are required, the On Job Training will have to be repeated three times

13 4 6 NDPF Manuals

The O&M manuals required to support NDPF operations will be provided by the equipment vendor for off-the-shelf items and by the equipment designer for development items The basic manual requirements are identified in this section.

It should be noted that the time phasing of this report precludes listing specific manuals to be provided by the ADP equipment suppliers The standard operator, equipment and software manuals will be provided however, as part of the ADP procurement and the NDPF application software development effort

These manuals will form the backbone of the NDPF training program described in the previous section This approach offers the personnel operating and maintaining the NDPF an opportunity to become thoroughly familiar with the contents of these documents and to become efficient in their use Moreover, during the course of instruction the instructor-designer can make certain that concepts requiring particular emphasis are highlighted, and the personnel in attendance can obtain interpretations of the document pertinent to his particular area of concern

14 3 6 1 Image Processing Manuals

13.4 6.1.1 Image Processing Familiarization Manual

This manual covers the subsystem with a brief physical and functional description This manual is to be used in the orientation of management and program personnel.

13 4 6 1 2 O&M Manuals
Type I manuals will be prepared in accordance with GSFC STD-256-4, Preparation of Operation and Maintenance Manual

1. Image Processing Subsystem Operation and Maintenance Manual covers the integrated operation and maintenance of the subsystem with reference to the Subsystem Element, Component or vendor commercial manuals as appropriate

2 The following Operation and Maintenance Manuals will be prepared covering the elements of the Image Processing Subsystem Reference will be made as appropriate to commercial equipment manuals for the detailed operation and maintenance of off-the-shelf components Element manuals will be delivered with the equipment

   a Bulk Processing Element Operation and Maintenance Manual

   b Precision Processing Element Operation and Maintenance Manual.

   c. Special Processing Element Operation and Maintenance Manual

   d Photo Processing Equipment Operation and Maintenance Manual

13 4 6 2 <u>Photographic Processing, Computation and Support Source Manuals</u>
For each major piece of off-the-shelf equipment, the vendor shall supply O&M manuals The computer vendor shall provide all necessary hardware and software manuals

The software vendor shall prepare the following documents All documents shall be available in draft form by February 1971 Because documents relate to procedures which may be modified during the assembly and integration stages, all documents will be revised and printed on or before 1 January 1972

13 4 6 2 1 Program Maintenance Documentation
This shall contain an overview of the executive software, a functional description and operational block diagram of each major module, a glossary of terms, linkage maps and core and storage requirements for the system Each subroutine will be documented with calling sequence, functional description, and flow chart Instructions for subroutine modifications shall be included and any software constraints or interfaces shall be clearly specified A fully documented computer program listing a control run with inputs and outputs and a control program deck or tape shall be available as an appendix

Program Maintenance Documents shall be prepared for

1 Information Retrieval System
   Volume 1 - Executive
   Volume 2 - Application

2. PCM Processing System

3. DCS Processing System

4. User Product Generation Software

13 4 6 2 2 Operations Manuals

These manuals shall contain complete instructions on the use of the software packages Included shall be all control card setups, error messages, average operating times, and sample outputs. Where a sophisticated command language is available, elementary functions will be described to operate from a simple subset of the language Each manual will be aimed at its particular user group and will provide a general introduction to the function of the operation in the NDPF

The following Operations Manuals shall be prepared for use by NDPF data technicians

DCS Production Programs

PCM Production Programs

Information Retrieval Production Control/Report Programs

User Product Operation Programs

A comprehensive reference Operation Manual shall be prepared for the Information Retrieval System

A short user oriented manual will serve as an introduction to the ERTS Query System

13 4 6 2 3 Standard Operating Procedures

Procedures for each NDPF Photographic Processing function shall be prepared These are

1 Production Control
2 Production Photographic Processing
3 Photographic Quality Control
4 Request Services
5 Packaging and Shipment
6 Storage and Data Maintenance
7 Information System File Maintenance
8 Publications Services
9 User Abstracts
10. Microfilm Production
11 Image Assessment
12 Montage Preparation
13. Administrative

There is other recommended ERTS related documentation which has not been called for in the Phase B/C study specification but which should be considered in Phase D These include

1 ERTS Data Utilization Manual
2 Services of the NDPF
3 Other user-oriented materials

13.5 NDPF MAINTENANCE AND LOGISTICS

Estimations of the NDPF spare parts and expendable logistics requirements and of maintenance requirements have continued since submittal of the GDHS Interim Report. Discussions have been held with equipment vendors and subcontractors to examine the maintenance and logistics aspects of activation and to seek out a most efficient approach The general NDPF approach developed is as follows

1. Procurement of spares in the form of kits from manufacturers as part of equipment procurements

2. Inclusion of appropriate vendor activation and operation support requirements in the equipment purchase

3. Capitalization on vendor ability to provide repair or replacement services in lieu of stocking spares at the GDHS

4. Consideration of open-order arrangements for procurement of expendables

5. Prompt entry of GDHS spares and expendables items into the NASA/GSFC logistics system.

13.5 1 NDPF MAINTENANCE AND SPARE PARTS

13.5 1 1 Image Processing Maintenance and Spare Parts

The maintenance philosophy for the Image Generation Subsystem is based on the premise that the equipment will be operating for 16 hours per day, 5 days per week. The equipment is designed for self-checking and fault isolation to the replaceable unit level to minimize down time during 2-shift operations Vendor service contracts will be established for off-the-shelf equipment. Preventive and corrective maintenance will be performed as necessary during the 16-hour operation period. The third shift will be reserved for performance of scheduled maintenance that requires equipment shutdown.

For image generation equipments which are off-the-shelf items, spares requirements will be included in the vendor service contracts For the subsystems which are under development, a replaceable parts and recommended spares list will be prepared in accordance with GSFC Standard S-535-P-1A NASA/contractor approval of the spares lists will be established prior to the critical design review date, so that spares can be manufactured along with the prime equipment Spares requirements prior to preparation of lists will be estimated as a percentage of production hardware cost.

13 5 1 2 Photographic Processing Maintenance and Spare Parts

NDPF equipment calibrations will be conducted as a routine part of the quality control cycle and no special setups or processing times will be required. Maintenance of photo-processing equipment will include once-per-week tear-down and cleaning, a nominal 2-hour operation. Automatic chemical replenishment will be provided for in the photo-processing equipment design and photo-chemicals will not require changing unless they become contaminated.

The equipment tentatively selected for the NDPF is such that, in general, standard spare parts kits or manufacturer-recommended spare parts kits are readily available and can be included in equipment procurement. This is reflected in the estimated spare parts list shown in Table 13.5-1. Furthermore, all vendors expected to be involved will have local supply centers, so that no spares backup will be required in such cases. Wolf experience in operation of the National Space Science Data Center supports this approach

Table 13.5-1 Photographic Processing Spare Parts Estimate

Equipment Name	Spare Name	Quantity (1-yr operations)
Photo Processing		
Contact Printer - B&W	Mfr Spares Kit (standard)	1
Strip Printer - B&W	Mfr. Spares Kit (standard)	1
Paper Print Processor - B&W	Mfr Recommended Spares Kit	1
Film Processor - B&W	Mfr. Recommended Spares Kit	1
Paper Cutter - Auto	Spare Sensor Bulbs	TBD
Color Contact Printer	Spare Parts Kit including Module Set	1
Color Paper Processor	Mfr Recommended Spare Parts Kit	1
Image Assessment and File Mount Equipment	Mfr. Recommended Spare Parts Kit	1
Microfilm Processing and Reproduction	Spare Parts Kits	1 set

13.5.2 NDPF EXPENDABLES

The current estimates of expendable materials required for activation (pre-launch) and for post-launch operations on a monthly basis, are shown in Table 13.5-2 and 13.5-3. The assumptions used for the operational estimates are shown as footnotes in the table The pre-launch estimates are indicative of basic activation requirements. For example, higher consumptions would occur if several operational level trial runs were made during activation

Table 13.5-2. Image Processing Expendables Estimate

Process	Expendable Name	Quantity	
		Pre-Launch (rolls)	90 Days Post-Launch (rolls/month)
RBV Video Tape Recording	2-in. Video Tape, 300-ft reel	788	182
MSS Video Tape Recording	1-in Video Tape, 9400-ft reel	788	182
RBV/MSS Annotation (Bulk Precision)	1-in. Short Computer Reels, 250-ft reel	4225	975
High Density Recording	1/2-in. Newell Tape, 9600-ft reel	192	44
Computer Program Recording	Punch Tape, Mylar - Roll	15	3
Computer Program Recording	Punch Tape, Paper - Roll	218	36
Computer Program Inputting	Ribbons, Teletypewriter, each	24	6
Computer Program Inputting	TTY Paper, 2 Part, roll	84	12
Computer Outputting	Computer Compatible Mag Tape, 2400-ft roll	TBD	TBD

Table 13.5-3. Photographic Processing Expendables Estimate

Process	Expendable Name	Quantity	
		Pre-Launch	90 Days Post-Launch
PhotoProcessing			
B&W Prints (See Notes 1 & 2)	B&W Paper, 10 in x 500 ft roll	250 rolls	800 rolls/mo
	Developer - 25-gal units	35 units	60 units/mo
	Fixer, 50-gal units	20 units	40 units/mo
	Stop Bath, 30-gal. units	25 units	50 units/mo
B&W Film (See Notes 2, 3 and 4)	70 mm film, 500-ft rolls	150 rolls	330 rolls/mo
	9 1/2 in film, 500-ft rolls	200 rolls	800 rolls/mo
	Developer, 20-gal units	50 units	40 units/mo
	Fixer, 20-gal units	50 units	40 units/mo
	70 mm SO-219 Kodak Film, 100-ft roll	468 rolls	108 rolls/mo
	9 1/2 in 4427 Kodak Film, 250-ft roll	1000 rolls	230 rolls/mo
Color Prints (See Note 5)	Color Paper, 10 in x 250-ft roll	75 rolls	160 rolls/mo
	Process Kits (5 step), 25-gal units	25 kits	
	Ektaprint C Developer/Replen, 25 gal	2 units	20 units/mo
	Ektaprint C Stop/Fix/Replen, 25 gal	2 units	20 units/mo
	Ektaprint C Bleach/Replen, 25 gal	2 units	20 units/mo
	Ektaprint C Fix/Replen, 25 gal	2 units	20 units/mo
	Ektaprint C Stabilizer/Replen, 25 gal	2 units	20 units/mo
	9x11 6110 Kodak Ektacolor Inter-negative Film, 100-sheet Box	450 Boxes	100 Boxes/mo
Microfilm (See Notes 6 & 7)	Camera Film, 16 mm x 100 ft film	50 rolls	35 rolls/mo
	Duplicating Film, 16 mm x 1000 ft	25 rolls	320 rolls/mo
	Developer, 20 gallon unit	10 units	15 units/mo
	Fixer, 20 gallon unit	10 units	15 units/mo
Miscellaneous Supplies	TBD	TBD	TBD

Notes
1 B&W print material usage based on 400,000 units/mo including waste
2 Chemical usage depends on replenishment rates which are TBD
3 70 mm usage based on 500,000 70 mm images/mo
4 9 1/2 in film usage based on 400,000 9 1/2 in images/mo
5 Color usage based on 40,000 units/mo
6 Camera film usage based on reducing one day's data to 1 roll of film
7 Duplicating film usage based on providing 10 users with 10 copes each per day, plus waste

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